PRINT ISSN: 1454-7414
ELECTRONIC ISSN: 2069-7627

UNIVERSITATEA PENTRU ŞTIINŢELE VIEȚII
"ION IONESCU DE LA BRAD" DIN IAŞI

LUCRĂRI ŞTIINŢIFICE

SERIA AGRONOMIE

VOL. 68, NR. 1

EDITURA "ION IONESCU DE LA BRAD" IAŞI

2025

ISSN 1454-7414
© Editura ,,Ion Ionescu de la Brad'' Iaşi
Lucrări Ştiinţifice - vol. 68(1) 2025, seria Agronomie

COORDINATORS OF JOURNAL "LUCRĂRI ŞTIINŢIFICE'

ISSN 1454-7414

Lucrări Ştiinţifice - vol. 68(1) 2025, seria Agronomie

CONTENT

THE INFLUENCE OF SOIL TILLAGE SYSTEMS ON BULK DENSITY IN THE BRAILA ISLAND

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Abstract

The paper analyzes the influence of three soil tillage systems: conventional (CT), minimum tillage (MT), and no-tillage (NT) on bulk density values, under the specific conditions of alluvial soils in the Great Island of Brăila, an area with unique soil characteristics, characterized by high textural variability and a marked degree of heterogeneity. The study was based on a field experiment in which soil samples were collected from four depths (0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm) at two key moments: three days after sowing and immediately after harvesting. The samples were analyzed in the laboratory according to the Canarache method (1991), and the bulk density values were correlated with the tillage system applied. The results showed a progressive increase in bulk density with depth. At sowing, the lowest values were recorded in MT (1.09 g/cm³), and at harvest, NT recorded the highest values (1.22 g/cm³) at a depth of 0–10 cm. However, all values determined were below the critical threshold of 1.4 g/cm³, indicating that none of the systems led to compaction harmful to root development. Statistical analysis (ANOVA) showed no significant differences between the tillage systems. The study confirms that the application of conservative systems does not adversely affect the physical structure of the soil and can be a viable alternative for the sustainable management of alluvial soils, while also offering stable and high agronomic potential.

Keywords: bulk density, working systems, conservation agriculture, alluvial soils, compaction

Soil cultivation using various farming techniques causes changes in its physical properties to a greater or lesser extent. This, in turn, affects crop development and, consequently, production results. In this regard, it is highly recommended to analyze the interaction between soil cultivation systems and the physical properties of the soil.

Soil preparation has always been the starting point for the idea of high-performance agriculture throughout history (Busari M.A. *et al*, 2015). The main soil tillage system that has generated the greatest advances in production has been the conventional system (CT). The value of CT was due to its good weed control capacity, combined with a significant increase in production results (Ashapure A. *et al*, 2019). Subsequently, as a result of the evolution of soil tillage systems, both under the pressure of climatic constraints and the desire to conserve the pedosphere, conservative systems were developed (Mihu G.-D. *et al*., 2022). These include minimum tillage (MT), i.e., cultivation techniques involving shallow soil mobilization, and direct seeding techniques, known as no-tillage (NT) (Giller K.E. *et al*., 2015). The main difference between conventional and conservation technologies is that there is no plowing (Cakpo S.S. *et al*., 2025). Furthermore, in the conservative system, the presence of plant residues on the soil surface is essential, taking the form of mulch, in a minimum percentage of 30% (Jităreanu G. *et al*, 2020).

In contrast to the conventional system, both minimum tillage and no-tillage have become increasingly interesting due to the reduction in diesel consumption, equipment wear, and labor requirements (Calistru A.E. *et al*., 2024). Furthermore, conservative systems offer real advantages in terms of soil physical properties (structure, porosity, water infiltration rate, hydraulic conductivity), thus promoting a high degree of sustainability and increased productivity (Villamil B.M. *et al*, 2015; Zhao X. *et al*, 2017).

In terms of aggregate size and stability, the direct seeding system favoured the formation of an exponentially higher number of macroaggregates,

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with superior water stability compared to those in CT (Mihu G.-D. *et al*. 2022). The percentage difference between the water-stable aggregates present in NT and CT was 36% in favor of the conservation system. Interestingly, compared to the BD values, influences also appear here with increasing time allocated to the experiment, but they are significantly higher. In the case of long-term experiments, over 10 years, the differences increased by 38.7%-69.2% in favor of the NT system (Blanco C.H. *et al*, 2009).

What is certain is that the sum of the studies analyzed concludes that regardless of the adoption period, regardless of rainfall or rotation, conservative systems favor a significant increase in the percentage of water-stable aggregates as well as macroaggregates. Continuing this line of thought, many studies indicate a 50% increase in large aggregates and a 32% increase in water-stable aggregates. The mechanisms behind this differentiation in soil formations are easy to identify as they represent the very essence of conservative systems (Mihu G.-D. *et al*., 2025). The first essential aspect for the occurrence of these transformations in the soil is the retention of plant residues, in a proportion that varies according to the chosen soil tillage system, but also the reduction of interaction with the soil, thus favouring the accumulation of organic matter in the upper part of the soil profile (Schmidt E.S. *et al*, 2018, Țopa D.-C. *et al*., 2025). Based on these changes, the aggregates are less wetted, considerably reducing the risk of destructuring (Blanco C.H. *et al*, 2018).

As the size of the aggregates and their water stability increase, the concentration of carbon in the soil also increases. The amount of organic carbon present in the conservation system is 10-29% higher than in the conventional system (Li Y. *et al*, 2019). Furthermore, by increasing the percentage of plant residues on the soil surface, there is also an increase in the population of soil microorganisms, which directly favors aggregation processes, practically supporting the formation of water-stable and large aggregates (Li Y. *et al*, 2018).

The aim of this study is to evaluate the influence of different soil tillage systems: conventional (CT), minimum tillage (MT), and no-tillage (NT) on bulk density values under the specific conditions of alluvial soils on the Insula Mare a Brăilei. This analysis contributes to identifying the most efficient soil tillage technologies from the perspective of preserving the physical structure and productive potential of the pedosphere.

To achieve this goal, the following specific objectives were set:

- determination of bulk density values for each soil tillage system at four profile depths (0–10 cm, 10–20 cm, 20–30 cm, and 30–40 cm) at two distinct times: before sowing and after harvest;
- comparative analysis of the variation in bulk density between conventional and conservation systems, in order to highlight possible differences in soil compaction during the growing season;
- highlighting the effects of conservation systems (MT and NT) on maintaining or improving the physical properties of alluvial soils, with an emphasis on porosity and water retention potential.
- identifying trends in bulk density depending on the type of work applied and the sampling depth, in order to assess the risks of compaction in the active soil layer.

Thus, the implementation of sustainable soil management systems can contribute significantly to maintaining the physical properties of the soil, preventing compaction, and optimizing conditions for the development of the plant root system. This paper aims to make a significant contribution in this regard by comparing the influence of conventional and conservation systems on soil bulk density, a key indicator in assessing the health of the pedosphere.

MATERIAL AND METHOD

The embanked area of Insula Mare a Brăilei is a territory that has undergone extensive land improvement works. Until this process began, the area in question was known as “Balta Brăilei.” The area occupied by this formation was approximately 99,000 hectares, bordered by the Danube and the Măcin branch. The island that was formed has an elongated shape and an impressive surface area, thanks to its length of approximately 65 kilometers and its width of between 12 and 16 kilometers (Titianu L., 2010).

The soil is underdeveloped, young, and constantly evolving, formed mainly by alluvial deposits. The Danube has exerted a series of highly intense actions, thus generating erosion, transport, and deposition of sediments. The Brăila Marsh, being a floodplain, is characterised by a low, flat relief. Due to the fact that its formation depended on how various alluvium were brought and deposited, there is a high degree of heterogeneity, both in terms of grain size and chemical composition. A more detailed analysis of the soil reveals areas characterized by coarse texture, in contrast to other areas with a clayey texture, and obviously areas with intermediate texture. The textural unevenness of the alluvial deposits differs both horizontally and vertically. As will be seen from the soil profile analysis, variations in texture occur with depth at the same location. Due to the fact that, until it was embanked, the island experienced annual periods of flooding and water retreat, the process of soil formation, and therefore humus accumulation, was hampered by the constant accumulation of new, raw sediments on top of the previous sediments. A characteristic of the soil formation of this type of land is that the soil tends to transform and acquire the characteristics of the genetic soil types already present in the area (Anup K.U. and Kalu S., 2015).

In order to collect soil samples for the analysis of bulk density values, two sampling periods were taken into account. Therefore, samples were taken shortly after sowing (3 days) and immediately after harvesting. In order to reflect the reality of the situation in the field as accurately as possible, the samples were taken from unmoved, uniform soil surfaces, in no case from tractor wheel tracks, and were selected at random. In addition, three sampling points were selected for each soil tillage system analyzed (CT, MT, NT), at a minimum distance of 10 meters from the access roads to the field.

Soil samples were collected in cylinders with a volume of approximately 100 cm^3 with the edges cut at an angle of approximately 150. Each point associated with each soil tillage system had four sampling depths: 0-10, 10-20, 20-30, and 30-40 cm. Special attention was paid to sample collection by removing plant debris from the surface of the sampling point so as not to distort the results. At the same time, an attempt was made to reduce sample handling in order not to degrade the structure of the soil sampled. After harvesting, the samples were taken to the laboratory, where they were dried in an oven (105ºC), and in order to determine the bulk density values for each working system, the formula proposed by Canarache was used, as it is considered one of the most effective for establishing these values (1991).

RESULTS AND DISCUSSIONS

The Great Island of Brăila is an area of land with unique characteristics compared to the rest of the soil found in Brăila County. As a result of the embankment process, the land within the enclosure has become agricultural. The land was formed by the gradual but constant accumulation of various quantities of water-borne sediments. The Danube has thus managed to shape and reshape the soil over time, giving it a fairly high degree of variability. Therefore, the land within the embanked area is classified as alluvial soil, which explains the high degree of variability in its physical properties, even over short distances.

At the first depth interval, at sowing, the lowest value is found in MT, with 1.09 g/cm³, followed by CT with 1.11 g/cm³ and NT with 1.12 g/cm³. Although there are differences between soil tillage systems, we can say with certainty that the differences are minor and that conservative systems do not hinder plant development. At a depth of 10-20 cm, the values increase exponentially, with the MT system, which previously had the lowest value, reaching the highest level, 1.30 g/cm³, followed by NT with 1.29 g/cm³ and CT with 1.26 g/cm³. Again, the data are very close to each other, the difference being negligible. At the third depth interval, 20-30 cm, the NT and MT values are similar, approximately 1.30 g/cm³, and CT is 1.29 g/cm³, and we can say that the tendency to show very small differences continues. For a depth of 30-40 cm, MT has the highest bulk density values, at 1.31 g/cm³, followed closely by NT at 1.30 g/cm³. However, there are greater differences between the conservative systems and the conventional system, with CT having a value of 1.26 g/cm³.

Harvest data indicate an increase in bulk density values, most evident at a depth of 0-10 cm, where NT reaches 1.22 g/cm³, followed by MT and CT with 1.19 g/cm³ and 1.18 g/cm³. Therefore, during the growing season, NT generated greater soil compaction than MT and CT, although the differences between the systems are not very large. At a depth of 10-20 cm, the hierarchical trend continues, with the highest values being found in NT, 1.34 g/cm³ compared to 1.30 and 1.31 g/cm³. At a depth of 20-30 cm, the NT and MT values are slightly lower than in the previous interval, at 1.33 g/cm³ and 1.30 g/cm³, respectively. The CT system this time shows a value similar to MT, also at 1.30 g/cm³. For the last depth range, 30-40 cm, the CT system maintains its value of 1.30 g/cm³, but we find increases in both NT and MT, both reaching 1.34 g/cm (Table 1).

We can observe fairly small differences in bulk density between the three systems analyzed. Furthermore, the values obtained across all depth intervals are not likely to cause problems for root system development. In this regard, we can conclude that, in this case, conservative systems will not harm crops in terms of this indicator.

Table 1

Bulk soil density values from the experiment

Depth	NT sowing	CT sowing	MT sowing	NT harvesting	CT harvesting	MT harvesting
0-10 cm	**1.12 -0.06a**	1.11 -0.08a	1.09 -0.05a	**1.22 +0.04a**	1.18 -0.01a	1.19 +0.05a
10-20 cm	**1.29 +0.03a**	1.26 -0.06b	1.30 -0.02a	**1.34 +0.08a**	1.30 -0.02b	1.31 -0.01a
20-30 cm	**1.30 +0.01ab**	1.29 -0.04a	1.30 -0.01ab	**1.33 +0.04b**	1.30 -0.03a	1.30 -0.01ab
30-40 cm	**1.30 -0.01a**	1.26 -0.05a	1.31 -0.01a	**1.34 +0.04a**	1.30 -0.01a	1.34 +0.02a

Note: NT – no-tillage system; CT – conventional tillage system; MT – minimum tillage system. Data are presented as mean ± standard error (n = 10). Within each column, values followed by the same lowercase letters are not significantly different, while values followed by different lowercase letters are significantly different (Tukey's test, $p \leq 0.05$).

Statistically, the data obtained this year indicate the following (Figure 1).

At a depth of 0-10 cm, in NT, the SD and SE values are 0.0916 and 0.0458, which is a low level of data variability and also associated with a high accuracy of the mean estimate.

In the CT system, the standard deviation and standard error values were lower than in NT, at 0.0534 and 0.0267. Therefore, data variability is lower and the accuracy of the mean estimate is higher.

For MT, we find the lowest values of standard deviation and standard error, and automatically, the most concentrated values of data distribution and the most accurate mean estimation, with the resulting data being 0.0428 and 0.0215.

The F and p values of 0.772 and 0.505 indicate the absence of significant differences in soil tillage systems.

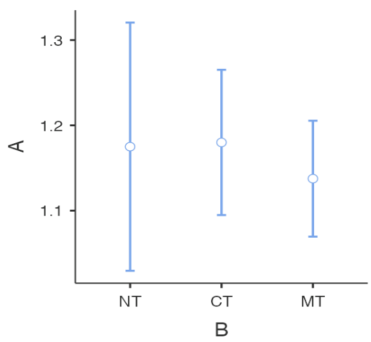

Figure 1 **Variability of specific data for bulk density at 0-10 cm., 2024**

For the depth range of 10-20 centimeters, based on ANOVA analysis, we can observe the following aspects (Figure 2):

In the NT system, the SD and SE values of 0.1284 and 0.0643 indicate the presence of data close to the mean and a low standard error level.

The CT system has a lower level of data variability and a higher accuracy of mean estimation, with values of 0.0828 for SD and 0.0413 for SE.

The MT system has the highest degree of data variability, with an SD of 0.1328.

In terms of standard error, this is not high, but it exceeds the results of the other two analyses (0.0664).

The F and p values of 0.340 and 0.725 indicate the absence of significant variability between the soil tillage systems, compared to the variability found within each analyzed system.

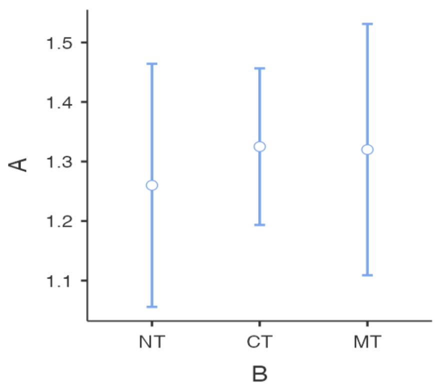

Figura 2 **Variability of specific data for bulk density at 10-20 cm., 2024**

For depths of 20-30 cm, ANOVA data indicate the following characteristics (Figure 3):

At the NT system level, we find a low degree of variability, associated with a fairly high precision of the mean, with SD and SE values of 0.1454 and 0.0727.

For the CT system, we note the most concentrated values within the group, as well as the most accurate estimate of the data mean, with 0.0773 and 0.0388 SD and SE.

In the case of MT, we find intermediate values, compared to CT and NT, for SD and SE, with 0.1311 and 0.0656.

The F and p values, 0.109 and 0.898, show no significant differences between the systems.

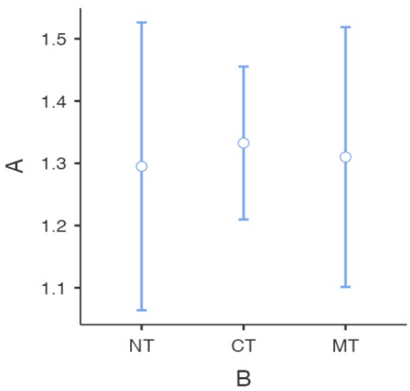

Figure 3. **Variability of specific data for bulk density at 20-30 cm., 2024**

At the last depth level, 30-40 cm, the statistical results are as follows (Figure 4):

In the direct sowing system, we have SD and SE values of 0.1437 and 0.0717, thus a low data variability and a low standard error in terms of mean estimation.

In the CT system, we find the most concentrated values and the most accurate estimate of the mean, with SD and SE values of 0.0501 and 0.0251.

The last system, MT, with its SD and SE values, has an intermediate level compared to NT and CT, with results of 0.1208 and 0.0602.

The F and p values of 0.0254 and 0.975 indicate the absence of significant differences between the analyzed groups.

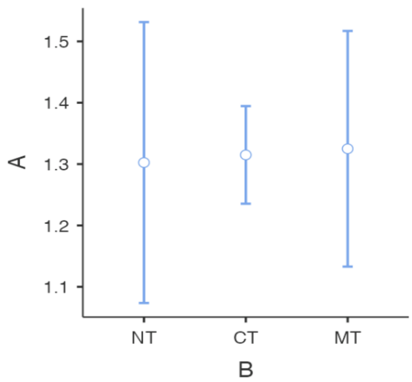

Figure 4 **Variability of specific data for bulk density at 30-40 cm, 2024**

The bulk density values were: 1.08 g/cm³ (0-10 cm), 1.29 g/cm³ (10-20 cm), 1.32 g/cm³ (20-30 cm), and 1.33 g/cm³ (30-40 cm). Based on these results, we can conclude that the tilled soil does not have a high degree of compaction. For the 0-10 cm interval, the value of 1.08 g/cm³ indicates the presence of soil with increased porosity, probably due to the fact that the soil was constantly mobilized superficially during the preparation of the seedbed. An increase in apparent density values can be observed with depth, which also implies an increase in penetration resistance, increased soil compaction, and implications that may be negative for the normal development of the plant root system. The highest value is identified at 30-40 cm, which is 1.33 g/cm³. However, the results obtained do not indicate a level of bulk density that could in any way impair the formation of an optimal root system for crop plants. In the literature, it is considered that in order to promote the development of a deep and adequate root system for plants, the bulk density values should be in the range of 1.1-1.4 g/cm³. Although at greater depths we find values of 1.32 and 1.34 g/cm³, we can conclude that these will not affect plants in the normal course of the ontogenetic cycle (Reynolds *et al*, 2002).

CONCLUSIONS

For sowing at a depth of 0-10 cm, conservative systems generally showed higher values than the conventional system. However, the CT and MT systems showed fairly similar values. The NT values were never at a level that could cause problems for the plants. At a depth of 10-20 cm, the trend in the 0-10 cm layer continued, with NT values being the highest, except that in the third year, the differences between the systems were the smallest. For a depth of 20-30 cm, based on the average values obtained, the MT system showed even lower values than CT. There is a noticeable trend towards balancing the differences between the systems, which are very close. The density in MT seems to be the one with the highest degree of stability. For the last depth interval analyzed, 30-40 cm, the variations associated with each cultivation technology are even smaller, but nevertheless, the CT system always has the lowest values.

At harvest, at a depth of 0-10 cm, we find an increase in the values of this indicator in all the systems analyzed, with NT having the highest result. At a depth of 10-20 cm, we find greater compaction in the NT system, which may also be associated with the transition period of the soil to this type of conservative system. The depth of 20-30 cm does not deviate from previous trends, as the bulk density values increase in all systems, especially in NT. For the 30-40 cm interval, we can distinguish the lowest variation of this indicator, although there is an increase here as well, and the system that most clearly shows this variation is NT.

The NT system tends to generate a higher level of bulk density as a result of soil compaction caused by the lack of pedosphere mobilization. However, the fact that the values never exceeded or reached 1.4 g/cm³, so as to impair the development of the root system, shows that NT cannot be associated with a limiting soil tillage system from the perspective of this indicator. The MT system, with intermediate values, leads to a similar conclusion. In the case of the CT system, although it presented the lowest values and considering that conservative systems do not raise the bulk density results to very high levels, we can say that it does not present any advantage in terms of soil compaction, thus calling for a transition to conservative agriculture.

REFERENCES

Busari M.A., Kukal S.S., Kaur A., Bhatt R. și Dulazi A.A., 2015 - Conservation Tillage Impacts on Soil, Crop and the Environment; Jurnal International Soil and Water Conservation Research, v 3, p. 119-129.

Ashapure A., Jung J., Yeon J., Chang A., Maeda M., Maeda A., Landivar J., 2019 - A novel framework to detect conventional tillage and no-tillage cropping system effect on cotton growth and development using multi-temporal UAS data; Jurnal ISPRS Journal of Photogrammetry and Remote Sensing; v. 152, p. 49-64; https://doi.org/10.1016/j.isprsjprs.2019.04.003

Mihu G.-D.; Țopa, D.; Calistru, A.E.; Jităreanu, G., 2022. The influence of tillage systems on soil compaction in the corn crop. *Journal of Applied Life Sciences and Environment*, 55 (4), 391-405. https://doi.org/10.46909/alse-554072

Jităreanu G., Țopa D., Ailincăi C., Calistru A.E. și colab., 2020 - Tratat de agrotehnică, Editura "Ion Ionescu de la Brad" Iași, ISBN: 978-973-147-353-6

Giller K.E., Andersson A.J., Corbeels M., Kirkegaard J., Mortensen D., Erenstein O., Vanlauwe B., 2015 - Beyon conservation agriculture; Jurnal Frontiers in Plant Science, v.6; https://doi.org/10.3389/fpls.2015.00870

Cakpo, S.S.; Aostăcioaei, T.G.; Mihu, G.-D.; Molocea, C.-C.; Ghelbere, C.; Ursu, A.; Țopa, D.C., 2025. Long-Term Effect of Tillage Practices on Soil Physical Properties and Winter Wheat Yield in North-East Romania. Agriculture, 15, 989. https://doi.org/10.3390/agriculture15090989

Villamil B.M., Little J., Nafziger D.E., 2015 - Corn residue, tillage, nitrogen rate effects on soil properties; Jurnal Soil and Tillage Research, v. 151, p 61-66; https://doi.org/10.1016/j.still.2015.03.005

Calistru, A.E.; Filipov, F.; Cara, I.G.; Cioboată, M.; Țopa, D.; Jităreanu, G., 2024. Tillage and Straw Management Practices Influence Soil Nutrient Distribution: A Case Study from North-Eastern Romania. Land, 13, 625. https://doi.org/10.3390/land13050625

Zhao X., Liu S., Pu C., Zhang X.Q., Xue J.F., Ren Y.X., Zhao X.L., Chen F., Lal R., Zhang L.G., 2017 - Crop yields under no-till farming in China: A meta-analysis; Jurnal European Journal of Agronomy; v.84, p 67-75; https://doi.org/10.1016/j.eja.2016.11.009

Mihu G.-D.; Țopa, D.; Calistru, A.E.; Jităreanu, G., 2022. The influence of tillage systems on soil compaction in the corn crop. Journal of Applied Life Sciences and Environment, 55 (4), 391-405. https://doi.org/10.46909/alse-554072

Blanco C. H., Stone L.R., Scheleged A.J., Lyon D.J., Vigil M.F., Stahlman P.W. și Mikha M., 2009 - No-till induced increase in organic carbon reduces near surface maximum bulk density pf soils; Jurnal Soil Sciences Society of America Journal, p. 1871-1879.; DOI:10.2136/sssaj2008.0353

Mihu, G.-D.; Aostăcioaei, T.G.; Ghelbere, C.; Calistru, A.-E.; Țopa, D.C.; Jităreanu, G., 2025. Exploring Soil Hy-dro-Physical Improvements Under No-Tillage: A Sustainable Approach for Soil Health. Agriculture, 15, 981. https://doi.org/10.3390/agriculture15090981

Schmidt E.S., Villamil M. B. și Amiotti N.M., 2018 - Soil quality under conservation practices on farm operations of the southern semiarid pampas region of Argentina; Jurnal Soil Tillage Research, p. 85-94; https://doi.org/10.31545/intagr/195906

Țopa, D.-C.; Căpșună, S.; Calistru, A.-E.; Ailincăi, C., 2025. Sustainable Practices for Enhancing Soil Health and Crop Quality in Modern Agriculture: A Review. Agriculture, 15, 998. https://doi.org/10.3390/agriculture15090998

Blanco C.H. și Ruis S.J., 2018 - No-tillage and soil physical environment; Jurnal Geoderma, p. 164-200; DOI:10.1016/j.geoderma.2018.03.011

Li Y., Cui S., Chang S. X., Zhang Q. P., Jagadamma S. și Cai Y., 2019 - Residue retention promotes soil carbon accumulation in minimum tillage systems- implications for conservation tillage; Jurnal Science of the total Environment. DOI: 10.1016/j.scitotenv.2020.140147

Li Y., Chang S.X., Tian L.H. și Zhang Q.P., 2018 - Conservation agriculture practices increase soil microbial biomass carbon and nitrogen in agricultural soils- a global meta-analysis; Jurnal Soil Biology & Biochemistry, p. 50-58; DOI:10.1016/j.soilbio.2018.02.024

Titianu L., 2010 - Studiu economic privind perfecționarea structurală a producției și a sistemelor de conducere în exploarațiile agricole din câmpia Brărilei; USV "Ion Ionescu de la Brad" din Iași;

Anup K.C. și Kalu, S., 2015 - Soil Remediation and Plants in Nepal; Jurnal Soil Remediation and Plants.

SOIL HEALTH UNDER CONVENTIONAL AND MINIMUM-TILLAGE PRACTICE: SOIL CARBON STORAGE AND NUTRIENT USE

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Abstract

Tillage is a fundamental soil practice that impacts various soil characteristics. However, the impact of tillage on soil health is complex and context-specific. Our study aimed to evaluate the soil carbon sequestration and nutrient use of two different tillage practices: conventional and minimum-tillage, at various depths ranging from 0 to 30 cm, using a chernozem soil type. The results of our study are consistent with the hypothesis that, over time, minimum-tillage typically boosts soil health in the 0-10 cm soil layer. Compared to the conventional practice (19.36 t C ha^{-1}), there was a significant accumulation of soil organic carbon (0-30 cm) in the minimum-tillage practice (23.21 t C ha^{-1}). Below 10 cm depth, the soil organic carbon stocks are close to those of the conventional layer (0-30 cm). Total nitrogen (TN), available potassium (AK), and phosphorus (AP) content in 0-10 cm depth under minimum-tillage practice were 19.5%, 2%, and 3%, respectively, compared to the conventional treatment. Overall, the values of TN, AP and AK decreased with depth within the soil profiles as a consequence of soil practice and minimum disturbance. The data indicate that minimum tillage is a sustainable and effective management practice that maintains soil health, promotes soil carbon increase, and facilitates efficient nutrient use.

Keywords: soil health, tillage, soil carbon, soil nutrients

The worldwide production of food depends on soil technologies, which can result in the loss of soil organic carbon (SOC) and nutrient availability, crucial indicators of the agroecosystems' sustainability and the general health of the soil. Preserving the soil's moisture content, organic matter content, nutrient availability to plants, and avoiding erosion and pollution are part of soil management. By using the right tillage techniques, these may be controlled efficiently.

Tillage is the process of preparing soil to support plant growth. Conventional tillage involves disturbing the soil, allowing plant roots to establish (Mihu *el al.,* 2025). This decreases the soil's capacity to retain water, increasing its erosion susceptibility. Conversely, conservative tillage is an approach that minimizes energy, equipment, and moisture loss in addition to promoting soil preservation. The three most common types of conservation tillage are min-tillage, mulch-tillage, and no-tillage. The percentage of surface soil covered by crop residue following planting is used to differentiate between various forms of conservative tillage (Amit *et al.,* 2018). Globally, the most widely used conservative tillage practice is min-tillage. By reducing soil erosion and disturbance of soil aggregates, min-tillage systems limit SOC degradation (Corbeels *et al.*, 2019; Miranda *et al.,* 2016). However, accumulating plant residues on the topsoil layer decreases the interaction between crop residues and soil minerals, which could eventually lead to a gradual decline in SOC stabilization. Additionally, it has been noted that long-term min-tillage or no-tillage adoption reduces crop output, compaction of the soil (Nunes, 2015), and the soil's C input (plant biomass and root exudate). The primary goal of conservation tillage is to prevent soil degradation by preserving agricultural residue in soil, promoting soil organic carbon. Conservation tillage preserves the soil's stability and proper pore distribution, compared to conventional tillage methods that break down soil aggregates and produce a hard pan. (Das *et al.,* 2020). Long-term conservation tillage strategies have been shown to improve nutrient cycling, energy transfers, and soil enzymatic activity; enzymatic activity and soil organic carbon are thought to be closely related to soil health (Dick, 1994).

This study aimed to compare soil organic carbon and nutrient content among two tillage systems (conventional and minimum tillage) in

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three depths (0-10 cm, 10-20 and 20-30 cm) under temperate conditions. We hypothesized that, in terms of improving the chemical quality and soil health, minimum tillage is a suitable practice.

MATERIAL AND METHOD

This study was established in 2019 in the Research Station of Iasi University of Life Sciences (IULS), Romania (47°07′ N latitude, 27°30′ E longitude) Soil is a clay-loam, classified as Chernozem (WRB Classification) with 35% clay, 25% silt and 36.9% sand. The region has a temperate humid subtropical climate—Cfa (Köppen classification), with a mean annual temperature and precipitation of 9.4°C and 517.8 mm (*figure 1*).

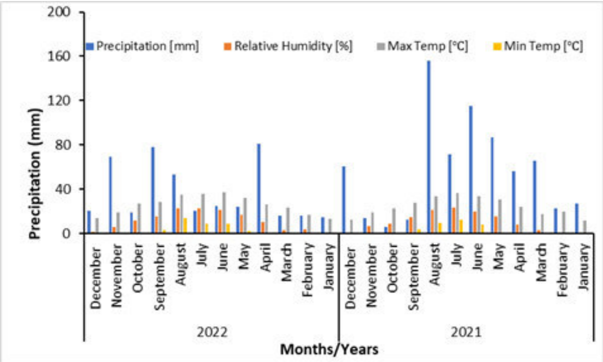

Figure 1 **Temperature, precipitation and humidity data of the study area**

The experiment was performed as a randomized block design with three repetitions, in a winter wheat-soybean-maize rotation system, with the current experiment in wheat. Each plot covered an area of 60 m^2 and was separated by a 1m buffer zone. The experiment was performed with two tillage practices: min-tillage (MT) and conventional tillage (CT) as main plot treatments. In the CT system, straw was chopped between 3-5 cm lengths and placed to a depth of 30 cm using moldboard plowing. For MT, the tillage process involved partial straw removal using a disc harrow treatment at a depth of 25 cm. Winter wheat was planted with the FABIMAG FG01 no-till seeding machine between September 25 and October 5. During the growth season, the recommended dose of 100 kg/ha urea (46% N) is used as base fertilizer before sowing, followed by 180 kg/ha NPK (12:32:16) complex fertilizers during the vegetative stage. The experiment was carried out in rainfed conditions without irrigation. Initially, 3 L/ha of glyphosate was used for weed management, and 0.6 L/ha of 6.25 g/L florasulam + 300 g/L acid 2.4-D EHE were applied to the vegetation.

Following the winter wheat harvest, soil samples of 0-10, 10-20, and 20-30 cm were collected at random from each plot. After removing plant residues, the soil sample was air-dried, mixed completely, sieved through a 2 mm screen, and stored at 4°C for future analysis. Using a Mettler Toledo S210 pH meter, the pH of the soil was measured in a 1:2.5 soil: water ratio. Soil organic carbon was determined using the modified Walkley and Black method, whereas total nitrogen was determined using the conventional Kjeldahl method. Specord Plus UV-Vis Spectrophotometer (Analytikjena, Jena, Germany) was used to measure the amount of accessible potassium and phosphorus at 715 nm after they had been extracted using 1 N NH_4OAc. An Atomic Absorption Spectrometer (ContrAA700, Analytik jena, Jena, Germany) was used to measure the soil's Zn, Cu, Fe, and Mn DTPA extractable micronutrients after they had been agitated for two hours at a 1:2 soil solution ratio and pH 7.3.

RESULTS AND DISCUSSIONS

Influence of tillage practice on soil pH

Our results indicate that the pH of the soil at a depth of 0–30 cm was impacted by the tillage method (*figure 2*). The soil pH levels in all the plots ranged from moderately acidic to neutral, as follows: CT < MT. Surface (0–10 cm depth) soil neutrality was performed with MT (6.87), whereas CT provided an acidified soil layer at 0–30 cm depth. The acidified plowed soil layer (6.29) might be explained by soil disturbance, which increased the rate of straw mineralization and decomposition due to aeration. A further contributor of soil acidity could be fertilizer distribution through the soil at a depth of 0-30 cm; fertilizers include nitrogen in amide form, and releasing protons-H^+ changes ammonium (NH_4-N) to nitrate (NO_3-N), acidifying the soil. These results are comparable with those reported by Dwivedi et al., who found that the tillage methods increased soil acidity in both layers investigated. The neutral pH values under MT might be linked to the soil water diffusion limiting phenomenon, which balanced the pH value by increasing the amount of Na^+, Ca^{2+} and Mg^{2+}, exchangeable cations.

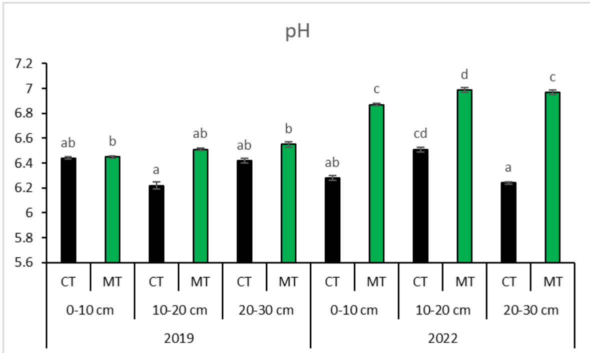

Figure 2 **Dynamics of soil pH at 0–30 cm depths under different tillage, MT: minimum tillage; CT: conventional tillage. Error bars represent the corresponding standard error of mean values. Different letters indicate significant differences between treatments during this period at the 0.05 level.**

Influence of tillage practice on soil SOC and total Nitrogen

Based on tillage practices, conservation tillage treatments can increase agricultural yields by protecting soil structure and enhancing its quality. Because of straw burying and/or mulching, as well as less physical disturbance, MT may improve the fraction of macro-aggregates with higher organic carbon content.

This study found that, compared with CT, MT considerably increased the amount of organic carbon in the 0–10 cm soil layer, from 24.26 t C/ha to 19.36 t C/ha (*figure 3*). MT increased surface soil organic content (0-10 cm), whereas at 10-30 cm depth, soil organic stocks are comparable to those of the plow layer (0-30 cm). Overall, using conservation tillage for two years (2021–2022) performed an increase in surface soil fertility compared to conventional tillage; minimum tillage combined with straw burying is beneficial for improving soil organic carbon because the straw area interacts with soil microorganisms and enzymes, which provide organic matter/humus buildup (Topa *et al.,* 2021).

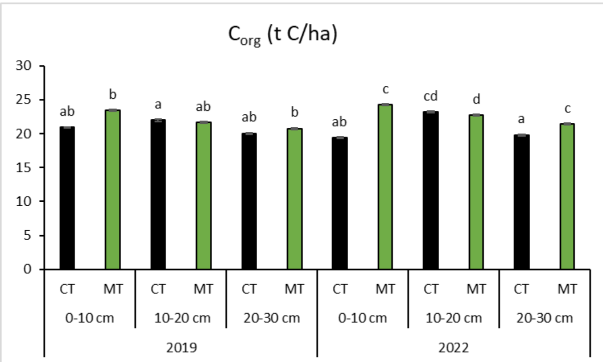

Figure 3 **Dynamics of soil organic carbon at 0–30 cm depths under different tillage, MT: minimum tillage; CT: conventional tillage. Error bars represent the corresponding standard error of mean values. Different letters indicate significant differences between treatments during this period at the 0.05 level**

A significant source of organic nitrogen is soil organic matter, and the dynamics and storage of this element are often linked to those of organic carbon/matter (Das *et al.,* 2020). The influence of the conservation tillage system on the total nitrogen content of the soil was only observed in the 0–10 cm layer, where it increased by 19.5 % in comparison to the CT. MT increased by 15.3 and 21.9%, respectively, in the 10–20 and 20–30 cm layers of total nitrogen. These findings are in line with earlier research showing that the adoption of conservation tillage increases the soil's overall nitrogen concentration. According to (Topa *et al.,*2021) soil total nitrogen buildup was higher under NT and MT after long-term experience.

Influence of Tillage Practice on Soil Available P and K

To ensure optimal crop productivity, phosphorus, a crucial plant nutrient, is required in constant amounts. *Figure 4* shows that under MT as compared to CT, the amount of phosphorus accessible in the 0–30 cm soil increased by 2%. This pattern may be explained by the mineralization and decomposition of soil organic matter driven by tillage practices, which alter the microbial population and soil enzyme diversity and activity, as well as the amount and stoichiometry of soil phosphorus. Increased P content in MT may be connected to higher soil organic carbon content because organic matter can adsorb P while also obstructing de-adsorption centers from clay surfaces, aluminum, and iron oxides. According to the conclusions of (Tiecher *et al.,2018)* the values of accessible P are assigned to higher soil organic matter, chelating the inorganic P linked with the enhancement of organic-inorganic P pool stability.

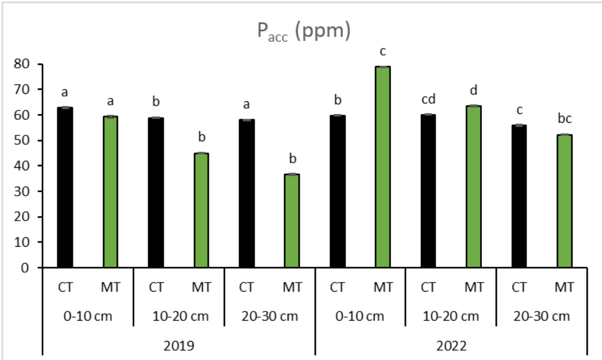

Figure 4 **Dynamics of soil available phosphorus at 0–30 cm depths under different tillage, MT: minimum tillage; CT: conventional tillage. Error bars represent the corresponding standard error of mean values. Different letters indicate significant differences between treatments during this period at the 0.05 level**

A similar trend to that of accessible phosphorus was observed in the distribution of soil-available potassium concentration in a 0–30 cm soil profile. Compared to conventional tillage (186 ppm), the min-tillage practice had more soil accessible K in the 0–10 cm depth (223 ppm). Additionally, the 0–30 cm soil profile was 2.3% higher in MT, which may be due to mineralization and organic matter breakdown. The residues from straw include large amounts of total potassium, which is rapidly transformed into forms that plants can absorb. These findings are following recent research that, in a no-tillage system, showed higher amounts of plant-available potassium at surfaces 0–20 cm, but found no differences at higher soil depths.

Influence of Tillage System on Soil Available and Total Zn, Cu, Fe and Mn

Zn, Cu, Fe, and Mn are micronutrients that are crucial to plant metabolism (Rusu *et. al,* 2023).

A general distribution pattern that followed the order CT > MT suggests that the content of accessible micronutrients is affected by tillage techniques. Table 1 shows a higher concentration and consistent pattern of the 0-30 cm soil accessible microelements under conventional tillage compared to the conservative tillage system MT. These microelements vary in concentration from 1.19 to 4.55 mg kg^{-1} (Zn), 1.09 to 2.10 mg kg^{-1} (Cu), 15.55 to 23.1 mg kg^{-1} (Fe), and 38.98 to 43.10 mg kg^{-1} (Mn), respectively.

Table 1

Effect of tillage and straw practices on soil available micronutrients.

Tillage 0-30 cm	Zn	Cu	Fe	Mn
CT	4.1 ± 0.08 a	1.9 ± 0.02 a	21.2 ± 0.26 a	42.3 ± 0.57 a
MT	1.2 ± 0.01 b	1.1 ± 0.07 b	15.7 ± 0.17 b	39.7 ± 0.54 a

MT: min-tillage; CT: conventional tillage. The date represents means ± SD. Different letters indicate significant differences at the 0.05 level.

In contrast, the stratification pattern/trend for the accessible Zn, Fe, and Mn content was noted, demonstrating the impact of tillage on these microelements. These results contrasted with those of other studies that found that conservation tillage had a greater impact on the soil's accessible micronutrients than CT techniques. Numerous studies indicate that the effects of conservation tillage on the availability, solubility, and mobility of soil micronutrients are extensive, unpredictable, and dependent on a variety of factors, including environmental conditions, soil features (such as soil reactivity and organic carbon concentration), and other factors.

CONCLUSIONS

The impact of conservative tillage on soil qualities and traits, as well as crop quality and quantity, was better understood due to our research conducted over an extended field experiment. The findings suggest that conservation tillage could potentially be used as a practical management option in the conventional farming system of Europe, given the beneficial effects on soil productivity. While maintaining the organic carbon and total nitrogen in a 0–30 cm soil profile, MT changes the chemical characteristics of the soil by reducing soil acidity and increasing the availability of macronutrients. The available micronutrient content (Zn, Cu, Fe, and Mn) showed a stratification tendency in conservative management practice compared to CT.

ACKNOWLEGMENTS

This research was supported by a grant from Climate Change Digital Twin Earth for forecast and societal redressement (grant number: DTEclimate PNRR/2022/C9/MCID/15).

REFERENCES

Amit Ray, 2018 -*Effect of Different Tillage Practices on Soil Health and Yield.* Trends in Biosciences 11(11), Print: ISSN 0974-8431, 2107-2112, https://doi.org/10.13140/RG.2.2.36070.88644.

Corbeels M, Cardinael R, Naudin K, Guibert H, Torquebiau E (2019) *The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-saharan* Africa. Soil Tillage Res 188:16–**26. https://doi.org/10.1016/j.still.2018.02.015.**

Das, A., Layek, J., Idapuganti, R. G., Basavaraj, S., Lal, R., Rangappa, K., et al. (2020). *Conservation tillage and residue management improves soil properties under a upland rice–rapeseed system in the subtropical eastern Himalayas. L*and Degrad. Dev. 31, 1775–1791. doi: 10.1002/ldr.3568.

Dick, R. P. (1994). "*Soil enzymatic activities as indicators of soil quality" in Defining Soil Quality for a Sustainable Environment.* eds. J. W. Doran, D. C. Coleman, D. F. Bezdicek, and B. A. Stewart (Hoboken, NJ: Wiley-Blackwell), 107–124.

Dwivedi, B.S.; Singh, V.K.; Shekhawat, K.; Meena, M.C.; Dey, A. *Enhancing use efficiency of phosphorus and potassium under different cropping systems of India.* Indian J. Fertil. 2017, 13, 20–41.

Miranda E, Carmo J, Couto E, Camargo P (2016) Long-term changes in soil carbon stocks in the Brazilian Cerrado under commercial soybean. L Degrad Dev 27:1586–1594. https://doi.org/10.1002/ldr.2473.

Nunes MR, Denardin JE, Pauletto EA, Faganello A, Pinto LFS (2015) *Mitigation of clayey soil compaction managed under no-tillage.* Soil Tillage Res 148:119–126. https://doi.org/10.1016/j.still.2014.12.007.

Mihu, G.-D.; Aostăcioaei, T.G.; Ghelbere, C.; Calistru, A.-E.; Topa, D.C.; Jităreanu, G. *Exploring Soil Hydro-Physical Improvements Under No-Tillage: A Sustainable Approach for Soil Health.* Agriculture 2025, 15, 981. https://doi.org/ 10.3390/agriculture15090981.

Rusu, M.; Cara, I.G.; Filip, M.; Calistru, A.-E.; Țopa, D.; Jităreanu, G. *Transfer of heavy metals in soil in-plum cultivation: a field study in Adamachi Iasi, Romania.* Journal of Applied Life Sciences and Environment 2023, 56 (1), 59-74.

Tiecher, T.; Gomes, M.V.; Ambrosini, V.G.; Amorim, M.B.; Bayer, C. *Assessing linkage between soil phosphorus forms in contrasting tillage systems by path analysis.* Soil till. Res. 2018, 175, 276–280.

Topa, D.; Cara, I.G.; Jitareanu, G.; 2021- *Long term impact of different tillage systems on carbon pools and stocks, soil bulk density, aggregation and nutrients: A field meta-analysis*. Catena, 199, 105102.

SALT ACCUMULATION IN POLYTUNNEL SOILS UNDER TOMATO CULTIVATION IRRIGATED WITH SURFACE WATER

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Abstract

Tomatoes cultivated in polytunnels require frequent irrigation due to high evapotranspiration rates and intensive production. When surface water from rivers or lakes is used, its elevated mineral content can gradually lead to soil salinization and structural alterations. The accumulation of salts in the root zone negatively affects tomato growth and yield, mainly by reducing water uptake and causing nutrient imbalances. This study investigates salt accumulation in the soil over the course of one growing season in a polytunnel located in Iași County, Romania. Soil samples collected before and after the season confirmed a progressive buildup of salts, highlighting the long-term risks associated with the repeated use of mineral-rich surface water in protected tomato cultivation systems. Every two weeks, analyses of irrigation water samples revealed carbonate concentrations ranging from 0.4 to 0.8 me/L, with maximum values of 2.85 me/L, and bicarbonate concentrations between 2.34 and 5.81 me/L. The results suggest that even within a single cultivation cycle, measurable salinization can occur, potentially predisposing soils to degradation over time.

Key words: carbonates, SAR, soil pH, soil salinity, TDS

The cultivation of tomatoes in polytunnels is an increasingly widespread agricultural practice in Romania, due to the advantages related to protection against adverse climatic factors and the extension of the growing season. However, the frequent use of irrigation water with high mineral content, often from surface water sources, can lead to the accumulation of salts in the soil and structural changes, negatively affecting crop growth and yield. Studies have shown that high soil salinity negatively influences tomato growth by reducing water uptake and causing nutrient imbalances (Roșca *et al*, 2023; Karaca *et al*, 2022).

In soil, salts gradually accumulate through repeated application of mineral-rich irrigation water, and their movement depends on soil texture, structure, and the irrigation regime. Consequently, salts can migrate to deeper layers, affecting the root zones and reducing nutrient uptake efficiency (Jiang et al., 2025; Cantore et al., 2012; Razi & Khadhir, 2021).

Over time, excessive salt accumulation can lead to increased soil electrical conductivity and osmotic stress in plants, precipitation of calcium and magnesium carbonates that can alter soil structure, as well as variations in soil pH. These changes may cause structural degradation of the soil, reducing its capacity to support optimal plant development (Yan *et al*, 2024; Furdi *et al*, 2013).

In this context, the present study aims to investigate salt accumulation in the soil over a growing season in a polytunnel located in Iași County, Romania. By monitoring irrigation water weekly and analyzing soil samples collected at different depths, the study seeks to highlight the long-term risks associated with the repeated use of mineral-rich water for irrigating tomatoes in protected systems.

MATERIAL AND METHOD

The experiment was carried out in a 600 m² polytunnel located in Iași County, cultivated with tomato, grown in a single cropping cycle The crop was established in March 2024, and harvesting was carried out from June 10 to October 22, 2024. Fertilization was applied at a rate of 60 tons/ha of fermented manure and incorporated into the soil prior to mulching. Soil beds were then covered with polyethylene film, and drip irrigation was applied. Irrigation water originated from the Jijia River and was collected directly from the drip irrigation tapes inside the polytunnel.

The applied irrigation regime provided a weekly water volume of 8–12 m³, depending on the developmental stage of the plants.

Soil sampling was performed before irrigation at four depths, taken at 10 cm intervals depth. The soil was analyzed for carbonate, bicarbonate, and TDS, as well as for organic matter, phosphorus (P), and potassium (K), with P

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and K extracted in water, in order to assess both salt accumulation and overall soil fertility. Water samples were collected at every two-week irrigation event. All analyses were conducted in the “Plant Nutrition and Soil Fertility” Laboratory of the “Ion Ionescu de la Brad” Iași University of Life Sciences.

The following analytical methods were applied:

- Soil and water pH was measured in a 1:5 soil-to-water suspension using a glass electrode from Hannah Instruments.
- Total dissolved salts (TDS) were determined using the gravimetric method, by evaporating the water and weighing the residual solids.
- Calcium and magnesium concentrations were quantified by complexometric titration with EDTA (Complexon III), classical method.
- Sodium and potassium content was measured using flame photometry, allowing precise determination of alkali metal concentration.
- Carbonates and bicarbonates in water were determined by acid titration with sulfuric acid in the presence of phenolphthalein and methyl orange indicators, a standard volumetric procedure.
- Chlorine concentration in soil was determined by Mohr method
- SAR Sodium Adsorption Ratio - mathematical calculation

Sampling and analyses were repeated every two weeks, throughout the growing season, for the irrigation water to assess the dynamics of salinity and mineral accumulation.

RESULTS AND DISCUSSIONS

During the vegetation period, the irrigation water content showed significant variations, influenced both by spring precipitation and by high summer temperatures. The values of the analyzed water parameters provide a clear picture of its quality and allow for their classification within the accepted limits (**Table 1**).

Table 1

Recommended chemical content of the irrigation water

Water Parameter	Desired Range
pH	6.5–8.4
ECw	<0.75 dS/m
TDS	<480 ppm
SAR	<6
Hardness	>50 and <150 ppm
CO_3^{2-}	<0.5 meq/L
HCO_3^-	<2 meq/L
Cl	<70 ppm
B	<0.5 ppm

The average concentrations of carbonates and bicarbonates were approximately twice the recommended levels, namely 0.9 meq/L for CO_3^{2-} and 4.3 meq/L for HCO_3^-. The pH of the irrigation water, recorded during the first five irrigations in April–May, remained within the neutral range. However, starting in June, the water reaction became alkaline, reaching maximum values of 9.1 (Table 2).

The slight variation in bicarbonate content indicates that these ions remained in solution, while the increase in carbonate concentration correlates with the marked rise in pH, which exceeded the maximum recommended value for irrigation water.

Table 2

Chemical content of the irrigation water*

Parameter	pH	TDS (mg/L)	SAR	CO_3^{2-} (meq/L)	HCO_3^- (meq/L)	Na^+ (meq/L)	Ca^{2+} (meq/L)	Mg^{2+} (meq/L)
U1	7.4	400	3.82	0.82	4.99	6.09	1.82	3.26
U2	7.7	470	4.04	0.61	4.79	6.26	2.02	2.78
U3	7.5	420	3.89	0.82	5.81	6.43	2.11	3.36
U4	7.7	330	4.00	0.41	4.79	6.22	1.82	3.02
U5	7.3	380	4.01	0.41	5.20	6.09	1.44	3.17
U6	8.1	330	4.40	0.41	2.34	6.26	1.06	2.98
U7	8.5	300	4.52	2.85	4.69	6.26	0.96	2.88
U8	8.8	320	4.40	1.20	3.46	6.09	1.06	2.78
U9	9.1	360	4.38	1.22	2.65	6.43	1.15	3.17
Mean	8.0	367	4.16	0.97	4.30	6.2	1.50	3.00
Min.	7.3	300	3.82	0.41	2.34	6.09	0.96	2.78
Max.	9.1	470	4.52	2.85	5.81	6.43	2.11	3.36
Median	7.7	360	4.04	0.82	4.79	6.26	1.44	3.02
Interval	1.8	170	0.70	1.44	3.47	0.34	1.15	0.58

*analyses were performed on 9 samples(U1-U9) taken in April-July

The concentrations of sodium, calcium, and magnesium were analyzed to determine the Sodium Adsorption Ratio (SAR). A greater variation was observed in calcium content (range: 1.15), a smaller variation in magnesium (range: 0.58), and high stability in sodium (range: 0.34). This indicates that calcium and magnesium ions are prone to precipitation, while sodium remains in solution. Under these conditions, the SAR showed slight increases, reaching a maximum value of 4.52, which remains below the maximum limit allowed for irrigation water. The total dissolved solids (TDS) content ranged between 300 and 470 ppm, with only the maximum value reaching the upper admissible limit (Table 2).

Soil analysis was carried out at the beginning of May at two depths. The soil is classified as moderately alkaline, with a pH of 8.1–8.2, and shows a higher TDS content in the upper layer. A higher concentration was also observed for chloride ions, with values decreasing from 22.5 meq/L to 15 meq/L at a depth of 20–40 cm (Table 3). These two factors negatively affect plant development due to their high presence in the plant root zone.

The observed vertical distribution of chloride and total dissolved solids indicates a strong accumulation of soluble salts in the upper 0–20 cm layer, which is typical for clay loam soils under greenhouse conditions (Table 3). Similar trends were reported in irrigated vegetable systems in northeastern Romania, where limited drainage and high evapotranspiration favored surface accumulation of salts (Stan et al., 2022). Such accumulation poses potential risks for tomato crops, as both salinity and alkalinity can alter nutrient uptake and root physiology (*Qadir et al*, 2007).

Table 3

Soil parameters in May, 2024

Parameters of soil salinity	0–20 cm depth	20–40 cm depth
pH	8.1	8.25
TDS (%)	0.49	0.17
Cl^- (meq/kg)	22.5	15.0
Ca^{2+} (meq/kg)	2.2	4.8
Mg^{2+} (meq/kg)	12.5	12.0
K^+ (meq/kg)	7.0	5.5
Na^+ (meq/kg)	3.4	3.0
CO_3^{2-} (meq/kg)	0.1	0.1
HCO_3^- (meq/kg)	0.8	1.01
$CaCO_3$ (%)	18.1	20.3

The seasonal evolution of total dissolved solids (TDS) in the soil profile is illustrated in Figure 1. The data reveal a distinct temporal and vertical pattern. The mean TDS values increased from 0.33% in May to a peak of 0.64% in July, followed by a decline to 0.36% in October.

This pattern corresponds to the combined influence of temperature, irrigation frequency and evapotranspiration intensity. During the summer months, higher evaporation rates and repeated irrigation promote the upward movement of salts, leading to surface accumulation (Rhoades *et al*, 1992; Qadir *et al*, 2007).

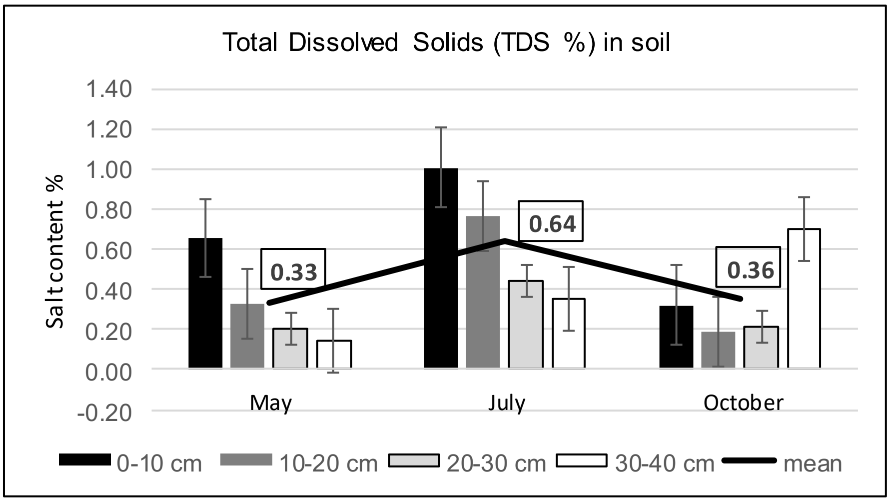

Figure 1 **The impact of irrigation water on soil TDS (%), year 2024**

Throughout the season, the highest TDS values were consistently recorded in the 0–10 cm soil layer, while the lowest values appeared at 30–40 cm, showing a decreasing gradient with depth. Such a distribution suggests limited leaching and confirms the tendency for salts to concentrate within the rhizosphere in greenhouse conditions (Bauder *et al*, 2014; Al-Rawahy *et al*, 2011).

The mid-season maximum observed in July coincides with periods of increased irrigation and the highest air temperatures, when evapo-concentration processes dominate. Similar behavior was described in studies on tomato crops irrigated with river and well water sources, where salinity peaks occurred during summer (Karaca *et al*, 2022).

The decline in TDS values recorded in October can be explained by reduced irrigation intensity and partial leaching due to autumn precipitation. These processes allow a temporary downward migration of salts, as also observed by Stan *et al* (2022) in Moldavian soils with comparable texture and water regime. However, the persistence of higher salt contents in the upper layer suggests that leaching is incomplete, emphasizing the importance of active management practices to prevent long-term accumulation.

The measured pH (up to 9.1), high bicarbonate and carbonate levels, and moderate TDS values point to a potential bicarbonate-induced alkalinity hazard. When calcium and magnesium precipitate as carbonates, the effective sodium proportion in the soil solution increases, potentially elevating SAR and impairing soil structure over time (Bauder *et al*, 2014; Jalali & Najafi, 2010). Although current SAR levels remain within the safe range, continued use of such irrigation water, combined with poor drainage typical of greenhouse systems, may gradually enhance sodicity risks (Ayers & Westcot, 1985; Al-Rawahy *et al*, 2011).

CONCLUSIONS

Irrigation with surface water characterized by elevated carbonate and bicarbonate levels led to slight soil alkalization and promoted salt accumulation in the upper soil layer.

Vertical distribution of salts revealed a decrease in TDS with depth, indicating limited leaching and a tendency for salt accumulation in the root zone.

Although SAR and TDS values remained within acceptable limits, continuous monitoring and periodic leaching are essential to prevent long-term soil salinization.

These findings highlight the importance of regular monitoring of irrigation water quality and soil salinity in greenhouse tomato cultivation. Implementing preventive management practices such as leaching and calcium amendments can ensure sustainable soil fertility and maintain long-term crop productivity under semi-arid conditions.

REFERENCES

Al-Rawahy, S. A., Ahmed, M., Prathapar, S. A., 2011 - *Impact of irrigation water quality on soil properties in arid regions.* Agricultural Water Management, 98(5), 795–801.

Ayers, R. S., Westcot, D. W., 1985 - *Water Quality for Agriculture.* FAO Irrigation and Drainage Paper 29 Rev.1.

Bauder, J. W., Bauder, T. A., Waskom, R. M., 2014 - *Managing Sodic Soils.* Colorado State University Extension.

Cantore, V., et al., 2012 – *Influence of Salinity and Water Regime on Tomato for Greenhouse Cultivation*, ScienceDirect, available on-line at: https://www.sciencedirect.com/science/article/pii/S1125471824008211

Furdi, F., et al., 2013 – *The Effect of Salt Stress on Proline Accumulation in Several Tomato Varieties*, CAB International, available on-line at: https://www.cabidigitallibrary.org/doi/pdf/10.5555/20133364773

Jalali, M., & Najafi, S., 2010 - *Effects of irrigation water quality on soil chemical properties in a semi-arid area of Iran***.** Irrigation and Drainage Journal, 59(3), 283–294.

Jiang, W., et al., 2025 – *Optimal Irrigation Water Salinity Enhances Tomato Growth in Yellow Sand Substrate*, ScienceDirect, available on-line at: https://www.sciencedirect.com/science/article/pii/S0378377425003464

Karaca, C., et al., 2022 – *Effects of Salinity Stress on Drip-Irrigated Tomatoes Grown in Two Different Growing Seasons*, MDPI Agronomy, available on-line at: https://www.mdpi.com/2073-4395/13/1/36

Malakar, A., et al., 2019 - *Irrigation water quality—A contemporary perspective***.** Water, 11(7), 1482.

Qadir, M., Qureshi, A. S., Cheraghi, S. A. M., 2007 - *Sodicity-induced land degradation and management options.* Land Degradation & Development, 19(4), 429–453.

Razi S., Khadhir FZ., 2021 - ***Effects*** *of salinity on growth and proline content on bean and alfalfa*, Journal of Applied Life Sciences and Environment 54, no. 2: 132-145. https://doi.org/10.46909/journalalse-2021-013

Rhoades, J. D., Kandiah, A., Mashali, A. M., 1992 - *The Use of Saline Waters for Crop Production.* FAO Irrigation and Drainage Paper 48.

Roşca, M., et al., 2023 – *Tomato Responses to Salinity Stress: From Morphological to Molecular Aspects*, Frontiers in Plant Science, https://www.frontiersin.org/articles/10.3389/fpls.2023.1118383/full

Stan, C. O., et al., 2022 - *Risk of salinization in the agricultural soils of semi-arid regions: Case study NE Romania*. Sustainability, 14(9), 5173.

Yan, B., et al., 2024 – *Towards Sustainable Productivity of Greenhouse Vegetables: Managing Soil Salinization*, MDPI, available on-line at: https://pmc.ncbi.nlm.nih.gov/articles/PMC11511448/

CAUSATIVE AGENTS OF ROOT ROT IN WINTER WHEAT

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Abstract

Knowledge of the composition of fungal species that cause root rot in common wheat is of great importance for the development of correct protection measures and serves as methodological support in pathogen resistance screening systems. In our research, 14 fungal species involved in the development of the disease in 2024 under the conditions of the Republic of Moldova were recorded. An increase in the frequency of the fungi *Fusarium culmorum* (24%) and *F. equiseti* (31.8%) was reported. Cluster analysis demonstrated the important role of the variety in the frequency of fungal spread. It was found that one of the most widespread causative agents of root rot – *Fusarium oxysporum* can cause both inhibition and stimulation of plant growth, as well as a change in the spectrum of phenotypic classes in segregating F_2 populations. The orientation of the crossing of the parents when creating F_1 wheat hybrids significantly influences the reaction of plants to the pathogen, but also their variability in terms of growth and development traits.

Keywords: wheat, fungi, root rot, variability.

In the context of increasingly alarming climate change over the last two decades, issues related to crop plant resistance to pathogens are becoming more relevant. Sudden fluctuations in temperature and humidity cause serious physiological disturbances in plants, making them increasingly susceptible to various fungal diseases.

Although common wheat (*Triticum aestivum* L.) is adapted to various growing conditions, it is vulnerable to soil-borne pathogens that cause various diseases, one of the most widespread being root rot – a major problem worldwide. The disease manifests itself through rotting of the root system in the soil, the base of the stem, wilting of plants, weight loss of plants and grains. Along with this, many pathogens are active producers of mycotoxins, thus contributing to the pollution of grains and increasing their toxicity. All these manifestations lead to plant weakness and crop losses (Kiecana I. *et al*, 2016). Root rot is a unique disease, as it is caused by different causative agents. Pathogens are extremely labile to climate changes – temperature, drought, humidity and soil acidity, but also to changes in agrotechnical conditions and the genotypic structure of the crops.

Recently, some authors have drawn attention to the important role of increasing the concentration of CO_2 in the atmosphere on the increase in the pathogenicity of some fungi involved in the development of the disease, such as *Fusarium equiseti* (Gilardi G. *et al*, 2018), which is usually considered a species with weak virulence.

Establishing of the composition of fungal species that cause one or another disease in crop plants is of great importance for the development of correct protection measures and serves as methodological support in pathogen resistance screening systems.

The purpose of the research was to establish the composition of fungal species that cause root rot in common wheat under the conditions of the Republic of Moldova and the influence of the most widespread ones on plant variability in segregating populations.

MATERIAL AND METHOD

The study material was winter wheat plants grown on the experimental sector of the Institute of Genetics, Physiology and Plant Protection, Moldova State University.

The samples presented individual selections from common wheat varieties approved in the Republic of Moldova and Romania. The research was carried out in the conditions of 2024.

The assessment of the degree of root rot attack was carried out at the technical ripening stage of the berries by examining the affected surface at the base of the stem on a 5-step scale: 0 – healthy plant, 0.1 – punctate necrosis, 1 – 5-10%, 2 – 20-50%, 3 – 60-100% of the surface.

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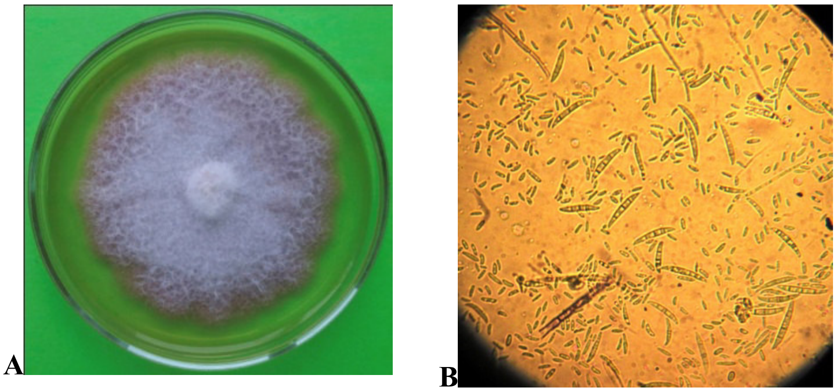
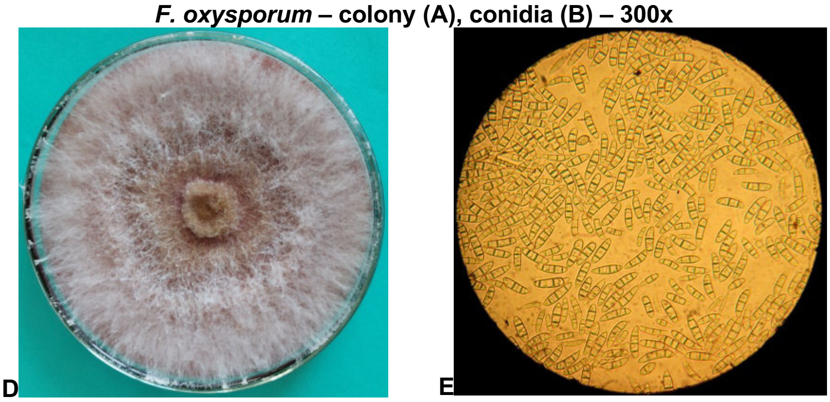
Figure 1 **Appearance of isolated fungi from the base of the wheat stem on PDA medium**



***F. oxysporum* – colony (A), conidia (B) – 300x**



***F. culmorum* – colony (A), conidia (B) – 300x**

Figure 2 **Macro- and microscopic aspects of some fungi isolated from the base of the wheat stalk**

Isolation of pathogens from plants with disease symptoms was performed on the solid nutrient medium PDA (Potatoe Dextrose Agar) (figure 1), and determination of the fungal species – based on macro- and microscopic analyses (Barnet H.L., Hunter B.B., 1998) (figure 2).

The Margalef diversity index of fungal species was calculated according to the formula (S-1/lnN), and the Berger-Parker dominance index: N max/N total (Margalef R., 1968; Caruso T. et al, 2007; Kitikidou, K. et al, 2024).

The F. oxysporum culture filtrate was prepared on the basis of Cszapek liquid nutrient medium (Methods of experimental mycology, 1982).

The obtained data were statistically processed in the STATISTICA 7 software package through variance analysis, cluster analysis (dendrograms, k-means), and plant distribution histograms.

RESULTS AND DISCUSSIONS

It was found that the degree of root rot attack on the 5 wheat genotypes under study was 1.07 ... 1.41, so the attack was of medium level (*table 1*). The frequency of isolated fungal species varied within wide limits: *F. oxysporum* (6.2%), *F. oxysporum* var. *orthoceras* (6.7%), *F. solani* (1,7%), *F. moniliforme* var. *lactis* (0.6%), *F. culmorum* (24%), *F. equiseti* (31.8%), *F. acuminatum* (5%), *F. graminearum* (0.6%), *Drechslera sorokiniana* (9.5%), *D. avenae* (4.5%), *D. biseptata* (1.1%), *Rhizoctonia solani* (1.1%), *Sclerotium rolfsii* (5%), *Mycelia sterilia* (2.2%).

F. oxysporum/F. oxysporum var. *orthoceras* were recorded in all samples. It is worth noting that *F. oxysporum* is one of the most widespread and virulent fungi that causes root rot in cereal crops, including wheat (Özer G. *et al*, 2023). In the Republic of Moldova, *Fusarium oxysporum* var. *orthoceras* are the more widespread variety (Lupașcu G. *et al,* 2008; Lupașcu G., 2020). Lately, in the conditions of the Republic of Moldova, there has been a decrease in the incidence of this fungus as a result of ecological imbalances that favor the development and spread of others.

Of interest is the rather high frequency (24%) of the fungus *F. culmorum* (*table 2*), which in previous years was not isolated at all from wheat plants with signs of root rot or was recorded in very limited numbers. The increase in the incidence of this fungus is probably due to the frequent association of dry periods with low nighttime temperatures in the conditions of the Republic of Moldova. According to some data, *F. culmorum* is dominant in colder and semi-arid areas, such as North Dakota (USA) (Shrestha S. et al, 2021), northern, central and western Europe (Wagacha J.M., Muthomi J.W., 2007).

Table 1

Composition of fungal species – causal agents of root rot in wheat

Genotype	Root rot, degree		Fungus species	Isolates, number	Frequency, %
	$x \pm m_x$	σ			
Moldova 16	1,07±0,12	0,67	*F. oxysporum* var. *orthoceras*	4	11,4
			F. solani	1	2,9
			F. culmorum	20	**57,1**
			F. equiseti	1	2,9
			F. acuminatum	3	8,6
			Drechslera avenae	3	8,6
			D.biseptata	1	2,9
			Rhizoctonia solani	2	5,7
			Total:	***35***	***100***
Amor	1,23±0,17	0,91	*F. oxysporum* var. *orthoceras*	2	7,1
			F. solani	1	3,6
			F. culmorum	12	**42,9**
			F. graminearum	1	3,6
			F. equiseti	7	**25,0**
			Sclerotium rolfsii	1	3,6
			Mycelia sterilia	4	14,3
			Total:	***28***	***100***
Miranda	1,33±0,12	0,68	*F. oxysporum* var. *orthoceras*	1	3,1
			F. moniliforme var. *lactis*	1	3,1
			F. equiseti	23	**71,9**
			F. acuminatum	5	**15,6**
			Sclerotium rolfsii	2	6,3
			Total:	***32***	***100***
Moldova 66	1,41±0,12	0,66	*F. oxysporum*	11	**21,6**
			F. culmorum	10	**19,6**
			F. equiseti	13	**25,5**
			F. acuminatum	1	2,0
			D. sorokiniana	10	**19,6**
			D. avenae	5	9,8
			D.biseptata	1	2,0
			Total:	***51***	***100***
Centurion	1,12±0,14	0,80	*F. oxysporum* var. *orthoceras*	5	15,2
			F. solani	1	3
			F. culmorum	1	3
			D. sorokiniana	7	21,2
			F. equiseti	13	**39,4**
			Sclerotium rolfsii	6	18,2
			Total:	***33***	
			TOTAL for 5 genotypes:	***179***	

Table 2

Frequency of fungal species – causal agents of root rot in wheat

Nr.	Species	Isolates, number	Frequency, %
1	*Fusarium oxysporum*	11	6,15
2	*F. oxysporum* var. *orthoceras*	12	6,70

3	*F. solani*	3	1,68
4	*F. moniliforme* var. *lactis*	1	0,56
5	*F. culmorum*	**43**	**24,02**
6	*F. equiseti*	**57**	**31,84**
7	*F. acuminatum*	9	5,03
8	*F. graminearum*	1	0,56
9	*Drechslera sorokiniana*	17	9,50
10	*D. avenae*	8	4,47
11	*D. biseptata*	2	1,12
12	*Rhizoctonia solani*	2	1,12
13	*Sclerotium rolfsii*	9	5,03
14	*Mycelia sterilia*	4	2,24
	Total:	***179***	***100***

It was found that the Margalef diversity index was 2.51, and the Berger-Parker dominance index: 0.32 for the species *F. equiseti*.

The dendrogram of the distribution of fungal species based on their frequency in the 5 wheat varieties demonstrates the existence of similarities but also differences, which led to the formation of clusters, different in size according to the number of members (species) and level of aggregation / similarity (*figure 3*).

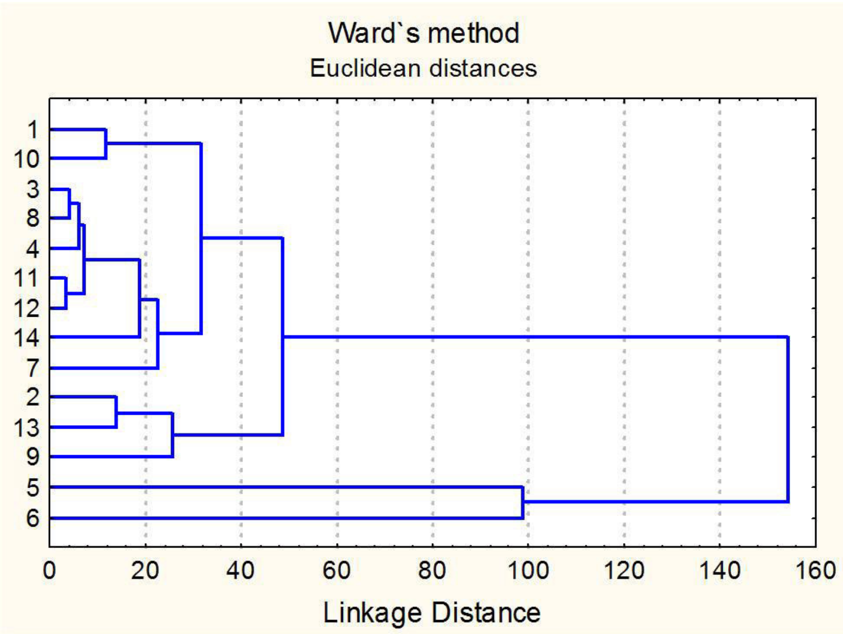


Figure 3 Dendrogram of fungal species distribution based on frequency similarity in wheat plants

Vertically: 1 – *Fusarium oxysporum,* 2 – *F. oxysporum* var. *orthoceras,* 3 – *F. solani,* 4 – *F. moniliforme* var. *lactis,* 5 – *F. culmorum* , 6 – *F. equiseti,* 7 – *F. acuminatum,* 8 – *F. graminearum,* 9 – *Drechslera sorokiniana,* 10 – *D. avenae,*11 – *D. biseptata,*12 – *Rhizoctonia solani,* 13 – *Sclerotium rolfsii,*14 – *Mycelia sterilia*

The calculation of inter- and intracluster distances by the centroid clustering method (k-means) demonstrated that, with the exception of the Moldova 66 variety, the distance between clusters was much greater than within it, which denotes the successful separation/classification of fungal species according to frequency. The ratio of intercluster to intracluster distance demonstrated that the highest capacity for differentiating fungi based on frequency was recorded by Moldova 16 and Miranda (*table 3*).

Table 3

Analysis of variance

Genotip	Between SS (1)	df	Within SS (2)	df	F	Signif. p	Variance ratio 1/2
Moldova 16	2821.64	2	135.57	11	114.47	0.00	20.8
Amor	1836.10	2	207.38	11	48.70	0.00	8.9
Miranda	4551.01	2	240.58	11	104.04	0.00	19.0
Moldova 66	570.78	2	702.68	11	4.7	0.04	0.81
Centurion	1123.55	2	744.24	11	8.0	0.01	1.5

From the first genotype were extracted the most isolates *F. culmorum* (57.1%), and from the 2nd – the most isolates *F. equiseti* (71.9%). Therefore, it could be assumed that wheat varieties exhibit some specificity of susceptibility to root rot causative agents.

Recently, there has been a growing interest in plant-fungal interactions that can have strong effects on plant density, both through direct actions on plant performance/vigor and indirectly – on fungal/plant competition, but also through selective promotions of some species. Most of the evidence demonstrating certain links between plant abundance derives from direct fungal effects on initial growth, but with little evidence linking fungal effects on plant-plant interactions in intact communities (Bennett J., Cahill J.F., 2016).

Our research on the influence of treating wheat grains with CF *F. oxysporum* for 18 hours demonstrated that in the segregating F_2 Moldova 11 x Centurion population, the pathogen produced inhibition of embryonic radicle growth by 17.3% (*figure 4*).

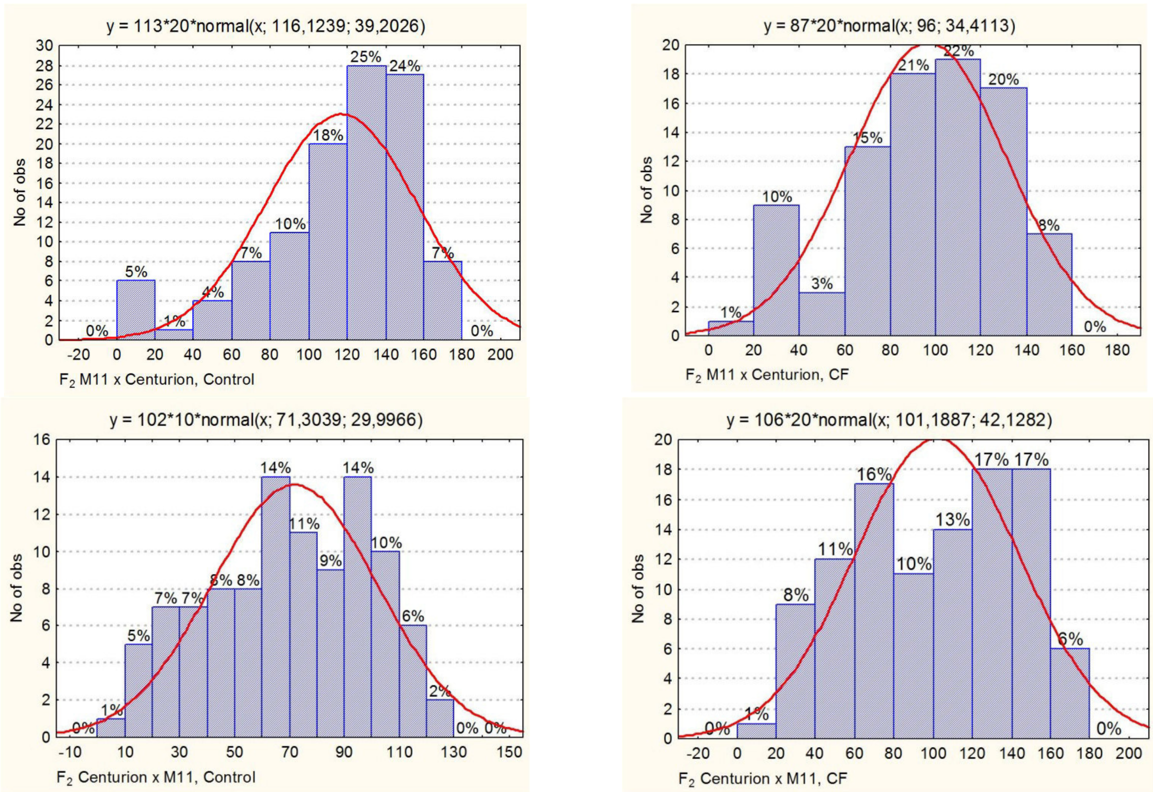


Figure 4 Influence of the *F. oxysporum* culture filtrate on the distribution of wheat plants into phenotypic classes based on embryonic root length

At the same time, changes in the spectrum of phenotypic classes were observed under the influence of the pathogen. Thus, in the CF variant, the "160-180 mm" class, recorded in the control variant, was not found.

It is worth noting that in the F_2 population Centurion x Moldova 11, unlike the previous population, CF stimulated the growth of the embryonic radicle, the length of which was 41.9% greater than in the control variant. At the same time, under the influence of CF in the spectrum of phenotypic classes, 2 new classes appeared: "140-160 mm" and "160-180 mm", which together constituted 23% of the general population.

The obtained data demonstrate that the phenomenon of *plant – F. oxysporum* interaction strongly influences the effect of the pathogen on plant growth, but also on their variability. At the same time, the direction of crossing parental forms to obtain F_1 hybrids significantly influences the reaction of wheat plants in segregating populations, which is of great importance in the development of strategies for carrying out breeding programs.

CONCLUSIONS

1. Macro- and microscopic research of 179 fungal isolates extracted from common winter wheat plants with signs of rot at the base of the stem established the presence of 14 species/variations – *Fusarium oxysporum* (6.2%), *F. oxysporum* var. *orthoceras* (6.7%), *F. solani* (1,7%), *F. moniliforme* var. *lactis* (0.6%), *F.*

culmorum (24%), *F. equiseti* (31.8%), *F. acuminatum* (5%), *F. graminearum* (0.6%), *Drechslera sorokiniana* (9.5%), *D. avenae* (4.5%), *D. biseptata* (1.1%), *Rhizoctonia solani* (1.1%), *Sclerotium rolfsii* (5%), *Mycelia sterilia* (2.2%).

2. Through cluster analysis methods (dendrogram, *k*-means) it was found that the wheat variety factor is of great importance in the classification of fungal species based on colonization frequency, which signifies some specificity of sensitivity of genotypes for the causal agents of root rot.

3. It was found that the treatment of wheat grains with *F. oxysporum* culture filtrate influences the growth of the embryonic radicle by inhibition or stimulation and the spectrum of phenotypic classes in the F_2 segregating populations. These phenomena are determined by the direction of crossing when obtaining F_1 hybrids, which should be taken into account when carrying out breeding programs for root rot resistance.

ACKNOWLEDGMENTS

The research was carried out within the framework of project "23.70105.5107.04. Identifying and capitalizing on the valuable parents of agricultural crops in the creation of a native genetic base of socio-economic interest", financed by the National Agency for Research and Development of the Republic of Moldova (2024-2025).

REFERENCES

Barnet H.L., Hunter B.B., 1998 - *Illustrated Genera of Imperfect Fungi*. 4th Edition, APS Press, 218. http://apspress.edu.com

Bennett J., Cahill J.F., 2016 - *Fungal effects on plant–plant interactions contribute to grassland plant abundances: evidence from the field*. Journal of Ecology, 104:755–764.

Caruso T., Pigino G., Bernini F., Bargagli R., Migliorini M., 2007 - The Berger-Parker index as an effective tool for monitoring the biodiversity of disturbed soils: A case study on Mediterranean oribatid (Acari: Oribatida) assemblages. Biodiversity and Conservation, 16:3277-3285.

Gilardi G., Garibaldi A., Gullino M. L., 2018 - *Emerging pathogens as a consequence of globalization and climate change: leafy vegetables as a case study*. Phytopathologia Mediterranea, 57, 1:146−152

Kiecana I., Cegiełko M., Rachoń L., Pastucha A., Wit M., Pojmaj M., 2016 - *The occurrence of fungi on roots and stem bases of Triticum aestivum ssp. spelta L. Thell. grown under two levels of chemical protection and harmfulness of Fusarium graminearum Schwabe to seedlings of selected genotypes.* Acta Agrobot., 69(3):1657.

Kitikidou, K., Milios, E., Stampoulidis, A., Pipinis, E., Radoglou, K., 2024 - *Using Biodiversity Indices Effectively: Considerations for Forest Management. Ecologies, 5*(1):42-51.

Lupașcu G., 2020 - Putregaiul de rădăcină la grâul comun de toamnă. Chisinău: Print-Caro, 120 p.

Lupaşcu G., Saşco E., Gavzer S., 2008 - *Componenţa speciilor de fungi care produc boli la Triticum aestivum L.* Buletinul A.Ş.M. Seria Ştiinţele vieţii, 2 (305):66-73

Margalef R., 1968 - Perspectives in Ecological Theory. University of Chicago Press, Chicago, IL, p.111.

Methods of experimental mycology, 1982, Kiev: Naukova dumka, 550 c. (Ru).

Özer G., Erper İ., Yıldız Ş., Bozoğlu T., Zholdoshbekova S., Alkan M., Tekin F., Uulu T.E., İmren M., Dababat A., Derviş S., 2023 - *Fungal Pathogens Associated with Crown and Root Rot in Wheat-Growing Areas of Northern Kyrgyzstan*. J. Fungi (Basel). 9(1), 124.

Shrestha, S., Poudel, R. S., Zhong, S., 2021 - *Identification of Fungal Species Associated with Crown and Root Rots of Wheat and Evaluation of Plant Reactions to the Pathogens in North Dakota.* Plant Dis., 105(11):3564-3572.

Wagacha, J.M., Muthomi, J.W., 2007 - *Fusarium culmorum: Infection Process, Mechanisms of Mycotoxin Production and Their Role in Pathogenesis in Wheat*. Crop Protection, 26:877-885

THE EVALUATION OF THE QUALITY INDICES OF - AGRICULTURAL RESIDUES- STRAW OF SOME *POACEAE* SPECIES

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Abstract

The objective of this research was to evaluate the quality indices of agricultural residues straws of *Avena nuda, Dactylis glomerata, Lolium perenne, Triticum aestivum ssp. spelta, Zea mays saccharata* collected in the experimental plot of the NBGI Chişinău. It has been found that biochemical composition of the collected dry phytomass was 47-64 g/kg CP, 38-72 g/kg ash, 382-473 g/kg CF, 407-501 g/kg ADF, 692-797 g/kg NDF, 38-64 g/kg ADL, 369-437 g/kg Cel, 254-299 g/kg HC. The forage value of studied straws was 49.9-57.2% DMD, 8.26-9.37 MJ/kg ME, 4.28-5.35 MJ/kg NEl. The substrates from studied straws achieved biochemical biomethane potential 271-309 L/kg organic dry matter and theoretical ethanol yield averaged 476-523 L/t organic dry matter. The net calorific value of studied straws varied from 14.7 to16.4 MJ/kg.

Keywords: agricultural residues, biochemical composition, biomethane potential, calorific value, feed value, straw, theoretical ethanol yield

Agriculture is one of the largest sectors, which produces high amounts of biomass that can be an important input for the bioeconomy.

Traditionally, some crop residues have been used as animal fodder, roof thatching, composting, soil mulching, matchstick and paper production.

Forest and crop residues biomass are the first and oldest source of energy that people used for heating, cooking and other purposes.

A considerable attention in recent years is given to alternative energy sources, and especially to plant biomass, which in contrast to the fossil fuels is continuously renewed in the nature. The lignocellulosic biomass from crop residues and energy crops can serve as a sustainable source of biodiesel, bioethanol, biogas, biohydrogen and solid fuel production, in order to mitigate the fossil fuel shortage and climate change issues.

Sweet corn *Zea mays saccharata* is a highly valued crop worldwide, cultivated for its tender kernels consumed as a vegetable, and global demand for sweet corn has increased steadily over the past two decades due to changing dietary preferences, urbanization, and rising health consciousness, leading to intensified research efforts focused on breeding, agronomy, and sustainability adaptability to various agro-climatic conditions. The cereals crops, naked oat *Avena nuda* and spelt wheat, *Triticum aestivum ssp. spelta* have received attention again in the past two decades, due to its healthy nutritional components and bioactive compounds, and including this crops and varieties in organic production it is the possible to increase the diversity of grains in the human diets.

The important temperate grasses are orchardgrass *Dactylis glomerata* and perennial ryegrass *Lolium perenne*, they are suitable for restoration and creation of temporary meadows, weeding of sports fields and lawns, and the requirement for seeds has skyrocketed in recent years.

In order to choose the most efficient way to valorize the straw from crops, it is necessary to know the quality indices and its economic potential as fodder or as raw material for the production of biofuels.

The goal of this study was to determine the quality indices of agricultural residues straws of *Avena nuda, Dactylis glomerata, Lolium perenne, Triticum aestivum ssp. spelta, Zea mays saccharata*, and prospect its use as feed for livestock and as substrates for bio fuels production.

MATERIALS AND METHODS

Agricultural residues in the form of straw from *Avena nuda*, *Dactylis glomerata*, *Lolium*

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perenne, *Triticum aestivum* ssp. *spelta*, and *Zea mays saccharata*, collected from the experimental plots of the NBGI in Chişinău, were used as research subjects. For this purpose, 100 kg samples of straw were collected from each species. The dry matter content was determined by drying the samples to a constant weight at 105°C. For biochemical analysis, the straw biomass was dehydrated in a forced-ventilation oven at 60°C. After drying, the material was finely ground using a laboratory ball mill. Biomass quality was evaluated by analyzing the following indices: crude protein (CP), crude fiber (CF), crude ash (CA), total soluble sugars (TSS), acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL). These parameters were determined using near-infrared spectroscopy (NIRS) with the PERTEN DA 7200 analyzer at the Research and Development Institute for Grassland, Braşov, Romania. Additional parameters - hemicellulose (HC), cellulose (Cel), digestible dry matter (DDM), digestible energy (DE), metabolizable energy (ME), net energy for lactation (NEl), total digestible nutrients (TDN), relative feed value (RFV), and relative forage quality (RFQ) - were calculated according to standard procedures. The carbon content of the substrates was estimated using an empirical equation by Badger *et al*. (1979), and the biochemical methane potential (BMP) was calculated following the method described by Dandikas V. *et al.* (2015). The Theoretical Ethanol Potential (TEP) was calculated according to the equations of Goff B.M. *et al.* (2010) based on conversion of cellulose and hemicellulose into hexose (H) and pentose (P) sugars. For densification, straw biomass was chopped into small pieces measuring 2-3 cm using a chopping unit. The chopped biomass was then crushed in a beater mill equipped with a 6 mm mesh sieve. Pelleting equipment was used to densify the biomass. Pelleting and selected quality indices of the dry biomass and pellets were determined following standard protocols at the Technical University of Moldova.

RESULTS AND DISCUSSIONS

The biochemical composition of agricultural residues, specifically – straw, is of critical importance in formulating homogeneous diets for livestock, particularly ruminants, as well as for use as a substrate in renewable energy production.

According to the results presented in Table 1, the dry matter of the studied straws contained the following ranges: 47-64 g/kg CP, 38-72 g/kg ash, 382-473 g/kg CF, 407-501 g/kg AD), 692-797 g/kg NDF, 38-64 g/kg ADL, 369-437 g/kg Cel and 254–299 g/kg HC.

Table 1

The biochemical composition of the studied agricultural residues- straws

Indices	*Avena nuda*	*Dactylis glomerata*	*Lolium perenne*	*Triticum aestivum spelta*	*Zea mays saccharata*
Crude protein, g/kg DM	51	64	63	51	47
Crude fiber, g/kg DM	453	448	392	473	382
Ash, g/kg DM	38	71	68	54	72
Acid detergent fiber, g/kg DM	464	498	414	501	407
Neutral detergent fiber, g/kg DM	718	797	681	778	692
Acid detergent lignin, g/kg DM	47	64	51	64	38
Cellulose, g/kg DM	417	434	363	437	369
Hemicellulose, g/kg DM	254	299	267	277	285

The straws of the perennial grasses *Dactylis glomerata* and *Lolium perenne* were characterized by higher levels of crude protein and ash. The content of fibrous components and lignin varied significantly between species. Lower values were observed in *Lolium perenne* and *Zea mays saccharata*, while notably higher levels were recorded in *Dactylis glomerata* and *Triticum aestivum* ssp. *spelta*.

The *figures 1-5* present the nutritional energy values of the straw biomass from the studied species. Notably, *Lolium perenne* and *Zea mays saccharata* straw displayed a higher degree of digestibility, relative forage value, and availability of metabolizable energy and net energy for lactation. *Avena nuda* straw showed more favorable nutritional indices compared to the straw of *Dactylis glomerata* and *Triticum aestivum* ssp. *spelta*.

Several authors have reported varying findings regarding the quality indices of straw biomass. According to Youngberg H. and Vough L. (1977) the nutrient content in perennial ryegrass straw – forage type was 2.5-7.2% CP, 72.1 % NDF, 41.7-52.6%ADF, 39.7-48.3% IVDDM; in orchardgrass straw 3.1-7.2% CP, 79.0 % NDF, 44.0-53.8%ADF, 28.2-42.0% IVDDM; but in wheat straw 1.8-3.7% CP, 52.1-56.9%ADF. Fisher M. J. (2004) reported that the biochemical composition of perennial ryegrass straw was 4.6% CP 63.0% NDF, 33.0% ADF, 55% TDN (Stanisavljević R. *et al.*, 2009) revealed that depending on the vegetation space and application of mineral fertilizers the yield of *Dactylis* *glomerata* remains, namely – straw, varied from 1.24 to 3.09 t/ha, the chemical composition of leaf biomass was 3.96-5.27% CP, 81.58-92.77% NDF, 44.94-52.83% ADF, but stem and panicle biomass 1.81-3.35% CP, 90.08-94.86% NDF and 45.36-55.29% ADF, respectively. Barbash V. *et al.*, (2011) mentioned that wheat straw had 4.2% ash, 26.4 % pentosans, 46.2 % cellulose, 18.6% lignin. Bohnert D.W. *et al.*, (2011) remarked that crude protein concentration in perennial ryegrass straw was 6.0%, but in orchardgrass straw 4.8%. Li S-M. *et al.* (2014) documented that naked oat straw had 3.3%CP and 45.2%% CF. Suthar M. *et al.*, (2012) mentioned that the crude protein content in sweet corn varieties, after harvesting the cobs, varied from 3.83 to 5.14%. Li H.Y. *et al.*, (2014) found that maize stover had 933.8 g/kg DM, 95.16% OM, 4.05% CP, 1.31% EE, 71.93% NDF, 41.36% ADF, 6.16% ADL. Isikgora F.H.&Remzi Becer C. (2015) remarked that the chemical composition of wheat straw was 35.0-39.0% cellulose, 23.0-30.0 % hemicellulose, 12.0-16.0% lignin; oat straw 31.0-35.0% cellulose, 20.0-26.0% hemicellulose, 10.0-15.0% lignin and corn stalks 35.0-39.6% cellulose, 16.8-35.0% hemicellulose, 7.0-18.4% lignin and grasses 25.0–40.0% cellulose, 25.0–50.0% hemicellulose, 10.0–30.0 % lignin, respectively. Kiro M. (2015) reported that wheat straw contained 73.75 % holocellulose, 39.17 % α-cellulose, 21.65 % lignin, 4.57 % soluble, 5.53% ash. Wattanaklang B. *et al.*, (2016) reported that the nutrient content of the maize stover was as follows: 5.8% crude protein, 27.38% crude fiber, 1.90% ether extract and 20.8% ash. Lukiwati D.R. *et al.*, (2018) found that the digestibility of fermented sweet corn stover was 552.3-646.8g/kg IVDMD and 517.1-628.4 g/kg IVOMD. Barros R.D.R.O. *et al.*, (2019) reported that spelt straw biomass had 14.9% moisture, 38.25 % cellulose, 24.28% hemicellulose, 14.77 % lignin, 5.71 % ash and 7.14% nitrogen free extract. Lukiwati D. R. (2019) stated that sweet corn stover contained 5.70-8.04% CP, 0.34-0.56% P and 0.17-0.53%Ca.

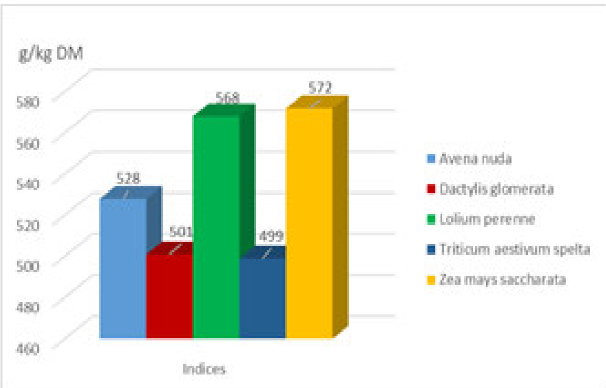

Figure 1 **Digestible dry matter**

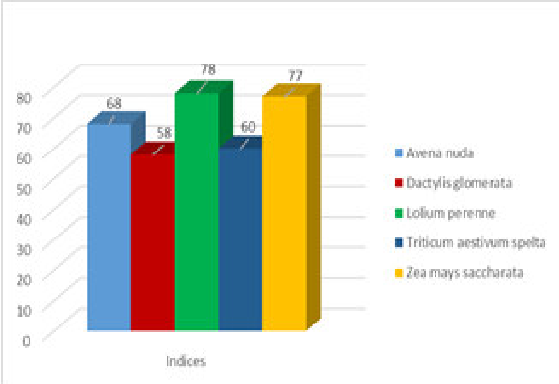

Figure 2 **Relative feed value**

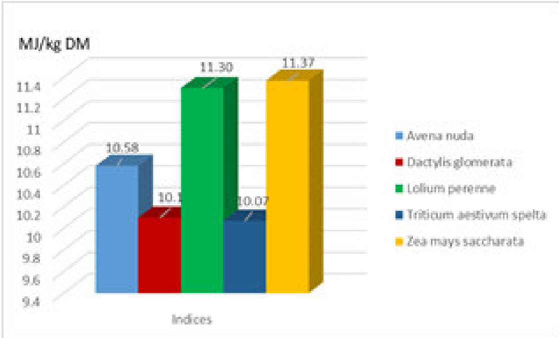

Figure 3 **Digestible energy**

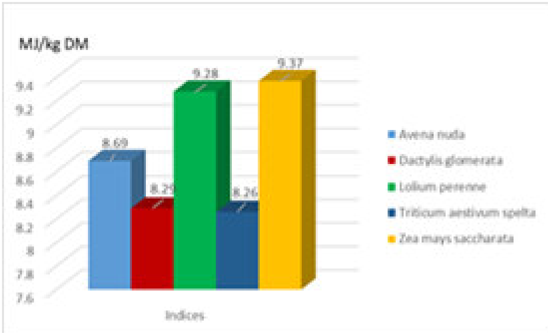

Figure 4 **Metabolizable energy**

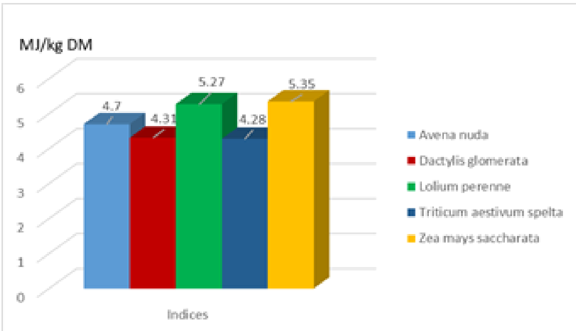

Figure 5 **Net energy for lactation**

Hejduk S. and Macháč R. (2019) mentioned that the concentration of nutrients in the Italian ryegrass 68.3 g/kg ash, 64.1 g/kg CP, 399 g/kg CF, 656 g/kg NDF, 442 g/kg ADF, 215 g/kg HC, but in perennial ryegrass straw 71.3 g/kg ash, 81.4 g/kg CP, 382 g/kg CF, 629 g/kg NDF, 412 g/kg ADF and 217 g/kg HC. Zhou X. *et al.*, (2019) revealed that the nutrient content in sweet corn stover was 72.3 g/kg CP, 18.1 g/kg EE, 134.1 g/kg WSC, 667.8 g/kg NDF, 426.3 g/kg ADF, 80.8 g/kg starch. Doroftei V. *et al.*, (2021) mentioned that biochemical composition of grass straws: 36-83 g/kg CP, 400-555 g/kg CF, 46-98 g/kg ash, 647-918 g/kg NDF, 424-604 g/kg ADF, 53-86 g/kg ADL, 371-518 g/kg Cel, 223-314g/kg HC, with nutritive and energy value 10.3-39.3 % DMD, 8.8-36.2 % ODM, 7.08-9.14 MJ/kg ME and 3.10-5.45 MJ/kg NEl, but wheat straw 37 g/kg CP, 488 g/kg CF, 498 g/kg ADF, 775 g/kg NDF, 68 g/kg ADL, 430 g/kg Cel, 277 g/kg HC, 45 g/kg ash, 13 g/kg TSS. Zheng M. *et al.*, (2021) showed that the naked oat straw digestibility of nutrients was 395.1 g/kg IVDMD, 302.5 g/kg IVNDFD and 288.0 g/kg IVADFD. Cerempei V. *et al.*, (2022) reported that straw collected from the studied cultivars of *Festuca* species contained 28-83 g/kg CP, 417-562 g/kg CF, 469-595 g/kg ADF, 720-889 g/kg NDF, 60-91 g/kg ADL, 0-60 g/kg TSS, 251-294g/kg HC, 406-504 g/kg Cel, while straw from *Avena sativa* 'Sorin' 62 g/kg CP, 487 g/kg CF, 82 g/kg ash, 499 g/kg ADF, 800 g/kg NDF, 56 g/kg ADL, 443 g/kg Cel, 301 g/kg HC, 161 g/kg TSS, respectively. Ma Y. *et al.*, (2022) revealed that the dry matter and nutrient content of naked oat straw was 906.6 g/kg DM, 5.94% CP, 63.83% NDF, 38.28% ADF, 7.99% ash, 3.81% starch, with estimated feeding value 53.61% TDN, 59.08% DDM, RFV=86.11 and RFQ=81.95. Gong X *et al.*, (2022) mentioned that maize straw had 31.99 % cellulose, 25.33 % hemicellulose and 21.17 % lignin. Nasir A.A.A. and Kamaruddin N.A. (2023) found that the leaves of sweet corn contained 19.04% CP, 5.22%EE and 5.44% ash, while sweet corn stalk had 10.47% CP, 1.32% EE, 4.56%ash and 27.05 % CF. Khan A. *et al.*, (2024) reported that maize stalk contained 41.43% cellulose, 26.10% of hemicellulose and 8.13% lignin.

The high volatility in fossil energy prices, along with environmental concerns such as climate change associated with their use, has steadily increased interest in alternative renewable energy sources. Feedstocks with broader geographic availability and lower costs - such as agricultural and forestry residue biomass and energy crops - are particularly attractive in this context. Straw is a promising lignocellulosic feedstock with a favorable greenhouse gas emissions profile, making it suitable for the production of biofuels and bio-based chemicals. Like all lignocellulosic materials, straw is naturally recalcitrant and requires thermochemical and enzymatic pretreatment to enable access to its three main biopolymers: the polysaccharides cellulose and hemicellulose and the polyaromatic compound lignin.

Straw is currently used in commercial production of cellulosic ethanol and biomethane. The carbon-to-nitrogen ratio and biomethane potential of the straw substrates from the studied species are presented in Figures 6-8. The C/N ratio of the investigated substrates ranged from 50 to 68. Their biochemical methane potential varied between 291 and 333 L/kg ODM, or 271 to 309 L/kg DM. A notably high biomethane potential was observed in the *Zea mays saccharata* substrate, likely due to its lower lignin content. In contrast, the straw substrates from *Dactylis glomerata* and *Triticum aestivum* ssp. *spelta* exhibited lower biomethane potential compared to that of *Avena nuda*.

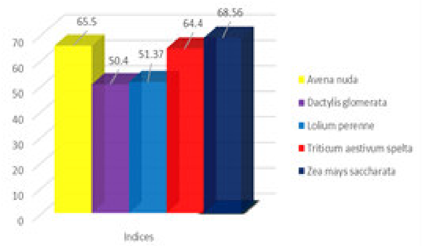

Figure 6 **Carbon to nitrogen ratio**

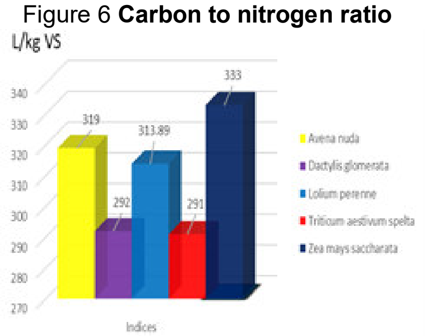

Figure 7 **Biomethane potential L/kg VS**

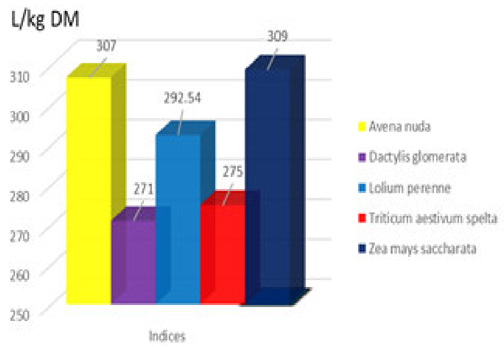

Figure 8 **Biomethane potential, L/kg DM**

Several studies have reported different data on the biomethane production potential of straw substrates. Vishnevskaya O.V. (2017) noted that substrates derived from *Dactylis glomerata* achieved methane yields 237-241 l/kg VS. Mazurkiewicz J. *et al.*, (2019) reported that the methane productivity of maize straw substrates was 201-207 m^3/t. Doroftei V. *et al.*, (2021) mentioned that grass straw substrates for anaerobic digestion have C/N=37-92 and biochemical methane potential varied from 254 to 313 l/kg ODM. Witaszek K. *et al.* (2025) noted that straw substrates derived from *Triticum aestivium* had 45.95-52.84% ADF, 77.07-87.09% NDF and methane yields varied from 200.8 to 272.08L/kg VS.

Liquid biofuels, namely cellulosic bioethanol, butanol and biodiesel, are of considerable interest to researchers, industry stakeholders and governments. Among these, cellulosic bioethanol is considered a promising drop-in fuel that could serve as an alternative to gasoline in the transportation sector. Ethanol offers several advantages over gasoline when used in internal combustion engines: it has a higher octane number, which enhances resistance to engine knock; it has a lower freezing point; and it results in lower CO_2 emissions. The production of cellulosic ethanol through biological conversion involves three key steps: pretreatment of biomass, hydrolysis of sugar polymers (such as cellulose and hemicellulose) into sugar monomers (hexoses and pentoses) and fermentation of these monomers into ethanol (Kumar & Murthy, 2011). Ethanol yield and conversion efficiency depend on several factors, including the type of biomass, plant species, variety, growth conditions and maturity stage.

Figures 9-11 present the results on quality indices and the theoretical bioethanol potential of the studied lignocellulosic substrates. The theoretical bioethanol yield from hexose sugars ranged from 275 to 329 L/ton of organic matter, while the yield from pentose sugars ranged from 174 to 205 L/ton of organic matter. The straw substrates of *Dactylis glomerata* and *Triticum aestivum* ssp. *spelta* were characterized by a high theoretical bioethanol potential. In contrast, the bioethanol potential of straw from *Avena nuda* and *Zea mays saccharata* showed no significant difference.

Several authors have reported varying results regarding the bioethanol potential of lignocellulosic substrates. According to Sveinsson T. & Hermannsson, J. (2010), ethanol production from *Phleum pratense* lignocellulosic biomass is estimated at 0.27 L of ethanol per kilogram of DM. Kumar D. & Murthy G. (2011) reported that estimated ethanol potential from C_6 sugars of tall fescue biomass achieved 360.57 L/ ton biomass; perennial ryegrass biomass- 297 L/ ton and from bentgrass 276 L/ ton. Orlygsson J. (2013) remarked that timothy substrates produced 4.2 mM of ethanol/g DM or about 0.24 litres ethanol/kg DM, or 1200-1700 l/ha ethanol. Hálfdánarson H.E. (2015) reported that ethanol production efficiency from timothy second-cut biomass was 346 L/ton of dry matter (DM), 298 L/ton DM at the third cut, and 313 L/ton DM at the fourth cut. Tang S. *et al.* (2019) reported that *Pennisetum alopecuroides* straw contained 41.8% Cel, 28.7% HC, and 17.5% lignin, with an ethanol potential reaching 744 mg/g after alkaline treatment. Goff B.M. *et al.* (2010) found that, for sorghum biomass, the theoretical ethanol potential ranged from 560 to 610 L/t of dry biomass. Doroftei V. *et al.* (2021) mentioned that the estimated theoretical bioethanol potential of grass straw substrates ranged from 432 to 605 L/t, while for wheat straw the potential was 513 L/t. Cerempei V. *et al.* (2022) reported that the theoretical bioethanol potential of straw substrates from *Festuca* species reached values between 477 and 580 L/t DM, and for oat straw, 541 L/t DM.

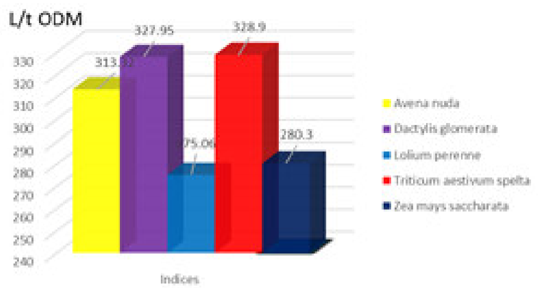

Figure 9 **Theoretical ethanol potential: from hexose sugars**

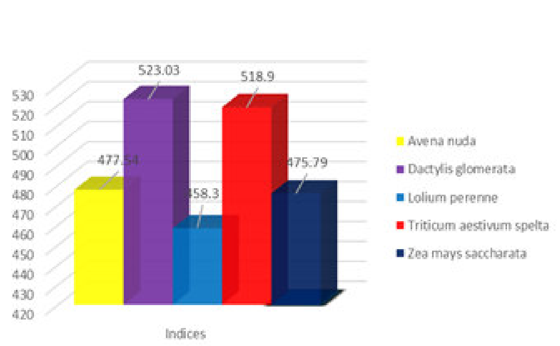

Figure 10 **Theoretical ethanol potential: from pentose sugars**

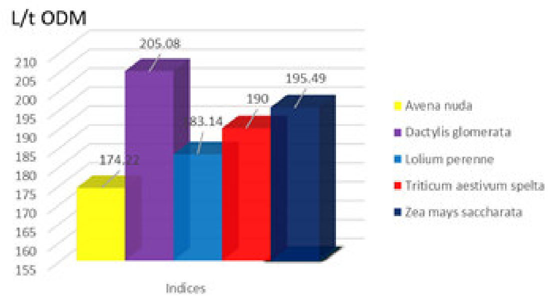

Figure 11 **Total theoretical ethanol potential**

One of the most economically advantageous methods of biomass densification is pelletization.

Through this process, raw biomass is converted into pellets with improved fuel properties, such as increased bulk density and uniform shape and size. Pelletized fuels also exhibit greater structural consistency, which is particularly beneficial for automated fuel systems in both industrial and domestic boilers. Some physical and mechanical properties of straw biomass and the resulting pellets are presented in Table 2 and Figures 12-13. Among the key quality indicators, ash content is particularly important, as high ash levels reduce the quality of solid fuels, accelerate corrosion and hinder the optimal performance of heating systems. A high ash concentration – ranging from 6.8% to 7.2% - was observed in the biomass of *Lolium perenne*, *Dactylis glomerata* and *Zea mays saccharata*, compared to lower values of 3.8% in *Avena nuda* and 5.4% in *Triticum aestivum* ssp. *spelta*. The volatile matter content in the studied straws ranged from 69% in *Zea mays saccharata* to 81% in *Avena nuda* and *Triticum aestivum* ssp. *spelta*. The biomass and pellets produced from *Avena nuda*, *Dactylis glomerata*, and *Triticum aestivum* ssp. *spelta* were characterized by an optimal energy value – higher than that of maize stalks (17.84 MJ/kg), and very low ash content (2.1%), significantly lower than that found in *Zea mays saccharata* and *Lolium perenne* straw. The bulk density of the produced pellets ranged from 443.6 kg/m³ for *Triticum aestivum* ssp. *spelta* pellets to 595.2 kg/m³ for *Dactylis glomerata* pellets. The mechanical durability of pellets made from *Zea mays saccharata* reached 97.39%, compared to 92.86% for pellets made from *Dactylis glomerata*.

Table 2

Some quality indices of biomass and pellets from studied agricultural residues- straws

Indices	*Avena nuda*	*Dactylis glomerata*	*Lolium perenne*	*Triticum aestivum spelta*	*Zea mays saccharata*
Ash content of biomass, % DM	3.8	7.1	6.8	5.4	9.2
Volatile matter , % DM	81.25	78.65	76.28	80.62	69.02
Gross calorific value of biomass, MJ/kg DM	18.5	18.4	18.0	18.4	17.7
Net calorific value of biomass, MJ/kg DM	17.2	17.1	16.7	17.0	16.4
Net calorific value of biomass, M10% MJ/kg DM	15.3	15.1	14.7	16.4	14.5
Ash content of pellets, % DM	3.8	8.0	6.4	5.9	10.1
Gross calorific value of pellets, MJ/kg DM	18.5	18.4	18.0	18.5	17.8
Net calorific value of pellets, MJ/kg DM	17.0	17.1	16.6	17.1	16.4
Net calorific value of pellets, M10% MJ/kg DM	15.0	15.1	14.7	15.1	14.5

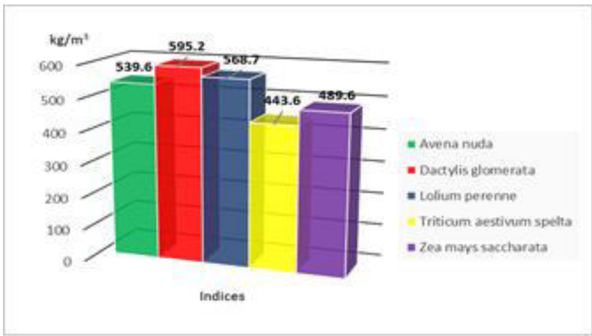

Figure 12 **Bulk density of pellets**

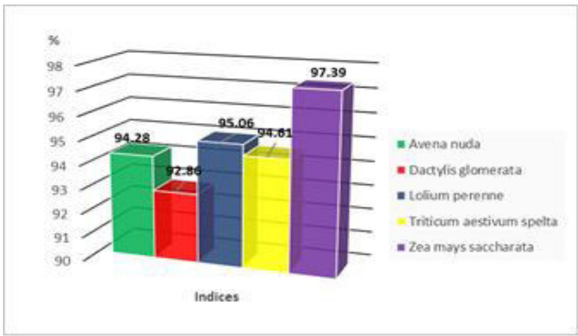

Figure 13 **Durability of pellets**

Morissette R. *et al*. (2011) reported that maize straw dry matter had 17.57 to 19.02 MJ/kg GCV and 4.73-9.25% ash. Kiš D. *et al*. (2017) found that the energy value of *Triticum aestivum* ssp. *spelta* stems ranged from 17.2 to 17.4 MJ/kg, while the chaff and glumes had a slightly lower energy value of 16.4-16.7 MJ/kg. In a previous study, Muntean I. *et al*. (2018) established that maize straw biomass contained 4.40% ash and 17.8 MJ/kg GCV, and a pellet bulk density of 701 kg/m³. In comparison, wheat straw had 4.93% ash, 17.4 MJ/kg GCV, 685 kg/m³. Petlickaite R. *et al*. (2022) reported that pellets made from maize straw had the following characteristics: 4.61% moisture (MC), 18.02 MJ/kg GCV, 16.87 MJ/kg NCV and a density of 1159.57 kg/m³. Yang W. *et al.* (2022) reported that maize stalks contained 2.86% MC, 20.90% FC, 64.49% VM, 13.49 MJ/kg NCV, and 6.58% ash. The elemental composition included 39.81% C, 5.93% H, 0.94% N, 0.23% S, and 0.61% Cl. Stolarski M.J. *et al*. (2019) found that solid fuels from wheat straw had 16.20% MC, 18.68 MJ/kg GCV, 15.26 MJ/kg NCV, 20.60% FC, 73.05% VM, and 6.35% ash; from ryegrass straw 15.35% MC, 19.03 MJ/kg GCV, 15.74 MJ/kg NCV, 21.50% FC, 75.83% VM, and 2.67% ash; corn stover had 69.80% MC, 18.28 MJ/kg GCV, 3.82 MJ/kg NCV, 20.42% FC, 75.15% VM, and 4.42% ash. Gageanu I. *et al.* (2018) reported that rapeseed stalk pellets had 10.54% moisture content, 3780.21 kcal/kg energy values, but pellets from wheat straws 8.16% moisture content, 3965.56 kcal/kg energy value, respectively. Stolarski M.J. *et al.* (2024) determined that oat straw had 11.68-12.85% MC, 19.44-20.66 % FC, 73.96-74.96% VM, 4.97-6.40% ash, 18.52-18.77 MJ/kg GCV and 14.98-15.20 MJ/kg NCV; wheat straw respectively 10.11-12.43% MC, 20.07-20.35 % FC, 72.83-75.09% VM, 4.52-6.82% ash, 18.40-18.84 MJ/kg GCV, 15.18-15.35 MJ/kg NCV; corn straw had 48.32-49.36% MC, 18.99-19.30 % FC, 76.35-77.74% VM, 4.16-4.35% ash, 18.20-18.51 MJ/kg GCV, 7.53-7.88 MJ/kg NCV. Güleç F., *et al.* (2022) reported that wheat straw biomass had 1.18% N, 45.58% C, 0.59% S, 6.04% H, 46.60% O, 5.30% ash. 76.00% VM, 18.20% FC, 17.34 MJ/kg GCV, while grass straw pellets 0.56% N, 47.89% C, 0.17% S, 5.51% H, 45.87% O, 9.80% ash, 79.00 %VM, 11.20% FC and 16.58 MJ/kg GCV. Stolarski M.J. *et al.* (2025) reported that wheat straw pellets are characterized by 7.58 % MC, 20.90 % FC, 74.98% VM, 628.85 kg/m^3 bulk density, 19.11 MJ/kg GCV.

CONCLUSIONS

Straws from *Avena nuda, Dactylis glomerata, Lolium perenne, Triticum aestivum ssp. spelta* and *Zea mays saccharata* can be used as sources of fibre in ruminant diets, for cattle and other ruminants, also as feedstock for production solid, liquid and gaseous fuels.

ACKNOWLEDGEMENTS

This study has been financially supported by the subprogram no. 01.01.02 *"Identification of valuable forms of plant resources with multiple uses for the circular economy".*

REFERENCES

Alluvione F., Moretti B., Sacco D., Grignani C. 2011- *EUE (energy use efficiency) of cropping systems for a sustainable agriculture*. Energy, 36 (7): 4468–4481.

Barbash V., Poyda V., Deykin I., 2011- *Peracetic acid pulp from annual plants.* Cellulose Chemistry and Technology, 45 (9–10): 613–618.

Barros R.D.R.O., Becarelli P., de Oliveira R. A., Tognotti L., da Silva Bon E.P., 2019- *Triticum spelta straw hydrothermal pretreatment for the production of glucose syrups via enzymatic hydrolysis.* Biochemical Engineering Journal, 151, 107340.

Bohnert D.W., Mehren M., Hunt C.W., 2011- *Nutritional considerations of grass seed straw for beef cattle.* Pacific Northwest Animal Nutrition Conference Proc. 1-18.

Cerempei V.; Țîței V.; Blaj V.A., Andreoiu A.C., Marușca T., Mazare V., Doroftel V.; Ababii A., 2022- *The physical properties of seeds and the biochemical composition of the straw of romanian cultivars of Festuca species grown under the conditions of the Republic of Moldova.* Lucrări Ştiinţifice, seria Agronomie, 65(2):75-80.

Dandikas V., Heuwinkel H., Lichti F., Drewes J.E., Koch K., 2015 - *Correlation between biogas yield and chemical composition of grassland plant species.* Energy Fuels, 29 (11): 7221-7229.

Doroftei V., Ţiţei V., Ababil A., Blaj V., Cozari S., Andreoiu A.C., Maruşca T., Coşman V., Guţu A., 2021- *Evaluarea calităţii biomasei din plantațiile semincere de ierburi perene și posibilități de valorificare.* Genetica, fiziologia şi ameliorarea plantelor, Chişinău, 305-308.

Fisher M.J., D. W. Bohnert, C. J. Ackerman, C. S. Schauer, T. DelCurto, A. M. Craig, E. S. Vanzant, D. L. Harmon, and F. N. Schrick. 2004-*Evaluation of perennial ryegrass straw as a forage source for ruminants*. Journal of Animal Science, 82:2175-2184.

Gong X., Yu Y., Hao Y., Wang Q., Ma J., Jiang Y., Lv G., Li L., Qian C., 2022- *Characterizing corn-straw-degrading actinomycetes and evaluating application efficiency in strawreturning experiments.* Frontiers in Microbiology. 13:1003157.

Gageanu I., Cujbescu D., Persu C., Voicu G., 2018- *Influence of using additives on quality of pelletized fodder.* In. Engineering for Rural Development. 17: 1632-1638.

Gaballah E.S., Abomohra A.E.F., Xu C., Elsayed M., Abdelkader T.K., Lin J., Yuan Q., 2020- *Enhancement of biogas production from rape straw using different co-pretreatment techniques and anaerobic co-digestion with cattle manure.* Bioresource Technology. 309. 123311. 10.1016/j.biortech.2020.123311.

Goff B.M., Moore K.J., Fales, L., Heaton A., 2010- *Double-cropping sorghum for biomass.* Agronomy Journal, 102:1586-1592.

Greenhalf C.E., Nowakowski D.J., Bridgwater A.V., Titiloye J., Yates N., Riche A., Shield I., 2012- *Thermochemical characterisation of straws and high yielding perennial grasses*. Industrial Crops and Products, 36:449–459.

Güleç F., Direnc P., Orla W., Lester E., 2022- *Predictability of higher heating value of biomass feedstocks via proximate and ultimate analyses -A comprehensive study of artificial neural network applications.* Fuel. 320. 123944. 10.1016/j.fuel.2022.123944.

Hálfdánarson H.E., 2015- *Ethanol production from timothy (Phleum pratense L.).* MS – thesis. Agricultural University of Iceland, 105p. *https://skemman.is › bitstream › PDF Ethanol Pro*.

Hejduk S., Macháč R., 2019- *Yield and quality of straw of italian and perennial ryegrass cultivated for seed production.* Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 67(4): 915-923.

Isikgora F.H., Remzi Becer C., 2015- *Lignocellulosic biomass: a sustainable platform for production of bio-based chemicals and polymers.* Polymer Chemistry, 6(25): 4497-4559.

Khan A., Mishra A., Patidar R., Pappu A., 2024- *Effect of lignocellulosic corn stalk on mechanical, physical, and thermal properties of injection moulded low density polyethylene composites: An approach towards a circular economy.* Heliyon, 10(4). DOI: 10.1016/j.heliyon.2024.e25287

Kiro M., 2015-*Cellulose fibers extracted from agricultural biomass.* Tekstilna industrija, 62(4): 15-19.

Kiš D, Jovičić N, Matin A, Kalambura S, Vila S, Guberac S., 2017- *Energy value of agricultural spelt* *residue (Triticum spelta L.) – forgotten cultures.* Tehnički vjesnik 24, Suppl. 2: 369-373

Kumar D., Murthy G., 2011- *Pretreatments and enzymatic hydrolysis of grass straws for ethanol production in the pacific northwest US.* Biological Engineering. 3. 97-110. 10.13031/2013.36314.

Li S.-M., Wang S.-N., Li M., Tian, J.-H., 2014- *Determination of naked oat straw nutrients and cultivation test of Agaricus bisporus.* Northern Horticulture, 15: 146–149.

Li H.Y., Xu L., Liu W.J., Fang M.Q., Wang N., 2014- *Assessment of the nutritive value of whole corn stover and its morphological fractions*. Asian-Australasian Journal of Animal Sciences, 27(2), 194.

Lukiwati D.R., Pujaningsih R.I., Murwani R., 2018- *The effect of organic phosphorus and nitrogen enriched manure on nutritive value of sweet corn stover*. In. IOP Conference Series: Earth and Environmental Science, 119(1): 012018

Lukiwati D.R., 2019- *Improvement of maize stover nutrition as ruminant feed with manure plus and inorganic*. Fertilizer. Journal of Animal Husbandry Sciences and Technics, 249:147-152.

Ma Y., Khan M.Z., Liu Y., Xiao J., Chen X., Ji S., Cao Z., Li S., 2021- *Analysis of nutrient composition, rumen degradation characteristics, and feeding value of chinese rye grass, barley grass, and naked oat straw.* Animals, 11, 2486. https://doi.org/10.3390/ani11092486

Mazurkiewicz, J., Marczuk, A., Pochwatka, P., & Kujawa, S. (2019). Maize *straw as a valuable energetic material for biogas plant feeding*. Materials, 12(23), 3848. https://doi.org/10.3390/ma12233848

Morissette R., Savoie P., Villeneuve J., 2011- *Combustion of corn stover bales in a small 146-kW boiler.* Energies, 4(7):1102-1111. https://doi.org/10.3390/en4071102

Nasir A.A.A., Kamaruddin N.A., 2023- *Assessing the nutritional composition of sweet corn (Zea mays L. var. saccharata) stover and kernel corn (Zea mays L. var. indentata) stover for ruminant feed*. Journal of Asian Scientific Research, 13(3) :136-148,

Niedziółka I., Kachel-Jakubowska M., Kraszkiewicz A., Szpryngiel M., Szymanek M., ZAKLIKA B., 2015- *Assessment of quality and energy of solid biofuel production*. Bulgarian Journal of Agricultural Science, 21 (2):461–466.

Orlygsson J. 2013- *Ethanol production from grass by Thermoanaerobacter B2 isolated from a hot spring in Iceland*. In The role of grasslands in a green future: threats and perspectives in less favoured areas,. 534-536.

Plíštil D., Brožek M., Malaák J., Roy A., Hutla P., 2005- *Mechanical characteristics of standard fuel briquettes on biomass basis*. Research in Agricultural Engineering, 51(2):66-72.

Petlickaite R., Jasinskas A., ˙Mieldažys R., Romaneckas K., Praspaliauskas M., Balandaite J., 2022- *Investigation of pressed solid biofuel produced from multi-crop biomass.* Sustainability ***2022****, 14, 799.* https:// doi.org/10.3390/su14020799

Suthar M., Singh D., Nepalia V., 2012- *Green fodder and cob yield of sweet corn (Zea mays. l. ssp. saccharata) varieties at varying fertility levels*. Forage Research., 38 (2) : 115-118.

Stasiak M., Molenda M., Bańda M., Wiącek J., Parafiniuk P., Gondek E., 2017- *Mechanical and combustion properties of sawdust—straw pellets blended in different proportions*. Fuel Processing Technology, 156:366-375.

Stanisavljević R., Marković J., Dinić B., Lazarević D., Milenković J., Đokić D., Anđelković B., 2009- *Yield and chemical composition of orchard grass harvest remains-straw (Dactylis glomerata L.) depending on the vegetation space and application of mineral fertilizers.* Biotechnology in Animal Husbandry, 25 (5-6):1233-1239,

Sveinsson T., Hermannsson, J., 2010- *Biomass production, premises and prospects* Fræðaþing landbúnaðarins, 7:36-45 [In Icelandic].

Stolarski M.J., Welenc M., Krzyżaniak M., Olba-Zięty E., Stolarski J., Wierzbicki S., 2024- *Characteristics and changes in the properties of cereal and rapeseed straw used as energy feedstock. Energies*, *17*(5), 1243. https://doi.org/10.3390/en17051243

Stolarski M.J, Rybczyńska B., Krzyżaniak M., Lajszner W., Graban Ł., Peni D., Bordiean A., 2019- *Thermophysical properties and elemental composition of agricultural and forest solid biofuels versus fossil fuels.* Jorunal of Elementology, 24(4): 1215-1228. DOI: 10.5601/jelem.2019.24.1.1819

Stolarski M. J., Krzyżaniak M., Olba-Zięty E., 2025- *Properties of pellets from forest and agricultural biomass and their mixtures.* Energies, 18*(*12), 3137. https://doi.org/10.3390/en18123137

Viel M., Collet F., Lanos C., 2018- *Chemical and multi-physical characterization of agro-resources' by-product as a possible raw building material*. Industrial Crops and Products, 120:214–237. doi: 10.1016/j.indcrop.2018.04.025.

Vishnevskaya O.V., 2017- *Alternative sources of vegetative mass for biofuels in Polissia zone.* Agricultural Science and Practice. 4(3): 35-42.

Witaszek K., Kupryaniuk K., Kupryaniuk J., Panasiewicz J., Czekała W., 2025- *Optimization of straw particle size for enhanced biogas production: a comparative study of wheat and rapeseed straw.* Energies, 18*(7),* 1794. https://doi.org/10.3390/en18071794

Wattanaklang B., Abrar A., Cherdthong A., 2016- *Nutritional value of fermented maize stover as feed for ruminant.* Jurnal Peternakan Sriwijaya, *5*(1), 44-51.

Yang W., Lv L., Han Y., Li Y., Liu H., Zhu Y., Zhang W., Yang H., 2022- *Effect of densification on biomass combustion and particulate matter emission characteristics*. Atmosphere *13*, 1582. https://doi.org/ 10.3390/atmos13101582

Youngberg H., Vough L., 1977- *A study of the nutritive value of Oregon grass straws.* O.S.U. Extension Service Special Report 473, 14p.

Zelenchuk T.V., Deikun I.M., Barbash V.A., 2017- *Obtaining of peracetic cellulose from oat straw for paper manufacturing.* Research Bulletin of the National Technical University of Ukraine, 5:123-131.

Zheng M., Zuo S., Niu D., Jiang D., Xu C., 2021- *Effect of four species of white rot fungi on the chemical composition and in vitro rumen degradability of naked oat straw*. Waste & Biomass Valorization, 12: 435–443.

Zhou X., Ouyang Z., Zhang X., Wei Y., Tang S., Ma Z., Tan Z., Zhu N., Teklebrhan T., Han X., 2019- Sweet *corn stalk treated with Saccharomyces Cerevisiae alone or in combination with Lactobacillus Plantarum*: *nutritional composition, fermentation traits and aerobic stability.* Animals*, 9*(9), 598.

THE QUALITY PARAMETERS OF GREEN BIOMASS FROM EASTERN GALEGA – A NEW LEGUMINOUS CROP IN MOLDOVA

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Abstract

The goal of this study was to determine the quality parameters of green biomass from eastern galega (*Galega orientalis* Lam.) which is a new leguminous crop grown under the agroecological conditions of the Republic of Moldova. The research was conducted on the newly developed local cultivar 'Sofia', grown in monoculture on the experimental plots of the National Botanical Garden Institute of the Moldova State University (NBGI MSU), Chişinău. The quality parameters of dry matter from the first cut were: 172-200 g/kg crude protein, 114-133 g/kg ash, 333-355 g/kg crude fiber, 335-390 g/kg acid detergent fiber, 542-636 g/kg neutral detergent fiber, 49-58 g/kg acid detergent lignin, 297-341 g/kg cellulose, 187-246 g/kg hemicellulose. Digestibility parameters included 58.5-62.8% DMD, RFV= 90-108, 9.53-10.16 MJ/kg ME and 5.55-6.18 MJ/kg NEl. The biochemical biomethane potential of eastern galega substrates ranged from 324 to 353 L/kg volatile solids.

The quality indices of the green biomass harvested from new local cultivar 'Sofia' of *Galega orientalis* indicate that it can be successfully used in livestock feed rations as well as substrates for renewable energy production.

Keywords: biochemical composition, biomethane potential, 'Sofia' cultivar, feed value, green mass, *Galega orientalis*

Galega orientalis Lam., commonly known as eastern galega, fodder galega, goat's rue, is a perennial herbaceous plant from the *Fabaceae* family, native to the North Caucasus. It grows 0.8-2.0 m tall, with upright, occasionally hairy stems, and compound leaves bearing 5-10 pairs of oblong leaflets. The plant produces dense terminal racemes (18-43 cm) with 25-70 blue-lilac to pale blue flowers, blooming from May to June. Its fruit is a smooth brown pod containing 3-8 kidney-shaped seeds. Seed viability lasts 4-7 years. Pollination is entomophilous (insect-mediated). *Galega orientalis* is a versatile crop, valued for its early spring growth, high biomass production (up to 100 t/ha green mass), rich protein content, and regenerative capacity, allowing for 2-3 harvests annually. It is widely used as forage, a honey plant, medicinal herb and energy biomass source. However, some eastern galega ecotypes show limited adaptability and reduced productivity under atypical growing conditions. To improve its agricultural potential, breeding efforts should focus on developing new cultivars of *Galega orientalis* with enhanced adaptability and economically valuable traits, and the development of new technologies for their optimal cultivation and use (Teleuţă A. *et al.*, 2015a.b; Povilaitis V. *et al.,*, 2016; Meripold H. *et al.,*, 2017; Cherniavskih V.I. *et al.,*, 2020; Rakhmetov D. *et al.,* 2021; Ţîţei V. and Roşca I., 2021; Żarczyński P.J. *et al.,* 2021; Ignaczak S. et al., 2022; Cerempei V. *et al.,* 2023; Biligetu B. et al., 2024; Pap N. *et al.,* 2024; Toth S. 2024).

The goal of this study was to determine the quality parameters of green biomass from the new local cultivar 'Sofia' of *Galega orientalis*, as feed for livestock and as substrates for biogas production.

MATERIALS AND METHODS

The new local cultivar 'Sofia' of eastern galega, *Galega orientalis*, created at the "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, registered in 2025 in the Catalogue of Plant Varieties and patented by the State Agency on Intellectual Property of the Republic of Moldova, plant variety patent no. 246/31.03.2025, maintained in pure culture in the experimental plot of the National Botanical Garden (Institute) Chişinău, served as subject of the research. Green mass samples were collected during the third – fifth growing seasons (2022–2024), the first cut was done at the flowering stage. The leaf-to-stem ratio was determined by manually separating the leaves and flowers from the stems, weighing them separately, and calculating the ratio between these

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components. Samples of 1.0 kg harvested plants were taken for this purpose. The dry matter content was determined by drying the samples to a constant weight at 105°C. For biochemical analyses, fresh biomass samples were dehydrated in a forced-ventilation oven at 60°C. After drying, the biological material was finely ground using a laboratory ball mill. Biomass quality was evaluated by analyzing the following indices: crude protein (CP), crude fiber (CF), crude ash (CA), total soluble sugars (TSS), acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL). These parameters were determined using near-infrared spectroscopy (NIRS) with the PERTEN DA 7200 analyzer at the Research and Development Institute for Grassland, Braşov, Romania. Additional parameters - hemicellulose (HC), cellulose (Cel), digestible dry matter (DDM), digestible energy (DE), metabolizable energy (ME), net energy for lactation (NEl), total digestible nutrients (TDN), relative feed value (RFV), and relative forage quality (RFQ) - were calculated according to standard procedures. The carbon content of the substrates was estimated using an empirical equation by Badger *et al.,* (1979), and the biochemical methane potential (BMP) was calculated following the method described by Dandikas *et al.,* (2015).

RESULTS AND DISCUSSIONS

The climatic conditions during the investigation period (2022–2024) deviated from the norm, influencing the agro-biological characteristics of the new local cultivar ‘Sofia’ of eastern galega (*Galega orientalis*), as well as its productivity and quality indicators.

According to the results presented in Table 1, at the time of the first cut for green mass, the plants had reached a height of 124-139 cm. The green mass yield ranged from 4.82 to 5.82 kg/m², while the dry matter yield ranged from 1.09 to 1.23 kg/m². The proportion of leaves and inflorescences ranged from 54.9% to 58.9%. The highest dry matter yield at the first cut was recorded in the fifth growing season (2024).

Several authors have reported various findings on the productivity of *Galega orientalis* under varying environmental and soil conditions. According to Adamovics A. *et al.,* (2011), pure *Galega orientalis* swards produced 50.81 t/ha of fresh biomass and 12.16 t/ha of organic dry matter. Slepetys J. (2010) mentioned that *Galega orientalis* produces the larger share of the total herbage yield at the first cut, that is 41.9–69.4% of the annual yield, and much less herbage from the second cut – 16.0-25.7% and the third cut, which is usually done in autumn, 8.2-33.6%. The highest productivity – 11.9 t/ha – was achieved in 10-11 growing years. Similarly, Avetisyan A.T. (2013) found that at the first cut, *Galega orientalis* yielded 28.6 t/ha of green mass or 7.72 t/ha of dry matter, and at the second cut, 14.0 t/ha of green mass or 3.3 t/ha of dry matter. For comparison, *Medicago sativa* produced 18.9 t/ha of green mass or 5.63 t/ha of dry matter at the first cut, and 11.26 t/ha of green mass or 2.60 t/ha of dry matter at the second cut. Zielewicz W. *et al.,* (2013) remarked that the galega dry matter yield at the first cut was 7.48 t/ha, at the second cut 2.15 t/ha and at the third cut 3.98 t/ha. Teleuţă A. *et al.,* (2015b) reported that yield of the ‘Speranţa’ cultivar of *Galega orientalis* harvested in bud formation stage was 4.5 kg/m² green mass or 0.7 kg/m² dry matter with 56% leaves in the fodder; while the plants started the flowering stage, the yield reached 5.85 kg/m² green mass or 1.02 kg/m² dry matter with 56% leaves and inflorescences in the fodder. Hein W. & Wasch H. (2018) revealed that the productivity of *Galega orientalis* harvested in May was 37.6 t/ha fresh mass or 9.4 t/ha dry matter. Ţîţei V. & Coşman S. (2019) mentioned that the productivity of *Galega orientalis* ‘Speranţa’ in the 7th growing season, at first cut, reached 1.10 kg/m² dry matter. Cherniavskih V.I. *et al.,* (2020) reported that the dry matter yield of *Galega orientalis* at the first cut was 639.0 g/m². According to Zolotarev V. & Korovina (2021), the newly developed cultivar ‘West’ of *Galega orientalis* demonstrated, under favorable conditions, a green mass productivity of 65-70 t/ha or more and a dry matter yield reaching 14 t/ha. Ignaczak S. *et al.,* (2022) found that *Galega orientalis* plants at the first cut reached heights of 90-119 cm, with dry matter yields ranging from 0.544 to 0.748 kg/m². Biligetu B. *et al.,* (2024) found that *Galega orientalis* yielded was 5.39 t/ha dry matter at the first cut. Tóth S. (2024) mentioned that the potential dry matter yield of eastern galega varied from 2.69 to 21.30 t/ha at the first cut, and from 1.05 to 9.06 t/ha at the second cut.

The biochemical composition of dry matter is a key parameter in evaluating feed quality. The quality indicators of the harvested green mass from the local cultivar ‘Sofia’ of *Galega orientalis* are presented in Table 2. Our analysis revealed that the dry matter content and associated quality parameters varied depending on the growing season: 172-200 g/kg CP, 114-133 g/kg ash, 333-355 g/kg CF, 335-390 g/kg ADF, 542-636 g/kg NDF, 49-58 g/kg ADL, 297-341 g/kg Cel, 187-246 g/kg HC with 58.5-62.8% DMD, RFV= 90-108, 9.53-10.16 MJ/kg ME, 5.55-6.18 MJ/kg NEl. In the third growing season, the dry matter from the first cut exhibited high levels of crude protein, minerals, cellulose, and hemicellulose, along with a lower level of acid detergent lignin. In the fifth growing season, the concentration of structural carbohydrates in the dry matter was lower, which had a positive effect on the forage value and energy content of the feed compared to the third and fourth growing seasons. Additionally, the high cellulose content in the fifth season also contributed positively to forage quality and energy supply, especially in comparison to the fourth growing season.

Several authors have reported varying findings regarding the nutrient quality of the green mass of *Galega orientalis*. According to Skórko-Sajko H. *et al.,* (2005) the dry matter of *Galega orientalis* fresh mass had 906.9 g/kg OM, 245.5 g/kg CP, 57.4 g/kg PDIA, 150.1 g/kg PDIN, 103.4 g/kg PDIE, with 0.77 UFL/kg, 0.70 UFV/kg and 1.19 CFU/kg. Bull I. *et al.,* (2011) reported that the galega forage from the first cut contained 149-157 g/kg DM with 20.7-20.9 % CP, 1.7-2.3 % EE, 34.3-37.5 % CF, 8.0-8.5 % ash. Klimenko V.P. (2012) found that *Galega orientalis* harvested at the shoot development to early budding period contained 144.3 g/kg DM, 26.7% CP, 6.9% sugars, 9.70% starch, 21.23% Cel, 6.71% HC and 4.95% lignin. Truzina L.A. *et al.,* (2013) reported that the biochemical composition of *Galega orientalis* harvested in early flowering period was 220.2 g/kg CP, 44.8 g/kg EE, 301.7 g/kg CF, 362.2 g/kg NFE and 71.1 g/kg ash. Zielewicz W. *et al.,* (2013) mentioned that the concentration of nutrients in the galega forage at the first cut was 12.67% CP, 1.63% sugars, 28.77% Cel, 15.93 % HC, 8.95% ash and 4.04 % lignin. Teleuţă A. *et al.,* (2015a) found that the first cut eastern galega contained 17.80% CP, 3.55% EE, 30.56% CF, 39.47% NFE, 8.69% ash with 147 g digestible protein per nutritive unit, in contrast, alfalfa forage had 16.16% CP, 1.88% EE, 34.74% CF, 37.22% NFE, 10.00% ash, and 145 g digestible protein per nutritive unit. Hein W. & Wasch H. (2018) revealed that the nutrient content of *Galega orientalis* dry matter was 14.21-18.69% CP, 1.54-2.09% EE, 20.39-32.49% CF, 36.29-49.55% NFE, 9.28-11.43% ash, 10.95-18.78 g/kg Ca, 3.00-4.09 g/kg P. According to Skórko-Sajko H. *et al.,* (2016), the nutrient concentration and feed value of *Galega orientalis* green forage harvested at the beginning of the flowering period was: 178.9 g/kg DM, 89.39% OM, 22.97% CP, 3.33% EE, 52.80% NDF, 35.38% ADF, 3.81-4.52% ADL, 17.00% Cel, 30.85% HC, 34.68% NFE, 4.78% soluble sugars, with 18.58 MJ/kg GE, 9.62 MJ/kg ME, 5.65 MJ/kg NEl, 5.4 MJ/kg NEm, 0.79 UFL, 0.76 UFV. Slepetiene A. *et al.,* (2016) reported the chemical composition of the fodder galega biomass included 3.129% N, 47.44% C, 45.16% NDF, 43.45% ADF, 14.85%% ADL, 8.33% ash, 5.83% WSC, 1.71% HC and 28.60% Cel. Coşman S. *et al.,* (2017) reported that in *Galega orientalis* 'Speranţa', at the first cut, the dry matter content varied from 125.2 to 180.7 g/kg, with 16.18-22.94% CP, 3.26-3.90% EE, 31.95-36.85% CF, 46.5-57.9% NDF, 28.8-37.7% ADF, 3.9-6.3% ADL, 32.18-38.06% NFE, 7.51-8.86% ash, 64.0-82.0% DDM, and RFV ranging from 97 to 133. Meripõld H. *et al.,* (2017) found that pure *Galega orientalis* forage at the first cut had 17.0-17.8% CP, 48.9-49.5% NDF, and 40.8-43.9% ADF, while eastern galega mixed with grasses had 9.4-13.4% CP, 50.9-55.4% NDF, and 36.9-39.6% ADF. Chornolata L.P. *et al.,* (2018, 2023) reported that eastern galega in the budding-flowering stages contained 16.86-19.07% CP, 15.10-18.10% Cel, 12.20-14.48% HC, 6.50-7.10% lignin, 6.20-6.40% sugars, 4.90% starch, while alfalfa *Medicago sativa* green mass forage had 15.28-16.39% CP, 11.45-16.10% Cel, 12.90-13.11% HC, 4.50-6.00% lignin, 4.80-7.50% sugars, 5.27-5.65% starch. Kuchin N.N. & Ivashin I.I. (2019) observed that nutrient concentrations in *Galega orientalis* dry matter differed among phenological stages. In the budding phase, the forage contained 19.4-21.6% CP, 2.29-3.07% EE, 19.6-23.0% CF, 46.5-51.6% NFE, 6.1-6.9% ash and 10.8-11.5 MJ/kg ME, while in the flowering stage14.4-16.7% CP, 24.8-26.4% CF, 10.2-10.6 MJ/kg. ME. Burykina S.I. (2019) stated that the forage from *Galega orientalis* harvested in the budding-flowering stages contained 3.04-3.08% nitrogen, 33.08-38.88% CF, 21.50-21.66% Cel, 6.04-7.21% HC, 11.00-13.43% lignin, 2.04-2.75% sugars, 0.55-0.70% starch. Nechunaev M.A. & Falaleeva L.V. (2020) reported that *Galega orientalis* forage contained 271.3 g/kg CP, 57.7 g/kg EE, 264.1 g/kg CF, 299.7 g/kg NFE, 109.4 g/kg ash, 16.2 g/kg Ca, 3.4 g/kg P and 9.8 MJ/kg ME, while for *Trifolium pratense* – 186.7 g/kg CP, 66.2 g/kg EE, 306.5 g/kg CF, 335.6 g/kg NFE, 106.7 g/kg ash, 12.6 g/kg Ca, 3.2 g/kg P and 8.9 MJ/kg ME, respectively. Darmohray L. *et al.,* (2021) found that *Galega orientalis* harvested at the early flowering stage contained 21.09% CP, 2.95% EE, 27.29% CF, 60.55% NDF and 5.18% ash. Simonov *et al.,* (2021) reported that the studied *Galega orientalis* plants, cut in the budding - beginning of flowering stage, had 140-200 g/kg DM with 25-26 % CP, 3-6% sugars, 25-30 % CF, 0.72-0.74 nutritive units, 160-260 g digestible protein per nutritive unit and 9.0-9.7 MJ/kg ME. Ignaczak S. *et al.,* (2022) reported that at the first cut, whole plants of *Galega orientalis* contained 168–278 g/kg DM with 15.7-23.3% CP, 32.7-37.8% ADF, 45.8-52.7% NDF, 6.0-7.5% ash, and 729-800 g/kg

IVTD. Cerempei V. *et al.,* (2023) noted that *Galega orientalis* forage dry matter had 23.4% CP, 26.6% CF, 10.5% ash, 28.8% ADF, 3.6% ADL, 47.7% NDF, 25.2% Cel, 18.9% HC, 66.0% DDM, RFV=128, 10.63 MJ/kg ME and 6.76 MJ/kg NEl, while *Medicago sativa* forage contained 17.2 CP, 9.1 ash, 33.1% CF, 34.7% ADF, 5.8% ADL, 51.0% NDF, 28.9% Cel, 16.3% HC, 61.9 %DDM, RFV=113, 10.26 MJ/kg ME and 6.04 MJ/kg NEl. Kobyrenko Y. (2023) revealed that the fodder productivity of *Galega orientalis*, depending on the type of fertilizer applied, varied from 9.45 to 10.65 t/ha fodder units and digestible protein yield from 1.1 to 1.6 t/ha. Tóth S. (2023) reported that the lignocellulosic composition of green phytomass from *Galega orientalis* included 24.68-49.89% ADF, 34.56-61.69% NDF, 4.98-14.16% ADL, 18.74-40.09% CEL, and 9.17-18.01% HC with gross energy value 14.871-19.707 MJ/kg. Biligetu B. *et al.,* (2024) found that galega forage dry matter had 10-17 % CP, 20-29 % ADF and 36-46 % NDF, while sainfoin forage 8-13 % CP, 21-33% ADF and 33-44 % NDF, respectively. Kosolapova E.V. *et al.,* (2024) remarked that wilted green mass of goat's rue contained 240.3 g/kg DM, 15.77 % CP, 1.92% EE, 19.13 % CF, 4.7 % sugars, 9.0 % ash, 118.00 g digestible protein, 0.88 nutritive units and 9.76 MJ/kg ME. Pap N. *et al.,*, 2024 reported that the green biomass from fodder galega had 128 g/kg DM, 27.0% CP and 8.3% ash; while red clover forage contained 171 g/kg DM, 19.3% CP and 11.0% ash; faba bean – 188 g/kg DM, 23.4% CP and 6.2% ash; green pea – 278 g/kg DM, 13.1% CP and 4.9% ash, and timothy grass – 118 g/kg DM, 18.6% CP and 7.8% ash, respectively.

The results for the quality indices of the studied *Galega orientalis* substrates and their potential for biomethane production are presented in *table 3*. Our analysis showed that the investigated substrates had a C/N ratio ranging from 15.05 to 17.89. The levels of acid detergent lignin (49-58 g/kg) and hemicellulose (187-246 g/kg) met established standards. The biochemical methane potential of the substrates varied from 324 to 353 L/kg of organic dry matter (ODM). A notably high BMP was also observed in the *Galega orientalis* substrate from the third growing season.

Table 1

Agrobiological characteristics of the local cultivar 'Sofia' of *Galega orientalis*

Indices	Third growing season	Fourth growing season	Fifth growing seasons
Plant height, cm	124	139	128
Fresh mass yield,	5.82	5.71	4.82
Dry matter,	1.09	1.17	1.23
Content of leaves and flowers in fodder, %	58.9	58.6	54.9

Table 2

The biochemical composition and feed value of the green mass of *Galega orientalis* 'Sofia'

Indices	Third growing season	Fourth growing season	Fifth growing season
Crude protein, g/kg DM	200.00	172.00	176.00
Crude fiber, g/kg DM	355.00	346.00	333.00
Ash, g/kg DM	133.00	114.00	114.00
Acid detergent fiber, g/kg DM	390.00	377.00	335.00
Neutral detergent fiber, g/kg DM	636.00	592.00	542.00
Acid detergent lignin, g/kg DM	49.00	58.00	56.00
Cellulose, g/kg DM	341.00	319.00	297.00
Hemicellulose, g/kg DM	246.00	215.00	187.00
Digestible dry matter, g/kg DM	585.00	595.00	628.00
Relative feed value	90.00	94.00	108.00
Metabolizable energy, MJ/kg DM	11.61	11.78	12.38
Net energy for lactation, MJ/kg DM	9.53	9.67	10.16
Digestible energy, MJ/kg DM	5.55	5.70	6.18

Table 3

The biochemical composition and biomethane potential of the substrates from *Galega orientalis* 'Sofia'

Indices	Third growing season	Fourth growing season	Fifth growing season
Organic dry matter, g/kg	867.00	886.00	886.00
Minerals, g/kg DM	133.00	114.00	114.00
Crude protein, g/kg DM	200.00	172.00	176.00
Nitrogen, g/kg DM	32.00	27.52	28.16
Carbon, g/kg DM	481.67	492.22	492.22
Ratio carbon/nitrogen	15.05	17.89	17.48
Hemicellulose, g/kg DM	246.00	215.00	187.00
Acid detergent lignin, g/kg DM	49.00	58.00	56.00
Biomethane potential, L/kg DM	299.00	287.00	289.00
Biomethane potential, L/kg ODM	345.00	324.00	326.00

Several studies have reported data on the biomethane production potential of *Galega orientalis* biomass. Dubrovskis V. *et al.,* (2008) found that galega substrates achieved a methane yield of 384.2 L/kg VS. Adam L. (2009) reported that the methane yield in a batch test for galega substrate from the first cut was 412 L/kg VS, while the second cut substrate yielded 282 L/kg VS. Bull I. *et al.,* (2011) observed that the methane yield of first-cut galega substrates ranged from 270.9 to 288.6 L/kg ODM, while second-cut substrates yielded between 303.2 and 315.1 L/kg ODM. According to Adamovics A. *et al.,* (2011), a substrate composed of 75% galega and 25% cow manure reached the highest biogas yield – 628 m³/t DOM, with a methane content of 61.2%, during anaerobic digestion. Mihic D. *et al.,* (2012) reported that *Galega orientalis* substrate reached a biogas yield of 610 L/kg ODM with a methane concentration of 62.6%. Slepetienė A. *et al.,* (2016) analyzed the chemical composition of biomass substrate from third-cut fodder galega, reporting: 3.129% N, 47.44% C, 45.16% NDF, 43.45% ADF, 14.85% ADL, 8.33% ash, 5.83% WSC, 1.71% HC, and 28.60% Cel. Povilaitis V. *et al.,* (2016) found that the elemental composition of fodder galega substrates included 2.71-2.99% nitrogen, 43.67-47.35% carbon, 0.13-0.17% sulphur, and a C/N ratio of 15.91-16.33. Ababii A. *et al.,* (2023) reported that the biochemical methane potential of *Galega orientalis* green mass substrate was 371 L/kg VS. Vishnevskaya O.V. (2017) noted that substrates derived from *Galega orientalis* plants had methane yields of 291-301 L/kg VS, while those from *Dactylis glomerata* yielded 237-241 L/kg VS. Titei V. and Roşca I. (2021) found that the biomethane production potential of *Galega orientalis* substrates varied from 300 to 360 L/kg VS.

CONCLUSIONS

The local cultivar ‘Sofia’ of *Galega orientalis* demonstrated good adaptability under variable climatic conditions (2022-2024), with stable biomass yields across growing seasons.

The forage quality was high, with favorable levels of crude protein, cellulose, hemicellulose, and energy value indicators.

The biomass also showed strong potential for renewable energy production, with a biochemical methane potential ranging from 324 to 353 L/kg ODM and an optimal carbon to nitrogen ratio.

The results confirm that the local cultivar *‘Sofia’* of *Galega orientalis* can be effectively utilized both as a high-quality forage crop and a valuable substrate for biomethane production, especially in the context of climate-resilient and sustainable agriculture.

ACKNOWLEDGEMENTS

This study has been financially supported by the subprogram no. 01.01.02 *“Identification of valuable forms of plant resources with multiple uses for the circular economy".*

REFERENCES

Ababii A., Cerempei V., Ţîţei V., Guțu A., Cîrlig N., Gadibadi M., Mardari, L., Doroftei, V., Cozari, S., Andreoiu, A., Garştea, N., Mazăre, V., 2023- *Some seeds characteristic and biomass quality of some Brassicaceae and Fabaceae species in Moldova.* Scientific Papers. Series A. Agronomy, 66(1):645-654.

Adam L., 2009- *Sudangras - erste Anbauergebnisse aus Brandenburg.* Bauernzeitung, 20:15–16

Adamovics A., Dubrovskis V., Plime I., Adamovicsa O., 2011- *Biogas production from Galega orientalis Lam. and galega-grass biomass.* Grassland Science in Europe, 16:416–418.

Avetisyan A.T., 2013- *Introduction of new, rare fodder crops in the forest-steppe conditions.* Bull. KrasGAU, 7:72-74. [in Russian].

Badger C.M., Bogue M.J., Stewart D.J., 1979 - *Biogas production from crops and organic wastes.* New Zealand Journal of Science, 22:11-20.

Biligetu B., Bainard J., Khanal N., Wang H., 2024- *A comparative study of fodder Galega (Galega orientalis Lam.) and common forage legumes in monoculture and grass–legume binary mixture in Canadian Prairies.* Canadian Journal of Plant Science, 104:1-12.

Bull I., Gienapp C., Wiedow D., Burgstaler J., 2011- *Galega orientalis – a new persistant plant as fodder crop and substrate for biogas production.* Journal für Kulturpflanzen, 63 (12):423–429.

Burykina S.I., 2019- *Carbohydrate and protein complex are less common forage crops in Odessa region.* Taurida Scientific Herald. Series: Rural Sciences, 107:192-197. [in Ukrainian].

Cerempei V., Ţîţei V., Vlăduț V., Moiceanu G.A., 2023- *Comparative study on the characteristics of seeds and phytomass of new high-potential fodder and energy crops.* Agriculture, 13, 1112. https://doi.org/10.3390/agriculture13061112

Cherniavskih V.I., Dumacheva E.V., Lisetskii F.N., Tsugkieva V.B., Gagieva L.C., 2020- *Productivity of galega (Galega orientalis) in single-species and binary crops with sainfoin (Onobrychis arenaria): A case study of forest-steppe of European Russia.* Bioscience Biotechnology Research Communications, 13(1):15-22.

Chornolata L.P., Horbachuk T.V., Liakhovchenko I.A., 2018- *Carbohydrate fractions in the green mass of forage crops*. Feeds and Feed Production, 85:132-137. [in Ukrainian].

Chornolata L., Lykhach S., Zdor L., 2023- *Protein complex of the forage crops green mass.* Feeds and Feed Production. 96:180-189. [in Ukrainian]

Coşman S., Ciopată A.C., Coşman V., Bahcivanji M., Ţîţei V., 2017- *Study on the chemical composition* *and nutritional value of the Galega orientalis Lam. and the prospects of its valorification in the Republic of Moldova.* Scientific Papers, series D, Animal Science, 60:75-80.

Dandikas V., Heuwinkel H., Lichti F., Drewes J.E., Koch K., 2015 - *Correlation between biogas yield and chemical composition of grassland plant species.* Energy Fuels, 29 (11): 7221-7229.

Darmohray L., Luchyn I., Perih M. 2021- *Sustenance, the safety of plants and feed of Galega orientalis (Lam.).* AgroLife Scientific Journal, 10(1):91-100.

Dubrovskis V., Plūme I., Adamovics A., Auziņš V., Straume I., 2008- *Galega biomass for biogas production*. Engineering for Rural Development, 61-**65.**

Hein W., Wasch H. 2018- *Unbekannte leguminosen: esparsette, galega orientalis und andenlupinen - Erste Erfahrungen Österreichische* Fachtagung für Biologische Landwirtschaft, 35 – 46.

Ignaczak S., Andrzejewska J., Sadowska K., Albrecht K.A., 2022- *Fodder galega vs. alfalfa: yield and feed value of leaves, stems, and whole plants.* Agronomy, 12, 1687. https://doi.org/10.3390/agronomy12071687 Accessed on July 09, 2025.

Klimenko V.P., 2012-*Effectiveness of the multienzyme preparation ferkon during preserving of fodder galega (Galega orientalis Lam.).* Russian Agricultural Sciences, 38(4):285–288.

Kobyrenko Y., 2023- *The role of legumes grass mixture in the restoration of degraded land. Modern Science:* Processes of Globalisation and Transformation, 1-4.

Kosolapova E.V., Kuchin N.N., Kosolapov V.V., 2024- *Study of the influence of combined canning on the quality of fermentation during ensiling of sluggish green mass of goat's rue*. Bulletin NGIEI, 8(159):17-31. [in Russian].

Kuchin N.N., Ivashin I.I., 2019- *Seasonal and daily changes in biochemical structure of plants.* Bulletin NGIEI, 3 (94):51-61. [in Russian]

Meripold H., Tamm U., Tamm S., Vosa T., Edesi L., 2017- *Fodder galega (Galega orientalis Lam) grass potential as a forage and bioenergy crop.* Agronomy Research, 15:1693-1699.

Mihic D., Kralik D., Kalafatic A., Jovicic D., Kanizai-Saric G., 2012- *Application of Galega orientalis in biogas production.* Krmiva, 54 (6):183-188.

Nechunaev M.A., Falaleeva L.V., 2020- *Analysis of the chemical composition and nutritional value of forage from perennial grasses of the Middle Urals.* Izvestia Orenburg State Agrarian University, 6 (86):66-69 [in Russian].

Pap N., Granato D., Järvenpää E., Tienaho J., Marnila P., Hellström J., Pihlava J.M., Franco M., Stefański T., Rinne M., 2024- *Biorefining of legume and grass biomasses: technological properties and bioactivities of the green juice*. Future Foods, 9, 100331. https://doi.org/10.1016/j.fufo.2024.100331

Povilaitis V., Šlepetienė A., Šlepetys J., Lazauskas S., Tilvikienė V., Amalevičiūtė K., Feizienė D., Feiza V., Liaudanskienė I., Cesevičienė J., Kadžiulienė Z., Kukujevas A., 2016- *The productivity and energy potential of alfalfa, fodder galega and maize plants under the conditions of the nemoral zone.* Acta Agriculturae Scandinavica, Section B - Soil & Plant Science, 66(3): 259-266

Simonov G., Starkovskiy B., Simonov A., 2021- *Quality of feed species from eastern galega (Galega orientalis Lam.).* Molochnokhozyaystvennyy vestnik, 1 (41):81-88.

Skórko-Sajko H., Tywończuk J., Skomiał J., Pająk J.J., Minakowski D., Sajko J., 2005- *Nutritional value of galega (Galega orientalis Lam.) forage and silage for ruminants*. Journal of Animal and Feed Sciences, 14(1):311-314.

Skórko-Sajko H., Lipinski K., Tywonczuk J., Minakowski D., 2016- *Amino acids profile of protein and nutritional value of fodder galega (Galega orientalis Lam.) depending on the phenological stage.* Zeszyty Naukowe Uniwersytetu Przyrodniczego we Wrocławiu. Biologia i hodowla zwierząt, 618:19-26.

Slepetiene A., Slepetys J., Tilvikiene V., Amaleviciute-Volunge K., Liaudanskiene I., Ceseviciene J., Kadžiulienė Ž., Dabkevičius Z., Buliauskaite R., 2016- *Evaluation of chemical composition and biogas production from legumes and perennial grasses in anaerobic digestion using the oxitop system.* Fresenius Environmental Bulletin, 25:1342-1347.

Slepetys J., 2010- *Influence of cutting and management regimes on fodder galega for forage and seed production.* Agronomy Research 8 (Special Issue III), 711–720.

Teleuţă A., Ţîţei V., Coşman S., 2015a- *Biological peculiarities and nutritional value of Astragalus galegiformis L. and Galega orientalis Lam. species in Moldova.* Journal of Botany, 1(10):127-133.

Teleuţă A., Ţîţei V., Coşman S., Lupan A., 2015b- *Forage value of the species Galega orientalis Lam. under the conditions of the Republic of Moldova.* Research Journal of Agricultural Science, 47 (2):226-231.

Ţîţei V., Coșman S., 2019- *Some agro biological features and hay quality of fodder galega, Galega orientalis.* Romanian Journal of Grassland and Forage crops, 19:79-86.

Ţîţei V., Roşca I., 2021- *Bunele practici de utilizare a terenurilor degradate în cultivarea culturilor cu potenţial de biomasă energetică (Good practices for the use of degraded lands in crop cultivation with a potential of energetic biomass).* In Romanian. Chişinău, 80p.

Toth S., 2024- *Yield potential of newly introduced energy and fodder crop Galega orientalis Lam. on marginal heavy soils under moderate Central European continental climate.* Agriculture (Poľnohospodárstvo), 70(3):133-150.

Truzina L.A., Mosin S.V., Fedorina A.I., 2013- *Cultivation of Galega orientalis in the Central part of the Non-Chernozem zone.* Feeds and Feed Production, 76:178-183. [in Russian].

Vishnevskaya O.V., 2017- *Alternative sources of vegetative mass for biofuels in Polissia zone.* Agricultural Science and Practice. 4(3): 35-42.

Żarczyński P.J., Sienkiewicz S., Wierzbowska J., Krzebietke, S.J., 2021- *Fodder galega—a versatile plant. Agronomy,* 11, 1797. https://doi.org/10.3390/agronomy1109179

Zielewicz W., Golembka D., Kozlowski S., 2013- *Response of Galega orientalis to changes in the plant defoliation frequency from the point of view of its biological and chemical properties*. Grassland Science in Poland, 16:129-140. [in Polish].

Zolotarev V., Korovina V., 2021-*Eastern goat's rue variety (Galega orientalis Lam.) with a marker characteristic. Adaptive Fodder Production, 1:6-14. 10.33814/*AFP-2222-5366-2021-1-6-14. [in Russian].

THE QUALITY INDICES OF ENERGY BIOMASS FROM SOME *BRASSICACEAE* SPECIES IN MOLDOVA

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Abstract

The Brassicaceae family includes many economically important species used as edible crops, industrial oilseeds, spices, fodder, and vegetables. This study was aimed to determine the quality indices of energy biomass from four Brassicaceae species - *Brassica napus*, *Bunias orientalis*, *Isatis tinctoria*, and *Sinapis alba* - grown in the experimental plots of the "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, Chișinău. The lignocellulosic composition of the harvested biomass showed that the dry matter contained 401-424 g/kg of cellulose, 191-226 g/kg of hemicellulose, and 83-88 g/kg of acid detergent lignin. The theoretical ethanol yield from cell wall carbohydrates was estimated to range from 430 to 473 L/t. The biochemical methane potential of the substrates varied from 232 to 268 L/kg of organic dry matter, indicating their suitability as co-substrates in biogas production systems.

The physical and mechanical properties of the biomass included: ash content of 5.48-6.40%, 18.34-18.60 MJ/kg higher heating value, and 17.00-17.40 MJ/kg lower heating value. These characteristics suggest that the studied species can also serve as suitable feedstock for the production of solid densified fuels such as pellets.

Keywords: biochemical methane potential, *Brassica napus*, *Bunias orientalis*, energy biomass, *Isatis tinctoria*, pellets, *Sinapsis alba*, theoretical ethanol yield

The global demand for energy continues to rise in order to meet increasing consumption. Environmental concerns and the depletion of fossil fuel reserves have prompted both the scientific and industrial communities to focus on the development of alternative, renewable energy sources. Among these, biomass is considered one of the most promising renewable energy sources, with significant potential to meet the energy needs of both developed and developing countries. Its use contributes to reducing greenhouse gas emissions and addressing the broader challenges of climate change. Although the concept of generating energy from biomass is not new – humans have burned plant biomass, such as wood, for cooking and heating for thousands of years – modern technologies now allow for more efficient and sustainable energy conversion. Lignocellulosic biomass residues, derived from agricultural crops and livestock manure, offer several advantages, including sustainability, availability and low greenhouse gas emissions. The conversion of agro-industrial waste into bioenergy or biofuels has gained growing attention in recent years, particularly because it does not compete with food production and supports the transition toward a circular bioeconomy. As a result, this area of research continues to attract significant interest from scientists worldwide (Alluvione F. *et al*. 2011; Habashescu I., Cerempei V., 2012; Marian G., 2014; Gudîma A., 2017; Pavlenco A. *et al*. 2018; Doroftei V. *et al*. 2021; Rozenfelde, L. . *et al*. 2021; Casau M. *et al*. 2022- Marian G. *et al*. 2022; Akter, M.M. *et al*., 2024; El-Araby R. 2024; Naveed M. *et al*. 2024; Ye Y. *et al*. 2024; Abbasi-Riyakhuni M. et al. 2025; Guo T.X., and Liang K.W., 2025; Liang K.W., and Yan S.D., 2025).

Brassicaceae is one of the most important plant families, comprising 338 genera and 3,709 species distributed worldwide. In the spontaneous flora of Bessarabia, the Brassicaceae family is represented by 49 genera and 97 species. This family includes numerous economically important species, cultivated for edible use, industrial oilseeds, condiments, fodder, and as vegetables. Among these, canola or oilseed rape (*Brassica napus*) is the most important oil crop within the Brassicaceae family. Additionally, *Brassica oleracea* and *Raphanus sativus* are significant vegetable crops. The family also includes species with potential in biodiesel and protein production, such as: *Camelina sativa, Eruca vesicaria, Crambe abyssinica* and *Brassica carinata*, while *Isatis tinctoria* is historically known as a source of the blue dye indigo. In the "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova

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State University, various *Brassicaceae* species have been studied over the past decades for their potential as fodder plants, melliferous resources and energy crops (Teleuta A.S., 1989a, 1989b; Teleuta A.S. & Cretu L.G., 1989; Ţîţei V., 2016, 2021, 2022a, 2022b; Ţîţei V. & Roşca I., 2021; Cozari S. et al., 2022; Cîrlig N. et al., 2023, 2024).

Additionally, the study explores the potential valorization of this biomass as a feedstock for solid, liquid and gaseous biofuels.

The main goal of this study was to determine the quality indices of energy biomass from four Brassicaceae species - *Brassica napus*, *Bunias orientalis*, *Isatis tinctoria* and *Sinapis alba*, to obtain various types of biofuels as sources of clean and renewable energy.

MATERIALS AND METHODS

The Brassicaceae species *Brassica napus*, *Bunias orientalis*, *Isatis tinctoria* and *Sinapis alba*, cultivated in the experimental plots of the "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University, Chișinău, were selected as the subjects of this research.

Figure 1. **Barssicaceae species in the collection of "Alexandru Ciubotaru" National Botanical Garden (Institute) of Moldova State University**

After seed harvesting, the residual biomass was chopped using a stationary forage unit, then milled in a beater mill with a 6 mm mesh sieve. For analysis, samples were oven-dried at 85°C, ground to <1 mm, and homogenized. Elemental composition, specifically, the total carbon (C), hydrogen (H), nitrogen (N), and sulfur (S) content, was determined by dry combustion using a Vario Macro CHNS analyzer (Elementar Analysensysteme GmbH, Langenselbold, Germany). Biomass densification was carried out using pelleting equipment. The ash content and energy value of both the dry biomass and the resulting pellets were measured according to standardized protocols at the Technical University of Moldova.

To analyze the cell wall composition of the biomass, the contents of neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined using Near-Infrared Spectroscopy (NIRS) with a PERTEN DA 7200 analyzer at the Research-Development Institute for Grassland, Brașov, Romania. The cellulose content was calculated as ADF minus ADL, and hemicellulose – as NDF minus ADF. The Theoretical Ethanol Potential (TEP) was calculated based on the equations proposed by Goff et al. (2010), considering the conversion of cellulose and hemicellulose into hexose (H) and pentose (P) sugars. The biochemical methane potential (BMP) was estimated following the method described by Dandikas V. *et al.* (2015).

RESULTS AND DISCUSSIONS

Biomass can be converted into solid, liquid or gaseous fuels through various physical, chemical and biological conversion processes. Defining clear evaluation criteria to assess biomass quality has become increasingly important, both regionally and globally, to identify the most suitable processing technologies and optimize the type of biofuel produced, thereby enhancing the efficiency of biomass utilization for renewable energy generation.

The quality indices of the studied Brassicaceae biomass, including elemental composition, ash content and calorific value, are presented in Table 1. The dry matter of the analyzed biomass samples contained: 44.31-45.64% carbon, 4.99-5.17% hydrogen, 0.62-1.58% nitrogen, 0.07-0.23% sulphur, 5.48-6.40% ash, 18.34-18.60 MJ/kg GCV and 17.00-17.40 MJ/kg NCV.

Table 1.

The elemental composition, ash content and the energy value of biomass and pellets from the studied *Brassicaceae* species

Indices	*Brassica napus*	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*
Elemental composition				
Carbon, % DM	45.60	45.24	44.36	45.64
Nitrogen, % DM	0.92	1.22	0.61	1.58
Hydrogen, % DM	5.14	5.17	4.99	5.12
Sulphur, % DM	0.07	0.19	0.13	0.23
Oxygen, % DM	48.30	48.18	49.91	47.43
Ash content of biomass, % DM	5.85	6.40	6.04	5.48

Gross calorific value of biomass, MJ/kg DM	18.60	18.45	18.34	18.57
Net calorific value of biomass, MJ/kg DM	17.40	17.08	17.00	17.20
Net calorific value of pellets, MJ/kg DM	15.70	15.04	15.01	15.23

Among the species analyzed, *Isatis tinctoria* had the lowest carbon and hydrogen content, which negatively affected its calorific value compared to the other Brassicaceae species. It is worth noting that the biomass residues of all studied Brassicaceae species showed relatively high levels of nitrogen, sulphur and ash. Particularly high concentrations of nitrogen and sulphur were found in the biomass of *Bunias orientalis* and *Sinapis alba*, which may contribute to increased emissions of toxic gases during combustion. Additionally, the elevated ash content observed in *Bunias orientalis* biomass may promote slag formation on heating equipment surfaces. The pellets produced from these biomass sources, with a moisture content of approximately 10%, exhibited a net calorific value of 15.01-15.70 MJ/kg. Among them, pellets derived from *Brassica napus* and *Sinapis alba* demonstrated higher energy content, making them more suitable for bioenergy applications.

Several authors have reported varying results regarding the quality indices of biomass and solid biofuels derived from Brassicaceae species. Karaosmanoğlu F. *et al.* (1999) reported that rapeseed straw and stalks contained 12.64% moisture, 5.87% ash, 75.55% volatile matter, 18.58% fixed carbon, and had a bulk density of 141.17 kg/m³. Heneman P. & Červinka J. (2007) observed a gross calorific value of 18.50 MJ/kg for *Isatis tinctoria* biomass and 17.48 MJ/kg for *Brassica napus* straw. Zabaniotou A. *et al.* (2008) reported that rapeseed residues had 3.95% ash, 71.01% volatile matter, 23.04% fixed carbon, a gross calorific value of 16.8MJ/kg, and a net calorific value of 16.37 MJ/kg. Chico-Santamarta L. *et al.* (2009) noted an average gross calorific value of 17.4 MJ/kg in canola straw, while in a later study, Chico-Santamarta *et al.* (2012) reported rapeseed stalk pellets had 6.74-9.75% ash and gross calorific value values of 16.91-17.89 MJ/kg.

Greenhalf C.E. *et al.* (2012) found rapeseed straw to contain 6.58% ash, 76.9% volatile matter, 11.88% fixed carbon, and a gross calorific value of 18.94 MJ/kg, while wheat straw, by comparison, had 4.89% ash, 79.92% volatile matter, 15.18% fixed carbon and a gross calorific value of 18.69 MJ/kg. Habashescu I.and Cerempei V. (2012) reported that rapeseed straw had 6.20% ash and 16-17 MJ/kg calorific value. Fuksa P. *et al.* (2013) reported a gross calorific value of 17.29-18.72 MJ/kg for *Brassica napus* biomass and 17.03-18.46 MJ/kg for *Sinapis alba*. Maroušek J. (2013) found that rapeseed straw pellets had a gross calorific value of 15.4 MJ/kg and a specific density of 944 kg/m³. According to Plíštil D. et al. (2014), crambe briquettes had a BD of 670-800 kg/m³, destruction force of 25-55 N/mm, and compaction pressure of 14-21 MPa; while rapeseed straw briquettes had 800–860 kg/m³ BD, 24-40 N/mm destruction force and 35-40 MPa compaction pressure.

I. Niedziółka et al. (2015) reported that pellets made from rape straw were characterized by 12.3% moisture content, a calorific value of 17.3 MJ/kg, and 82.4% mechanical durability. Gao Y. et al. (2017) noted that rapeseed stalk contained 47.47% C, 5.96% H, 41.09% O, 0.47% nitrogen, and 0.22% S. Stasiak M. *et al.* (2017) found that rapeseed straw pellets had 7.92% ash, a lower calorific value of 14.3-16.5 MJ/kg, and 40.6-54.8% mechanical durability. Cástková T. *et al.* (2018) reported that unmodified rape straw contained 95.52% volatile solids, 1,340 mg/kg sulphur, and a calorific value of 17.79 MJ/kg, while modified rape straw had 94.60–96.97% volatile solids, 323-436 mg/kg sulphur and a calorific value of 17.6-18.4 MJ/kg. Gageanu I. *et al.* (2018) found that pellets made from rapeseed stalk had 10.54% moisture content and an energy value of 3780.21 kcal/kg.

Maj G. *et al.* (2019) determined that the heat of combustion of white mustard biomass was 15.55 MJ/kg. Stolarski M.J. *et al.* (2019) found that rapeseed straw contained 27.98% moisture content, 18.93 MJ/kg gross calorific value, 12.95 MJ/kg net calorific value, 20.69% fixed carbon, 73.84 volatile matter, 5.47% ash, 46.89% carbon, 5.46% hydrogen, 1.26% nitrogen, 0.315% sulphur, 0.418% chlorine. Kachel M. *et al.* (2020) stated that rapeseed straw pellets had 89.08 % durability, 18.45 MJ/kg gross calorific value, 17.27 MJ/kg net calorific value, 9.59% ash, 47.42% carbon, 5.38 % hydrogen, 1.15% nitrogen, 0.78 % sulphur, 0.84% chlorine. Vergun O. *et al.* (2021) reported that in *Bunias orientalis* plants ash content ranged from 6.79 to 9.2% and the energy value of the phytomass ranged from 3337 to 3498 cal/g. Stolarski M.J. *et al.* (2024) determined that rapeseed straw had 15.85-25.09% moisture content, 17.97-19.95 % fixed carbon, 72.48-74.69% volatile matter, 5.95-7.56% ash, 43.41-45.70% carbon, 5.12-5.61% hydrogen, 0.97-1.18%% nitrogen, 0.193-0.394% sulphur, 0.233-0.425% 17.97-18.42 MJ/kg gross calorific value, 12.14-14.35 MJ/kg net calorific value. Jankowski

K. J. (2025) reported that lower heating value of white mustard straw varied from 15.42 to15.99 MJ/kg. According to Stolarski M.J. *et al.* (2025) the rapeseed biomass pellets is characterized by 8.19 % moisture content, 19.65 % fixed carbon, 75.3%5 volatile matter, 607.85 kg/m^3 bulk density, 18.91 MJ/kg gross calorific value, 16.03 MJ/kg net calorific value, 5.95-7.56% ash, 48.38% carbon, 6.04% hydrogen, 0.84 % nitrogen, 0.19% sulphur, 0.071% chlorine.

Organic compounds from renewable raw materials like plant biomass are increasingly central to research in renewable energy and the circular economy. Biomass serves as a key feedstock for bioconversion, with microorganisms converting cellulose, hemicellulose, and lignin into bio-based products such as bioethanol, butanol, and acetone. Second-generation ethanol from lignocellulosic biomass offers a promising alternative to fossil fuels, thanks to its low cost, wide availability and reduced emissions. Its antiknock properties also enhance fuel efficiency. Ethanol production efficiency largely depends on the plant cell wall composition, particularly the ratios of cellulose, hemicellulose and lignin.

The results concerning the quality of the investigated lignocellulosic Brassicaceae substrates and their theoretical ethanol potential are presented in Table 2. Notably, the concentrations of cellulose and hemicellulose in the *Isatis tinctoria* substrate are significantly higher compared to the other species. The cellulose content is similar in the substrates of *Sinapis alba* and *Brassica napus*, while hemicellulose levels do not differ substantially between *Brassica napus* and *Bunias orientalis*. Among the studied species, the *Sinapis alba* substrate is particularly rich in hemicellulose. The concentrations of acid detergent lignin across all substrates are within optimal ranges and show no significant variation. This consistency may positively influence the digestibility and decomposition efficiency of the lignocellulosic biomass. The estimated theoretical ethanol potential from fermentable sugars averaged 473 L/t in *Isatis tinctoria* substrate, 449 L/t in *Sinapis alba* substrate, 433L/t in *Bunias orientalis* substrate, as compared with 430 L/t in *Brassica napus oleifera* substrate.

Table 2

The biochemical composition and the theoretical ethanol potential of biomass from the studied *Brassicaceae* species

Indices	*Brassica napus*	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*
Acid detergent fibre, g/kg DM	484	489	512	484
Neutral detergent fibre, g/kg DM	675	682	738	701
Acid detergent lignin, g/kg DM	83	86	88	83
Cellulose, g/kg DM	401	403	424	401
Hemicellulose, g/kg DM	191	193	226	217
Theoretical ethanol potential:	429.62	432.54	472.98	448.77
from hexose sugars, L/t ODM	298.62	300.16	316.96	299.93
from pentose sugars, L/t ODM	131.00	132.38	155.02	148.84

Several literature sources describe the composition of cell walls in the biomass from the studied *Brassicaceae* species. According to Petersson A. *et al.* (2007) the oilseed rape straw had 907 g/kg dry matter and its chemical composition was 27.3 % glucan, 15.0 % xylan, 2.7 % galactan, 2.0 % mannan, 2.2% arabinan, 14.2% Klason lignin, 9.6% ash, 10.1 % extractives, and 17.0 % residual. Barbash V. *et al.* (2011) found that *Brassica napus* stalks had 3.2% ash, 29.6 % pentosans, 37.7 % cellulose, 26.4% lignin, while *Bunias orientalis* stalks had 5.1% ash, 19.9 % pentosans, 34.3 % cellulose, 22.2% lignin. Dukarska, D. *et al.* (2011) remarked that chemical composition of white mustard straw was 36.70% cellulose, 21.10% lignin, 3.46% extraction substances, 5.60% mineral substances.

Greenhalf C.E. *et al.* (2012) determined that rapeseed straw had 37.55% cellulose, 31.37% hemicellulose, 21.30% lignin, 3.76% soluble, 6.02% ash. Potucek F. *et al.* (2014) studied the chemical composition of rapeseed straw found that stalks had 4.45% ash, 76.15 % holocellulose, 33.90 % cellulose, 28.83 % α-cellulose, 21.35% lignin, while valves of siliques contained 7.83% ash,71.59 % holocellulose, 28.35% cellulose, 25.73% α-cellulose, 14.14 % lignin. Kiro M. (2015) reported that rapeseed straw contained 72.28 % holocellulose, 45.39 % α-cellulose, 19.43 % lignin, 3.32 % soluble, 4.27% ash. Viel M. *et al.* (2018) remarked that the chemical characterization of agro-resources of rapeseed straw had the following indices: 53.06% cellulose, 18.13% hemicellulose, 9.63 % lignin, 17.68% soluble and 0.79% ash. Hajj Obeid M. *et al.* (2022) mentioned that the chemical composition of the rapeseed straws was 51.40-55.20% cellulose, 9.30-15.00% hemicellulose, 8.40-10.90 % lignin, 20.90-29.90% soluble and 0.40-0.90% inorganic materials. Chen, S *et al.* (2018) mentioned that Rapeseed after the seeds had been collected had 51.15 g/kg CP, 114.48 g/kg WSC, 33.07 g/kg ADF, 47.34 g/kg

NDF. Comlekcioglu1 N. *et al.* (2018) remarked that stalks from *Isatis tinctoria* had 4.9% ash, 67.1 % holocellulose, 48.5% α-cellulose, 23.9 % lignin and 4.9% extractives, while *Isatis buschiana* – 11.1% ash, 70.1 % holocellulose, 32.9% α-cellulose, 19.9 % lignin and 4.1% extractives. Akgül M. *et al.* (2018) canola stalks contain 72.10% holocellulose, 42.55% α-cellulose, 13.15% lignin and 8.2% ash. Guo T.X. and Liang K.W., 2025, determined that from the pre-treated rapeseed straw, under the best conditions the ethanol output can reach 12.2 g/L.

As the availability of traditional fossil-based energy sources continues to decline and the global energy demand steadily increases, the transition toward renewable energy alternatives is becoming more urgent and vital. One such promising renewable energy sources is the generation of biogas through anaerobic fermentation. This process is increasingly recognized as a sustainable energy solution with a wide array of environmental and socio-economic benefits. Biogas production plays a significant role in reducing greenhouse gas emissions, thereby contributing to climate change mitigation. Additionally, it aids in the destruction of harmful pathogens, promotes the recycling of nutrients, and can stimulate economic growth at both regional and local levels by creating jobs and supporting agricultural development. In biogas reactors, organic material derived from various sources, such as biomass, agricultural residues, organic waste, or wastewater, is biologically broken down in the absence of oxygen. This anaerobic digestion process results in the formation of biomethane (the primary energy component of biogas), along with carbon dioxide and other by-products such as hydrogen sulfide, ammonia, and digestate. While biomethane serves as a clean and renewable energy source, the resulting digestate is rich in nutrients and can be utilized as a valuable organic fertilizer in agriculture, further closing the loop in sustainable resource use.

The evaluation of several Brassicaceae plant substrates for their potential in biogas production is summarized in Table 3, which presents various quality indices relevant to anaerobic digestion. The analysis indicated that the carbon-to-nitrogen (C/N) ratios of the tested substrates ranged between 29 and 73. Of all the species examined, only the substrate derived from *Sinapis alba* demonstrated a C/N ratio that falls within the optimal range typically recommended for efficient anaerobic digestion, which enhances microbial activity and methane production. In terms of structural biomass composition, the concentration of acid detergent lignin (a component that affects biodegradability) was found to be between 83 and 88 grams per kilogram across the different Brassicaceae species. Meanwhile, the hemicellulose content ranged from 191 to 226 grams per kilogram. These compositional factors influence the efficiency of the anaerobic fermentation process and the resulting methane yields. The biochemical methane potential, which is a key metric for evaluating a substrate’s capacity to generate methane, was observed to range from 232 to 268 litres per kilogram of organic dry matter. These values confirm that all tested Brassicaceae substrates are suitable candidates for use as co-substrates in biogas production systems. Notably, *Sinapis alba* exhibited the highest BMP value among the tested species, highlighting its superior potential as a feedstock for efficient biogas generation.

Table 3

The biochemical composition and the theoretical ethanol potential of biomass from the studied *Brassicaceae* species

Indices	*Brassica napus*	*Bunias orientalis*	*Isatis tinctoria*	*Sinapis alba*
Crude protein, g/kg DM	*58.00*	*76.30*	*38.30*	*98.80*
Nitrogen, g/kg DM	*9.30*	*12.22*	*6.10*	*15.80*
Ash, g/kg DM	*58.50*	*64.00*	*60.40*	*54.80*
Organic matter, g/kg DM	*941.50*	*936.00*	*939.60*	*945.20*
Carbon, g/kg DM	*456.00*	*452.4*	*443.60*	*456.40*
Carbon/nitrogen ratio	*49.00*	*37.08*	*72.72*	*28.89*
Acid detergent lignin, g/kg DM	*83.00*	*86.00*	*88.00*	*83.00*
Hemicellulose, g/kg DM	*191.00*	*193.00*	*226.00*	*217.00*
Biomethane potential, L/kg VS	*258.00*	*232.00*	*249.00*	*268.00*
Biomethane potential, L/kg DM	*243.00*	*223.00*	*234.00*	*253.00*

Multiple studies have provided data on the biomethane production potential of biomass from the examined Brassicaceae species. According to Petersson A. *et al.* (2007) the biogas yield from oilseed rape straw was 0.42 m^3/kg VS, while from winter rye straw was 0.36 m^3/kg VS and from faba bean straw 0.44 m^3/kg VS. Carchesio M. *et al.* (2014) noted that substrates derived from *Isatis tinctoria* plant in the anaerobic digestion test achieved net methane yield 153.1 l/kg VS, with

33% estimated degrees of conversion. Ţîţei V. (2016) reported that the gas forming potential of organic digestible matter of studied substrates from *Isatis tinctoria* varied from 438 l/kg to to 465 l/kg VS and methane yield from 242 to 251/kg VS. Gaballah E.S. *et al.* (2020) found that methane yield of in combined pretreatment of rapeseed straw substrate archived 305.7 L/kg VS, which was 77.84% higher than the untreated rape straw substrate. Ţîţei V. (2021, 2022 a,b) reported that the biochemical methane potential of fresh and ensiled biomass substrates from *Brassica napus* was 303-324 L/kg, but from *Sinapis alba* reached 273-330 L/kg organic matter and from *Crambe cordifolia* 254 L/kg organic matter. According to Guo T.X., and Liang K.W., 2025, under optimal conditions, the methane output of rapeseed strawcan can reach up to 365 L/kg of volatile solids. Witaszek K. *et al.* (2025) noted that straw substrates derived from *Brassica napus* contained 49.22-66.52% ADF, 59.52-80.99% NDF and methane yields varied from 86.69 to 202.06L/kg VS, while those from *Triticum aestivium* 45.95-52.84% ADF, 77.07-87.09% NDF and methane yields varied from 200.8 to 272.08L/kg VS.

CONCLUSIONS

The elemental composition and calorific values of the studied biomass samples demonstrated their suitability for solid biofuel production. Notably, *Brassica napus* and *Sinapis alba* showed the highest energy content in pellet form, with net calorific values ranging from 15.01 to 15.70 MJ/kg.

Sinapis alba met the optimal range recommended for anaerobic digestion, further reflected in its highest biochemical methane potential (268 L/kg ODM) among the evaluated species.

Isatis tinctoria dry biomass substrates are significantly higher concentrations of cellulose and hemicellulose and the estimated theoretical ethanol potential averaged 473 L/t.

Overall, *Sinapis alba* emerged as a highly versatile lignocellulosic feedstock, combining strong performance in both thermochemical (combustion, pelletization) and biochemical (bioethanol, biomethane) energy pathways. These findings support its integration into diversified bioenergy systems aimed at enhancing sustainability and resource efficiency.

ACKNOWLEDGEMENTS

This study has been financially supported by the subprogram no. 01.01.02 *"Identification of valuable forms of plant resources with multiple uses for the circular economy".*

REFERENCES

Ababii A., Cerempei V., Ţîţei V., Guţu A., Cîrlig N., Gadibadi M., Mardari, L., Doroftei, V., Cozari, S., Andreoiu, A., Garștea, N., Mazăre, V., 2023- *Some seeds characteristic and biomass quality of some Brassicaceae and Fabaceae species in Moldova.* Scientific Papers. Series A. Agronomy, 66(1):645-654.

Abbasi-Riyakhuni, M., Hashemi, S. S., Denayer, J. F., Aghbashlo, M., Tabatabaei, M., & Karimi, K. (2025). Integrated biorefining of rapeseed straw for ethanol, biogas, and mycoprotein production. *Fuel*, *382*, 133751.

Alluvione F., Moretti B., Sacco D., Grignani C. 2011- *EUE (energy use efficiency) of cropping systems for a sustainable agriculture*. Energy, 36 (7): 4468–4481.

Akgül M., Erdönmez I., Çiçekler, M., Tutus A., 2018- *The investigations on pulp and paper production with modified kraft pulping method from canola (Brassica napus L.) stalks.* Kastamonu Univ., Journal of Forestry Faculty, 8 (3): 357-365.

Akter, M. M., Surovy, I. Z., Sultana, N., Faruk, M. O., Gilroyed, B. H., Tijing, L., Kabir, M. M. (2024). Techno-economics and environmental sustainability of agricultural biomass-based energy potential. *Applied Energy*, *359*, 122662.

Barbash V., Poyda V., Deykin I., 2011- *Peracetic acid pulp from annual plants.* Cellulose Chemistry and Technology, 45 (9–10): 613–618.

Carchesio M., Tatàno F., Lancellotti, I., Taurino, R.,Colombo, E., Barbieri, L., 2014 - *Comparison of biomethane production and digestate characterization for selected agricultural substrates in Italy.* Environmental Technology, 35:2212-2226.

Cástková T., Hýsek Š., Sikora A., Schönfelder O., Böhm M., 2018- *Chemical and physical parameters of different modifications of rape straw (Brassica napus L.).* BioResources, 13(1): 104-114.

Casau M.; Dias, M.F.; Matias, J.C.O.; Nunes, L.J.R., 2022- Residual Biomass: A Comprehensive Review on the Importance, Uses and Potential in a Circular Bioeconomy Approach. Resources 2022, 11, 35. https://doi.org/10.3390/ resources11040035

Chen S., Wan C., Ma Y., Zhang K., Wang F., Shen S., 2023- *Study on the quality of mixed silage of rapeseed with alfalfa or Myriophyllum.* International Journal of Environmental Research and Public Health, 20, 3884. doi.org/10.3390/ijerph20053884

Chico-Santamarta L., Humphries A.C., White D., Chaney K., Godwin R.J., 2009- *Effect of pre- and postpelletisation storage of canola (oilseedr ape) straw on the quality and properties of pellets.* ASABE Annual Meeting, no. 096105. 10.13031/2013.27054.

Chico-Santamarta L., Chaney K., Godwin R.J., White D.R., Humphries A., 2012- *Physical quality changes during the storage of canola (Brassica napus L.) straw pellets.* Applied Energy Journal, 95: 220-226.

Cîrlig N., Guţu A., Iurcu-Străistaru E., 2024- *Isatis tictoria L.– biological peculiarities and usage as honey plant.* In: Ştiinţa în Nordul Republicii Moldova: realizări, probleme, perspective, Chişinău, 445-449.

Cîrlig N., Ţîţei V., Guţu A., 2023- *High-value melliferous plant resources.* In. Instruire prin cercetare pentru o societate prosperă, Chişinău. 1: 172-175

Comlekcioglu N., Tutus A., Çiçekler M., Çanak A., Zengin G., 2016- *Investigation of Isatis tinctoria and Isatis buschiana stalks as raw materials for pulp and paper production.* Drvna Industrija. 67:249-255. 10.5552/drind.2016.1542

Cozari S., Ţîţei V., Guţu A., Andreoiu A.C., Coşman S., Coşman V., Mocanu N., Mardari L., 2022- *The quality of silage from Isatis tinctoria*. In: The scientific symposium Biology and Sustainable Development. Bacău. p. 84-85.

Dandikas V., Heuwinkel H., Lichti F., Drewes J.E., Koch K., 2015 - *Correlation between biogas yield and chemical composition of grassland plant species.* Energy Fuels, 29 (11): 7221-7229.

Doroftei V., Ţiţei V., Ababil A., Blaj V., Cozari S., Andreoiu A.C., Maruşca T., Coşman V., Guţu A., 2021- *Evaluarea calităţii biomasei din plantaţiile semincere de ierburi perene şi posibilităţi de valorificare.* Genetica, fiziologia şi ameliorarea plantelor, Chişinău, 305-308.

Dukarska D., Bartkowiak M., Stachowiak-Wencek, A., 2015- *White mustard straw as an alternative raw material in the manufacture of particleboards resinated with different amounts of urea-formaldehyde resin*. Drewno, *58*(194):49-63.

Dukarska D., Łęcka J., Szafoni K., 2011- *Straw of white mustard (Sinapis alba) as an alternative raw material in the production of particle boards resinated with UF resin.* Acta Sci. Pol. Silv. Colendar. Rat. Ind. Lignar. 10(1) :19-28.

El-Araby R., 2024- *Biofuel production: exploring renewable energy solutions for a greener future.* Biotechnol Biofuels 17, 129 https://doi.org/10.1186/s13068-024-02571-9.

Fuksa P., Hakl J., Brant V., 2013- *Energy balance of catch crops production.* Zemdirbyste-Agriculture, 100(4):355–362.

Gageanu I., Cujbescu D., Persu C., Voicu G., 2018- *Influence of using additives on quality of pelletized fodder.* In. *Engineering for Rural Development*. 17: 1632-1638.

Gaballah E.S., Abomohra A.E.F., Xu C., Elsayed M., Abdelkader T.K., Lin J., Yuan Q., 2020- *Enhancement of biogas production from rape straw using different co-pretreatment techniques and anaerobic co-digestion with cattle manure.* Bioresource Technology. 309. 123311. 10.1016/j.biortech.2020.123311.

Gao Y., Wang X., Chen Y., Li P., Liu H., Chen H., 2017- *Pyrolysis of rapeseed stalk: Influence of temperature on product characteristics and economic costs*. Energy, 122: 482-491.

Goff B.M., Moore K.J., Fales, L., Heaton A., 2010- *Double-cropping sorghum for biomass.* Agronomy Journal, 102:1586-1592.

Greenhalf C.E., Nowakowski D.J., Bridgwater A.V., Titiloye J., Yates N., Riche A., Shield I., 2012- *Thermochemical characterisation of straws and high yielding perennial grasses*. Industrial Crops and Products, 36:449–459.

Gudîma A., 2017- *Evaluarea utilizării reziduurilor agricole pentru scopuri energetice. Studiu de caz pentru raionul Soroca, Republica Moldova.* Meridian ingineresc, 1: 26-29. I

Guo T.X., Liang K.W., 2025- *Bioenergy production from rapeseed straw: a feasibility study*. Journal of Energy Bioscience, 16(4): 163-171.

Habashescu I., Cerempel V., 2012- *Energetic potential of vegetable mass in agriculture of Republic of Moldova*. International conference "Energy of moldova –regional aspects of development", 355-359.

Hajj Obeid M., Douzane O., Freitas Dutra L., Promis G., Laidoudi B., Bordet F., Langlet T., 2022- *Physical and mechanical properties of rapeseed straw concrete.* Materials, 15(23):8611. DOI: 10.3390/ma15238611

Heneman P., Červinka J. 2007- *Energy crops and bioenergetics in the Czech Republic.* Annals of Warsaw University of Life Sciences – SGGW Agriculture (Agricultural Engineering), 51: 73-78.

Jankowski K.J., 2025- *White mustard: energy balance at different nitrogen management strategies*. Industrial Crops and Products, 225, 120420. https://doi.org/10.1016/j.indcrop.2024.120420

Kachel M., Kraszkiewicz A., Subr A., Parafiniuk S., Przywara A., Koszel M., Zając G., 2020- *Impact of the type of fertilization and the addition of glycerol on the quality of spring rape straw pellets.* Energies, 13(4), 819. https://doi.org/10.3390/en13040819

Karaosmanoglu F., Tetik E., Gollu E., 1999- *Biofuel production using slow pyrolysis of the straw and stalk of the rapeseed plant.* Fuel Processing Technology, 59:1-12.

Kiro M., 2015- *Cellulose fibers extracted from agricultural biomass.* Tekstilna industrija, 62(4): 15-19.

Kord B., Zare H., Hosseinzadeh A., 2016- *Evaluation of the mechanical and physical properties of particleboard manufactured from canola (Brassica napus) straws.* Maderas. Ciencia y tecnología. 18(1): 9 – 18. 10.4067/S0718-221X2016005000002.

Liang K.W, Yan S.D., 2025- *Exploring the potential of rapeseed biomass for renewable energy*. Journal of Energy Bioscience, 16(3): 105-116

Marian G., 2014- *Managementul biomasei agrosilvice pentru scopuri energetice.* Chişinău: 264 p.

Marian G., Ianuş G., Istrate B., Banari A., Nazar B., Munteanu C., Măluţan T., Gudima A., Ciolacu F., Daraduda N., Paleu V., 2022- *Evaluation of agricultural residues as organic green energy source based on seabuckthorn, blackberry, and straw blends*. Agronomy, 9(12):1-14. DOI: *https://doi.org/10.3390/agronomy12092018*

Maroušek J., 2013- *Study on commercial scale steam explosion of winter Brassica napus straw.* International Journal of Green Energy, 10: 944–951.

Maj G., Krzaczek P., Stamirowska-Krzaczek E., Lipińska H., Kornas R., 2019- *Assessment of energy and physicochemical biomass properties of selected forecrop plant species.* Renewable Energy, 143:520-529.

Naveed M.H., Nouman M., Khan A., Mukarram M., Raza Naqvi S., Abdullah A., & *Ul Haq Z., Ullah, H., Mohamadi H., 2024-* *Cellulosic biomass fermentation for biofuel production: Review of artificial intelligence approaches.* Renewable and Sustainable Energy Reviews. 189. 113906. 10.1016/j.rser.2023.113906.

Niedziółka I., Kachel-Jakubowska M., Kraszkiewicz A., Szpryngiel M., Szymanek M., ZAKLIKA B., 2015- *Assessment of quality and energy of solid biofuel production*. Bulgarian Journal of Agricultural Science, 21 (2):461–466

Pavlenco A., Marian G., Gudîma A., 2018- *Potenţialul energetic al reziduurilor agricole: studiu de caz pentru regiunea de dezvoltare nord, Republica Moldova.* Ştiinţa Agricolă, 2-:141-149.

Petersson A., Thomsen M.H., Hauggaard-Nielsen H., Thomsen A.B., 2007- *Potential bioethanol and* *biogas production using lignocellulosic biomass from winter rye, oilseed rape and faba bean.* Biomass and Bioenergy, 31(11–12):812–819.

Plištil D., Brožek M., Malaák J., Roy A., Hutla P., 2005- *Mechanical characteristics of standard fuel briquettes on biomass basis*. Research in Agricultural Engineering, 51(2):66-72.

Potucek F., Gurung B., Hájková K., 2014- *Soda pulping of rapeseed straw.* Cellulose Chemistry and Technology, 48 (7-8):683-691

Rahim M., Douzane O., Le A.T., Promis G., Langlet T., 2015- *Characterization and comparison of hygric properties of rape straw concrete and hemp concrete.* Construction and Building Materials, 102:679–687.

Rozenfelde, L., Puke, M., Vedernikovs, N., Scherbaka, R., Rapoport, A. (2021). Catalytic treatment of rapeseed straw for enhanced production of furfural and glucose for bioethanol production. *Process Biochemistry*, *102*: 102-107.

Stasiak M., Molenda M., Bańda M., Wiącek J., Parafiniuk P., Gondek E., 2017- *Mechanical and combustion properties of sawdust—straw pellets blended in different proportions*. Fuel Processing Technology, 156:366-375.

Stolarski M.J., Welenc M., Krzyżaniak M., Olba-Zięty E., Stolarski J., Wierzbicki S., 2024- *Characteristics and changes in the properties of cereal and rapeseed straw used as energy feedstock.* Energies, 17*(5),* 1243. https://doi.org/10.3390/en17051243

Stolarski M.J, Rybczyńska B., Krzyżaniak M., Lajszner W., Graban Ł., Peni D., Bordiean A., 2019- *Thermophysical properties and elemental composition of agricultural and forest solid biofuels versus fossil fuels.* Jorunal of Elementology, 24(4): 1215-1228. DOI: 10.5601/jelem.2019.24.1.1819

Stolarski M. J., Krzyżaniak M., Olba-Zięty E., 2025- Properties of pellets from forest and agricultural biomass and their mixtures. *Energies*, *18*(12), 3137. https://doi.org/10.3390/en18123137

Teleuta A. S., 1989a- *Biochemical characteristics of mustard green mass in Moldovan conditions.* In. Abstracts of reports of the 2nd All-Union Seminar of Young Scientists and Specialists on New Forage Crops. Odessa, p. 15. [in Russian].

Teleuta A., 1989b- *Energy and nutritional value of spring turnip rapeseed in Moldovan conditions.* In. Abstracts of reports of the 2nd All-Union Seminar of Young Scientists and Specialists on New Forage Crops. Odessa, p. 52 [in Russian].

Teleuta A. S., Cretu L.G. 1989- *Feeding qualities of spring rape green mass in Moldovan conditions.* In. Feed plant resources - a factor of scientific and technical progress in forage production. Kyiv – Belaya Tserkov, p. 35. [in Russian].

Ţîţei V., 2016- *Agrobiological peculiarities and prospects for valorification of woad, Isatis tinctoria L., in Moldova.* Lucrări Ştiinţifice, seria Agronomie, 59 (2):267-272.

Ţîţei V., 2022a- *Calitatea silozului din unile specii din familia Brassicaceae și posibilități de valorificare în Republica Moldova.* Știința și inovarea în nordul Republicii Moldova: probleme, realizări, perspective. Bălți, 277-281.

Ţîţei V., 2021- *The quality of fresh and ensiled biomass of Brassica napus oleifera and prospects of its use.* Scientific Papers. Series A. Agronomy, 64(2):330–335.

Ţîţei V., 2022b- *The quality of fresh and ensiled biomass from white mustard, Sinapis alba, and its potential uses***.** Scientific Papers. Series A. Agronomy, 65(1): 559-566.

Ţîţei V., Roşca I., 2021- *Bunele practici de utilizare a terenurilor degradate în cultivarea culturilor cu potenţial de biomasă energetică (Good practices for the use of degraded lands in crop cultivation with a potential of energetic biomass).* In Romanian. Chişinău, 80p.

Vergun O., Rakhmetov, D., Shymanska, O., Rakhmetova S., Bondarchuk O., Fishchenko, V.. 2021-*Morphometric and biochemical features of different Bunias orientalis L. genotypes in the M. M. Gryshko National Botanical Garden of the NAS of Ukraine.* Plant Varieties Studying and Protection, 17: 66-72. 10.21498/2518-1017.17.1.2021.228213.

Viel M., Collet F., Lanos C., 2018- *Chemical and multi-physical characterization of agro-resources' by-product as a possible raw building material*. Industrial Crops and Products, 120:214–237. doi: 10.1016/j.indcrop.2018.04.025.

Witaszek K., Kupryaniuk K., Kupryaniuk J., Panasiewicz J., Czekała W., 2025- *Optimization of straw particle size for enhanced biogas production: a comparative study of wheat and rapeseed straw.* Energies, 18*(7),* 1794. https://doi.org/10.3390/en18071794

Yang B., Na N., Wu N., Sun L., Li, Z.; Qili M., Han H., Xue Y., 2024- *Impact of additives and packing density on fermentation weight loss, microbial diversity, and fermentation quality of rape straw silage.* Microorganisms 12*,* 1985. *https://doi.org/10.3390/microorganisms12101985*

Ye Y., Guo W., Ngo H.H., Wei W., Cheng D., Bui X.T., Hoang N.B., Zhang H., 2024- *Biofuel production for circular bioeconomy: Present scenario and future scope.* Science of The Total Environment, 935:172863. doi: 10.1016/j.scitotenv.2024.172863.

Zabaniotou A., Ioannidou O., Skoulou V., 2008- *Rapeseed residues utilization for energy and 2nd generation biofuels.* Fuel, 87(8-9):1492-1502.

Zarajczyk, J., 2013- *Technical and technology conditions of plant biomass pellets for energy purposes.* Monografi e i rozprawy. Inżynieria Rolnicza, 1 (142), 2:81.

THE ELEMENTS OF POTENTIAL SOIL FERTILITY RELATING TO WINTER WHEAT PRODUCTION IN THE NORTHERN AGRICULTURAL AREA OF THE REPUBLIC OF MOLDOVA

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Abstract

The Northern Development Region of the Republic of Moldova (NDR) includes 11 administrative districts (Briceni, Edineţ, Donduşeni, Drochia, Făleşti, Floreşti, Glodeni, Ocniţa, Rîşcani, Sângerei, Soroca), including the municipality of Bălţi. The NDR corresponds to the Northern Agricultural Zone, representing 32.9% of the total area of the Republic of Moldova. The area has significant potential in the cultivation of the main strategic and export crops of the region - wheat, corn, sunflower and others, an area characterized by highly fertile soils - chernozems, with favorable grades of soil creditworthiness. In food security, the soil represents an important link regarding the fertility and productivity of cultivated crops. Currently, these are vulnerable to climate change and the risks that accompany them, including high temperatures during critical phases of plant development, lack of moisture in the soil due to insufficient atmospheric precipitation, lack of nutritional elements for plants and others. The elements of potential fertility with a determining role in food security are climatic conditions and soil characteristics: texture, organic matter content (humus), nutrients - NPK, which as a whole will determine the physical, hydro-physical characteristics and the conditions for plant growth and development. These characteristics have a major role in the accumulation, mobility and storage of moisture reserves, providing the plant with water and nutrients. In 2025, along with production, the quality of winter wheat on loamy-clay and clay-loamy leached chernozems was also researched. The comparative evaluation on several polygons highlighted varieties with high protein content (10.5%), gluten (26%), Zeleny index (56 ml), compared to agrocenoses characterized by low protein indices – 8.1%, gluten – 16%, Zeleny index – 38ml.

Keywords: winter wheat, leached chernozems, harvest quality, gluten, climatic conditions.

Winter wheat is a strategic and food security crop. In the Republic of Moldova, the areas cultivated with winter wheat have varied over the last 45 years, between 212 and 300 thousand ha annually, and the annual global harvest has varied within very wide limits from 407 to 1300 thousand tons (statistical data, 1980 - 2024). The average weighted yield per 1 ha of winter wheat in the Republic of Moldova deviates significantly in the last five years, from 1.8 t/ha (2020) to 4.18 t/ha (2023), with maximum values of about 4.69 t/ha in 2021.

Some elements of potential and actual fertility were researched for cambic (leached) chernozems with winter wheat, Northern area of the Republic of Moldova, agricultural year 2024-2025. For comparison, some representative data for the agricultural year 2023-2024 were also included.

Soil texture is the main physical property, with a particularly important role in determining most of the other physical properties, as well as many chemical properties. As a result, texture is of particular importance in relation to the soil's productive capacity, its agronomic and ameliorative characteristics, and the technology of superior utilization of soil resources. The characteristic of soil texture must be researched not only in terms of evaluating the properties of the pedogenetic profile, but also in terms of the role of the soil grain size composition in shaping agricultural production and the quality of food products. Agricultural practice has proven that the most favorable soils by texture are loamy and loamy-clayey soils that contain proportionally sandy and clay particles.

In 2025, based on pedological studies for 20 localities in the northern agricultural area of the Republic of Moldova, the main textural varieties of representative soils with reference to some field crops were highlighted. It was highlighted that under the conditions of the soil cover with highly fertile loamy-clay and clay-loamy chernozems, with a soil creditworthiness of over 80 points, the winter wheat harvest varied in 2025 within the limits of 6-9 t/ha, with an average of approx. 6.7 t/ha (Plop village, Donduseni district). The 2024-2025 agricultural year was

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more favorable for winter wheat, compared to the 2023-2024 agricultural year, in which the harvest was 3.5-7.0 t/ha, the average of 5.5 t/ha.

MATERIALS AND METHODS

In the context of highlighting some elements of soil fertility and indicators of agricultural crop productivity regarding ensuring food security in the Republic of Moldova under climate change conditions, representative localities of the 5 pedogeographical districts, located in the North Moldavian Plateau, the North Moldavian Plain and the Soroca-Rezina Height, were researched in 2025: pedogeographical district 1 of gray soils, luvic and leached chernozems of the forest-steppe of the Northern Plateau; ecopedological district 2 of typical and leached chernozems of the forest-steppe of the Middle Prut Hills; district 3 with typical chernozems, the steppe of the Balti Plain, including microdistricts 3a, 3b, 3c; pedogeographical district 4 with leached chernozems, typical and gray soils of the forest-steppe of the Soroca Hills; district 5 of leached and luvic chernozems with gray soils, forest-steppe of the Rezina Hills.

For assessment were selected 20 localities, where the soil cover structure, types, subtypes, textural varieties and soil quality score were evaluated, according to soil properties with a determining role in influencing potential and actual fertility. The soil cover was investigated based on previous pedological studies and current research. Methods for determining the physico-chemical and physical properties according to the methods accepted by the ecopedological monitoring (Andriucă V., 2008, 2021; Cerbari V., 2010). Determining the granulometric composition according to N. Cacinschi (pipette method), soils dispersion degree using tetra sodium pyrophosphate ($Na_4P_2O_7$) of 4% (STAS 12536-79).

Currently, this method is very laborious and is related to the method of determining soil texture using the Anton Paar Sedigraph. The determination of the qualitative indices of winter wheat was carried out instrumentally, applying Multi-Bruins Instruments CHECK, by evaluating the content of: protein, %; gluten, %; Zeleny index, ml; moisture, % and others.

RESULTS AND DISCUSSIONS

The production of field crops is significantly influenced by the plant variety, climatic and ecopedological conditions, and the technology practiced. Soil texture is the main physical property, with a particularly important role in determining most of the other physical properties, as well as many chemical properties. As a result, texture is of particular importance in relation to the production capacity of the soil, its agronomic and ameliorative characteristics, and the technology of superior utilization of soil resources (Canarache A., 1990). The textural variety of the soil determines the aero-hydric conditions, porosity, hydro-permeability, hydro physical capacities, the total adsorption capacity of chemical elements, including nutritional elements, the content of humus (organic matter), the content of microelements, the thermal regime, the potential and effective fertility. The characteristic of soil texture must be researched not only in terms of evaluating the properties of the pedogenetic profile, but also in terms of the role of the soil in the formation of agricultural production and the quality of food products.

In agroecological research we find established correlative relationships between various textural types, subtypes and varieties) with the harvest of cereal and grain crops (Duda G. *et. al.,* 1973, cited after Kruglov N. *et al.,* 2002), *table 1-3*. Agricultural practice has proven that the most favorable soils by texture are loamy and loamy-clayey soils that contain proportionally sandy and clay particles. The soils of the Republic of Moldova for the most part (Cerbari V., 2010) have a favorable and homogeneous arable horizon by texture, with the exception of silted soils (chernozems and grizioms), salinized soils, predominantly solonets, which are specific objects for field crop agriculture.

Numerous studies of the influence of soil grain size composition on grapevine productivity have determined and indicated the optimal clay content in the soil that ensures maximum production of this crop (Valicov V., Fisicov A., 1981, cited after Kruglov N. *et al.,* 2002). It has been shown that on soils heavy in texture, the sugar content of grapes decreases and the acidity increases. It has also been shown that red technical varieties are more plastic to the soil texture, compared to white technical varieties of grapes. It is evident from the bibliography that the analysis of the soil grain size composition constitutes an important part of analytical research into the fertility and productivity elements of agricultural lands. In 2025, based on pedological studies for localities in the northern agricultural area of the Republic of Moldova, the main textural varieties of representative soils were highlighted (*table 4*). It was highlighted that the predominant soils represented by leached chernozems are loamy-clayey and smaller areas are clay-loamy (*table 4-5*).

Table 1

Influence of soil texture on production harvest of agricultural crops
(Duda G. *et al.*, 1973, quoted after Kruglov N. *et al.,* 2002)

Soil subtype and textural variety	Average yield of cereal and grain crops, t/ha
Grey soils:	
Sandy-loamy	3.7
Loamy-sandy	5.9
Loamy	6.9
Loamy-clayey and clayey	5.0
Molic-gray soils:	
Loamy	7.7
Loamy-clayey	7.5
Clay-iluvial chernozems:	
Loamy	10.3
Loamy-clayey	9.3
Cambic chernozems (leached):	
Loamy	10.8
Loamy-clay	9.8
Clay	9.5

Table 2

Correlation of crop yield with the size of the sand diameter in the investigated substrate
(Mitcerlih A., cited after Kruglov N. *et al.,* 2002).

Crop	Average yield, g/vegetable pot	Harvest (average%) depending on the size of the sand diameter, mm.				
		0.25-0.5	0.5-1.0	1.0-2.0	2.0-4.0	4.0-6.8
Potatoes	95.5	128	116	94	92	71
Peas	71.3	143	104	98	78	77
Rye	2.9	173	161	77	47	43

Table 3

Influence of the granulometric composition of ordinary chernozem on corn production
(Lebedeva I. *et al.,* cited after Kruglov N. et al., 2002).

Soil name	Physical clay content in A+B1 horizons	Corn harvest, green mass, t/ha
Ordinary chernozem, weak humifying, medium deep, loamy-clayey	52	21,5
Ordinary chernozem, weak humifying, medium deep, loamy	35	23,1
Ordinary chernozem, weakly humifying, medium deep, sandy-loamy	26	18,8
Ordinary chernozem, weak humifying, medium deep, sandy-loamy	13	16,8

In researching potential and actual fertility as elements of food security, an important role should be given to previous complex pedological research, current agroecosystem research, according to data for the Northern agricultural zone of the Republic of Moldova.

An essential role is played by monographic research on monitoring the ecopedological characteristics of soils, including those in the Northern agricultural zone (Cerbari V., 2010; 2023; Ursu A., 2011; Krupenikov I. A, 1985). Research on some fertility elements of leached chernozems in the Northern agricultural zone (Andriuca V., 2008; 2017; Racoviţa, Gh., 2018) indicates favourable pedological quality for field crops, expressed by neutral reaction of the soil solution, average total cation exchange capacity (30-33 me/100 g soil) with a Ca:Mg ratio of 4.5:1, moderate humus content, deep humification of the profile.

The data on the characteristics of the textural varieties of the Northern agricultural zone of the Republic of Moldova show the predominance of loamy-clayey soils (*table 4*) by 99-100% in the transition localities from the 1st ecopedological district to the 2nd ecopedological district.

On the polygons of the current study, soils with loamy-clayey texture predominate, and in the composition of the granulometric fractions, fine clayey and dusty fractions predominate (*table 5*).

The most representative soils of Plop locality, Donduşeni district are presented in *table 6.* The soils are characterized by a high score (62-100 points) according to properties, but also according to the productivity of field crops. The lands fall into the class of good and very good soils according to the degree of fertility, *table 6-7.*

The representative soils investigated in Donduşeni district, Plop locality are Chernozems, Phaeozems, Greyzems (Luvisol), corresponding to the general zonal pedoecological diagnoses according to the soil profile, the particularities of the distribution of granulometric fractions, humus, nutritional elements. The arable Phaeozems and Greyzems investigated have a lower humiferous thickness of the upper layers (0-50 cm), compared to the Chernozems which are medium and high humiferous, deep (*table 7*).

In the research locality Vasileuţi (*table 8*) the soil cover is more homogeneous, mostly represented by the leached loamy-clayey chernozem. The soils are fertile and highly fertile according to the soil valuing grade (table 8-9). The high fertility of these soils has caused intensive exploitation under field crops, which has led to weak, medium and high erosion of the leached chernozems. In the soil cover of the locality, both eroded soils and cumulation soils are recorded.

The soils on the slopes are characterized by a lower fertility level, according to the thickness of the humiferous layer, humus content, cationic adsorption capacity. Here the soils are homogeneous according to the granulometric composition throughout the pedogenetic profile, with small exceptions induced by the cambic process (depth 50-70 cm), *table 9*.

Table 4

Characteristics of textural varieties (% of the total surveyed area) of some lands in the Northern agricultural zone of the Republic of Moldova

No.	Locality, district, year of research	Ecopedological district/microdistrict	Total area, ha/average rating score	Heavy clays, %	Clay Loam, %	Clay-loam, %	Loamy, %	Sandy, %
1	Plop, Donduşeni, 2008	1	3088/72	-	29.2	68.3	2.5	-
2	Moşana, Donduşeni, 2008	1/8	2080/68	-	25.2	72.1	2.7	-
3	Ţaul, Donduşeni, 2008	1	3547/72	+	23.2	76.0	0.8	-
4	Lincăuţi, Ocniţa, 2009	1	2235/73	-	32.0	68.0	-	-
5	Briceni, Briceni, 2005	1	207/59	1,7	32.8	65.5	-	-
6	Corjeuți, Briceni, 2004	1	3640/66	-	59.8	40.2	-	-
7	Șofrâncani, Edineţ, 1993	2/14	2765/70	-	0.8	99.2	-	-
8	Vasileuţi, Rîşcani, 1994	2	2181/71	-	-	100	-	-
9	Rubleniţa, Soroca, 2012	4	2054	-	48.8	48.8	2.4	-
10	Corlăteni, Rîşcani, 1993	3	2015/70	-	66.8	30.5	2.7	-
11	Limbenii Noi, Glodeni, 2023	3	1669/69	-	6.1	91.0	2.9	-
12	Glinjeni, Făleşti, 2007	3	5047/50	-	32.5	67.5	-	-
13	Hiliuţi, Făleşti, 2007	3	2158/71	-	54.1	45.9	-	-
14	Cetâreni, Ungheni, 2002	3	2207/56	-	21.6	71.2	7.2	-
15	Todireşti, Ungheni, 2002	3	3594/59	-	21.5	78.0	0.5	-
16	Pohoarna, Şoldăneşti, 2019	5	2700/64	-	8.8	72.8	17.4	1

Table 5

Characteristics of the percentage content of granulometric fractions of leached chernozems from the Northern Agricultural Zone of the Republic of Moldova

No.	Soil type	Sample depth, cm	Percentage content of fractions, %						
			1.0-0.1	0.1-0.05	0.05-0.01	0.01-0.001	0.001	>0.01	<0.01
1	Leached chernozem	0-20	0.74	12.63	33.04	25.66	27.93	46.41	53.59
		30-40	0.80	12.15	34.99	24.91	27.15	47.94	52.06
		50-60	0.56	11.64	31.94	26.33	29.63	44.04	55.96
		90-100	0.36	10.25	34.42	26.25	28.72	45.03	54.97
		190-200	-	8.64	32.75	28.57	30.64	40.79	59.21
2	Leached chernozem, slightly eroded	0-20	1.28	15.25	24.41	28.64	30.73	49.63	59.37
		30-40	1.36	14.63	25.96	27.91	30.15	41.94	58.06
		50-60	0.86	14.64	26.34	27.95	30.21	41.64	58.16
		70-80	0.70	11.05	28.93	28.18	31.14	40.68	59.32
		190-200	0.32	8.23	30.87	28.65	31.93	39.42	60.58

Table 6

Representative soils in Plop village, district Donduşeni

№	Soil type	Area, ha	% of the total area	Bonitation degree
				According to characteristics
1	Greyzem (luvisol luvic) clay-loamy	49	1.56	68
2	Phaeoziom haplic loamy-clay	31	0.99	78
3	Phaeoziom haplic clay-loamy	465	14.79	78
4	Phaeoziom haplic weakly eroded clay-loamy	201	6.39	62
5	Luvic chernozem loamy-clay	23	0.73	88
6	Luvic chernozem clay-loamy	173	5.50	88
7	Luvic chernozem weakly eroded clay-loamy	24	0.76	70
8	Levigated chernozem loamy-clay	106	3.37	94
9	Levigated chernozem clay-loamy	461	14.66	94
10	Levigated weakly eroded loamy-clay chernozem	185	5.88	75
11	Levigated moderately eroded clay-loamy chernozem	18	0.57	66
12	Typical clay-loamy chernozem	23	0.73	100
13	Typical deep humiferous clay-loamy chernozem	198	6.30	82
14	Typical deep humiferous loamy chernozem	15	0.48	74
15	Typical deep humiferous weakly eroded clay-loamy chernozem	125	3.98	66
16	Levigated chernozems weakly and moderately eroded loamy-clay	154	4.90	71
Plop		Total, 3144ha		Medium - 72

Table 7

Physico-chemical indices of the soils in Plop village, Donduseni district

№	Soil type	Depth, cm	Hygroscopic water, %	Humus According to Tiurin, %	The sum of adsorbed cations, me/100g sol	Adsorbed cations, me/100 g sol		Carbonate content, %	pH_{KCl}	pH_{H2O}	Granulometric composition, %	
						Ca^{++}	Mg^{++}				>0,01	<0,01
1	2	3	4	5	6	7	8	9	10	11	12	13
1	Greyzem (luvisol luvic) clay-loamy	0-20	5.15	2.34	31.1	23.9	7.2	-			47.71	52.29
		35-45	5.04	1.41								
		55-65	4.93	0.75				9.2		7.9	40.40	59.60
		75-85	4.82	0.66								
		90-100	8.71	0.43								
2	Phaeoziom haplic clay-loamy 3.-79	0-20	5.04	2.50	27.2	23.2	4.0		5.9		48.08	51.92
		30-40	5.15	1.86								
		50-60	5.26	1.28								
		70-80	5.37	0.95								
		90-100	5.48					7.0		8.5	37.00	63.00
3	Phaeoziom haplic weakly eroded clay-loamy	0-20	4.73	2.21	24.7	22.2	2.5		5.0		46.40	53.60
		30-40	4.46	1.38					5.2			
		50-60	4.48	0.87					5.4			
		75-85	4.62	0.47					5.7			
		190-200	4.60	-					7.4		46.51	53.49
4	Luvic chernozem clay-loamy	0.-20	5.70	3.22	27.6	22.4	5.2		5.6		44.09	55.91
		35-45	5.70	3.02					5.8		41.97	58.03
		55.65	5.60	1.73								
		110-120	5.61					8.6		8.1	37.82	62.18
5	Levigated chernozem clay-loamy	0-30	4.75	3.16	27.8	22.6	5.1			6.7	46.40	53.60
		30-40	4.67	3.06								
		5-60	4.02	2.31								
		70-80	4.53	1.40								
		90-100	4.45	0.83				6.9		8.0	40.80	59.20

continuation table 7

1	2	3	4	5	6	7	8	9	10	11	12	13
6	Levigated weakly eroded loamy-clay chernozem	0-20	6.15	2.90	31.0	27.3	3.7		6.3		39.94	60.04
		30-40	6.04	1.84							36.86	63.14
		55-65	6.15	1.34								
		90-100	5.82					7.1		8.2	33.79	66.21
7	Typical clay-loamy chernozem	0-20	5.47	4.41	31.0	36.7	4.3			6.9	41.12	58.88
		30-40	5.36	3.94								
		50-60	5.35	2.40								
		70-80	5.25	1.62				3.8		8.1		
		90-100	5.01	1.39								
		110-120	4.70					12.5		8.2	42.28	57.72

Table 8

Representative soils in Vasileuti village, Riscani district

№	Soil type and texture	Area, ha	% of the total area	Bonitation degree, point
				According to characteristics
1	Chernozem levigated (cambic) deep humiferous clay-loamy	554	25.4	94
2	Chernozem levigated moderately humiferous clay-loamy	210	9.63	85
3	Chernozem levigated weakly eroded clay-loamy	569	26.09	75
4	Chernozem levigated moderately eroded clay-loamy	56	2.57	56
5	Typical weak humiferous (deep)clay-loamy chernozem	55	2.52	82
6	Typical weak humiferous (moderately) clay-loamy chernozem	58	2.66	74
7	Typical weak humiferous weakly eroded clay-loamy chernozem	32	1.47	66
8	Carbonate Chernozem weakly eroded clay-loamy	32	1.38	43
9	Cumulic chernozemoid soil clay-loamy	28	1.28	89
10	Chernozems levigated weakly and moderately eroded clay-loamy	225	10.32	65
Medium				71

Table 9

Physico-chemical indices of the soils in Vasileuti village, Riscani district

№	Soil type	Depth, cm	Hygro scopic water, %	Humus According to Tiurin, %	The sum of adsorbed cations, me/100g sol	Adsorbed cations, me/100 g sol		Carbonate content, %	pH $_{H2O}$	Granulometric composition, %	
						Ca^{++}	Mg^{++}			>0,01	<0,01
1	2	3	4	5	6	7	8	9	10	11	12
1	Chernozem levigated (cambic) deep humiferous clay-loamy (nr. 52)	0-20	5.2	3.04				-	6.3	48.91	51.09
		30-40	5.0	2.74					6.4	46.56	53.44
		50-60	5.2	2.55					6.3	47.20	52.80
		70-80	4.9	1.85					6.5	49.22	50.78
		90-100	4.7	1.26					6.8	50.54	49.46
		140-150	4.7	-				1.6	7.4	52.88	47.12
2	Chernozem levigated (cambic) deep humiferous clay-loamy (nr. 57)	0-20	5.2	3.31	32.8	24.4	8.4		6.5	49.34	50.66
		30-40	5.0	3.02	33.1	25.0	8.1		6.7	47.26	52.74
		50-60	4.9	2.74	31.2	26.0	5.2		6.7	48.07	51.93
		75-85	4.8	1.04					7.1	45.84	54.16
		90-100	4.9	0.79				11.4	7.6	47.14	52.86
		140-150	4.7	-				9.0	7.6	44.09	55.91
3	Chernozem levigated (cambic) deep humiferous clay-loamy (nr. 58)	0-20	5.2	3.69	31.2	23.4	7.8		6.7	47.76	52.24
		30-40	5.4	3.18	32.8	27.1	5.7		6.8	46.26	53.74
		50-60	5.3	2.46					6.9	48.14	51.86
		70-80	5.0	0.82					7.2	45.72	54.28
		90-100	4.9	0.80				12.2	7.7	44.92	55.08
		140-150	4.7					12.2	7.7	46.87	53.13

continuation table 7

1	2	3	4	5	6	7	8	9	10	11	12
4	Chernozem levigated weakly eroded clay-loamy (nr. 7)	0-20	5.5	2.99	29.4	22.3	7.1		6.5	45.03	54.97
		30-40	5.3	2.02	28.9	22.2	6.7		6.8	46.18	53.82
		50-60	5.4	1.24	30.3	22.1	8.2		6.8	45.27	54.73
		65-75	5.0	0.79					6.7	48.63	51.37
		90-100	4.9					5.2	7.5	51.74	48.26
		140-150	4.6					5.6	7.6	54.40	45.60
5	Typical weak humiferous (moderately) clay-loamy chernozems (nr. 41)	0-20	5.8	3.62	30.3	22.7	7.6		6.9	57.23	42.47
		30-40	5.6	2.99	29.2	23.0	6.2		6.7	55.64	44.36
		45-55	5.5	2.49	29.7	21.7	8.0		6.8	54.86	45.12
		60-70	5.4	1.61				0.2	7.5	56.42	48.58
		80-90	5.3	0.69				4.2	7.8	58.40	41.60
		140-150	5.0					13.4	7.8	59.59	40.41

In 2025, 3 varieties of winter wheat approved in the Republic of Moldova and Romania were subjected to qualitative evaluations in production: Alcantara (approved in Romania, production conditions - Agro-Panfil, Plop locality, Donduşeni district); Glossa variety (approved in the Republic of Moldova, 2017 production conditions - Agro-Panfil, Plop locality, Donduşeni district); Dumbraviţa variety (approved in the Republic of Moldova, 2017 production conditions - Vasileuţi locality, Rîşcani district).

The determination of winter wheat quality indices was carried out in the Soil Analysis Laboratory, UTM, 2025 using the Multi-Bruins Instruments CHECK apparatus. A significant differentiation of winter wheat quality was highlighted, largely influenced by the variety (tab. 10) and the year of reproduction of the seed material. The 2024-2025 agricultural year was a favorable year in terms of climatic conditions for the northern agricultural area of the RM.

According to (Andries S., 2011) the level of crop yield depends largely on the level of effective soil fertility and the natural environment, but according to current data the level of yield depends significantly on the seed material. This is explained by the current decentralized way of managing agricultural land.

Elite varieties in the conditions of the Northern Agricultural Zone of the Republic of Moldova recorded approx. 9t/ha. In the locality of Vasileuţi, Rîşcani, the productivity of varieties from the third year of reproduction recorded lower harvest values with an unsatisfactory quality of wheat for bread making (*table 10*).

According to the qualitative indices of protein content, gluten and Zeleny Index, the varieties cultivated in Agro-Panfil (Alcantara and Glossa) stand out as highly productive, where the protein content was 10.5%, gluten, 21-26%, Zeleny Index 48-56 ml. More poor in quality, both in 2024 and 2025, was the winter wheat cultivated on the leached loamy-clay chernozem in Vasileuţi, Rîşcani, which does not meet the quality standards for food wheat.

Table 10

Winter wheat quality in the Northern Agricultural Zone of the Republic of Moldova, agricultural year 2024-2025

Locality	Variety	Harvest, t/ha	Moisture %	Protein, %	Gluten, %	Zeleny index, ml
Plop village, Donduseni district, “Agro-Panfil”	Alcantara	9.0	13.3	9.6	21	40
Plop village, Donduseni district, “Agro-Panfil”	Glossa	7.0	13.7	10.4	26	56
Vasileuti village, Riscani, 2025	Dumbravita	6.0	15.4	8.00	14	38
Vasileuti village, Riscani, 2024	Dumbravita	4.2	13.7	8.8	22	38
			DL_{05}=0,092	DL_{05}=0,231	DL_{05}=1,086	DL_{05}=4,805

CONCLUSIONS

The Northern agricultural zone of the Republic of Moldova is characterized by highly productive soils, expressed by high fertility potential, as consequence of the loam-clay and clay-loam texture.

The soil cover of the land is mostly made up of chernozems, lands suitable enough for field crops, including winter wheat.

In the texture of the researched leached chernozems, fine clayey and coarse dusty fractions predominate.

The soils of ecopedological districts 1 and 2, including those in Plop locality, Donduşeni district have high natural fertility potential, with possibilities for applying effective fertility elements, fertilizers and others.

Under the production conditions of winter wheat in the 2024-2025 agricultural year, the researched production varied within the limits of 6-9 t/ha.

In agroecosystems with the application of individually reproduced seed material in farmers' households in the Northern agricultural zone of the Republic of Moldova, the harvest and quality of production was significantly inferior in quantity and quality, and the use of this product induces consequences of food insecurity.

ACKNOWLEGMENTS

This paper has been founded by Research Project (RM) 25.80012.5107.17SE

REFERENCES

Andries S., 2011 - *Agrochimia elementelor nutritive. Fertilitatea şi ecologia solurilor*. Chişinău, Pontos, p. 13.

Andriucă V., 2008 - *The modification of ecopedologica indexes under the long term antropogenic impact.* In: Present Environment and Sustainable Development. Volume II, Iaşi, available online at:http://pesd.ro/Pesd%20vol%202%20-%202008.html

Andriucă V., Bacean I., Cazmali N., Cojocaru O., Melnic R., 2017 - *Influenţa benefică a sistemului conservativ de lucrare No-till asupra densităţii aparente şi umidităţii solurilor silvostepei Podişului de Nord a Republicii Moldova.* In: Materialele conferinței științifice cu participare internațională a Societății Naționale a Moldovei de Știința Solului "Cercetarea și gestionarea resurselor de sol", 8-9 septembrie, Chișinău: CEP USM, p. 139-150.

Canarache A., 1990 – *Fizica solurilor agricole.* Ceres, Bucureşti. p. 224-227.

Cerbari V., 2010 – *Monitoringul calităţii solurilor Republicii Moldova*. Pontos, Chişinău, 476 p.

Cerbari V., 2023 – *Solurile Moldovei. Geneza, clasificarea, bonitarea, utilizarea durabile.* Lexon-Prim, Chişinău, 524 p.

Kruglov N.M., Budantsev P.B., Tarasenko N.M., 2002 – *Evaluarea agroecologică a principalelor proprietăți ale solurilor*. Voronej, 151-155.

Krupenikov I. A. Ursu A. F,1985-. Solurile Moldovei. T. 2. „Știintsa", Chișinău, 288 p.

Racoviţa, Gh., Andriucă, V., 2018 - *Estimarea pierderilor de recoltă la cultura grâu de toamnă şi a efectelor de agroecosistem și securitate alimentară.* In: Lucrări ştiinţifice. Volumul 52 (1). Simpozion Ştiinţific Internaţional, UASM, 4-6 Octombrie. Chişinău, available on-line at: https://ibn.idsi.md/ro/vizualizare_articol/89547.

Ursu A., 2011. Solurile Moldovei. Ch.: Î.E.P. Ştiinţa, 323

THE QUALITY OF THE GREEN MASS AND HAY FROM *VICIA TENUIFOLIA* IN THE REPUBLIC OF MOLDOVA

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Abstract

The goal of this research was to determine the quality indices of harvested green mass and hay from the local ecotype of the perennial leguminous species, fine-leaf vetch (*Vicia tenuifolia*), maintained in monoculture in the experimental plot of the NBGI MSU Chişinău. The biochemical composition and nutritive value of the dry matter of the harvested green mass were as follows: 200 g/kg CP, 118 g/kg ash, 305 g/kg CF, 313 g/kg ADF, 488 g/kg NDF, 44 g/kg ADL, and 95 g/kg TSS, with 65.1% DMD, 12.79 MJ/kg DE, 10.50 MJ/kg ME, and 6.52 MJ/kg NEl. The studied fine-leaf vetch hay contained: 195 g/kg CP, 121 g/kg ash, 309 g/kg CF, 331 g/kg ADF, 505 g/kg NDF, 48 g/kg ADL, and 78 g/kg TSS, with 63.1% DMD, 12.43 MJ/kg DE, 10.21 MJ/kg ME, and 6.22 MJ/kg NEl. The studied substrates for biogas production had a favourable carbon-to-nitrogen ratio (C/N = 14–18), and the estimated biomethane potential varied from 343 to 350 l/kg organic dry matter. The results indicate the potential use of the harvested green mass and prepared hay from the local ecotype of *Vicia tenuifolia* as feed for livestock, as well as substrates in biogas reactors for biomethane production as a renewable energy source.

Keywords: biochemical composition, biomethane potential, feed value, green mass, hay, *Vicia tenuifolia*

The interest in agricultural systems based on leguminous species increased significantly over the recent decades due to economic and environmental reasons (European Parliament resolution 2011, 2018). The diversification of leguminous crop production may be achieved and by mobilizing ecotypes from the local flora and other regions.

The genus *Vicia* L. belongs to the tribe *Vicieae* of the *Fabaceae* family and consists of approximately 230 species distributed throughout the temperate regions of Europe, Asia, North America and South America. These species include food and fodder crops, medicinal and honey plants, soil nitrogen fixers, dune stabilizers etc. In the spontaneous flora of Basarabia, the genus *Vicia* is represented by 19 annual and perennial species (Izverscaia T., 2020).

The fine-leaved or bramble vetch – *Vicia tenuifolia* Roth. (syn. *V. antiqua* Grossh., *V. boissieri* Freyn, *V. brachytropis* Kar. & Kir. *V. cracca* subsp. *tenuifolia* (Roth) Gaudin, *V. tenuifolia* subsp. boissieri (Freyn) Radzhi, *V. variabilis* (Freyn & Sint.) Dinsm., *Cracca tenuifolia* (Roth) Gren. & Godr., *Ervum tenuifolium* (Roth) Trautv.) is a perennial herb with well-branched, numerous, rigid, slightly pubescent, and almost upright stems, reaching 50-90 cm in height. Its leaves are compound pinnate, with 8-12 pairs of opposite leaflets, each 2.5-3.0 cm long and 2-3 mm wide. The leaflets are lanceolate, covered with hairs on both sides, and greenish-grey in colour. The racemes are laxiflorous, bearing 15-20 pale blue or violet flowers, each 14-15 mm long. The plant produces elongated pods, 20-30 mm long and 5-7 mm wide, containing 3-5 brown seeds. It is a cross-pollinated species, primarily pollinated by bees. Flowering occurs in May-June, and seed ripening takes place in July-August. The chromosome number is 2n = 24. This species typically grows on open dry slopes, in meadows, shrub lands, along the edges of woods, rivers, and roads, and in mountainous areas up to the mid-altitude zone. In terms of xerophilicity, it is comparable to sainfoin. However, it does not tolerate flooding or excessive soil moisture. *Vicia tenuifolia* is currently being studied in several universities and scientific research centres (Koeva R. *et al.* 2002; Maevsky V.V. *et al.* 2003, 2013; Dzyubenko N.I.& Dzyubenko E.A., 2008; Vishnyakova M.A. *et al.* 2014; Fort F. *et al.* 2015; Coulot, P. & Rabaute P. 2020).

The goal of this research was to evaluate the quality indices of harvested green mass and prepared hay from fine-leaf vetch (*Vicia tenuifolia*) and the prospects of its use as fodder for farm animals or as substrates for biomethane production.

MATERIAL AND METHOD

The local ecotype of the perennial leguminous species fine-leaf vetch (*Vicia tenuifolia*), grown in monoculture on the

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experimental land of the National Botanical Garden (Institute), MSU Chişinău, served as the subject of this research. Traditional leguminous fodder crops – alfalfa (*Medicago sativa*), common sainfoin (*Onobrychis viciifolia*), and red clover (*Trifolium pratense*) – were used as control variants. The experiment was set up as a randomized complete block design with four replications. Each experimental plot measured 10 m². The leaf/stem ratio was determined by manually separating the leaves from the stems, weighing them individually, and calculating the ratio of leaf to stem mass. The hay was prepared by drying the green mass directly in the field. The dry matter (DM) content was determined by drying samples to a constant weight at 105°C. For biochemical analyses, plant samples were dried in a forced-air oven at 60°C and then milled using a beater mill equipped with a 1 mm sieve. Several key biochemical parameters were assessed, including: crude protein (CP), ash, acid detergent fibre (ADF), neutral detergent fibre (NDF), acid detergent lignin (ADL), total soluble sugars (TSS), digestible dry matter (DDM) has been determined by using near infrared spectroscopy (NIRS) technique PERTEN DA 7200. The concentration of hemicellulose (HC), cellulose (Cel), digestible energy (DE), metabolizable energy (ME), net energy for lactation (NEl) and relative feed value (RFV) were calculated according to standard procedures.

The carbon content of the substrates was determined using an empirical equation according to Badger C.M. *et al.* (1979). The biochemical methane potential (BMP) was estimated following the method described by Dandikas V. *et al.* (2015).

RESULTS AND DISCUSSIONS

Analyzing the results of the agro-biological assessment of the studied local ecotypes of fine-leaf vetch (*Vicia tenuifolia*) over seven growing seasons, it can be noted that during the flowering period, when the green mass was harvested, the semi-erect shoots reached a height of 119-127 cm. The green mass yield averaged 4.48 kg/m², with a dry matter content of 22.1%.

The nutrient content and fodder value of the green mass from fine-leaf vetch (*Vicia tenuifolia*) are presented in Table 1. A comparative analysis of the biochemical composition revealed that the fresh forage from fine-leaf vetch had a higher crude protein and mineral content as compared to traditional leguminous fodder crops. The concentration of crude fibre in fine-leaf vetch forage was lower than in alfalfa but higher than in common sainfoin and red clover. The cell wall content in fine-leaf vetch was higher than in common sainfoin and red clover, but lower than in alfalfa. The acid detergent lignin content in fine-leaf vetch forage was lower than in alfalfa and common sainfoin but higher than in red clover. The total soluble sugar content in fine-leaf vetch fresh forage was higher than in alfalfa but much lower than in red clover. The cellulose content in fine-leaf vetch was comparable to that of common sainfoin and higher than that of corn forage. The hemicellulose content in fine-leaf vetch forage reached 175 g/kg dry matter, significantly higher than in the control leguminous fodder crops. As compared to alfalfa, fine-leaf vetch showed favourable values for dry matter digestibility, relative feed value, metabolizable energy, and net energy for lactation, although these values were lower than those observed in red clover forage.

Table 1

The biochemical composition and the fodder value of the green mass from *Vicia tenuifolia*

Indices	*Vicia tenuifolia*	*Medicago sativa*	*Onobrychis viciifolia*	*Trifolium pratense*
Crude protein, g/kg DM	*200*	172	177	169
Crude fibre, g/kg DM	*305*	*331*	*293*	*231*
Minerals, g/kg DM	118	*91*	*96*	*89*
Acid detergent fibre, g/kg DM	*313*	*347*	*309*	*252*
Neutral detergent fibre, g/kg DM	*488*	*510*	*447*	*422*
Acid detergent lignin, g/kg DM	*44*	*58*	*49*	*31*
Total soluble sugars, g/kg DM	*95*	*72*	*114*	*222*
Cellulose, g/kg DM	*269*	*289*	*260*	*221*
Hemicellulose, g/kg DM	*175*	*163*	*138*	*170*
Digestible dry matter, g/kg DM	*651*	*619*	*648*	*692*
Relative feed value	*124*	*113*	*135*	*153*
Digestible energy, MJ/ kg	*12.79*	*12.21*	*12.73*	*13.52*
Metabolizable energy, MJ/ kg	*10.50*	*10.02*	*10.45*	*11.10*
Net energy for lactation, MJ/ kg	*6.52*	*6.04*	*6.48*	*7.12*

Some authors have reported various findings regarding the productivity and dry matter nutrient concentration of the green mass from *Vicia* species. According to Larin Y.V. (1951), the nutrient content in *Vicia tenuifolia* ranged from 18.7 to 22.3% CP, 2.4 to 4.2% EE, 24.2 to 32.6% CF, 35.5 to 42.9% NFE, and 6.9 to 9.1% ash. Burlacu G. *et al.* (2002) reported that *Vicia sativa* harvested during the flowering period contained 170 g/kg DM, 10.5% ash, 18.4% CP, 28.2% CF, 58.2% DOM, 18.24 MJ/kg GE, 11.13 MJ/kg DE, and 8.94 MJ/kg ME. Maevsky V.V. et al. (2003) mentioned that *Vicia tenuifolia* achieved a green mass yield of 55.0 t/ha, with 20.7% CP and 3.9% EE. Hoffmann R. & Kovács B. (2011) found that the productivity of *Vicia pannonica* was 20.3 t/ha green mass or 3.35 t/ha dry matter, with 23.9% CP and 24.3% CP. Ates S. *et al.* (2013) presented quality characteristics of grazing dry herbage from three *Vicia* species and found that *Vicia ervilia* contained 21.5% CP, 28% NDF, 19.5% ADF and 72% IVDMD; *Vicia sativa* contained 21.5% CP, 31% NDF, 22% ADF and 60% IVDMD; and *Vicia villosa* ssp. *dasycarpa* contained 16.5% CP, 40% NDF, 31% ADF, and 46% IVDMD. Maevsky V.V. *et al.* (2013) found that *Vicia tenuifolia* harvested in the small pod stage contained 20.97% CP, 1.48% EE, 31.19% CF, 39.50% NFE, 6.86% ash and 51.83 mg/kg carotene. Vishnyakova M.A. e*t al.* (2014) reported that *Vicia* samples collected from different habitats had the following protein content in green mass: 20.4-21.9% for *Vicia sativa*, 18.1-20.6% for *Vicia amoena*, 18.4-22.3% for *Vicia cracca*, 19.5% for *Vicia tenuifolia* and 20.60-23.38% for *Vicia villosa*. Heuzé V. *et al.* (2015) mentioned that the average feed value of *Vicia sativa* was 193 g/kg DM, 23.0% CP, 2.5% EE, 25.4% CF, 36.7% NDF, 28.9% ADF, 6.1% lignin, 9.8% ash, 69.8% DOM, 18.6 MJ/kg GE, 12.4 MJ/kg DE and 9.8 MJ/kg ME. Georgieva N. *et al.* (2016) reported that the chemical composition and feeding value of forage from studied *Vicia sativa* cultivars ranged as follows: 182.4-197.0 g/kg CP, 254.0-264.8 g/kg CF, 316.2-396.9 g/kg ADF, 380.3-446.7 g/kg NDF, 51.7-93.2 g/kg ADL, 264.5-303.6 g/kg Cel and 29.6–82.0 g/kg HC, with 57.7-66.2% IVDMD and 57.5-66.9% IVDOM. For *Vicia villosa* cultivars, the values were 211.3-211.5 g/kg CP, 228.2-232.7 g/kg CF, 374.4-382.5 g/kg ADF, 451.2-452.6 g/kg NDF, 70.6-77.4 g/kg ADL, 303.8-305.1 g/kg Cel, and 70.1-76.8 g/kg HC, with 50.8-55.0% IVDMD and 51.9-60.2% IVDOM. Ţîţei V.&Coşman S. (2018) reported that the productivity of *Vicia tenuifolia*, cut at the budding-flowering stage, was 4.18 kg/m² green mass or 0.76 kg/m² dry matter, with 23.50% CP, 3.65% EE, 29.08% CF, 37.53% NFE, 8.10% ash, and 192 g DP per nutritive unit. In comparison, the productivity of *Medicago sativa* was 3.44 kg/m² green mass or 0.68 kg/m² dry matter, with 16.50% CP, 2.59% EE, 34.48% CF, 37.95% NFE, 8.48% ash and 142 g DP per nutritive unit. Parissi Z. *et al.* (2022) noted that dry matter from common vetch forage contained 170.4-229.2 g/kg CP, 221.3-243.5 g/kg ADF, 328.7-368.1 g/kg NDF, and 50.7-60.2 g/kg ADL. Ţîţei V. & Cozari S. (2023) found that the biochemical composition and fodder value of green mass from studied *Vicia* species ranged as follows: 17.2-20.8% CP, 9.6-11.3% ash, 29.7-32.5% CF, 32.6-34.6% ADF, 51.9-53.6% NDF, 4.8-6.4% ADL, and 17.4-19.0% TSS, with 620-635 g/kg DMD, RFV = 108-113, 12.06-12.50 MJ/kg DE, 9.90-10.26 MJ/kg ME, and 6.05-6.28 MJ/kg NEl. Belete S. *et al*. (2024) found that *Vicia* sp. green mass forage contained 9.1% ash, 21.4% CP, 45.9% NDF, 33.6% ADF, 9.3% ADL, 705 g/kg DMD, and 11.0 MJ/kg ME; another sample contained 12.9% ash, 17.0% CP, 47.6% NDF, 27.8% ADF, and 6.5% ADL. In comparison, *Medicago sativa* contained 11.7% ash, 20.8% CP, 45.9% NDF, 31.8% ADF, and 7.3% ADL.

Fodder conservation is essential worldwide to ensure livestock have a consistent feed supply, especially during periods such as late autumn, winter, and early spring when grazing is scarce. Several methods of fodder conservation exist, each with its own advantages and considerations. The two most common methods are haymaking and silage making. Natural drying of mown herbage by sun and wind remains the most widespread method of conserving fodder. Hay is particularly suitable for small-scale producers, as it requires minimal equipment and cost, and once properly cured, it is easy to transport and store – usually baled in the recent decades. Hay can be produced from natural herbage or from sown grasses and leguminous crops. According to research results presented in Table 2, fine-leaf vetch hay is characterized by an optimal nutrient concentration. Hay prepared from fine-leaf vetch contains higher levels of crude protein and minerals, along with lower amounts of cell wall components, resulting in greater digestibility and energy value compared to hays from alfalfa and common sainfoin. Compared to red clover hay, fine-leaf vetch hay has a higher concentration of structural carbohydrates and a lower content of total soluble sugars, which negatively impacts its digestibility, relative feed value and energy concentration.

Several literature sources describe the biochemical composition and nutritional performance of hay from *Vicia* species. According to Gonean G.G. (1961), *Vicia variabilis* (syn. *Vicia tenuifolia*) hay was characterized by 18.26-24.72% CP, 1.95-2.40% EE, 33.23-35.41% CF, 30.71-37.31% NFE and 6.49-8.16% ash, including 1.75-2.5% Ca and 0.43-0.70% P. Hadjipanayiotou M. *et al.* (1983) reported that the hay from *Vicia tenuifolia* contained 890 g/kg dry matter with 9.7% CP, 2.1% EE, 40.7% CF, 62% NDF, 48% ADF, 11.7% lignin, 7.4% ash, 550 g/kg DDM, 430 g/kg DOM and 8.2 MJ/kg energy content. Burlacu G. *et* *al.* (2002) mentioned that *Vicia sativa* hay contained 850 g/kg DM, 10.0% ash, 16.5% CP, 2.6% EE, 32.0% CF, 54.0% DOM, 18.22 MJ/kg GE, 10.39 MJ/kg DE and 8.35 MJ/kg ME. Kitaw G. *et al.* (2010) remarked that the forage value of hay from *Vicia dasycarpa* was 19.9% CP, 37.7% ADF, 54.5% NDF, 10.8% ADL, 68.0% IVOMD, 8.0% ash and 10.97 MJ/kg ME. Larbi A. et al. (2011 abc) studied *Vicia* species and found that hay from *Vicia sativa* contained 141–188 g/kg CP, 262–287 g/kg ADFom, 364–435 g/kg aNDFom, and 752–782 g/kg IVOMD. Hay from *Vicia villosa* ssp. *dasycarpa* contained 174–183 g/kg CP, 264–278 g/kg ADFom, 417–433 g/kg aNDFom and 683–708 g/kg IVOMD. Hay from *Vicia ervilia* had 146–178 g/kg CP, 200–230 g/kg ADFom, 335–395 g/kg aNDFom and 742–777 g/kg IVOMD. Heuzé V. *et al.* (2015) mentioned that hay made from *Vicia sativa* contained 16.9–22.5% CP, 0.7–2.4% EE, 20.4–28.5% CF, 27.1–47.8% NDF, 20.6–35.2% ADF, 4.4–8.5% lignin, 9.0–12.3% ash, 11.1–17.91 g/kg Ca, 0.9–7.0 g/kg P, 64.4–72.9% DOM, 18.1 MJ/kg GE, 11.0 MJ/kg DE and 8.7 MJ/kg ME. Ţîţei V. & Coşman S. (2018) reported that hay from *Vicia tenuifolia* contained 21.94% CP, 1.49% EE, 31.78% CF, 36.71% NFE, 8.08% ash, 0.76 nutritive units/kg, 8.27 MJ/kg ME for cattle, and 189.0 g DP/nutritive unit. In comparison, hay from *Medicago sativa* contained 15.10% CP, 1.57% EE, 36.26% CF, 37.77% NFE, 9.30% ash, 0.73 nutritive units/kg, 7.94 MJ/kg ME for cattle, and 153.00 g DP/nutritive unit. Abera M. *et al.* (2021) noted that the quality indices of hay from *Vicia dasycarpa* were 915 g/kg OM, 100 g/kg ash, 135 g/kg CP, 552 g/kg NDF, 406 g/kg ADF, 63 g/kg ADL, and 667 g/kg IVOMD. Hay from *Vicia villosa* had 915 g/kg OM, 108 g/kg ash, 163 g/kg CP, 502 g/kg NDF, 395 g/kg ADF, 62 g/kg ADL and 686 g/kg IVOMD. *Vicia sativa* hay contained 913 g/kg OM, 88 g/kg ash, 104 g/kg CP, 519 g/kg NDF, 460 g/kg ADF, 69 g/kg ADL, and 646 g/kg IVOMD. Ciftci B. *et al.* (2021) mentioned that the chemical composition of *Vicia cracca* hay was 1.62–2.97% EE, 14.11–19.50% CP, 6.12–8.74% ash, 26.90–39.09% ADF, and 39.74–46.49% NDF. Kaya E. (2021), evaluating the forage quality of *Vicia* species grown in native pasture in Turkey, reported that hay from *Vicia sativa* had 17.5% CP, 0.7% EE, 26.0% ADF, 48.6% NDF, 7.6% ash, 71.0% DOM and 9.5 MJ/kg ME, while hay from *Vicia tenuifolia* contained 17.2% CP, 1.2% EE, 39.2% ADF, 61.5% NDF, 6.3% ash, 60.2% DOM and 7.8 MJ/kg ME. Ţîţei V.&Cozari S. (2023) remarked that quality indices of hay from *Vicia* species ranged as follows: 17.4–18.9% CP, 9.9–11.0% ash, 32.2–35.6% CF, 34.5–39.3% ADF, 51.0–60.6% NDF, 5.0–6.5% ADL, 0.6–8.3% TSS, 29.5–32.8% Cel, and 16.5–21.3% HC, with 593–620 g/kg DMD, RFV = 90–113, 11.57–12.24 MJ/kg DE, 9.50–10.26 MJ/kg ME and 5.51–6.05 MJ/kg NEl. Belete S. *et al.* (2024) reported that hay from *Vicia* sp. contained 10.2% ash, 18.6% CP, 48.2% NDF, 36.6% ADF, 7.9% ADL, 663 g/kg DDM, and 10.6 MJ/kg ME. In comparison, hay from *Medicago sativa* contained 12.9% ash, 17.0% CP, 47.6% NDF, 27.8% ADF and 6.5% ADL.

Table 2

The biochemical composition and the fodder value of the hay from *Vicia tenuifolia*

Indices	*Vicia tenuifolia*	*Medicago sativa*	*Onobrychis viciifolia*	*Trifolium pratense*
Crude protein, g/kg DM	*195*	164	163	183
Crude fibre, g/kg DM	*309*	*349*	*338*	*244*
Minerals, g/kg DM	121	*113*	*99*	*95*
Acid detergent fibre, g/kg DM	*331*	*365*	*350*	*265*
Neutral detergent fibre, g/kg DM	*505*	*540*	*496*	*415*
Acid detergent lignin, g/kg DM	*48*	*59*	*52*	*34*
Total soluble sugars, g/kg DM	*78*	*56*	*64*	*161*
Cellulose, g/kg DM	*283*	*306*	*298*	*231*
Hemicellulose, g/kg DM	*174*	*175*	*146*	*150*
Digestible dry matter, g/kg DM	*631*	*605*	*616*	*683*
Relative feed value	*116*	*104*	*116*	*153*
Digestible energy, MJ/ kg	*12.43*	*11.96*	*12.16*	*13.36*
Metabolizable energy, MJ/ kg	*10.21*	*9.82*	*9.98*	*10.97*
Net energy for lactation, MJ/ kg	*6.22*	*5.83*	*6.01*	*5.98*

The biomethane produced from phytomass has a great importance and can successfully replace natural gas to obtain electric power and heat, can be compressed and used as transport fuel. The nutrient concentration of the phytomass substrate and its biodegradability influence the stability and the productivity of biogas reactors. The quality indices of the substrates from the investigated *Vicia tenuifolia* and their biochemical methane potential are shown in Table 3. The carbon to nitrogen ratio in the investigated leguminous phytomass substrates varied from 15.31 to 18.35, therefore, it met the established standards. The calculated biochemical biomethane potential of investigated substrates varied from

318 l/kg to 362 L/kg VS. The best biomethane potential was achieved in red clover substrates due to the lower concentration of structural carbohydrates. The biochemical biomethane potential of fine-leaf vetch phytomass substrates was 343-349 l/kg to 362 L/kg VS, exceeding the biomethane potential of substrates from alfalfa and common sainfoin.

Table 3

The biochemical biomethane production potential of the studied substrates from *Vicia tenuifolia*

Indices	Vicia tenuifolia		*Medicago sativa*		*Onobrychis viciifolia*		*Trifolium pratense*	
	green mass	*hay*	*green mass*	*hay*	*green mass*	*hay*	*green mass*	*hay*
Organic matter, g/kg DM	*882.00*	*879.00*	*909.00*	*887.00*	*904.00*	*901.00*	*911.00*	*905.00*
Minerals, g/kg DM	*118.00*	*121.00*	*91.00*	*113.00*	*96.00*	*99.00*	*89.00*	*95.00*
Carbon, g/kg DM	*490.00*	*488.00*	*505.00*	*492.00*	*502.00*	*500.55*	*506.11*	*502.77*
Crude protein, g/kg DM	*200.00*	*195.00*	*172.00*	*164.00*	*177.00*	*163.00*	*169.00*	*183.00*
Nitrogen, g/kg DM	*32.00*	*31.20*	*27.52*	*26.24*	*28.32*	*26.08*	*27.04*	*29.28*
Ratio carbon/nitrogen	*15.31*	*15.64*	*18.35*	*18.75*	*17.72*	*19.19*	*18.71*	*17.17*
Acid detergent lignin, g/kg DM	*44.00*	*48.00*	*58.00*	*59.00*	*49.00*	*52.00*	*31.00*	*34.00*
Hemicellulose, g/kg DM	*175.00*	*174.00*	*163.00*	*175.00*	*138.00*	*146.00*	*153.00*	*150.00*
Biomethane potential, L/kg VS	*349.00*	*343.00*	*321.00*	*318.00*	*335.00*	*327.00*	*362.00*	*360.00*
Biomethane potential, L/kg VS	*308.00*	*301.00*	*292.00*	*282.00*	*303.00*	*295.00*	*330.00*	*326.00*

Several publications have documented the biomethane potential of *Vicia* species substrates. According to Oleskowicz-Popiel P. (2010) the *Vicia villosa* substrate achieved a methane yield of 279 L/kg VS. Pakarinen A. *et al.* (2011) mentioned that the whole crop substrate from *Vicia faba* had and 387 L/kg VS methane yield. Molinuevo-Salces B. *et al.* (2014) found that after 57 days of anaerobic digestion the specific methane yield of *Vicia sativa* substrate was 186 L/kg VS, but in *Trifolium pratense* substrate and 195 L/kg VS. Ahlberg and Nilsson (2015) reported that methane yield of *Vicia villosa* biomass substrates varied from 305 to 343 L/kg VS. Ţîţei V. & Coșman S. (2018) remarked that the gas-producing potential of fermentable organic matter from *Vicia tenuifolia* substrates reached 235-284 L/kg methane, while *Medicago sativa* substrates 217-244 l/kg methane. Hunady I. *et al.* (2021) reported that the methane yield of the biomass from *Onobrychis viciifolia*, *Astragalus cicer*, *Dorycnium germanicum* and *Vicia sylvatica* ranged from 0.141 to 0.160 m^3/kg VS. In our previous research (Ţîţei V. and Cozari S. 2023), we found that the biochemical methane yield of *Vicia* species substrates was 320-343 L/kg VS and *Lathyrus* species substrates 322-378 L/kg VS.

CONCLUSIONS

The studied local ecotype of *Vicia tenuifolia* is of great interest for expanding the range of leguminous crops. It can serve as starting material for breeding and developing new cultivars of leguminous species for the production of protein-rich forages, as well as substrates for biomethane production as a renewable energy source.

ACKNOWLEDGEMENTS

This study has been financially supported by the subprogram no. 01.01.02 *"Identification of valuable forms of plant resources with multiple uses for the circular economy"*.

REFERENCES

Abera M., Tolera A., Nurfeta A., Geleti D., 2021 - *Herbage accumulation and nutritive value of mixtures of desho grass and Vicia spp. in southern Ethiopia.* Agronomy Journal. 114. 10.1002/agj2.20891.

Ahlberg I., Nilsson T., 2015- *Investigation on the use of intermediate crops for anaerobic digestion as a renewable source of energy.* https://lup.lub.lu.se/student-papers/search/publication/5472252

Ates S., Feindel D., El Moneim A., Ryan J., 2013- *Annual forage legumes in dryland agricultural systems of the West Asia and North Africa Regions: research achievements and future perspective.* Grass and Forage Science, 69: 17-31

Badger C.M., Bogue M.J., Stewart D.J., 1979 - *Biogas production from crops and organic wastes.* New Zealand Journal of Science, 22:11-20.

Belete S., Tolera A., Betsha S., Dickhöfer U., 2024- *Feeding values of indigenous browse species and forage legumes for the feeding of ruminants in ethiopia: a meta-analysis. Agriculture, 14,* 1475. https://doi.org/10.3390/agriculture14091475

Burlacu G., Cavache A., Burlacu R., 2002- *Potentialul productiv al nutreturilor si utilizarea lor.* Ceres. București. 501

Ciftci B., Okumus O., Uzun S., Kaplan M., 2021-*Effect of maturity stages on potential nutritive value of Vicia cracca (L.) hay.* Current Trends in Natural Sciences. 10(20): 43-47.

Coulot, P., Rabaute, P. 2020- *Third supplements to the Monographie des Leguminosae de France*. Carnets Botaniques https://sbocc.fr/wp-content/uploads/2020/12/Carnets-botaniques-n%C2%B031.pdf

Dandikas V., Heuwinkel H., Lichti F., Drewes J.E., Koch K., 2015 - *Correlation between biogas yield* *and chemical composition of grassland plant species.* Energy Fuels, 29 (11): 7221-7229.

Dzyubenko N.I., Dzyubenko E.A., 2008- *Vicia tenuifolia Roth. -Brambled vetch.* AgroAtlas.Interactive agricultural ecological atlas of Russia and neighboring countries: Economic plants and their diseases, pests, and weeds *http://www.agroatlas.ru/en/content/related/Vicia_tenuifolia/index.html.*

European Parliament resolution of 8 March 2011 on the EU protein deficit: what solution for a long-standing problem? (2010/2111(INI)) *https://www.europarl.europa.eu/doceo/document/TA-7-2011- 0084_EN.html 4.*

European Parliament resolution of 17 April 2018 on a European strategy for the promotion of protein crops – encouraging the production of protein and leguminous plants in the European agriculture sector (2017/2116(INI)) *https://www.europarl.europa.eu/doceo/document/A-8-2018-01*

Fort F., Jouany C., Cruz P., 2015- *Hierarchical traits distances explain grassland Fabaceae species' ecological niches distances.* Frontiers in Plant Science. 6. 10.3389/fpls.2015.00063

Georgieva N., Nikolova I., Naydenova Y., 2016- *Nutritive value of forage of vetch cultivars (Vicia sativa L., Vicia villosa Roth.).* Banats Journal of Biotechnology, 10.7904/2068–4738–VII(14)–5

Gonean G.G., 1961- *Biological features Vicia varibilis Fr. et Sint.* http://biology.asj-oa.am/1210/ .[in Russian]

Hadjipanayiotou M., Economides S.S., Hadjidemetriou D., 1983- *The chemical composition of feedstuffs commonly used in ruminant diets.* Miscellaneous reports 9 Nicosia1-10

Heuzé V., Tran G., Baumont R., 2015- *Common vetch (Vicia sativa).* Feedipedia. https://www.feedipedia.org/node/239

Hoffmann R., Kovács B., 2011- *Compare to different green roughage nutritional value and productivity on southern transdanubian region.* Bulletin UASVM Agriculture, 68(1):168-173.

Hunady I., Ondrísková V., Hutyrová H., Kubíková Z., Hammerschmiedt T., Mezera J., 2021- *Use of wild plant species: a potential for methane production in biogas plants.* International Journal of Renewable Energy Research, 11(2).

Izverscaia T., 2020- *Familia Fabaceae*. In. Flora Basarabiei, vol. III. Chişinău, Universul, 388-592.

Kaya E., 2021- *Effect of species on nutritive value and antimethanogenic potential of vetch hays grown in native pasture in Turkey*. Progress in Nutrition, 22(3): *DOI: 10.23751/pn.v22i3.9870*

Kitaw G., Melaku, S., Seifu, E., 2010- *Replacement of concentrate mix with vetch (Vicia dasycarpa) hay on feed intake,digestibility, milk yield and composition of lactating crossbred dairy cows fed urea-molasses treated wheat straw.* East African Journal of Sciences, 4 (1): 11-19.

Koeva R., Angelova S., Guteva Ya., 2002- *Plant genetic resources and their biological potential integrated to the agricultural and ecological systems.* Biotechnology and Biotechnological Equipment, 16 (2): 26-35

Larbi A., El-Moneim A.M., Nakkoul H., Jammal B., Hassan S., 2011a- *Intraspecies variations in yield and quality determinants in Vicia species: 3. Common vetch (Vicia sativa ssp. sativa L.).* Animal Feed Science and Technology. 164:241-251.

Larbi A., El-Moneim A.M., Nakkoul H., Jammal B., Hassan S., 2011b- *Intraspecies variations in yield and quality determinants in Vicia species: 4. Woolly-pod vetch (Vicia villosa ssp. dasycarpa Roth).* Animal Feed Science and Technology. 164:252-261.

Larbi A., El-Moneim A.M., Nakkoul H., Jammal B., Hassan S., 2011c- *Intra-species variations in yield and quality determinants in Vicia species: 1. Bitter vetch (Vicia ervilia L.).* Animal Feed Science and Technology, 165: 278-287.

Larin Y.V. (Ed)., 1951- *Forage plants of hayfields and pastures of the USSR.* Seligozizdat, Leningrad; Moscow, vol.2 , 948p. [in Russian].

Maevsky V.V., Lyashenko Z. D., Nazarova N. V., Kurkin N. S., Boyakov M. H., 2003- *The introduction of non-traditional crops in the Lower Volga region.* Bulletin of Botanic Garden of Saratov State University, 2(1): 166-168 [in Russian].

Maevsky, V.V., Gorbunov V. S., Gudkova E. V., Derbiev D. B., Ierov D. D., Bayakov D. A., 2013- *Preliminary results of introduction of wild plants for the aim of feed***.** Bulletin of Botanic Garden of Saratov State University, 11: 193-199. [in Russian].

Molinuevo-Salces B., Larsen S.U., Ahring B.K., Uellendahl H., 2014- *Biogas production from catch crops: a sustainable agricultural strategy to increase biomass yield by co-harvest of catch crops and straw. https://www.academia.edu/24795592/Biogas_Production_from_Catch_Crops*

Pakarinen A., Maijala P., Stoddard F., Santanen A., Kymäläinen M., Viikari L., 2011- *Evaluation of annual bioenergy crops in the Boreal zone for biogas and ethanol production.* Biomass & Bioenergy, 35: 3071-3078.

Oleskowicz-Popiel P., 2010- *Biogas and ethanol potentials in selected biomasses for organic farming.* PhD Thesis, Technical University of Denmark. *http://orgprints.org/19318/4/19318.pdf*

Parissi Z., Irakli M., Tigka E., Papastylianou P., Dordas C., Tani E., Abraham E.M., Theodoropoulos A., Kargiotidou A., Kougiteas L., Kousta, A., Koskosidis, A., Kostoula S., Beslemes D., Vlachostergios D.N., 2022- *Analysis of genotypic and environmental effects on biomass yield, nutritional and antinutritional factors in common vetch.* Agronomy, 12, 1678. https://doi.org/10.3390/agronomy12071678

Ţîţei V., 2021- *Some biological features and the quality of fodder from fine-leaved vetch, Vicia tenuifolia Roth.* Romanian Journal of Grassland and Forage crops, 23:105-113.

Ţîţei V., Coşman S., 2018- *Agroeconomic value of fine-leaf vetch, Vicia tenuifolia, under the conditions of Republic of Moldova.* Lucrări Ştiinţifice, seria Agronomie, 61(1): 49-54.

Ţîţei V., Cozari S., 2023- *Agroeconomic value of some Lathyrus and Vicia species in the Republic of Moldova.* Romanian Agricultural Research, 40:633-643.

Vishnyakova M.A., Burlyaeva M.O., Semenova E.V., Seferova I.V., Solov'eva A.E., Shelenga T.V., Bulyncev S.V., Buravceva T.V., Yan'kov I.I., Aleksandrova T.G., Egorova G.P., 2014- *The starting material for selection for grain quality and green mass in the VIR collection of leguminous genetic resources.* Legumes and Groat Crops, 2(10): 6-16. [in Russian]

STUDY OF THE INSTALLATION RATE OF SOME SPECIES AND MIXTURES FOR LAWNS

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Abstract

The evolution of society has led to an increase in aesthetic and functional requirements, which has transformed lawns into an essential element for enhancing everyday comfort. The considerable expansion of lawn-covered areas in recent decades reflects the reinterpretation of natural lawns in a modernized version, corresponding to current functional and aesthetic requirements. The purpose of this study is to monitor the growth rate of five mixtures and two species in pure lawn culture: a_1-Speedy Green (100% *Lolium perenne*); a_2- SuperSport (50% *Lolium perenne*+50% *Poa pratensis*); a_3-RPR Sport (50% *Lolium perenne* RPR+50% *Lolium perenne*); a_4-Bar Power RPR (30% *Lolium perenne* RPR+25% *Lolium perenne*+ 30% *Festuca rubra commutata*+15% *Festuca rubra*); a_5-Resilient Blue Lawn (25% *Lolium perenne* + 45% *Festuca trichophylla, Festuca rubra rubra, Festuca rubra commutata* + 30% *Poa pratensis*); a_6-Resilient Blue Sport (30% *Poa pratensis* with YJWM + 46% *Lolium perenne* + 24% *Lolium perenne* RPR); a_7- Turf Clover (100% *Trifolium repens*), under the conditions of the urban area of Iași. The observations were made visually and expressed with scores, according to the NTEP (National Turfgrass Evaluation Program) rating scale. Observations were made at intervals of 20, 25, 30, and 90 days after sowing, representing the ability of the species in the mixture or pure crops to cover the entire surface in the shortest possible time. According to the observations made to monitor the rate of establishment, the best germination was recorded in variant a_7-Turf Clover (100% *Trifolium repens*), with a score of 8 at 90 days after sowing, and the slowest germination was recorded in variant a_5-Resilient Blue Lawn (25% *Lolium perenne* + 45% *Festuca trichophylla, Festuca rubra rubra, Festuca rubra commutata* + 30% *Poa pratensis*) with an average score of 2.33 at 20 days after sowing.

Keywords: ornamental turf, installation rate, germination, NTEP, grass mixtures

The grassland flora of our country includes approximately 226 grass species belonging to 71 genera, reflecting the high diversity and ecological plasticity of these species within natural phytocoenoses. Approximately 50 species are used for lawns, selected based on their adaptability and the aesthetic or functional qualities they provide (Vîntu V. *et al.,* 2004).

Research by Larsen S.U. *et al.,* (2004) showed that when *Festuca rubra* and *Lolium perenne* were sown simultaneously with *Poa pratensis*, the latter accounted for only 3–30% of the total germinated plants, although its seeds represented 50–59% of the sowing mixture. In contrast, when *Festuca rubra* and *Lolium perenne* were sown several days after *Poa pratensis*, the establishment of *Poa pratensis* was significantly improved. The germination rate of this species increased by up to 0.08% for each day of delayed sowing. Therefore, adjusting sowing times according to species-specific germination rates and temperature requirements can substantially enhance the successful establishment of each component within a turf mixture.

Studies conducted by (Charif K. *et al.* 2019) show that *Lolium perenne* seeds germinate rapidly, reaching 92% germination within just 7 days, reflecting a high germination capacity and very fast establishment. In contrast, *Poa pratensis* exhibits the lowest germination rate, only 61%, with germination occurring over 30 days, indicating slow germination and a longer establishment period. This difference underscores the importance of selecting appropriate species based on lawn requirements and environmental conditions.

For *Lolium perenne*, emergence and tillering occur within 7 days, whereas *Poa pratensis* and *Festuca rubra* show slower growth, taking up to 20 days during the first year after sowing. *Lolium perenne* stands out for its superior aesthetic appearance, high turf density, and vigorous root development. *Festuca rubra* is notable for its fine leaves, disease resistance, and uniform coloration. At the end of the vegetative growth period, the

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highest turf and root density was recorded in *Lolium perenne* (Mastalerczuk, G. *et al.,* 2012).

Studies on *Lolium perenne* and *Festuca arundinacea* showed that germination rates were faster at 21°C than at 5°C. At 5°C, seeds required up to 20 additional days to reach maximum germination compared to seeds tested at 21°C (Braun R. *et al.,* 2023).

Buru T. *et al.* (2021) investigated eight grass seed mixtures sown under controlled temperature and light conditions for 14 days to identify the mixture with the highest germination rate. The Landscaper Pro Rapid mixture, consisting of *Festuca rubra* 'Cathrine' (15%), *Lolium perenne* 'Vermino' (40%), *Lolium perenne* 'Groundforce' (35%), and *Poa pratensis* 'Heatmaster' (10%), achieved the highest germination rate of 28% after 7 days, indicating superior adaptation and viability compared to the other mixtures tested.

The objective of the present study is to evaluate the establishment rate under field conditions of five mixtures and two pure species of turfgrass.

MATERIAL AND METHOD

The experiment was established on May 14, 2025, in three replicates, with seven randomly arranged variants—two with pure species and five with different mixtures for ornamental turf—on cambic chernozem soil in the Agronomy Student Campus area of the "Ion Ionescu de la Brad" University of Life Sciences in Iași (coordinates: 47°11'34.2"N, 27°33'35.6"E). Each experimental variant covered 8 m² (4 m × 2 m), with the total experimental area totaling 210 m².

The site was prepared by removing existing vegetation with a systemic glyphosate-based herbicide, followed by soil loosening using a Maschio Gaspardo vertical drum cutter. The surface was then cleared of remaining debris, leveled, and covered with a layer of manure and sand to optimize drainage and soil texture. BioStart fertilizer, containing both mineral and organic nutrients and designed to stimulate rapid and uniform germination, was applied at sowing. The site was irrigated three times daily, adjusted according to rainfall, to maintain adequate soil moisture for germination and subsequent turf growth. During the 90 days following germination, climatic conditions were favorable, with minimum temperatures of 12°C, maximum temperatures of 25°C, and accumulated rainfall of 75.45 mm.

The research aims to identify the most effective turfgrass mixtures or species that ensure rapid and uniform establishment, a process closely related to germination speed and subsequent plant growth and development.

In this study, the establishment rate was evaluated for seven experimental variants, as follows:

a_1-Speedy Green (100% *Lolium perenne*); **a_2**- SuperSport (50% *Lolium perenne*+50% *Poa pratensis*); **a_3**-RPR Sport (50% *Lolium perenne* RPR+50% *Lolium perenne*); **a_4**-Bar Power RPR (30% *Lolium perenne* RPR+25% *Lolium perenne*+ 30% *Festuca rubra commutata*+15% *Festuca rubra*); **a_5**- Resilient Blue Lawn (25% *Lolium perenne* + 45% *Festuca trichophylla, Festuca rubra rubra, Festuca rubra commutata* + 30% *Poa pratensis*); **a_6**- Resilient Blue Sport (30% *Poa pratensis cu YJWM* + 46% *Lolium perenne* + 24% *Lolium perenne RPR*); **a_7**- Turf Clover (100% *Trifolium repens*).

The turfgrass varieties used in the experiment are available on the Romanian market, being imported from the Dutch company Barenbrug, and are well adapted to local soil and climatic conditions. The turf establishment rate was assessed visually in the field using the NTEP (National Turfgrass Evaluation Program) rating scale, which ranges from 1 to 9. This scale, developed in the United States and widely used internationally, provides a standardized method for evaluating turfgrass performance. Each score reflects the degree of germination as follows: score 1 - almost no sprouting; score 2 - very poor germination; score 3 - low germination; score 4 - partial germination; score 5 - acceptable germination; score 6 - relatively uniform germination; score 7 - very good germination; score 8 - excellent germination; score 9 - exceptional germination and total coverage.

Statistical analysis of the data was performed using the ANOVA method, with significance determined by the Least Significant Difference (LSD) test.

RESULTS AND DISCUSSIONS

The establishment rate was determined immediately after sprouting began, at 20, 25, 30, and 90 days after sowing, based on visual assessments using the NTEP (National Turfgrass Evaluation Program) rating scale.

Twenty days after sowing, the fastest emergence was observed in the control variant, a_1 – Speedy Green (100% *Lolium perenne*), with an average score of 6.67, serving as the reference standard for the other variants. a7 – Turf Clover (100% *Trifolium repens*) established nearly as quickly as the control, scoring 6.33. In contrast, a_5 – Resilient Blue Lawn (25% *Lolium perenne* + 45% *Festuca trichophylla*, *Festuca rubra rubra*, *Festuca rubra commutata* + 30% *Poa pratensis*) exhibited the slowest establishment rate, with a score of 2.33, which was significantly lower but ultimately resulted in a dense and resilient lawn. The other mixtures showed slower establishment compared to the control (*table 1*).

Twenty-five days after sowing, the fastest establishment was again observed in the control variant, a_1 – Speedy Green (100% *Lolium perenne*), with an average score of 7.00, followed by a_7 – Turf Clover (100% *Trifolium repens*), which scored 6.67, the difference being statistically insignificant. At the opposite end, the slowest establishment was recorded in a_5 – Resilient Blue Lawn (25% *Lolium perenne* + 45% *Festuca trichophylla*, *Festuca rubra rubra*, *Festuca rubra commutata* + 30% *Poa pratensis*), which achieved a score of 2.67, representing a highly significant reduction *(table 2).*

Thirty days after sowing, the best establishment was observed in the control variant, a_1 – Speedy Green (100% *Lolium perenne*), with a score of 7.33. This was followed by a_7 – Turf Clover (100% *Trifolium repens*), which scored 6.67. The establishment rate of a7 was close to that of the control, with no statistically significant difference a_5 – Resilient Blue Lawn (25% *Lolium perenne* + 45% *Festuca trichophylla*, *Festuca rubra rubra*, *Festuca rubra commutata* + 30% *Poa pratensis*) achieved a score of 3.33, representing a difference of -3.67 compared to the control, which is highly significant (*table 3*).

Ninety days after sowing, the highest establishment rate was observed in a_7 – Turf Clover (100% *Trifolium repens*), which scored 8.00. The lowest establishment rate at this stage was recorded for a_5 – Resilient Blue Lawn (25% *Lolium perenne* + 45% *Festuca trichophylla*, *Festuca rubra rubra*, *Festuca rubra commutata* + 30% *Poa pratensis*), which achieved a score of 6.67, representing a highly significant reduction of -1.00 compared to the control (*table 4).*

Table 1

The rate of turf establishment 20 days after sowing

** Lp- Lolium perenne; Pp- Poa pratensis; Fr- Festuca rubra; Ft- Festuca trichophylla; Frr- Festuca rubra rubra;*

Variant*	Installation rate	Difference		Significance
	note	note	%	
	Control: a_1 - Speedy Green (100% Lp)			
a₁ - Speedy Green (100% *Lp*)	6.67	Control	100	Control
a₂- SuperSport (50% *Lp*+50% *Pp*)	4.00	60.0	-2.67	ooo
a₃- RPR Sport (50% *Lp* RPR+50% *Lp*)	5.33	80.0	-1.33	oo
a₄- Bar Power RPR (30% *Lp* RPR+25% *Lp*+ 30% *Frc*+15% *Fr*)	3.67	55.0	-3.00	ooo
a₅- Resilient Blue Lawn (25% *Lp + 45% Ft,Frr, Frc + 30% Pp)*	2.33	35.0	-4.33	ooo
a₆- Resilient Blue Sport (30% *Pp* cu YJWM + 46% *Lp*+ 24% *Lp* RPR)	5.00	75.0	-1.67	ooo
a₇- Turf Clover (100% *Tr*)	6.33	95.0	-0.33	-
	LSD 5%	0.84		
	LSD 1%	1.18		
	LSD 0.1%	1.66		

Frc-Festuca rubra commutate; Tr-Trifolium repens

Table 2

The rate of turf establishment 25 days after sowing

Variant*	Installation rate	Difference		Significance
	note	note	%	
	Control: a_1 - Speedy Green (100% Lp)			
a₁- Speedy Green (100% *Lp*)	7.00	Control	100	Control
a₂- SuperSport (50% *Lp*+50% *Pp*)	5.00	71.4	-2.00	ooo
a₃- RPR Sport (50% Lp RPR+50% *Lp*)	5.67	81.0	-1.33	oo
a₄- Bar Power RPR (30% *Lp* RPR+25% *Lp*+ 30% *Frc*+15% *Fr*)	3.67	52.4	-3.33	ooo
a₅- Resilient Blue Lawn (25% Lp + 45% Ft,Frr, Frc + 30% Pp)	2.67	38.1	-4.33	ooo
a₆- Resilient Blue Sport (30% *Pp* cu YJWM + 46% *Lp*+ 24% *Lp* RPR)	5.33	76.2	-1.67	oo
a₇- Turf Clover (100% *Tr*)	6.67	95.2	-0.33	-
	LSD 5%	0.90		
	LSD 1%	1.26		
	LSD 0.1%	1.78		

Table 3

The rate of turf establishment 30 days after sowing

Variant*	Installation rate	Difference		Significance
	note	note	%	
	Control: a_1 - Speedy Green (100% Lp)			
a₁- Speedy Green (100% *Lp*)	7.00	Control	100	Control
a₂- SuperSport (50% *Lp*+50% *Pp*)	5.67	81.0	-1.33	oo
a₃- RPR Sport (50% *Lp* RPR+50% *Lp*)	6.33	91.5	-0.67	-
a₄- Bar Power RPR (30% *Lp* RPR+25% *Lp*+ 30% *Frc*+15% *Fr*)	4.00	57.1	-3.00	ooo
a₅- Resilient Blue Lawn (25% Lp + 45% Ft.Frr. Frc + 30% Pp)	3.33	47.6	-3.67	ooo
a₆- Resilient Blue Sport (30% *Pp* cu YJWM + 46% *Lp*+ 24% *Lp* RPR)	6.00	85.7	-1.00	o

a_7- Turf Clover (100% *Tr*)	7.33	104.8	0.33	-
	LSD 5%	0.91		
	LSD 1%	1.28		
	LSD 0.1%	1.81		

Table 4

The rate of turf establishment 90 days after sowing

Variant*	Installation rate	Difference		Significance
	note	note	%	
	Control: a_1 - Speedy Green (100% Lp)			
a_1- Speedy Green (100% *Lp*)	7.67	Control	100	Control
a_2- SuperSport (50%Lp+50%Pp)	7.00	91.3	-0.67	o
a_3- RPR Sport (50% *Lp* RPR+50% *Lp*)	7.33	95.7	-0.33	-
a_4- Bar Power RPR (30% *Lp* RPR+25% *Lp*+ 30% *Frc*+15% *Fr*)	7.00	91.3	-0.67	o
a_5- Resilient Blue Lawn (25% *Lp* + 45% *Ft .Frr. Frc* + 30% Pp)	6.67	87.0	-1.00	oo
a_6- Resilient Blue Sport (30% *Pp* cu YJWM + 46% *Lp*+ 24% *Lp* RPR)	7.33	95.7	-0.33	-
a_7- Turf Clover (100% *Tr*)	8.00	104.3	0.33	-
	LSD 5%	0.63		
	LSD 1%	0.89		
	LSD 0.1%	1.26		

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CONCLUSIONS

Observing the germination dynamics, it is evident that a_1 and a_7, represented by *Lolium perenne* and *Trifolium repens*, respectively, are characterized by a rapid and uniform establishment rate. Even within the first 20 days after sowing, they achieved scores above 6, ensuring optimal turf density due to their favorable biological traits. Over the entire 90 day observation period, these variants maintained the highest performance, with final scores of 7.67 for a_1 and 8.00 for a_7**.**

The study data indicated that mixtures with a high proportion of *Festuca spp.* and *Poa pratensis* exhibited noticeably slower establishment, which reduced the rate of ground coverage, promoted weed emergence, and increased water losses through evapotranspiration. The most pronounced effects were observed in a_5, which showed a consistently slowed establishment process throughout the observation period, with scores of 2.33 at 20 days and 3.33 at 30 days.

In the long term, mixtures with slower establishment, resulting from the biological characteristics of their component species, provide good turf density and resistance (scores of 6.67 for a_5 and 7.0 for a_4 at 90 days after sowing). These mixtures are therefore suitable for areas subject to moderate or heavy traffic and for more challenging environmental conditions.

REFERENCES

Braun R. C., Courtney L. E., Patton A. J., 2023- Seed morphology, germination, and seedling vigor characteristics of fine fescue taxa and other cool-season turfgrass species. Crop Science, 63(3), 1613-1627.

Buru T., Buta E., Cantor M., Crişan I., Szekely-Varga Z., Dan V., 2021-Seed germination rate of different turfgrass mixtures under controlled conditions.

Charif K., Mzabri I., Chetouani M., Khamou L., Boukroute A., Kouddane N., Berrichi A., 2019- Germination of some turfgrass species used in the green spaces in eastern Morocco. Materials Today: Proceedings, 13, 713-719.

Mastalerczuk G., Borawska-Jarmułowicz B., Janicka M., 2012- Evaluation of the development and turf characteristics of lawn grass cultivars in the year of sowing. Grassland Sci Eur, 17, 523-525.

Larsen S. U., Andreasen C., Kristoffersen P., 2004 - Differential sowing time of turfgrass species affects the establishment of mixtures. Crop Science, 44(4), 1315-1322.

Vîntu V., Moisuc A., Motcă G., Rotar I., 2004 - Cultura pajiştilor şi a plantelor furajere. Editura "Ion Ionescu de la Brad

STUDY OF THE BEHAVIOR OF SOME SIMPLE MIXTURES OF GRASSES AND PERENNIAL LEGUMES UNDER CLIMATE CHANGE CONDITIONS

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Abstract

Romania has over 4.8 million hectares of permanent grasslands. Permanent grasslands contribute little to animal feed compared to temporary grasslands because they are of poor quality and produce low yields without proper management. Sown temporary grasslands are a good alternative to degraded or deteriorating permanent grasslands, providing high-quality feed in terms of both quantity and quality. To establish the relationship between species in a given pedoclimatic area, periodic research is required to develop and standardize new mixtures of perennial grasses and legumes. This experiment was conducted at the Ezăreni farm of the University of Life Sciences from Iasi. Observations within the sown variants focused on the number of shoots per m², plant height at harvest and dry matter production per hectare. In the first year of vegetation, a single mowing was performed, and yields ranged from 2446.1 kg/ha for variant a_6 to 4653.0 kg/ha for variant a_1. The average number of shoots/m² in the first year of vegetation ranged from 632 shoots/m² in variant a_1 to 2,757 shoots/m² in the case of the mixture variant a_9. In the first year of vegetation, high yields were recorded in the variants where *Onobrychis viciifolia* Scop. accounted for more than 50% of the crop.

Keywords: (temporary meadows, productivity elements, plant height, number of shoots, yield)

In simple or complex mixtures of grasses and perennial legumes, with different proportions of species, it appears that they behave differently over time. Some species can maintain their share in the mixture, while others may reduce their participation in the mixture. These variations in the share of a species in the composition of a mixture are attributed to competition between species.

Experimenting with simple or complex mixtures aims to identify those mixtures of perennial forage plants that can yield high, high-quality crops and in which the plants do not compete too much with each other for light, nutrition, and water (Rechitean, D., & Rechitean, I. I., 2021).

There may also be positive correlations between the percentage of participation in the mixture and the resulting dry matter production, such as the mixture consisting of *Festuca arundinacea* Schreb and *Trifolium pratense* L. in a ratio of 25-75% (Zaiț, T., *et al.*, 2022).

The quality of fodder produced on temporary sown grasslands is influenced by the proportion of different plant species that make up the sown mixture. Some mixtures may be more productive than others due to the plants that make up their composition. A concrete example is the difference in production between two simple mixtures, one consisting of *Onobrychis viciifolia* Scop. and *Bromus inermis* Leyss., which is superior in terms of quantity obtained compared to the mixture consisting of *Medicago sativa* L. and *Dactylis glomerata* L. (Samuil, C., *et al*, 2010, Samuil, C., *et al.*, 2012).

Another concern is the harvesting period, which takes into account the phenophase of the dominant species. Harvesting plants at late stages leads to a reduction in their quality (Türk, M., *et al.,* 2015).

The superiority of fodder in terms of quality and quantity is determined by the individual species and less by the complexity of the mixtures (Deak A *et al.,* 2007).

When making mixtures of grasses and perennial legumes, it must be taken into account that the species used may be influenced by climatic conditions, with qualitative and quantitative indices varying from one pedoclimatic zone to another (Naie M., *et al.,* 2016).

Mixtures of plant species increase productivity compared to pure crops by exploiting the complementarity between species in the use of resources over time and in different areas of space (Evers J. B., *et al.,* 2019).

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Productivity increased proportionally with the diversity of species sown, and this positive relationship remained constant over time. The performance of the mixtures was mainly due to the complementarity between the species in the mixture, rather than the selection effects of individual species (Picasso V. D., *et al.,* 2011).

Several studies have shown that it is difficult to predict the contribution of individual species to the positive relationship between species diversity and biomass production based on their behavior in pure culture (Roscher C., *et al.,* 2007).

Recent studies on forage plant mixtures have analyzed the relationship between environmental gradients and their diversity or productivity, examining how biotic and/or abiotic factors influence these characteristics (Assaf T. A*., et al.,* 2011).

Species diversity has increasingly powerful ecological effects over time due to the growth of functional complementarity between them. This dynamic allows for more efficient use of limited environmental resources (Reich, P. B., *et al.,* 2012).

Even when resources change, diversity and how species collaborate with each other remain essential for maintaining grassland productivity (Craven D., *et al.,* 2016).

MATERIALS AND METHODS

This research aimed to observe the behavior of simple mixtures of perennial grasses in the context of climate change.

It is an experiment established in 2024, in three replicates, of the subdivided plot type. It was established on the Ezăreni teaching farm, which belongs to the "Ion Ionescu de la Brad" University of Life Sciences in Iași. The farm's coordinates are 47°05'-47°10' north latitude and 27°28'-27°33' east longitude, which makes it part of the forest-steppe area of Moldova. The factor studied is represented by simple and complex species and mixtures as follows:

Factor A: species/mixture sown: a_1 – *Onobrychis viciifolia* Scop. (100%) (control); a_2 – *Onobrychis viciifolia* Scop. (75%) and *Bromus inermis* Leyss. (25%); a_3 - *Onobrychis viciifolia* Scop. (50%) and *Bromus inermis* Leyss. (50%); a_4 - *Onobrychis viciifolia* Scop. (25%) and *Bromus inermis* Leyss. (75%); a_5 – *Medicago sativa* L. (100%); a_6 – *Medicago sativa* L. (75%) and *Festuca pratensis* (25%); a_7 – *Medicago sativa* L. (50%) and *Festuca pratensis* (50%); a_8 – *Medicago sativa* L. (25%) and *Festuca pratensis* (75%); a_9 – *Medicago sativa* L. (20%), *Lotus corniculatus* L. (15%); *Festuca pratensis* (30%); *Lolium perenne* L. (10%) and *Dactylis glomerata* L. (25%) and a_{10} – *Onobrychis viciifolia* Scop. (20%), *Lotus corniculatus* L. (15%); *Agropyron pectiniforme* L. (30%); *Bromus inermis* Leyss. (25%) and *Lolium perenne* L. (10%).

The varieties used for the experiment are Romanian, well adapted to the soil and climate conditions of the experimental area.

The number of shoots per square meter and the height of the plants were determined in the experimental field.

The dry matter was determined in two stages: sampling in the field and processing in the university laboratory. In the laboratory, these samples were placed in an oven and dried for three hours at 105°C; standard - SR ISO 6496/2001.

The program used for statistics is ANOVA, and the test applied is LSD (Least Significant Difference).

RESULTS AND DISCUSSIONS

Analyzing the influence of the species or mixture of perennial grasses and legumes on the average number of shoots/m² in the first year of vegetation, it was found that the values obtained ranged from 632 shoots/m² in variant a_1, species *Onobrychis viciifolia* Scop. (100%) and 2757 shoots/m2 in the case of the complex mixture a_9, the mixture consisting of the species *M.s*. (20%) + *L.c*. (15%) + *F.p*. (30%) + *L.p*. (10%) and *D.g*. (25%) (*table 1*).

The data obtained in the first year of vegetation show that the highest number of shoots was obtained in the variants where the species *Medicago sativa* L. and *Festuca pratensis* L. were present, cultivated in simple and complex mixtures in different proportions (*table 1*).

Analyzing the influence of the species or mixture of grasses and perennial legumes on the average plant height, it was found that the values obtained ranged from 42.1 cm in variant a_8, the simple mixture consisting of the species *M.s.* (25%) + *F.p*. (75%) and 75.0 cm in variant a1, the species *Onobrychis viciifolia* Scop. (100%) (*table 2*).

From a statistical point of view, compared to the control variant, all other variants studied showed insignificant, distinctly significant, and highly significant negative differences (*table 2*).

In terms of the influence of the cropping system used on dry matter production at mowing I, in the first year of vegetation, the differences from the control in all variants analyzed were negative, with high yields recorded in the variants where the species *Onobrychis viciifolia* Scop. had a share of more than 50%. At mowing I, the highest production was obtained in the control variant a_1 - *Onobrychis viciifolia* (100%) (mt.) cultivated alone in unfertilized conditions, where a production of 4653kg/ha was recorded. (*table 3*).

Table 1

Influence of grass and legume species or mixtures on the number of shoots/m2 at the first cut in the first year of vegetation

Variant*	Number of shoots	Difference		Significance
	Shoots/m2	Shoots/m2	%	
	Control: a_1 - *O.v.* (100%)			
a_1 - *O.v.* (100%) (mt.)	632	Control	100	Control
a_2 - *O.v.* (75%) + *B.i.* (25%)	986	354	156.0	*
a_3 - *O.v.* (50%) + *B.i.* (50%)	1187	555	187.8	**
a_4 - *O.v.* (25%) + *B.i.* (75%)	819	187	129.6	
a_5 - *M.s.* (100%)	1506	874	238.3	***
a_6 - *M.s.* (75%) + *F.p.* (25%)	2192	1560	346.8	***
a_7 - *M.s.* (50%) + *F.p.* (50%)	2138	1506	338.3	***
a_8 - *M.s.* (25%) + *F.p.* (75%)	2437	1805	385.6	***
a_9 - *M.s.* (20%) + *L.c.* (15%) + *F.p.* (30%) + *L.p.* (10%) + *D.g.* (25%)	2757	2125	436.2	***
a_{10} - *O.v.* (20%) + *L.c.* (15%) + *A.p.* (30%) + *B.i.* (25%) + *L.p.* (10%)	1692	1060	267.7	***
	LSD 5% =	324		
	LSD 1% =	444		
	LSD 0.1% =	604		

* *Onobrychis viciifolia (O.V.); Bromus inermis (B.i.); Medicago sativa (M.s.); Festuca pratensis (F.p.); Lolium perenne (L.p.); Lotus corniculatus (L.c.); Dactylis glomerata (D.g.); Agropyron pectiniforme (A.p.)*

Table 2

Influence of grass and legume species or mixtures on plant height at first mowing in the first year of vegetation

Variant*	Plant height	Difference		Significance
	cm	cm	%	
	Control: a_1 - *O.v.* (100%)			
a_1 - *O.v.* (100%) (mt.)	75.0	Control	100	Control
a_2 - *O.v.* (75%) + *B.i.* (25%)	71.6	-3.4	95.4	
a_3 - *O.v.* (50%) + *B.i.* (50%)	69.5	-5.6	92.6	
a_4 - *O.v.* (25%) + *B.i.* (75%)	72.8	-2.3	96.9	
a_5 - *M.s.* (100%)	46.1	-29.0	61.4	oo
a_6 - *M.s.* (75%) + *F.p.* (25%)	45.5	-29.6	60.6	oo
a_7 - *M.s.* (50%) + *F.p.* (50%)	49.8	-25.2	66.4	oo
a_8 - *M.s.* (25%) + *F.p.* (75%)	42.1	-32.9	56.1	ooo
a_9 - *M.s.* (20%) + *L.c.* (15%) + *F.p.* (30%) + *L.p.* (10%) + *D.g.* (25%)	45.3	-29.8	60.3	oo
a_{10} - *O.v.* (20%) + *L.c.* (15%) + *A.p.* (30%) + *B.i.* (25%) + *L.p.* (10%)	60.3	-14.8	80.3	
	LSD 5% =	16.1		
	LSD 1% =	22.1		
	LSD 0.1% =	30.1		

* *Onobrychis viciifolia (O.v.); Bromus inermis (B.i.); Medicago sativa (M.s.); Festuca pratensis (F.p.); Lolium perenne (L.p.); Lotus corniculatus (L.c.); Dactylis glomerata (D.g.); Agropyron pectiniforme (A.p.)*

Table 3

Influence of grass and legume species or mixtures on dry matter production at the first cut in the first year of vegetation

Variant*	Production of DM	Difference		Significance
	kg/ha	kg/ha	%	
	Control: a_1 - *O.v.* (100%)			
a_1 - *O.v.* (100%) (mt.)	4653.0	Control	100	Control
a_2 - *O.v.* (75%) + *B.i.* (25%)	4249.1	-403.9	91.3	o
a_3 - *O.v.* (50%) + *B.i.* (50%)	3443.5	-1209.4	74.0	ooo
a_4 - *O.v.* (25%) + *B.i.* (75%)	4096.0	-557.0	88.0	oo
a_5 - *M.s.* (100%)	3979.4	-673.5	85.5	oo
a_6 - *M.s.* (75%) + *F.p.* (25%)	2446.1	-2206.8	52.6	ooo
a_7 - *M.s.* (50%) + *F.p.* (50%)	2887.5	-1765.5	62.1	ooo
a_8 - *M.s.* (25%) + *F.p.* (75%)	2642.3	-2010.7	56.8	ooo
a_9 - *M.s.* (20%) + *L.c.* (15%) + *F.p.* (30%) + *L.p.* (10%) + *D.g.* (25%)	4072.9	-580.0	87.5	oo
a_{10} - *O.v.* (20%) + *L.c.* (15%) + *A.p.* (30%) + *B.i.* (25%) + *L.p.* (10%)	3656.4	-996.5	78.6	ooo
	LSD 5% =	365.2		
	LSD 1% =	500.9		
	LSD 0.1% =	681.8		

* *Onobrychis viciifolia (O.v.); Bromus inermis (B.i.); Medicago sativa (M.s.); Festuca pratensis (F.p.); Lolium perenne (L.p.); Lotus corniculatus (L.c.); Dactylis glomerata (D.g.); Agropyron pectiniforme (A.p.)*

CONCLUSIONS

The average number of shoots/m² in the first year of vegetation ranged from 632 shoots/m² in variant a_1, species *Onobrychis viciifolia* Scop. (100%) and 2757 shoots/m2 in the case of the Complex a_9 mixture - the mixture consisting of the species *M.s*. (20%) + *L.c*. (15%) + *F.p*. (30%) + *L.p*. (10%) and *D.g.* (25%).

The best results in terms of shoot number were obtained in the variants that included *Medicago sativa* L. and *Festuca pratensis* in the simple and complex mixtures.

The highest plant height values (75 cm) were recorded when the species *Onobrychis viciifolia* Scop was present (variant a_1), the minimum value being 42.1 cm in variant a_8-– *Medicago sativa* L. (25%) and *Festuca pratensis* (75%).

In terms of yield, the highest yield was recorded in variant a1 with the species *Onobrychis viciifolia* Scop 100% (4653 kg/ha), with all other variants having lower yields than the control variant.

Although simple and complex fodder mixtures provide a more varied range of plants in their composition, they do not guarantee higher yields at harvest, which may be exceeded by species grown alone, as is the case with the variant sown with *Onobrychis viciifolia* Scop 100%, which obtained some of the best values for the indices monitored.

ACKNOWLEGMENTS

This research was supported by Ministry of Agriculture and Rural Development, project number ADER 15.2.2. No. 09/08/2023.

REFERENCES

Assaf T. A., Beyschlag W., & Isselstein J. 2011 - The relationship between plant diversity and productivity in natural and in managed grasslands. Applied Ecology and Environmental Research, 9(3), 157-166.

Craven, D., Isbell F., Manning P., Connolly J., Bruelheide H., Ebeling A., Eisenhauer N. (2016) - Plant diversity effects on grassland productivity are robust to both nutrient enrichment and drought. Philosophical Transactions of the Royal Society B: Biological Sciences, 371(1694), 2015-0277.

Deak A., Hall M. H., Sanderso M. A., & Archibald D. D. (2007) - Production and nutritive value of grazed simple and complex forage mixtures. Agronomy Journal, 99(3), 814-821.

Evers J. B., Van Der Werf W., Stomph T. J., Bastiaans L., & Anten, N. P. 2019 - Understanding and optimizing species mixtures using functional–structural plant modelling. Journal of experimental botany, 70(9), 2381-2388.

Naie M., Trotuș E., Buburuz A. A., Lupu C., & Gherasim Leonte A. 2016 - Research regarding the behaviour of some perennial grasses and legumes mixtures in order to establish temporary grassland exploited in meadow regime.

Picasso V. D., Brummer E. C., Liebman M., Dixon P. M., & Wilse B. J. 2011 - Diverse perennial crop mixtures sustain higher productivity over time based on ecological complementarity. Renewable Agriculture and Food Systems, 26(4), 317-327.

Rechitean D., Rechitean I. I., 2021 - Behavior of some legumes species in complex forage mixtures. *Life Science and Sustainable Development*, *2*(1), 159-165.

Reich P. B., Tilman D., Isbell F., Mueller K., Hobbie S. E., Flynn D. F., & Eisenhauer N., (2012) - Impacts of biodiversity loss escalate through time as redundancy fades. Science, 336(6081), 589-592.

Roscher C., Schumacher J., Weisser W. W., Schmid B., & Schulze E. D. 2007 - Detecting the role of individual species for overyielding in experimental grassland communities composed of potentially dominant species. Oecologia, 154(3), 535-549.

Samuil, C., Vintu, V., Sirbu, C., Surmei, G. M. 2012- Behaviour of fodder mixtures with alfalfa in north-eastern Romania, *Romanian Agricultural Research, No. 29*

Samuil, C., Vîntu, V., Surmei, G. M., Ionel, A. 2010- Research on the behaviour of simple mixtures of perennial grasses and legumes, under the conditions of Moldavian forest-steppe. *Romanian Journal of Grassland and Forage Crops*.

Türk M., Albayrak S., Bozkurt Y. 2015 - The change in the forage quality of smooth bromegrass (Bromus inermis L.) in grazing and non-grazing pastures.

Zaiț T., Nazare A. I., Samuil C., Vîntu V., 2022- Species productivity research for *Festuca arundinacea* Schreb and Trifolium Pratense L. cultivated alone or in simple mixtures, in the first year of vegetation, under the conditions of the Moldavian forest-steppe. *Romanian Journal of Grasslands and Forage Crops*, *26*, 9.

RESEARCH ON THE CURRENT STATUS OF THE GEODESIC BASE FOR MONITORING DISPLACEMENTS AT DAMS

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Abstract

Monitoring displacements at storage dams requires the presence of a geodetic network of a certain complexity. Dams in Romania were built over long periods of time, and most of them have an operating life of over 50-70 years. The geodetic network for monitoring displacements at these dams was executed according to the topographic plans existing at the time of design. At the current stage, the movement tracking system at a dam is carried out using the microtriangulation method. This system must be updated and optimized for the use of modern data acquisition equipment, for their rapid processing and transmission to decision-makers. Research conducted on a series of dams in eastern Romania has highlighted a series of problems that create a risk in the classic monitoring of dam displacements. A main problem at a series of dams is the updating of topographic plans, the geodetic tracking network and the equipment provided. Satellite techniques for taking over geodetic data are effective for monitoring displacements in "real time". Real-time monitoring of parameters at a dam allows for rapid intervention in assessing a risk and adopting safety measures. To this end, the current geodetic networks of dams must be analyzed and modernized by attaching modern equipment and software that can take over real-time displacements.

Keywords: displacements, geodetic network, GNSS, real time, robotic total stations

Monitoring the structural and functional parameters of dams aims to ensure operational safety, which effectively protects both the natural and human environment. One area of dam monitoring is the movement and deformation of structural elements (Popovici A., 2002). Movements in a dam vary depending on the nature of the material from which it is made, the forces acting upon it, and its structural condition over time. Horizontal and vertical displacements can occur in the body of the dam at the crest and on the slopes, settlements in the foundation, and at the abutments in the flanks, etc. Displacements in dams are monitored using a geodetic network designed and implemented during construction (Popovici A., 2002). The geodetic network deteriorates over time, being affected by physical and technical aging.

Romania has about 240 large-type dams, which have a service life of over 50–70 years. The geodetic network for monitoring movements at these dams was implemented according to the topographic plans available at the time of their design. The network was equipped with the equipment available at that time. Dams in Romania are classified into four categories of importance (A, B, C, D), where those in categories A and B are equipped with a "Structural Behaviour Monitoring (SBM)" service.

SBM manually collects geodetic data from the field through topographic measurements at intervals of time. Current climate change has disrupted the distribution of rainfall across Romania, a situation that has led to the occurrence of rapid floods with high flow rates. Classical geodetic networks are largely reactive, meaning they provide results after a longer period imposed by measurements and data processing.

The new climatic conditions also require the presence of a modern preventive geodetic network, which, along with the rapid acquisition and processing of data, can facilitate immediate decision-making. Research on the use of modern geodetic networks at dams is currently developing both nationally (Agapie – Mereuta I. *et al*, 2021, Negrilă A. and Onose D., 2013) and internationally (Corssetti M. *et al*, 2016, Maltese, A., *et al*, 2021, Wang T., *et al*, 2010, Zhang Y., *et al*, 2018).

There must be coordination between the two geodetic networks (classical and modern) in order to obtain viable measurement data. Some of the classical geodetic networks in their current state present a series of foundational and layout issues that hinder their proper functioning.

The paper presents the results of research on the analysis of the structural condition of the geodetic network used to monitor displacements at two dams located in the eastern part of Romania.

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At the same time, the paper argues for the need to modernize geodetic networks at dams through the introduction of modern equipment and technologies for real-time acquisition of topographic data.

MATERIAL AND METHOD

The research was carried out on geodetic networks implemented at two existing dams in the eastern region of Romania. In the study, a dam of category B importance, namely the Parcovaci Dam, and one of category A, namely the Stanca - Costesti Dam, were selected. The Parcovaci Dam is located on the Bahlui River, is of homogeneous type, and is made of earth. The dam's height is 25 m, and the crest length is 290 m. The dam is equipped with a geodetic network for monitoring the movements of the earth mass and concrete elements (*figure 1*).

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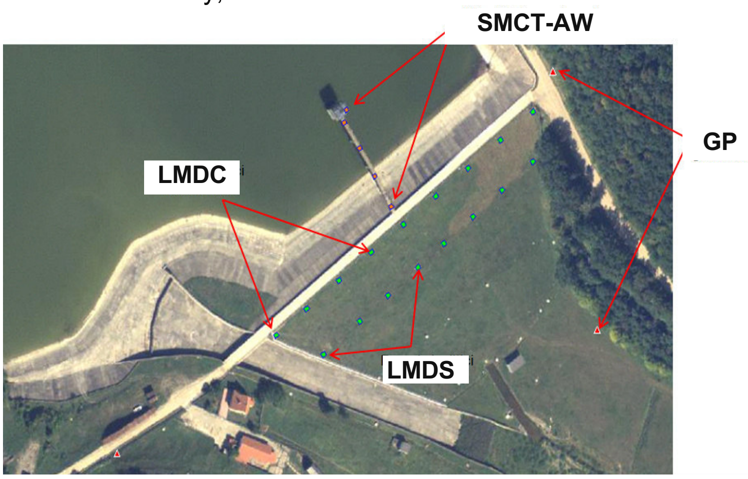


Figure 1 **Components of the geodetic network for displacement monitoring at Parcovaci Dam: GP – geodetic pillars; LMDC – level marks on the dam crest; LMDS – leveling marks on the downstream slope; SMCT-AW – settlement marks on the control tower and access walkway (Agapie-Mereuta I., 2025)**

Figure 2 **General view of the Stanca-Costesti Dam with the areas for placing the geodetic network: a – earth dam; b – concrete gravity dam (photo by the author, 2024)**

The Stanca-Costesti Dam is located on the Prut River and has a mixed structure, being constructed with both concrete and earth components. The dam has a height of 48 meters and a crest length of 1500 meters. The dam is equipped with a complex geodetic network for monitoring movements in the earth component and the concrete elements (Hidroconstructia, 2000).

The research method consisted of the following stages:

- analysis of the design documentation regarding the type and technical equipment of the geodetic network for monitoring displacements and deformations at the dam;
- analysis of the technical documentation regarding the modifications and rehabilitations carried out on the geodetic network for monitoring displacements;
- analysis of the technical documentation regarding the manner of performing measurements, processing the results, and interpreting them;
- field analysis of the structural and functional condition of the geodetic network for monitoring displacements after a long period of operation;
- performing topographic measurements on certain parts of the data acquisition circuits from the geodetic network for monitoring displacements;
- analyzing and developing a concept for modernizing the geodetic network for displacement

monitoring by introducing modern technologies and equipment that work together with the traditional ones.

During the field research, photos and videos were taken from the location of the studied geodetic network. A series of images were also captured with the help of a drone.

RESULTS AND DISCUSSIONS

Dams in Romania of categories A and B, about 181 in total, are equipped with geodetic networks to monitor displacements. Dams in categories C and D do not have geodetic networks for movement monitoring (Agapie - Mereuta I., 2025). Displacements monitoring is provided for in the dam operation regulations and carried out by the UCC department.

Horizontal and vertical displacements in the structural components of dams are of the following types:

a - partial or relative displacements, which result from the comparative analysis of the data from the latest measurement with those from the previous measurement;

b - total or absolute displacements, which result from the analysis of measurement series taken over time and their reference to the initial measurement (the "zero" measurement).

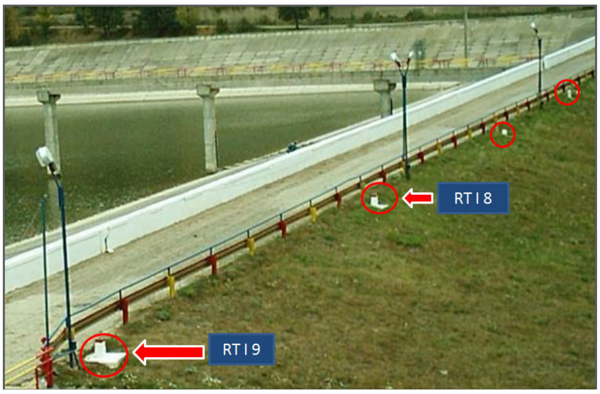
Displacement measurements are carried out at least once in the case of normal operating conditions. In special situations caused by extreme natural and anthropogenic phenomena (floods, earthquakes, accidents, exceeding critical settlement values, etc.), measurements will be performed immediately. Processed measurement data are entered into calculation programs to check the safety condition of the dam at various stages of operation (Chirilă C., and Căsăndrescu I.A., 2015, Agapie -Mereuță I., 2020).

In constructing the geodetic network for dams, the classic triangulation network of Romania (the "state" network) was used. This network consists of points with known coordinates across the territory of Romania. The points are classified into four orders of importance (I, II, III, IV), and the dam network relies on these points and supplements them with new points of order V.

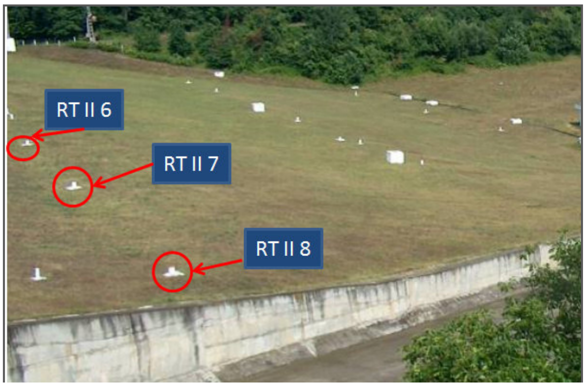
Classical geodetic networks for measuring displacements at dams use planimetric geodetic networks and altimetric geodetic networks. The system for monitoring displacements at a dam is currently carried out using the microtriangulation method and the high-precision geometric levelling method (Luca M., et al., 2013). Field research conducted at the two selected dams highlighted a series of problems that need to be addressed to achieve the most efficient measurement activity possible.

The Parcovaci Dam is equipped with a geodetic network for monitoring movements, consisting of six geodetic pillars and 17 levelling benchmarks with a vertical axis embedded in the dam body (*figure 1*). On the access walkway to the intake tower, four settlement marks are installed, and on the deck of the operating tower, there is one settlement mark (*figure 3*) (Agapie-Mereuta I., 2025).

The research conducted at the Parcovaci Dam highlighted the extent of aging of the geodetic network for monitoring displacements. The components of the network are in good working condition but show a certain degree of physical as well as moral wear.



a



b

Figure 3 **Visualization of the placement of the geodetic network at the Parcovaci Dam: a – benchmarks on the dam crest; benchmarks on the slope.**

The geodetic network for monitoring displacements at the Stanca-Costesti Dam (the Romanian sector) has a complex structure, in accordance with the verification requirements for a Category A dam (*figure 2*).

The research analyzed 15 points from the primary network, 19 points from the support network, and 203 mobile study benchmarks (*figure 4*). The analyzed mobile benchmarks are distributed as follows: 82 altimetric study benchmarks embedded in the concrete dam crest; 4 altimetric study benchmarks embedded in the emergency intake; 85 mobile planimetric and altimetric study benchmarks embedded in the concrete dam; 12 planimetric and altimetric study benchmarks embedded in the spillway; 10 mobile planimetric and altimetric study benchmarks embedded in the sluice gate. In the earth dam, 10 mobile planimetric and altimetric study benchmarks are embedded.

The monitoring of displacements and deformations at the Stanca - Costesti Dam is carried out for the following structures: the concrete dam, the earth dam, the spillway, the right shoulder consolidation dam, the sluice gate, and the spillway. The purpose of the monitoring is to determine the spatial coordinates X, Y, Z of the points of the support network, the auxiliary network, and the study benchmarks, to process them, and to calculate the longitudinal L and transverse T deviations for the study benchmarks. Geodetic measurements are carried out periodically, specifically on an annual basis.

In the first stage, the situation plans with the location of the designed and executed geodetic network were analyzed. An initial conclusion indicates the need to update the situation plans to reflect the reality on the ground. Furthermore, the situation plans need to be digitized to comply with current displacement monitoring techniques and to create a modern GIS-based database.

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a b c d

Figure 4 **Components of the geodetic network for measuring displacements at the Stanca-Costesti Dam investigated: a – pillar on the crest; b – station point on the spillway; c, d – benchmarks on the berms and earth slope (author photo, 2025).**

Field research highlighted the following situations:

- the components of the geodetic network for monitoring displacements are degraded to various degrees depending on the construction material and the period of operation; at the time of the research, this equipment had been in use for over 50 years (the construction of the dam began in 1973 and was completed in 1978);

- the concrete infrastructure of the pillars, benchmarks, and markers is deteriorated due to the action of climatic factors, as well as anthropogenic factors; the metal components already exhibit advanced degrees of rust (*figure 4*);

- On the earth component of the dam, vegetation has developed consisting of trees, shrubs, and bushes, which in the current stage obstructs the line of sight between stations and benchmarks (*figure 5*);

- conducting cycles of verification measurements of the circuits highlighted limited visibility between network points, especially on berms 1 and 2, and on the downstream slope; this situation is caused by uncontrolled vegetation growth (figures 5 and 6);

Figure 5 **Pillar with visibility blocked by vegetation on the downstream slope of the earth dam (author photo, 2025).**

- uncontrolled vegetation growth, particularly of trees, has created visibility problems during measurements on the crest;

- field research highlighted possible deteriorations on some pillars, benchmarks, and marks, a situation that caused difficulty in making microtriangulation observations with the required accuracy (*figure 4*);

Figure 6 **Pier with visibility blocked by vegetation on berm 2 of the downstream slope of the earth dam (photo author, 2025)**.

- the analysis conducted in the field indicated that, compared to the time of commissioning the geodetic network, approximately 40–50% of the sightlines between points are no longer visible in the field; in (*figure 7*), routes with visibility are shown with a solid line, and routes without visibility with a dashed line.

Within geodetic networks for monitoring movements at dams, maintaining direct visibility between benchmarks is essential for obtaining adequate measurement accuracy.

Figure 7 **Checking the sight lines on the dam crest and the downstream slope of the dam.**

Disturbing or even blocking the visibility paths of the geodetic network with various obstacles affects the functional state of the monitoring network. The most common obstacles at earth dams are uncontrolled vegetation growth, construction of buildings along the line of sight, and the placement of local structures and installations (electric poles, signs, panels, etc.). Such situations, present at the analyzed dams, can compromise the integrity of geodetic observations. Similar situations also arise from the lack of periodic maintenance and annual repair work necessary to maintain optimal conditions for monitoring displacements.

The traditional system for collecting topographic data currently includes a series of modern optical equipment for acquiring coordinates in the field. This system has the great advantage of obtaining very precise data. However, it has the disadvantage of requiring special viewing conditions, more time for data processing, and transmission to the beneficiary.

The modern GNSS system uses satellites to collect data, which it processes quickly in a relatively short time / or "in real time" and transmits to the recipient for decision-making. The disadvantage of this system is the relatively lower accuracy of the data obtained compared to the classical system.

Increasing the efficiency of the dam displacement monitoring system must be achieved at the current stage, considering the high frequency of climatic risk factors in recent times. At the same time, geodetic systems for monitoring dam displacements must be modernized through the use of state-of-the-art technologies and equipment.

Monitoring the behaviour of dams over time is mandatory according to regulations in the field, with the aim of early detection of potential stability problems.

In economically advanced countries, in recent years there has been a shift to using satellite technologies for topographic measurements, as well as the use of scanners and drones, etc. The most commonly used techniques are GNSS networks (Global Navigation Satellite Systems), LiDAR scanning technologies (TLS/ALS), and InSAR technology. These technologies have also begun to be used in Romania, starting with GNSS (Vele D. and Stoian I., 2014, Agape-Mereuta I. *et al.,* 2021, Chirilă C., et al., 2013, Luca M., and Agape-Mereuta I., 2022), and laser scanning (Negrilă A. and Onose D., 2013).

Dams of special importance should be monitored with a GNSS system, using ”robotic total stations” that continuously collect field data, process it, and transmit it in real time to the dam operation department.

A robotic total station (RTS) can continuously measure horizontal and vertical angles as well as distances using reflective prisms mounted on the structure. This allows the calculation of the spatial coordinates of the monitored points. Through automatic target recognition (ATR) technology, the instrument detects and tracks the target prisms without human intervention. The data is transmitted in real time to a control computer, where it is automatically processed, and displacements are calculated and analyzed almost instantly.

CONCLUSIONS

1. The current method of monitoring movements at dams is carried out using classical geodetic methods, namely the micro-triangulation method and the high-precision geometric leveling method. These methods have the advantage of high accuracy, but a significant disadvantage due to the long time required for data acquisition and processing.

2. The current state of geodetic networks for monitoring movements shows an advanced degree of wear at some dams and is equipped with technology outdated by current standards. Some of the geodetic points in the primary and support networks, as well as the altimetric and planimetric reference benchmarks, need to be rehabilitated structurally and also re-calibrated regarding their spatial coordinates.

3. A large part of the dams require an update of the topographic plans in correlation with the changes in the site. Additionally, the topographic plans must be digitized for their inclusion in tracking programs that use the GIS method to monitor the dam's operation process.

4. The need to make decisions in a short time in response to natural actions affecting the dam necessitates the modernization of the geodetic network through the use of modern technologies and equipment for monitoring movements, such as GNSS, particularly those that acquire and process data in real time.

5. Dams of particular importance, such as the Stanca-Costesti dam located on a border river, must be equipped with geodetic networks to monitor movements in real time, in order to prevent disasters by quickly acquiring and processing high-risk data.

ACKNOWLEGMENTS

Thanks to the Company "Complex Exploitation Stânca – Costești" for the help provided in carrying out research on the dam's geodetic network.

REFERENCES

Agapie (Mereuță) I., Luca M., 2020 - *Settlement monitoring of the earth dams by performance periodical topo-geodetic measurements*. J. PESD, vol. 14 nr. 1, pp. 99-109 edited by "Al. I. Cuza University of Iasi". doi.org/10.15551 /pesd2020141008.

Agapie (Mereuță) I., 2025 - *Contributions to monitoring the stability of earth masses through modern technologies.* Doctoral thesis. Technical University "Gh. Asachi" of Iasi, Romania. (in Romanian)

Agapie (Mereuță) I., Luca M., Gherasim P.M., Dominte V., 2021 - *Design of GNSS networks for monitoring earth dams deformations.* Journal of Applied Life Sciences and Environment Vol. LIV, Issue 4 (188) / 2021: 354-369.https://doi.org/10.46909/journalalse-2021-031

Chirilă C., Popia C.A., Smadici A.V., 2013 - *Testing coordinates of network control points for monitoring horizontal displacements of hydrotechnical constructions.* RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 15, 51-60.

Chirilă C., Căsăndrescu I.A., 2015 - *Study on application of microtrilateration geodetic network for monitoring of hydrotechnical constructions*. RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 19, pg. 41-48.

Corsetti M., Aranno P.J.V.D, Giancola F., Marsella M., Scifoni S., Sonnessa A., 2016 - *Satellite techniques: new perspectives for the monitoring of dams*, Engineering Geology for Society and Territory, vol. 5, p. 989-993.

Hidroconstrucţia S.A., 2000 - The 50th Anniversary of S.C. Hidroconstrucţia S.*A., 1950 – 2000*. Edit. Hidroconstrucţia, Bucureşti.

Luca M., Agapie (Mereuta) I., 2022 - *Research on the topology of earth dam by using GNSS technology*. RevCAD, Journal of Geodesy and Cadastre, no. 32, „1 December" University of Alba Iulia, Aeternitas Publishing House Alba Iulia, p. 59-68.

Luca M., Dominte (Croitoru) V., Marcoie N., Agapie (Mereuță) I., 2023 - *Verification of topographic drawing parameters of water outlets at earth dams.* RevCAD, no. 35, „1 December" University of Alba Iulia, Aeternitas Publishing House Alba Iulia, p. 15-24.

Maltese, A., *et al.* 2021 - *Toward a Comprehensive Dam Monitoring: On-Site and Remote-Retrieved Forcing Factors and Resulting Displacements (GNSS and PS–InSAR).* Remote Sensing, 13(8): 1543. DOI: 10.3390/rs13081543.

Negrilă A., Onose D., 2013 - *Dam monitoring using terrestrial laser scanning*. Journal RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 15, pg. 149-158.

Popovici A., 2002 - Dams for water reservoirs. Edit. Tehnică, Bucureşti. (in Romanian)

Scaioni, M., *et al.* 2018 - *Geodetic and Remote-Sensing Sensors for Dam Deformation Monitoring*. Sensors, 18(11): 3682. DOI: 10.3390/s18113682.

Vele D., Stoian I., 2014 - *GNSS technology application for the monitoring of Fantanele dam, in county Cluj*. J. RevCAD, Univ. "1 Decembrie 1918" din Alba Iulia, nr. 17, pg. 169-176.

Wang T., Perissin D., Rocca F., Liao M.S., 2010 - *Three Gorges Dam stability monitoring with time-series InSAR image analysis.* Science China, Earth Sciences, p. 1-13.

Zhang Y., Yang S., Liu J., Qiu D., Xiaoyan Luo X., Jianhong Fang J., 2018 - *Evaluation and analysis of dam operating status using one clock-synchronized dual-antenna receiver*. Hindawi, Journal of Sensors, Volume 2018, Article ID 9135630, 12 pages. https://doi.org/10.1155/2018/9135630

CAN REMOTE SENSING VEGETATION INDICES BE USED IN IDENTIFYING EROSION-PRONE AREAS?

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Abstract

In this study six vegetation indices were analyzed for Tutova Hills, years 2014-2023, highlighting spatio-temporal variations in the health of vegetation, soil moisture and surface temperatures, parameters directly correlated with land susceptibility to erosion.
Of the six indices, the one with the highest accuracy in detecting water stress and implicit areas with moisture deficit was NDII. This index correlates very well with high soil water content and the health of the vegetation, which makes it accurate in estimating the risk of erosion.
The conclusion is that such indices can be highly useful in predicting erosion-prone areas, because vegetation cover plays a major role in stabilizing soil and reducing erosion risk, being frequently integrated in erosion prediction models, from estimating RUSLE C-factor to temporal analyses or machine learning programs. Still, there are limitations related to data accuracy, but mostly to the need for an extensive field validation.

Keywords: vegetation indices, erosion, Landsat - 8 OLI/TIRS

Erosion-prone areas are regions that are highly susceptible to soil erosion, meaning the removal of the top layer of soil by water, wind or human activities. As a rule, these areas imply steep slopes, sparse vegetation cover, high rainfall or intense rainfall events, loose or loamy-sandy soils, poor land management (overgrazing, improper farming practices, hillsides cleared for agriculture etc.), semi-arid climate with strong winds, and little vegetation.

In short, erosion-prone areas are landscapes vulnerable to losing soil due to a combination of natural conditions and human influences.

Although erosion processes have been intensely studied in our study area (Tutova Hills - (Ioniță, 2000; Stângă, 2012; Niacșu, 2017; Niculiță, 2020), covering large surfaces in measuring soil erosion is time and energy consuming.

Our idea departed initially from a study regarding vegetation health but ended in including Remote Sensing (RS) and Geographical Information Systems (GIS) to identify and estimate erosion-prone areas.

Such an approach might prove helpful in the fast identification, followed by the validation on field of areas at risk, to finally propose and implement efficient measures of soil conservation and sustainable land management.

MATERIAL AND METHOD

Tutova Hills represent one of the regions of Romania characterized by a complex of interactions between natural environmental frailty and human-induced vulnerability, being among others highly exposed to erosion and land degradation. All the elements mentioned in introduction as defining erosion-prone areas are found alone or combined on large surfaces of the region. Most of the studies regarding erosion mention rates above the national means, reaching alarming values of up to 10 - 12 tons/ha of soil loss.

1. **Geospatial data processing**

The geospatial data used is available on online platforms. Computing the vegetation indices and biophysical parameters chosen for monitoring the vegetation state involved downloading multispectral satellite images of high accuracy, available for a longer period (in our case 2014-2023). LANDSAT-8 images have been downloaded using Google Earth Engine (https://earthengine.google.com).

The scenes used were recorded using three sensors: LANDSAT 7 TM, LANDSAT-8 ETM+ and LANDSAT-8 OLI. The scenes are divided according to the multispectral information intercepted in visible (RGB), near infrared (NIR), short-wave infrared (SWIR), thermal infrared (TIRS) and panchromatic (PAN). The images have

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a relatively fine spatial resolution (30 meters), with increased accuracy of the spectral details.

Each band offers unique characteristics depending on the wavelength and provides different results in mapping environmental components (differentiating bare soil from vegetation; evaluating vegetation development, plant vitality and health; differentiating biomass content, soil moisture, land surface temperature).

To have the most realistic results it is important to choose images in which the nebulosity is zero. The images were subjected to a sorting operation, in which a total of 334 images were selected from the total of 1050 downloaded. To reduce the time of downloading and processing, the R Studio tool library "landsat-util" was used.

Images have also a low temporal resolution, the satellite passing over the study area once every 16 days. After the sorting process, it was found that the number of images does not meet the minimum requirements to perform a coherent temporal analysis.

Thus, it was necessary to increase the nebulosity threshold by up to 50% for downloading the images. Using the Dineof algorithm from the sinkr R package (Beckers M. J., Rixen M., 2003), the data set was successfully reconstructed.

To have the same working format for all files, ArcGis Pro 3.0 was used for the automated extraction of vector and raster data according to the study area boundary. Data was reprojected using the arcpy module to avoid pixel distortion in the spectral bands and reprojected according to the Romanian coordinate system (Datum Dealul Piscului 1970 - Stereo 70 projection - EPSG 31700 code). The script was run as a batch process to have the same working structure for all files.

2. **Vegetation indices and biophysical indicators**

Spectral observations can easily help identifying the level of stress, health and radiative reflectance of vegetation. Simple numerical indicators, they reduce multispectral data by combining the values of different spectral bands to a single variable, for the prediction and evaluation of vegetation characteristics (Bannari *et al*., 1995).

Six spectral indices recognized for the increased degree of accuracy in monitoring vegetation and soil water and thermal conditions were used and applied, namely: Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Infrared Index (NDII), Normalized Difference Moisture Index (NDMI), Vegetation Health Index (VHI) and Land Surface Temperature (LST) (IDB, 2023; Kai *et al*., 2023). Formulas for all indices are available at https://www.indexdatabase.de/db/i.php.

The automated calculation of the indices was performed with the help of ArcGis Pro 3.0 and the Python workflow for the multiannual period, the average annual warm season and multiannual warm season.

NDVI is a numerical indicator of the amount and vigor of vegetation, effective for agricultural lands, dense forest, semi-arid areas. It can be used in vegetation monitoring applications such as evaluating crop growth patterns, biomass quantity, photosynthetic activity, and the percentage of land cover with vegetation. NDVI values range between -1 and 1; with negative ones indicating clouds or water, and positive values approaching 0 indicating areas not covered by vegetation.

NDWI is used to detect water bodies, with values >0.3 for aquatic surfaces and between -1 and 0 for vegetated surfaces. It is designed to delimit the boundaries of aquatic surfaces and the distribution of suspended sediments.

NDII is used to extract impervious surfaces, being used in drought monitoring and the assessment of agricultural land and forest health.

VHI estimates the health and condition of vegetation and the impact of drought on agriculture, being a comprehensive indicator of vegetation vigor or stress. It is a combination of the Vegetation Condition Index (VCI) and the Thermal Condition Index (TCI). The two sub-indices reflect the moisture and thermal conditions, respectively.

NDMI is useful in monitoring soil moisture and vegetation, having wide applications in drought monitoring, water management in agriculture, forest fire risk assessment and climate change prediction.

LST represents the temperature of the land surface, helping in delineating vegetation canopies, soil and built-up areas, and is influenced by factors such as solar radiation, land cover, vegetation density, soil moisture and atmospheric conditions. It is a critical parameter in the assessment of surface energy balance and drought monitoring.

RESULTS AND DISCUSSIONS

Analysis of vegetation indices and land surface temperature (LST) for the Tutova Hills (2014-2023) reveals consistent spatial and temporal patterns influenced by precipitation, temperature, humidity and solar radiation. Across all indices, a clear contrast emerges between the northwestern (NW) and central-northern (CN) sectors, characterized by dense, moisture-rich vegetation, and the southeastern (SE) and central-southern (CS) sectors, where vegetation is sparse and soil vulnerability is high.

High NDVI values (0.65–>0.70) dominate the NW and CN areas, corresponding to forests and meadows above 300 m altitude with limited agricultural use. Low values (-0.45 - 0.50) occur in the CS and SE sectors, particularly on SE and SW slopes, reflecting intensive agriculture, poor vegetation cover, and exposure to erosion.

NDWI (*fig. 1*) and NDII show similar spatial patterns, with maximum values in the NW and CN regions, indicating high vegetation water content, while SE and S areas exhibit low values, consistent with deforested slopes and water stress.

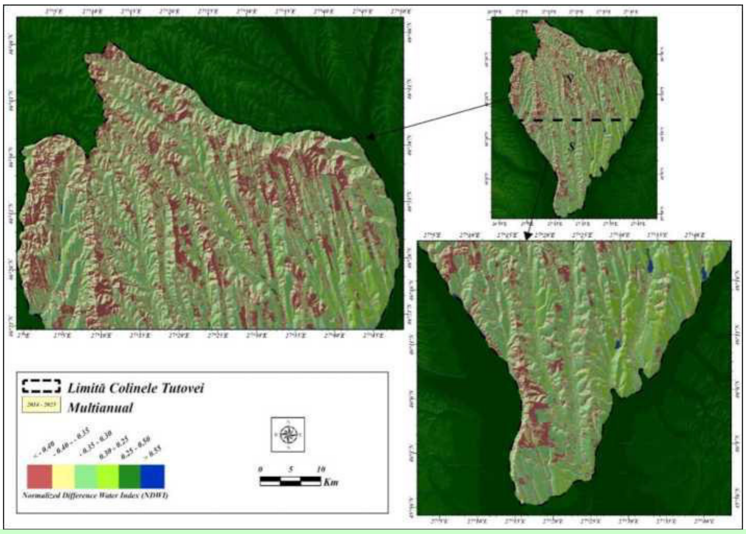

Figure 1 **Spatial distribution of the NDWI mean multiannual values**

NDMI and VHI confirm these patterns: NW sectors maintain high moisture and vegetation health, whereas SE areas show water stress, vegetation degradation, and elevated risk of crop disease.

The LST index highlights thermal contrasts, with high temperatures (24–26 °C) on SE slopes and degraded lands versus lower values (13-16 °C) in NW vegetated zones, reflecting the moderating effect of denser vegetation.

During the summer season, spatial variability is more pronounced. Multiannual NDVI peaks above 0.79 in the NW, indicating dense vegetation, and drops below 0.45 in the SE, where steep slopes, geomorphology, and land use exacerbate water stress and erosion. NDWI highlights soil and vegetation moisture deficits, particularly in interfluves with rapid runoff, while valleys retain higher humidity.

NDII confirms low water availability in southern sectors due to high temperatures, low rainfall and higher values of evapotranspiration. NDMI further identifies areas of water stress and erosion risk, and VHI captures the combined effect of thermal and hydric stress on vegetation health. LST (*fig. 2*) shows extreme surface heating in the SE (33-35°C), whereas the north experiences cooler conditions (<23°C), reinforcing the link between vegetation cover, soil protection, and thermal regulation.

Temporal analysis of annual summer values over 2014-2023 reflects the impact of climatic variability on vegetation and soil moisture. NDVI had values above average during 2014-2016, supported by moderate summer precipitation, while drought and high temperatures in 2017–2018 caused sharp declines in vegetation cover, particularly in central and southern areas.

The period 2021–2023 showed alternating years of stress and recovery, with 2021 marked by prolonged drought and thermal stress, followed by improved vegetation growth in 2022–2023. NDWI and NDII mirrored these trends, reflecting moisture availability and soil vulnerability, whereas NDMI highlighted vegetation recovery and erosion-prone areas.

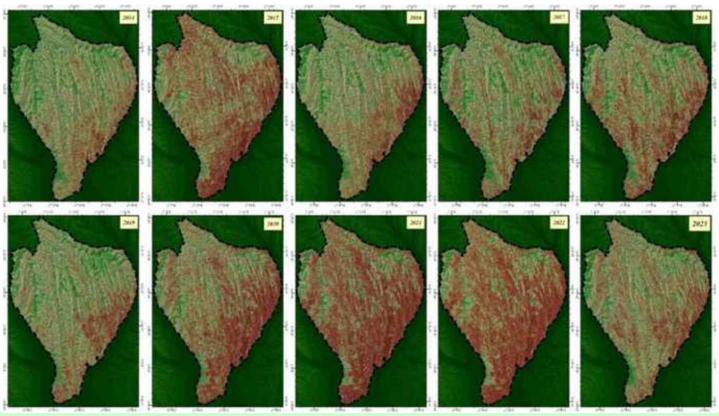

Figure 2 **Spatial distribution of mean annual values in the summer season of LST**

VHI integrated vegetation and thermal stress patterns, with high values in favorable years (2014 - 2016) and low values during drought episodes (2017, 2020–2022). LST captured thermal extremes (30–36 °C in the hottest years) and, when combined with spectral indices, provided a comprehensive view of vegetation health, water stress, and soil vulnerability, despite some limitations due to atmospheric conditions.

Overall, the integrated analysis of NDVI, NDWI, NDII, NDMI, VHI, and LST demonstrates that the NW and CN sectors of the Tutova Hills maintain denser, healthier and moisture-rich vegetation, while the SE and CS areas are prone to water stress, vegetation degradation, and soil erosion, particularly during dry, high-temperature summers. These findings emphasize the need for targeted water and vegetation management strategies to mitigate soil degradation and support sustainable land use.

CONCLUSIONS

In this study, six vegetation indices were analyzed for the period 2014 - 2023, highlighting spatio-temporal variations in the health of vegetation, soil moisture and surface temperatures, parameters directly correlated with land susceptibility to erosion.

Of the six indices, the one with the highest accuracy in detecting water stress and implicitly areas with moisture deficit was NDII. This index correlates very well with high soil water content and the health of the vegetation, which makes it extremely accurate in estimating the risk of soil erosion.

Multiannual averages provided an overall mosaic image for the study period. The data obtained correlates with areas affected by erosion, validated by literature data. The accuracy of this dataset for general assessments is vast but limited for spatial detail.

The conclusion is that such indices can be highly useful in predicting erosion-prone areas because vegetation cover plays a major role in stabilizing soil and reducing erosion risk.

Still, there are limitations related to data accuracy, but mostly to the need for an extensive field validation or comparison between the areas identified as prone with existing inventories of eroded soils, landslides or other degradation processes.

REFERENCES

Bannari A., Morin D., Bonn F., Huete A. R., 1995 - *A review of vegetation indices*. Remote Sensing Reviews, 13(1–2), 95–120. https://doi.org/10.1080/02757259509532298.

Beckers J. M., Rixen M., 2003 - *EOF Calculations and Data Filling from Incomplete Oceanographic Datasets*. Journal of Atmospheric and Oceanic Technology (JTECH), 1839–1856.

IDB, 2023 - *List of Available Indices*. Available online: https://www.indexdatabase.de/db/i.php (accessed on 18 Oct. 2025).

Ioniță I., 2000 - *Geomorfologie aplicată (procese de degradare a versanților din zonele deluroase)*. Editura Universității Alexandru Ioan Cuza din Iași.

Kai et al., 2025 - *A global systematic review of the remote sensing vegetation indices*, Int. J. Appl. Earth Obs. and Geoinf., 139, https://doi.org/10.1016/j.jag.2025.104560.

Niacșu L., 2017 - *Land degradation and soil conservation within the Moldavian Plateau*. Habilitation Thesis. Alexandru Ioan Cuza University of Iași.

Niculiță M., 2020 - *Evaluarea activității alunecărilor de teren din Podișul Moldovei în holocen și antropocen: element fundamental pentru evaluarea hazardului alunecărilor de teren în contextul schimbărilor climatice (LAHAMP). Raport de cercetare*. Editura Tehnopress, Iași.

Stângă C.I., 2012 - *Bazinul Tutovei. Riscuri naturale și vulnerabilitatea teritoriului*. Editura Universităţii “Alexandru Ioan Cuza” Iaşi.

THE INFLUENCE OF TREATMENTS WITH VARIOUS PHYTOSANITARY PRODUCTS (FUNGICIDES) ON THE ATTACK OF SOME PHYTOPATHOGENIC FUNGI ON WHEAT HARVEST – GLOSA VARIETY - IN 2024 PEDOCLIMATIC CONDITIONS OF THE EASTERN BARAGAN

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Abstract

This study aims at monitoring the dynamics of the occurrence and evolution of the attack of some pathogens to Glosa Romanian wheat variety, among which we mention: *Puccinia recondita* f. sp. tritici (sin. *Puccinia triticina*) which produces wheat's brown rust and *Septoria* sp. which produces wheat's brown leaf spotting (septoriosis). The influence of applying some fungicides on the harvest, as compared to the untreated control variant, has been monitored. One experiment with 7 variants (6 variants with phytosanitary treatment, plus one control variant not treated) was taken into consideration for this study, for which the following phytosanitary products were used, as follows: CYDELI TOP (**125** g/l difenoconazole, 15 g/l cyflufenamid)**,** EVALIA (250g/l azoxystrobin) and MYSTIC GOLD (250 g/l tebuconazole). The treatment variants were the following: V1 – CYDELI TOP 0.5 L/HA - treatment applied at straw's extension + 1 treatment at the filling of a wheat grain, V2--CYDELI TOP -0.5 L/HA - treatment applied in booting phase, V3 - EVALIA 1.0 L/HA - treatment applied at straw's extension + 1 treatment at the filling of a wheat grain; V4 - EVALIA 1.0 L/HA - treatment applied in booting phase, V5 - MYSTIC GOLD 1.0 L/HA - treatment applied at straw's extension + 1 treatment at the filling of a wheat grain, V6- MYSTIC GOLD 1.0 L/HA - treatment applied in booting phase and V7 - Control variant not treated. The experiment was placed in Latin square, the 7 variants being placed in 7 repetitions. The year 2024 was a year with a relatively wet spring and early summer for the area where the experiment was performed. The experiment was established after corn. The climatic conditions were favorable to the attacks of some wheat pathogens, especially those of *Septoria* sp. genus. The yields of the variants were as follows: V1 – 8.565 to/ha, V2 – 8.421 to/ha, V3- 8.579 to/ha, V4 – 8.351 to/ha, V5 8.584 to/ha, V6 – 8.345 to/ha and V7 (control variant not treated) – 7.587 to/ha.

Keywords: *Puccinia, Septoria*, latin square experimental design

The wheat, *Triticum aestivum,* is attacked by many pathogenic agents, such as: mildew - *Blumeria graminis* f.sp. *tritici*, brown rust - *Puccinia recondita* f. sp. *tritici*, brown leaf spotting (septoriosis) - *Septoria tritici*, *Septoria nodorum*, stem's fusariosis and ear's rot *Giberella zeae*, *Giberella avenacea* (Iacob Viorica, Hatman, M., Ulea, E., Puiu, I. 1998).

The first half of 2024 was, for wheat, relatively favorable in terms of climatic conditions, somehow similar to the first half of 2023. Average temperatures were slightly higher than the same period in 2023. In February, the average temperature was 7ºC, rainfall totaled 11 l/m² and the average relative humidity of the air was 70%. In March, the average temperature was 8.5ºC, the average relative humidity of the air was 72% and rainfall totaled 30 l/m². In April, the average temperature was 14.5ºC, rainfall totaled 41 l/m² and the average relative humidity of the air was 56%. In May, the average temperature recorded was 17ºC, rainfall totaled 37 l/m² and the average relative humidity of the air was 57.5%. In June, the average temperature recorded was 25ºC, rainfall totaled 42 l/m^2 and the average relative air humidity was 48.7%. Under these conditions, the presence of the Septoria sp. fungus, which causes, in wheat, diseases known as brown leaf spots (septorioses), made itself felt. The phytopathogenic fungus *Puccinia recondita* f. sp. *tritici* showed a weaker presence than the previously mentioned one. The attack of fungi of the genus *Gibberella* was practically absent, probably due to the fact that June came with high temperatures and an air humidity of only 48%.

The experiment received a watering amounting to 800m^2 in May 2024, to complete the amount of water coming from rainfall. This watering contributed substantially to achieving a good wheat yield, especially since the month of June proved to be poorer in precipitation than April and May of 2023.

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Table 1

The results of the experiment with fungicide products (6 variants of treatment + 1 untreated control variant) in what concerns the attack (D.A.%) of *Septoria* sp. fungus ("flag" leaf and the next leaf). The observations had been made on 17th June 2024

	"Flag" leaf			Second leaf		
Variant	D.A%	Difference as compared to the control variant	Significance	D.A.%	Difference as compared to the control variant	Significance
V1-CYDELI TOP 0.5 L/HA, 1 treatment applied at straw's extension + 1 treatment applied at wheat grain filling	19.20	29.72	**	66.07	24.63	**
V2--CYDELI TOP 0.5 L/HA, 1 treatment applied in booting phase	16.56	32.36	**	70.07	20.63	**
V3--EVALIA 1.0 L/HA, 1 treatment applied at straw's extension + 1 treatment applied at wheat grain filling	16.30	32.62	**	61.43	29.27	**
V4-EVALIA 1.0 L/HA, 1 treatment applied in booting phase	20.61	28.31	**	64.80	25.90	**
V5-MYSTIC GOLD 1.0 L/HA, 1 treatment applied at straw's extension +1 treatment applied at wheat grain filling	19.49	29.43	**	70.30	20.40	**
V6-MYSTIC GOLD 1.0 L/HA, 1 treatment applied in booting phase	19.64	29.28	**	66.36	24.34	**
V7- Untreated control variant	48.92	-		90.70	_	

LD D.A. % for the "flag" leaf
LD 5% = 7.73%
LD 1% = 10.40%

LD D.A. % for the second leaf
LD 5% = 12.52%
LD 1% = 16.90%

Table 2

The results of the experiment with fungicide products (6 variants of treatment + 1 untreated control variant) in what concerns the yield (t/ha) obtained at the treated variants, as compared to the untreated control variant

Variant	Yield (t/ha)	Difference as compared to the control variant (t/ha)	Significance
V1-CYDELI TOP 0.5 L/HA, 1 treatment applied at straw's extension +1 treatment applied at wheat grain filling	8,5650	0.978	**
V2-CYDELI TOP -0.5 L/HA, 1 treatment applied in booting phase	8,4210	0.834	**
V3-EVALIA 1.0 L/HA, 1 treatment applied at straw's extension +1 treatment applied at wheat grain filling	8,5790	0.992	**
V4--EVALIA 1.0 L/HA, 1 treatment applied in booting phase	8,3510	0.764	**
V5-MYSTIC GOLD 1.0 L/HA, 1 treatment applied at straw's extension +1 treatment applied at wheat grain filling	8,5840	0.997	**
V6-MYSTIC GOLD 1.0 L/HA, 1 treatment applied in booting phase	8,3450	0.758	**
V7- Untreated control variant	7,5870	-	-

LD 5% = 0.4284 to/ha
LD 1% = 0.5775 to/ha

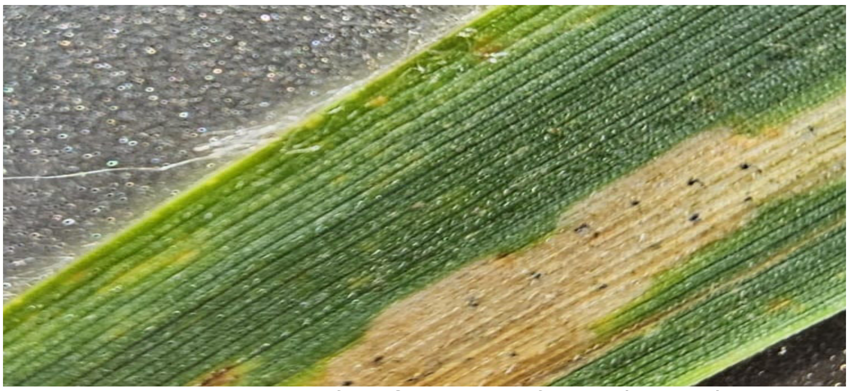

Figure 1 **Pycnidia of the Septoria sp. fungus (original).**

Figure 2 **- Aspects from the experimental field (original).**

MATERIAL AND METHOD

One experiment with 7 study variants had been conceived for performing the observations. This experiment comprised 6 phytosanitary treatment variants (fungicide products containing various active substances) and one untreated control variant. The variants of the experiment were the following:

- V1: CYDELI TOP 0.5 L/HA, 1 treatment applied at straw's extension + 1 treatment applied at wheat grain filling;
- V2: CYDELI TOP 0.5 L/HA, 1 treatment applied in booting phase;
- V3: EVALIA 1.0 L/HA, 1 treatment applied at straw's extension + 1 treatment applied at wheat grain filling;
- V4: EVALIA 1.0 L/HA, 1 treatment applied in booting phase;
- V5: MYSTIC GOLD 1.0 L/HA, 1 treatment applied at straw's extension +1 treatment applied at wheat grain filling;
- V6: MYSTIC GOLD 1.0 L/HA, 1 treatment applied in booting phase;
- V7: untreated control sample.

The experiment was placed in Latin square; the 7 variants were placed in 7 repetitions. Each experimental plot had an area of 12 m^2 (6 x 2m). The total number of experimental plots was 49. The surface of an experimental variant was of 12 m^2 x 7 repetitions = 84 m^2. The total area of the experiment was of 84 m^2 x 7 = 588 m^2.

The treatments had been performed manually, with a "Vermorel" type of equipment. Weed control was achieved with the help of Mustang herbicide (6.25 g / l florasulam + 300 g / l 2.4-D EHE acid) at a dosage of 0.6 l / ha applied, separately, with the Vermorel. The experiment has monitored the effectiveness of the above-mentioned phytosanitary products in relation to their price. The efficiency and, respectively, the profitability of applying a single treatment to a product with a fungicidal effect or two phytosanitary treatments with a product with a fungicidal effect were also monitored during wheat's vegetation period. It was taken into account that the spring of 2024 was relatively rainy

The assessment of the attack's frequency (F%), of attack's intensity (I%) and respectively of the degree of attack (D.A.%) was done separately, on each and every experimental plot, being analyzed 10 plants / experimental plot. The degree of affectation (attack intensity, I%) of the last two leaves was assessed, especially of the "flag" leaf which has the greatest contribution to the ear's production at strawy cereals. The phytosanitary analyses on the plants' samples had been done with the help of the stereo-microscope and of the optic microscope at the laboratory of Braila's Phytosanitary Office – National Phytosanitary Authority, institution subordinated to the Ministry of Agriculture and Rural Development. These analyses have revealed in the analyzed samples the presence of *Septoria* sp. fungus which produces in wheat the disease known as septoriosis. Other pathogenic agents specific to wheat (*Blumeria sp. Puccinia sp.*) were signaled in the climatic conditions of the first half of the year 2024, but in a smaller percentage.

For assessing the yield of each variant under study, samples of wheat grains from each experimental plot, 5 samples each / plot, had been analyzed by spot check. Each sample contained 20 plants, so 100 plants had been taken from each experimental plot, for which the yield was weighted manually. The delimitation of each sample was done with a metric frame with an area of 0.25 m2 (0.5/0.5m). The average of the samples from the experimental plots was used for calculating the yield of each experimental parcel. The statistic interpretation was executed with the help of limit differences (LD %) (Săulescu N).

The used variety, Glosa, is a Romanian variety created by the Fundulea National Agricultural Research & Development Institute. Glosa variety is an early variety. It has good resistance to falling, resistance to wintering, drought and heat and it has a good resistance at sprouting into ear. It has average resistance to brown rust and is resistant to mildew and to the actual strains of yellow rust (Fundulea Seeds Company 2021).

The assessment of pest attack can be done with the help of the following values (Methods of Prognosis and Warning 1980):

- Frequency of attack (F%);
- Intensity of attack (I %);

- Degree of attack (D.A %).

- The frequency of attack represents the relative value of the number of plants or organs of the plant under attack (n) reported to the number of observed plants or organs (N). The value of the frequency is established by direct observation on a number of plants or organs, according to the case and to the conditions, existing different methods of sample taking and for performing the observations. In the case of our observations, for the foliar diseases, the number of attacked plant organs out of the total of observed plant organs (leaves) was taken into consideration, being thus established the attack's frequency expressed in percentages %. In the case of blights (*Ustilago* sp), it is used the number of wheat's attacked ears, as reported to the total number of observed ears. The frequency is calculated with the formula F%= nx100/N.

- The intensity of the attack represents the degree or percentage whereby a plant or a plant's organ is attacked and how much from the surface of the plant or of the organ analyzed (leaf, fruit) is covered by the disease under study.

The assessment of the surface under attack is done with the naked eye or with the magnifying glass, assessing the percentage occupied by spots or burns caused by the pathogenic agent. The affectation percentages can be noted or grades can be given for each plant or organ attacked by the disease and/or by the pest. The usage of grades can make easier data summarization in a great extent. It can be used a scale with 6 degrees of intensity, as follows:

- Grade 0 no attack
- Grade 1 attack between 1 and 3%
- Grade 2 attack between 3 and 10%
- Grade 3 attack between 11 and 25%
- Grade 4 attack between 26 and 50%
- Grade 5 attack between 51 and 75%
- Grade 6 attack between 76 and 100%

After data's summarization, the attack's intensity is determined by the formula:

$$I\% = \frac{\Sigma (i \times f)}{n}$$

Where:

I% – attack's intensity (in %);

i – intensity according to the grade given to the organ or plant under attack;

f – number of cases (plants, organs) attacked;

n – number of plants attacked.

Grades from 1 to 6, separately, to the "flag" leaf and to the next leaf situated beneath it, had been awarded in our experiment.

- The degree of attack is the expression of the extension of the severity of the attack onto the crop or onto the total number of plants on which we perform the observations. The following relation gives the value expression of D.A.:

$$D.A\ (\%). = \frac{F \times I}{100}$$

In most cases, there is a negative correlation between the degree of attack of a pathogenic agent or pest and the quantitative and/or qualitative yield level.

RESULTS AND DISCUSSIONS

The first half of 2024 was more favorable to the onset of the attack of the wheat-specific pathogen complex. February, March, April and May months had relatively similar rainfall compared to 2023. In the autumn of 2023, there was relatively sufficient rainfall. Under these conditions, the plants emerged in time to successfully survive the winter of 2023-2024. This winter was relatively warmer than the average of previous years. The crop was irrigated in the spring of 2024 with 800 m^2 of water per ha.

Regarding the dynamics of the occurrence of pathogen attacks on wheat, we mention that the pathogen that appeared in the experiment in 2024 was the *Septoria* sp. fungus which produces wheat septoriosis. Besides *Septoria* sp., symptoms produced by *Puccinia recondita* f. sp. *tritici* were also accidentally observed.

If we analyze the data in table 1, we notice that the degree of attack of the pathogens monitored, on each treatment variant, was as follows:

-V1 determined a degree of attack (D.A.%) of the *Septoria* sp fungus % on the "flag" leaf of 19.20% and 66.07% on the second leaf, therefore lower by 29.72% and respectively by 24.63% compared to the untreated control variant (V7).

-V2 determined a degree of attack (D.A.%) of the *Septoria* sp fungus of 16.56% on the "flag" leaf and 70.07% on the second leaf, therefore lower by 32.36% and respectively by 20.63% compared to the untreated control variant (V7).

-V3 determined a degree of attack (D.A.%) of the *Septoria* sp fungus. of 16.30% on the "flag" leaf and 61.43% on the second leaf, therefore lower by 32.62% and respectively by 29.27% compared to the untreated control variant (V7).

-V4 determined a degree of attack (D.A.%) of the fungus *Septoria* sp of 20.61% on the "flag" leaf and 64.80% on the second leaf, therefore lower by 28.31% and respectively by 25.90% compared to the untreated control variant (V7).

-V5 presented a degree of attack (D.A.%) of the fungus *Septoria* sp. of 19.49% on the "flag" leaf and 70.30% on the second leaf, therefore lower by 29.43% and respectively by 20.40% compared to the untreated control variant (V7).

-V6 presented a degree of attack (D.A.%) of the fungus *Septoria* sp. of 19.64% on the "flag" leaf and 66.36% on the second leaf, therefore lower by 29.28% and respectively by 24.34% compared to the untreated control variant (V7).

-V7 The untreated control presented a degree of attack (D.A.%) of the fungus *Septoria* sp. of 48.92% on the "standard" leaf and 90.70% on the second leaf

All differences in terms of attack degree (D.A.%) are statistically assured, according to table 1.

From the analysis of table 2, the yield differences compared to the untreated control V7 can also be observed as follows:

-V1 achieved a yield of 8.5650 to/ha, therefore with 0.978 to/ha lower than the control variant.

-V2 achieved a yield of 8.4210 to/ha, therefore with 0.834 to/ha higher than the control variant.

-V3 achieved a yield of 8.5790 to/ha, therefore with 0.992 to/ha higher than the control variant.

-V4 achieved a yield of 8.3510 to/ha, therefore with 0.764 to/ha lower than the control variant.

-V5 achieved a yield of 8.5840 to/ha, therefore with 0.997 to/ha lower than the control variant.

-V6 achieved a yield of 8.3450 to/ha, therefore with 0.758 to/ha higher than the control variant.

-V7: The untreated control variant achieved a yield of 7.5870 to/ha.

CONCLUSIONS

The observations made in the summer of 2024 on the experiment with the Romanian wheat-variety Glosa, led to the following conclusions and recommendations:

1. The attacks of some pathogens were relatively high in 2024. Among them, *Septoria* sp appeared mainly, which causes in wheat diseases known as septoriosis. The degree of attack of this phytopathogenic fungus, both on the flag leaf and on the second leaf, had significantly higher values compared to the untreated control.

2. For good protection of the wheat crop, when using the Romanian variety Glosa, we recommend performing, especially in years with moderately humid and cool springs, a single treatment with fungicidal products, applied in the booting - flowering phase of the wheat plants.

3. During the years with springs with rainfall, higher atmospheric humidity and lower temperatures, we recommend performing two treatments with plant protection products with fungicidal effect.

4. The prices of products (2025) with fungicidal effect used in 2024 are as follows:

– Cidely Top costs approximately 270 lei/ha, i.e. approximately 54 €/l. Applying 0.5 l/ha means 135 lei/ha (27 €/l/ha)
– Evalia costs approximately 240 lei /ha, i.e. 48 €/1/ha. Applying 1 l/ha means 240/lei/ha (47.34 €/1/ha).
– Mystic Gold costs approximately 110 lei/l (22 €/1/ha). Applying 1 l/ha means 110/lei/ha (22 €/1/ha).

In variant V1, 2 treatments with the product Cydeli Top 0.5 l/ha were applied, meaning the total cost of the phytosanitary product/ha was 270 lei/ha (55 €/ha)

In variant V2, 1 treatment with the product Cydeli Top 0.5 l/ha was applied, meaning the total cost of the phytosanitary product/ha was 135 lei/ha (27 €/ha).

In variant V3, 2 treatments with the product Evalia 1l/ha were applied, meaning the total cost of the Evalia fungicide product was 480 lei/ha (96 €/ha)

In variant V4, 1 treatment with the product Evalia 1l/ha was applied, meaning the total cost of the fungicide product/ha was 240 lei/ha (48 €/ha).

In variant V5, 2 treatments with the Mystic Gold product 1l/ha were applied, meaning the total cost of the fungicide product was lei/ha 220 lei /ha (44€/ha).

In variant V6, 1 treatment with the Mystic Gold product 1l/ha was applied, meaning the total cost of the fungicide product/ha was 110 lei/ha (22€/ha).

The yield differences, expressed in value (lei) compared to the untreated control (V7), were the following:

-V1: The yield difference was 0.978 to/ha, amounting to 782 lei/ha (156.4 €/ha);

-V2: The yield difference was 0.834 to/ha, amounting 667 lei/ha lei/ha (133.4€/ha);

-V3: The yield difference was 0.992 to/ha, amounting 794 lei/ha (158.8€/ha);

-V4: The yield difference was 0.764 to/ha, amounting 611 lei/ha (122.2€/ha);

-V5: The yield difference was 0.997 to/ha, amounting 798 lei/ha (159.6€/ha);

-V6: The yield difference was 0.758 to/ha, amounting 606 lei/ha (121.2€/ha);

-V7 The yield of the untreated control was 7.587 to/ha.

We emphasize that all variants presented statistical assurance.

5. From the analysis of economic profitability, in the climatic conditions of 2024, all variants with treatment achieved economically profitable yields, of course, some of them offering a better economic output. Under these conditions, we recommend, in years with relatively wet and cool springs, performing a single treatment, in the booting -flowering vegetation phase of the wheat, with a treatment with a more efficient fungicidal product, such as two of those used in this experiment: Cydeli Top (125 g/l difenoconazole, 15 g/l cyflufenamid) – if it will also be approved for wheat in Romania, and Evalia (250 g/l azoxystrobin). In the years with springs where precipitation falls above the multi-annual average of the area and temperatures are lower than usual, we recommend performing two treatments with more efficient fungicidal products.

6. In the years with dry and warm winters and springs, a single treatment with cheaper fungicidal products such as those based only on tebuconazole can be applied to wheat. Here we mention: ARMADA (250 g/l tebuconazole) at a dosage of 0.5 l/ha, ORIUS 25 EW (SALVATOR 25 EW - the second commercial name) 0.5 l/ha, MYSTIC GOLD -1.0 l/ha according to the Pest-Expert website of the National Phytosanitary Authority, a structure subordinated to the Ministry of Agriculture and Rural Development of Romania.

7. The Cydeli Top product is not approved for wheat, being used in this experiment exclusively for experimental purposes. It is approved for some vegetable species (tomatoes, peppers, eggplants, cucumbers, and zucchini) as well as for strawberries at a dosage of 1l/ha for the prevention and control of specific pathogens such as the genera of phytopathogenic fungi: *Alternaria, Colletotrichum, Cladosporium,* etc. It is a relatively expensive product. In wheat, under the climatic conditions of the first half of 2024, it proved effective at a dosage of only 0.5 l/la applied in a single treatment in the booting stage. Of course, it remains at the discretion of the manufacturer (Syngenta Company) whether it wishes to extend its approval in Romania to wheat.

8. The price of wheat, quoted for export, was, in Romania, on 13th August 2025, approximately 0.8 lei/kg - approximately 160€/to (Cereal Exchange 2025).

9. The average exchange rate leu/€, in the months of April, May and June of 2025, was 5.0626 lei/€1, according to the website of the National Bank of Romania.

REFERENCES

Iacob Viorica, Hatman, M., Ulea, E., Puiu, I., 1998 – "Ion Ionescu de la Brad" Publishing House, *Agricultural phytopathology,* p. 16-18, 26-28, 31-33.

Săulescu, N. 1967 - *Experiment field*, Agro-Silvică (Agro–Sylvan) Publishing House, Bucharest, p. 217, 311.

Velichi, E. 2012 - *General and special phytopathology*, Universitară (University) Publishing House, Bucharest, p. 136-137.

*** *National Bank of Romania* 2025 (web page).

******* *Cereal Exchange 2025* (web page)

*** *Fundulea Seeds Company 2021* (web page).

*** 1980 *Methods of Prognosis and Warning*, 1980 M.A.I.A., Bucharest, p. 7-9.

*** *Pest – Expert website*, the National Phytosanitary Authority, Ministry of Agriculture and Rural Development.

THE INFLUENCE OF TREATMENTS WITH VARIOUS PHYTOSANITARY PRODUCTS (FUNGICIDES) ON THE ATTACK OF SOME PHYTOPATHOGENIC FUNGI ON BARLEY HARVEST, TEPEE VARIETY, IN 2024 PEDOCLIMATIC CONDITIONS OF THE EASTERN BARAGAN

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Abstract

This study aims at monitoring the dynamics of the occurrence and evolution of the attack of some pathogens to barley, among which we mention: mildew (*Blumeria graminis* f.sp. *hordei*), leaf stripe and spotting of the leaves produced by fungi of *Pyrenophora* genus and barley's rust (*Puccinia hordei*). Also, the influence of applying these fungicides on the harvest, as well as of the number of treatments/ha as compared to the untreated control variant, has been monitored. For this study, an experiment with 5 treatment variants was created (4 variants with phytosanitary treatment, plus a control variant not treated), being used the following phytosanitary products: ORTIVA TOP (200 g/l azoxystrobin+ 125 g/l difenoconazole) and MYSTIC GOLD (tebuconazole 250 g/l). The treatment variants were the following: V1- ORTIVA TOP 0.5 L/HA – 1 treatment applied at straw's extension + 1 treatment applied at barley grain filling, V2 – ORTIVA TOP 0.5 L/HA – treatment applied at ear release phase, V3- MYSTIC GOLD 1.0 L/HA - treatment applied at straw's extension + 1 treatment applied at barley grain filling, V4 - MYSTIC GOLD 1.0 L/HA - treatment applied at ear release phase and V5 – Control variant not treated. The experiment was placed in Latin square, the 5 variants being placed in 5 repetitions. The year 2024 was a year with a relatively wet spring and early summer. The climatic conditions were favorable to the attacks of barley-specific pathogens. The experiment was not irrigated, being established after corn. Among the pathogens followed, attacks produced by fungi of *Pyrenophora* sp. genus were observed, fungi producing in barley diseases known as spotting and leaf stripes. This led to obtaining a relatively different yield for the variants studied. Between the untreated control variant and some of the variants that were treated with fungicides, there were significant yield differences in the climatic conditions of 2024. The variant's yields were: V1- 7.951 to/ha, V2– 8.047 to/ha, V3-8.058 to/ha, V4–8.211 to/ha and V5–7.221 to/ha.

Keywords: *Pyrenophora, Blumeria,* Latin square experimental design

Hordeum vulgare barley is attacked by many pathogenic agents, such as: mildew - *Blumeria graminis* f.sp. *hordei*, leaf stripe, various spotting - *Pyrenophora sp*, rust - *Puccinia hordei* (Iacob Viorica, Hatman, M., Ulea, E., Puiu, I. 1998). The first half of 2024 was favorable for obtaining good barley yields. Average temperatures were slightly higher than the same period in 2023. For example, in February, the average temperature was 7ºC, rainfall totaled 11 l/m² and the average relative humidity was 70%. In March, the average temperature was 8.5ºC, average relative humidity was 72% and rainfall totaled 30 l/m². In April, the average temperature was 14.5ºC, rainfall totaled 41 l/m² and the average relative humidity was 56%. In May, the average temperature recorded was 17ºC, rainfall totaled 37l/m² and the average relative humidity was 57.5%. Barley emergence in the fall of 2023 was relatively good. The winter between 2023 and 2024 was relatively warm, like the previous winter, which allowed the plants not to freeze, barley being a species more sensitive to cold than wheat. The rainfall that fell between February and May in 2024 was relatively equal to that of the previous year. This led to a good barley production compared to the production obtained in the previous year. Among the pathogens that appeared, we mention the fungus *Pyrenophora* sp. which produces, in barley, diseases known under different names: stripe, spotting, etc. This pathogen attacks barley crops every year, at attack intensities that vary from one year to another.

Other pathogens, specific to barley, had a reduced presence - for example, mildew - *Blumeria graminis* f.sp. *hordei* or even very low, practically accidental presence – for example, rust - *Puccinia hordei*.

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Figure1 **Attack of *Pyrenophora* sp. Fungi on the date of 4th April 2024 (original).**

Figure 2 **Aspects from the experimental field (original)**

Table 1

The results of the experiment with fungicide products (4 variants of treatment + 1 untreated control variant) in what concerns the attack (D.A. %) of Pyrenophora sp. fungus on barley ("flag" leaf and the next leaf). The observations were performed on the date of 20th May 2024

	The "flag" leaf			The second leaf		
Variant	D.A%	Difference as compared to the control variant	Significance	D.A%	Difference as compared to the control variant	Significance
V1-ORTIVA TOP 0.5 L/HA at straw extension + 1 treatment at grain filling	**14.40**	**18.00**	**	**44.3**	**22.54**	*
V2-ORTIVA TOP 0.5 L/HA at ear release phase	**15.54**	**16.86**	**	**38.6**	**28.24**	*
V3-MYSTIC GOLD 1.0 L/HA at straw extension + 1 treatment at grain filling phase	**14.18**	**18.22**	**	**32.56**	**34.28**	*
V4-MYSTIC GOLD 1.0 L/HA at ear release phase	**14.84**	**17.56**	**	**38.54**	**28.30**	*
V5- Untreated control variant	**32.40**	-	-	**66.84**	-	-

LD D.A.% for the „flag" leaf
LD 5% =11.66%
LD 1% =16.06%

LD D.A.% for the second leaf:
LD 5% =21.35%
LD 1% =29.40%

Table 2

The results of the experiment with fungicide products (4 variants of treatment + untreated control variant) in what concerns the yield (t/ha) obtained at the treated variants as compared to the untreated control variant

Variant	Prod. (to/ha)	Difference against mt (to/ha)	Significance
V1 - ORTIVA TOP 0.5 L/HA at straw extension + 1 treatment at grain filling	7.951	0.730	*
V2 - ORTIVA TOP 0.5 L/HA at ear release phase	8.047	0.826	*
V3 - MYSTIC GOLD 1.0 L/HA at straw extension + 1 treatment at grain filling	8.058	0.837	*
V4 - MYSTIC GOLD 1.0 L/HA at ear release phase	8.211	0.990	*
V5 - Untreated control variant	7.221	-	-

LD 5% = 0.6784 to/ha
LD 1% = 0.9344 to/ha

MATERIAL AND METHOD

An experiment with 5 study variants was designed for carrying out the observations. This experiment included 4 phytosanitary treatment variants (fungicidal products, their combinations, no. of treatments) and an untreated control variant. The experiment variants were as follows (tab.1):

- V1 - ORTIVA TOP 0.5 L/HA at straw extension + 1 treatment at grain filling
- V2 - ORTIVA TOP 0.5 L/HA at ear release phase
- V3 - MYSTIC GOLD 1.0 L/HA at straw extension + 1 treatment at grain filling
- V4 - MYSTIC GOLD 1.0 L/HA at ear release phase
- V5 - Untreated control variant

The experiment was set up in a Latin square. The 5 variants were set up in 5 repetitions. Each experimental plot had an area of 15 m^2 (5 x 3 m). The total number of experimental plots was 25. The area of an experimental variant was 15 m^2 x 5 repetitions = 75m^2. The total area of the experiment was 75 m^2 x 5 = 375 m^2. The treatments were performed manually, with a “Vermorel” type of equipment. Weed control was carried out using the Mustang herbicide (6.25 g/l florasulam + 300 g/l 2.4-D EHE acid) at a dosage of 0.5 l/ha applied, separately, with Vermorel. The experiment has monitored the effectiveness of the above-mentioned phytosanitary products in relation to their price, as well as the efficiency and, respectively, the profitability of applying one or two phytosanitary treatments, during the barley vegetation period.

The evaluation of the attack’s frequency (F%), of the attack’s intensity (I%) and respectively, of the degree of attack (D.A.%) was done separately, on each and every experimental plot, analyzing 10 plants/experimental plot. Their degree of affectation (the intensity of the attack I %) of the last 2 leaves, especially of the “flag” leaf which has the biggest contribution to the ear’s yield at strawy cereals, had been assessed. The phytosanitary analyses of the plant’s samples were done with the help of the stereomicroscope and optic microscope at Brăila Phytosanitary Office’s laboratory – Phytosanitary National Authority, institution subordinated to the Ministry of Agriculture and Rural Development. These analyses had revealed the presence of *Pyrenophora* fungus in the samples analyzed, fungus which produces barley’s leaf stripe and spotting.

In order to assess the yield of each variant under study, barley grain samples from each experimental plot, 5 samples / plot, had been analyzed by sampling. Each sample comprised 20 plants, so, from each experimental plot, 100 plants were taken over, from which the yield was manually weighted. The demarcation of each sample was performed with a metric frame with the area of 0.25 m^2 (0.5/0.5m). The average of the experimental plot samples had served for calculating the yield of each and every experimental plot. The statistic interpretation had been done with the help of the limit differences (LD %) (Săulescu N).

TEPEE variety was used. This is a new variety of barley for beer, traded by Soufflet French Company. The variety is early.

Assessing the pest attack can be done with the help of the following values (Prognosis and Warning Methods, 1980):

- Attack frequency (F %);
- Attack intensity (I %);
- Degree of attack (D.A %).
- <u>Attack frequency</u> represents the relative value of the number of plants or organs of the plant under attack (n) reported to the number of plants or organs observed (N). The value of the frequency is established through direct observations on a number of plants or organs, according to the case and to the conditions, existing different methods of collecting the samples and for performing the observations. In the case of our observations regarding the foliar diseases, the number of attacked plant organs from the total of observed plant organs (leaves) had been taken into

consideration, establishing thus the frequency of the attack expressed in percentages %. In case of blights, the number of attacked ears reported to the total number of observed ears had been used. The frequency was calculated with the help of the F%= nx100/N formula.

- Attack intensity represents the degree or percentage where a plant or an organ of the plant is attacked and how much from the area of the plant or of the organ analyzed (leaf, fruit) is covered by the disease under study.

The assessment of the area attacked had been done with the naked eye or with the magnifying glass, assessing the percentage occupied by spots or burns caused by the pathogenic agent. The damage percentage can be recorded or grades can be awarded for each plant or organ attacked by the disease or/and by the pest. Grades usage can ease up greatly data summarizing. It can be used a scale with 6 degrees of intensity, as follows:

- Grade 0 no attack
- Grade 1 attack between 1 and 3%
- Grade 2 attack between 3 and 10%
- Grade 3 attack between 11 and 25%
- Grade 4 attack between 26 and 50%
- Grade 5 attack between 51 and 75%
- Grade 6 attack between 76 and 100%

After summarizing the data, the attack intensity had been determined with the following formula:

$$I\% = \frac{\Sigma (i \times f)}{N}$$

Where:

I% – Attack intensity (in %);

i – The intensity according to the grade awarded to the organ or plant attacked;

f – The number of cases (plants, organs) attacked;

n – The number of plants attacked.

In our experiment, grades from 1 to 6 had been separately awarded to the “flag” leaf and to the next leaf situated below it.

- The Degree of Attack is the expression of the attack severity’s extension on the crop or of the total number of plants for which we are making the observations. D.A.’s value expression is given by the ratio:

$$D.A. (\%) = \frac{F \times I}{100}$$

In most of the cases, there is a negative correlation between the degree of attack of a pathogenic agent or pest and the quantitative and/or qualitative level of a crop’s yield.

RESULTS AND DISCUSSIONS

The 2023–2024 agricultural year was a relatively favorable year for barley cultivation. It should be emphasized that barley (*Hordeum vulgare*) is a species much more sensitive to disease attack and wintering than wheat. The months of February, March, April and May of 2024 were relatively favorable in terms of precipitation. These months were warmer than the similar period in 2023. In the fall of 2023, sufficient precipitation fell for barley to germinate in optimal conditions. The winter of 2023-2024 was warmer than the average of previous years

Regarding the dynamics of the appearance of pathogen attacks on barley, we mention the following aspects:

– *Pyrenophora* sp affected barley in 2024 to a relatively similar extent compared to 2023. The degree of attack (D.A.%) was at the V5-untreated control variant of 32.4%, at the “flag” leaf on 20th May 2024.

If we analyze the data in table 1, we note that the degree of attack of the *Pyrenophora* sp fungus was differentiated as follows:

-V1 determined a degree of attack of the *Pyrenophora* sp. fungus of 14.40% on the “flag” leaf and of 44.3% on the second leaf, therefore lower by 18.00% and, respectively, by 22.54% compared to the untreated control variant (V5).

-V2 determined a degree of attack of the *Pyrenophora* sp. fungus of 15.54% on the “flag” leaf and of 38.6% on the second leaf, therefore lower by 16.86% and, respectively, by 28.24% compared to the untreated control variant (V5).

-V3 determined a degree of attack of the *Pyrenophora* sp. fungus of 14.18% on the “flag” leaf and of 32.56% on the second leaf, therefore lower by 18.22% and, respectively, by 34.28% compared to the untreated control variant (V5).

-V4 determined a degree of attack of the *Pyrenophora* sp. fungus of 14.84% on the “flag” leaf and of 38.54% on the second leaf, therefore lower by 17.56% and respectively by 38.54% compared to the untreated control variant (V5).

-V5 (untreated control variant) determined a degree of attack of the *Pyrenophora* sp. fungus of 32.4% on the “flag” leaf and of 66.84% on the second leaf.

From the analysis of table 2, the yield differences compared to the untreated control variant V5 can be observed as follow:\

-V1 achieved a yield of 7.951 to/ha, respectively with 0.730 to/ha higher than the untreated control (V5).

-V2 achieved a yield of 8.047 to/ha, respectively with 0.826 to/ha lower than the untreated control (V5).

-V3 achieved a yield of 8.058 to/ha, respectively with 0.837 to/ha higher than the untreated control (V5).

-V4 achieved a yield of 8.211 to/ha, respectively with 0.990 to/ha higher than the untreated control (V5).

-V5 the untreated control variant achieved a production of 7.221 to/ha.

CONCLUSIONS

The observations made in the spring of 2024 on the barley crop, under the pedoclimatic conditions of the Eastern Bărăgan, led to the following conclusions and recommendations:

1. The attack of the *Pyrenophora* sp. fungus, which produces diseases known by popular names as leaf stripe, spotting, made its presence felt in 2024. The attack of this fungus was, this year, relatively similar to that of 2023 and began relatively early. This was caused by: the relatively high amount of precipitation, the average temperatures and the relatively high average air humidity, recorded in the first 5 months of 2024.

2. The treated variants achieved the following differences in yield and profit, compared to the untreated control variant:

- V1-0.730 to/ha, amounting to 657 lei (131.4 €)
- V2-0.826 to/ha, amounting to 743 lei (148.6 €)
- V3-0.837 to/ha, amounting to 753 lei (150.6 €)
- V4-0.990 to/ha, amounting to 891 lei (178.2 €)

3. The Tepee beer barley variety proved, in the climatic conditions of the spring of 2024, to be relatively resistant to the attack of phytopathogenic fungi from the *Pyrenophora* and *Blumeria* genera. V5 (untreated control variant) achieved a relatively good yeild (7.221 to/ha), in the climatic conditions of 2024, which were favorable to attacks by phytopathogenic fungi from the mentioned genera

4. The experiment was located on a plot that was cultivated with sunflower the previous year. As a result, the inoculum reserve of the *Pyrenophora* sp fungus remaining in the soil from the previous year was practically zero. Under these conditions, we consider that the general condition of the vegetation of the crop where the experiment was located was very good also due to the sunflower that preceded the barley. The crop received large quantities of fertilizers to counteract the fact that sunflower is a large consumer of nutrients.

5. The price of barley, in mid-2024, is approximately 0.90 lei (approx. €0.18)/kg (Cereal Exchange, May 2025).

6. The yields obtained in the studied variants were significantly higher than those achieved by the untreated control variant (V5) which achieved 7.221 to/ha.

7. Regarding the costs/ha of some plant protection products, they vary, in 2024 as follows:

- Ortiva Top costs approximately 320 lei/l – approximately 64 €/l. A single treatment with 0.5 l/ha (160 lei/ha–32 €/ha) was applied to V2. 2 treatments with 0.5 l/ha were applied to V1, i.e. a total of 1 l/ha (320 lei/ha – 64 €/ha).
- Mystic Gold costs 110 lei/l – 22 €/l. 1 l/ha (110 lei/ha – 22 €/ha) was applied to V4. In V3, 2 treatments with 1l/ha were applied, i.e. 220 lei/ha – 44 €/ha, i.e., a total of 2 l/ha.

8. From the analysis of the economic profitability of the production increase, in the climatic conditions of 2024, which was rainier and somewhat warmer in the first 5 months, compared to 2023, all variants proved to be profitable. The achieved yield increases covered the cost of the phytosanitary product relatively well, even if we add the other related expenses (labor costs, for example). However, we emphasize the very good profitability of applying a single treatment with 1l/ha Mystic Gold, which achieved a yeild increase of 0.990 to/ha (891 lei-178.2€/ha) with a cost of only 110 lei -22€/ha.

9. The Ortiva Top product is not approved for barley, in this experiment it is used exclusively for experimental purposes. It is approved for numerous vegetable species (tomatoes, peppers, eggplants, cucumbers, zucchini, onions, carrots) as well as for raspberries, at a dosage of 1l/ha for the prevention and control of specific pathogens such as the phytopathogenic fungi genera: *Alternaria, Colletotrichum, Cladosporium, Peronospora, Botrytis, Phytophthora*, etc. It is a relatively expensive product. In barley, in the climatic conditions of the first half of 2024, it proved relatively effective at a dosage of only 0.5 l/ha applied in a single treatment in the booting phase. Of course, it remains at the discretion of the manufacturer (Syngenta Company) whether it

wishes to extend its approval, in Romania, to barley as well. However, the Mystic Gold product proved to be more cost-effective in phytosanitary protection than the Ortiva Top product. We emphasize the fact that this is the first test of the Ortiva Top product on barley, in the pedoclimatic conditions where the experiment was carried out.

10. Barley grown after sunflower, even in the conditions of a year more favorable to the attack of specific pathogens, behaves relatively well in terms of the general phytosanitary condition. Of course, larger amounts of fertilizers must be applied when barley follows sunflower.

11. The Tepee barley variety presented, under conditions of 0 phytosanitary treatments, a relatively good tolerance to the attack of specific pathogens of barley. We emphasize that the first half of 2024 was very favorable to the attack of specific pathogens of barley.

12. The average exchange rate leu/€, in the months: April, May and June of 2025 was of 5.0626 lei/1€, according to the website of the National Bank of Romania.

REFERENCES

Iacob Viorica, Hatman, M., Ulea, E., Puiu, I., 1998 – “Ion Ionescu de la Brad” Publishing House, *Agricultural phytopathology*, p. 37-39.

Săulescu, N. 1967 - *Experiment field*, Agro-Silvică (Agro–Sylvan) Publishing House, Bucharest, p. 217, 311

Velichi, E. 2012 - *General and special phytopathology*, Universitară (University) Publishing House, Bucharest, p. 151 -153.

*** *National Bank of Romania 2025* (web page).

*** *Methods of Prognosis and Warning*, 1980 M.A.I.A., Bucharest, p. 7-9.

****Soufflet Agro.ro*, 2025 (web page).

******* *Cereal Exchange 2025* (web page)

ORGANIZATION OF THE BREEDING PROCESS AS A MEANS OF INCREASING THE EFFICIENCY OF BREEDING HETEROSIS F_1 TOMATO HYBRIDS

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Abstract

The article presents the results of a comprehensive approach to research using mutant tomato genotypes as source material and combining classical breeding methods with gametic technologies. It provides a description of F_1 tomato hybrids (10 combinations) obtained by crossing cultivated lines with mutant lines that carry marker genes (*sp*$^{+}$, *sp*$^{\pm}$, *rin, nor, alc, u, ls, br, β, gs, Wo*^{m}, *j-2*, and others) of high economic value. These are high-tech, heteritic F_1 tomato hybrids with yields ranging from 27.8 kg/m² to 36.5 kg/m² and a marketability of fruits from 89.1% to 95.6%. They are indeterminate (*sp*$^{+}$) and semi-determinate (*sp*$^{\pm}$) in growth type, with large (120...250 g) brightly colored fruits of red, pink, and orange. The high content of dry matter (5.2…6.8%), sugar (4.2…5.5%), and vitamin C (29.0…47.4 mg/%) provides high taste qualities to the fruits. A differential reaction of F_1 tomato hybrid pollen to high and low temperatures tested *in vitro* has been demonstrated. The results obtained indicate the effectiveness of heterosis breeding using complementary methods with simultaneous assessment of morpho-biological, economically valuable traits, and resistance to various temperature stress factors. This has made it possible to create F_1 tomato hybrids capable of realizing their genetically determined productivity potential in climatic conditions that are far from optimal, and to recommend them for cultivation in industrial greenhouses in the Republic of Moldova.

Keywords: tomato, breeding, methods, F_1 heterotic hybrids, economically valuable traits

Climate change and the problems arising from it are leading to the intensification of genetic erosion not only of tomatoes but also of other agricultural crops, and as a result, to a decrease in the efficiency of their cultivation (Kang M.S., 2004; Ettore Pacini & Rudi Dolferus, 2016). The negative impact of environmental factors is compounded by changes in the requirements of the vegetable consumption market, which makes it necessary to determine the relevance of tasks and new directions for breeding. Breeding is the most valuable, accessible, and cost-effective means of achieving high scientific intensity in the process of creating new tomato varieties and hybrids that can withstand the effects of adverse environmental factors and rapidly changing demands from both producers and consumers. This process should be based on an active search for sources of new germplasm with higher genetic diversity. Of particular interest in this regard are genetically and geographically distant forms, including the genetic potential of mutant tomato forms, which are a unique source of valuable germplasm for solving theoretical and practical breeding problems (Makovei, 2022). When defining the objectives and possibilities of breeding, it is necessary to identify ways to achieve them, taking into account the availability of complementary methods for rapid evaluation, identification of source material, and its effective use in creating tomato varieties and F1 heterotic hybrids capable of realizing their genetically determined productivity potential under conditions that are less than optimal. This can be facilitated by a comprehensive approach to research, combining classical breeding methods with modern gamete technologies. This makes it possible to evaluate a large amount of experimental material at the early and most vulnerable stages of ontogenesis and to select valuable genotypes that are resistant to biotic and abiotic stress factors (Makovei, 2018).

Of great interest in this regard are heterotic tomato hybrids, which could replace existing varieties created through a lengthy breeding process, thereby significantly reducing the time

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required to create new tomato varieties of better quality and higher yield.

According to existing theories (Dowker et al., 1987; Khotileva et al., 2016), heterotic hybrids are the most valuable source material for subsequent selection of genotypes with the necessary combination of traits. F1 hybrids can combine a complex of genes that determine resistance to major tomato diseases. They are also indispensable in creating forms that are resistant to abiotic stress factors such as low and high temperatures, drought, nutritional disorders and others (Khotileva et al., 2016).

Based on this, the aim of this work was to develop approaches to the use of heterosis in tomato breeding as a valuable biological phenomenon for determining conceptual research directions.

MATERIAL AND METHOD

The experimental material consisted of about 40 hybrid combinations of F_1 tomatoes obtained using specially created breeding lines with an original combination of economically valuable traits, including those controlled by mutant genes (*sp^+, $sp^{\pm}$, nor, rin, j-2, u, bk, gs, β*), as well as semi-mutant L11069 (*$sp^{\pm}$, nor, br, Tm-2a, ls, j*), mutant (Mo 341 *Wo^m* and Mo 835 *Ln*) and lines of the cultivated type with high combinative ability – L16, L187, L202, L 454, L828, L1033, v. Stefani, and others. Plants from each F_1 hybrid combination and their parental forms were grown on 5 m² plots with 20 plants in 3 replicates at the experimental site (in a greenhouse) of the Institute of Genetics, Physiology, and Plant Protection in three different climatic years (2022-2024). The nature of the phenotypic manifestation of morpho-biological traits and the quantitative expression of economically valuable traits was determined using methods commonly accepted for tomatoes (Orzan *et al.*, 1987, Tomato-Upov). In laboratory conditions, under artificially simulated stress conditions (Makovei, 2018), F_1 hybrids were tested for resistance to high (45°C/8 hours) and low temperatures (6°C/24 hours) based on male gametophyte characteristics (pollen viability, pollen tube length – control; pollen heat resistance and tube length resistance; pollen cold resistance and pollen tube length resistance). For each F_1 combination, 20 economically valuable quantitative traits were studied. A comparative analysis of the indicators of the studied traits in the parental forms and F_1 hybrids obtained on their basis was carried out. The effect of heterosis was determined (Daskalov, 1987).

RESULTS AND DISCUSSIONS

For tomatoes grown in the ecological conditions of the Republic of Moldova, the following research areas are fundamental:

The first is the creation of F_1 hybrids with a high heterosis effect for the main breeding traits for their industrial cultivation, but at the same time, it should be noted that heterotic F_1 tomato hybrids are one of the most valuable sources of starting material for the subsequent selection of genotypes with the necessary combination of traits and the creation of new lines and varieties based on them. However, this requires the special selection of parent forms with a complex of complementary traits and high combination ability. Parent forms, differing genotypically, must have a set of desirable recessive genes. This will most likely ensure the selection of valuable genotypes from subsequent splitting hybrid populations F_2 and F_3. In our work, the progenitor of a whole range of new tomato varieties was the highly heterotic F_1 hybrid (L106152 x v. Ruslan), obtained using genetically and geographically distant forms (USA, Moldova). On its basis, a number of highly productive (from 56.4 t/ha to 73.8 t/ha) tomato varieties with varying levels and types of resistance to abiotic stress factors such as low and high temperatures and drought have been developed – *Stefani, MaKrista, MilOranj, Vivat, Matriona* and others. They are characterized by excellent taste, with fruits of various colors – red, orange, and pink. Their exceptional taste is due to their high dry matter content and balanced sugar-acid index (from 12.8 to 21). The high β-carotene content in the fruits of the *MilOranj* variety allows us to recommend it for children's dietary nutrition. These and other varieties have successfully passed testing and are homologated in the Republic of Moldova [Catalog, 2024]. For example, some of them are shown in *Figure 1 (a, b, c)*.

The use of this principle, with the simultaneous involvement in the selection process of mutant and semi-mutant tomato forms (Mo 341, Mo 443, Mo 835, L 111, L 11069) and cultivated lines (L 16, L 28, L 187, L 202, L 828, L 1033) with high combinational ability allowed us to obtain a number of homozygous lines with valuable marker traits: – 2/23; 8/234; 32/23; 33/241; 62/22; L79/22; 135/23 and 454/24. Three of them – 8/234, 33/241, and 62/22 – are being tested by the State Variety Testing Commission of the Republic of Moldova.

Figure 1 **High-performance tomato varieties *a* - Matriona, *б* - MilOranj, and *c* - MaKrista homologated in the Republic of Moldova**

They carry the *nor, rin*, and *alc* genes, which control fruit ripening and ensure high quality and uniformity in shape, size, and color, and are presented in the corresponding order in *Figure 2 (a, b, c)*. The remaining lines are undergoing competitive testing and are simultaneously used in breeding programs as donors of valuable traits for obtaining F_1 heterotic hybrids.

Figure 2 (*a, b, c*) **Homozygous tomato lines: L 8/234 with the *nor* gene; L 33/241 with the *rin* gene; L62/22 with the *alc* gene**

The next area of application for heterosis is the creation of high-yielding's F_1 tomato hybrids for industrial greenhouses. Our programs are testing more than 20 combinations of F_1 hybrids from crosses between genetically diverse lines, carriers of mutant marker genes (*sp^+, $sp^{\pm}$, nor, rin, alc, ls, br, j-2, u, bk, gs, β*) that control a range of economically valuable traits. The results show that 84% of F_1 hybrids exhibit a high heterosis effect in terms of productivity and fruit quality (*Tables 1 and 2*). They are characterized by high fruit set under high-temperature conditions and uniform ripening. Two F_1 hybrids named *Ingstar* and *RozaMak* (*Figure* 3 *a,b*) have been homologated and included in the Catalog of new Varieties of the Republic of Moldova (Catalog, 2024-2025). Other F_1 hybrids numbered 11, 29, 32, 39, and 54 have been evaluated in the competition test nursery and are ready to be submitted to the State Commission for further testing (*Table 1*). They produce fruits that ripen 5-7 days earlier than the early-maturing parent form, are highly productive and have good fruit quality. At the same time, it should be noted that as one of the components of crossing (usually maternal), it is necessary to involve forms with large fruits of earlier ripening, which, with an intermediate type of inheritance, balances the negative influence of the second parent. Our results show that in such crosses, it is advisable to use specially created homozygous lines with mutant marker traits (L8/234, L33/241, L187/12, and L1033) as parental forms, as they have high combinational ability. In combinations of F_1 tomato hybrids involving them, a high heterosis effect is observed in almost all cases in terms of productivity and fruit quality (shape, size, uniformity in ripening and color). They are more resistant to mechanical stress and to high and low temperature stress factors (*Table 2*). They do not have such negative characteristics as sparse placement of clusters, long internodes and tall stems, and small fruits.

Figure 3 (*a*, *b*) **High-tech heterotic F_1 tomato hybrids – *Ingstar* and *RozaMak, are homologated* in the Republic of Moldova and intended for cultivation in industrial greenhouses.**

Table 1

Characteristics of promising F_1 heterotic tomato hybrids according to key breeding traits (average values for 2022-2024)

F_1 hybrid number and cross combination	Vegetative period, days	Yield		Fruit mass, g	Biochemical indicators of fruits			
		total, kg/m^2	marke-table, %		dry matter, %	total sugar, %	acidity, %	ascorbic acid, mg, %
F_1 Ingstar	114	35.2	93.5	120	6.12	4.8	0.50	36.3
F_1 RozaMak	105	30.4	94.8	110	5.17	4.7	0.47	43.2
11. (L8/234 × L16)	108	30.5	95.6	140	5.21	4.4	0.51	32.7
17. (L8/234 × Mo835)	117	32.3	95.2	160	5.44	4.8	0.54	31.2
21. (L33/241×Stefani)	115	30.2	94.4	120	5.16	4.2	0.47	28.8
24. (L33/241 × L 828)	106	31.2	90.4	100	5.21	4.3	0.53	25.1
29. (L33/241 × L1033)	108	36.4	90.2	105	5.12	3.8	0.46	24.8
32. (L187 × L965)	101	33,6	91.1	90	5.74	4.9	0.48	31.2
39. (L187 × L828)	105	28.6	93.4	100	6.08	4.8	0.53	26.4
43. (L828 × L11069)	114	24.6	89.1	70	6.32	4.6	0.49	29.3
54. (L1033 × L8/234)	106	35.1	92.7	120	6.84	6.1	0.56	47.6
58. (L1033 × Mo 341)	113	27.7	93.5	110	6.23	5.5	0.58	34.4
F_1 Markiza (stand. I)	113	23.1	85.7	100	5.0	3.3	0.47	23.0
F_1 Malike (stand. II)	110	26,2	88.4	110	4.6	3.7	0.41	24.1
NSR_{05}		3.9						

Another valuable and relevant area of research is the use of heterosis in breeding for increased adaptability to biotic and abiotic stress factors. The relevance of this issue is beyond doubt, as every other year in the Republic of Moldova is accompanied by extremely high temperatures, drought, and viral epiphytotics. Breeding work in this area should begin with the evaluation of initial forms on selective backgrounds with high differentiation capacity. To this end, we use artificially created stress backgrounds (low and high temperatures) with evaluation at one of the most vulnerable stages of plant ontogenesis – mature male gametophyte (pollen). The study and analysis of pollen-based resistance traits in parental forms and their inheritance characteristics by F_1 hybrids allows for the early evaluation of a large amount of material and the selection of the most valuable and resistant traits. The results show that resistance to the studied temperature stress factors is inherited by F_1 hybrids mainly from maternal forms. Therefore, this should be taken into account when selecting pairs for crossing. Determination of the heterosis effect in F_1 hybrids for resistance to various temperature stress factors, both in terms of pollen germination and pollen tube length, revealed high indicators in almost all F_1 tomato hybrids (*Table 2*). The exception was hybrid No 43 from the L828 × L11069 cross, which involved the semi-mutant line 11069 with a complex combination of mutant genes. It is likely that the presence of the *ls, br*, and *ps-2* genes in the genome of this F_1 hybrid has a negative effect on pollen quality, which did not germinate well, and pollen grains that germinated under influence of stress factors were unable to form tubes of sufficient length for fertilization. In this combination, resistance to high and low temperatures based on the characteristics of the male gametophyte is inherited by the F_1 hybrid in an intermediate type. Knowledge of these characteristics makes it possible to correctly and more effectively approach the selection of pairs for crossing in order to obtain F_1 hybrids with high adaptive potential to the action of abiotic stress factors.

Step-by-step recording of morphological, biological, and economically valuable traits, along with simultaneous assessment of resistance to high- and low-temperature stress factors on artificially created selective backgrounds, made it possible to evaluate more than 40 combinations of F_1 tomato hybrids, determine their adaptive potential, and select the best ones. Of greatest interest are eight promising F_1 hybrids with a high heterosis effect for all studied traits. Hybrids No. 21, No. 29, and No. 54 stand out in particular, with a lower response of their pollen to stress factors and, especially, their ability to form long pollen tubes (*Table 2*). This ensures high fruit setting and, as a result, high productivity, which is confirmed by the indicators of heterosis effect on total and marketable yield (*Table 2*). They are distinguished by a developed root system, an optimal ratio of the sizes of the vegetative parts of the plant with frequent inflorescence arrangement, and high fruit setting under high temperatures with unregulated irrigation in a soil greenhouse. Of the F_1 hybrids presented in *Table 2*, five have a semi-determinate growth type with a shorter fruit ripening period (from 101 to 106 days). Plants of other F_1 hybrids are characterized by indeterminate growth type, with a longer fruit ripening period (from 108 to 117 days). All F_1 hybrids are characterized by high productivity (from 24.6 kg/m² to 36.4 kg/m²) and marketability (90.2%... 95.4%) with uniformly colored red, pink, and orange fruits. They carry marker traits that allow the hybridity of plants to be determined at early stages of growth and development, ensuring high quality and decorative appeal of the fruits and plants in general.

Table 2

Heterosis effect on the main economically valuable traits in promising F_1 tomato hybrids

F_1 hybrid number and cross combination	Traits and heterosis effect index (X, %)						
	Yield		Fruit mass	Resistance to pollen germination		Resistance along the length of pollen tubes	
	total	marketable		to > t	to < t	to > t	to < t
11. (L8/234 × L16)	167	204	154	108	99	126	94
17. (L8/234 × Mo835)	103	166	171	108	137	103	101
21. (L33/241 × Stefani)	211	278	163	101	164	132	207
24. (L33/241 × L 828)	138	182	114	103	101	167	184
29. (L33/241×L1033)	229	176	192	142	178	151	191
32. (L187 × L965)	114	132	111	98	101	104	94
39. (L187 × L828)	126	124	108	118	97	100	109
43. (L828 × L11069)	115	101	74	105	81	93	86
54. (L1033 × L8/234)	271	143	123	103	186	102	206
58. (L1033 × Mo 341)	152	131	117	104	101	107	101

Another equally important area of using for heterosis is the creation of F_1 hybrids for plastic greenhouses. Since most tomato production in the Republic of Moldova (76.3%) is concentrated in small and medium-sized farms and on private plots (Botnari & Cebotari, 2013), varieties and hybrids for cultivation in unheated plastic greenhouses are in high demand. To create them, we used an original method specially developed by us, which consists of crossing early-maturing, high-yielding breeding lines and varieties that are resistant to low positive temperatures with heterotic F_1 hybrids with high genetic resistance to various diseases (*Fr, C, Ph, ToMV*). The results of its application are quite promising. F_1 hybrids – 60/04, 60/21, 60/57, 60/84, and 60/96 were obtained, which exceeded standard samples (*F_1 Markiza* and *F_1 Malike*) in early and total yield by 1.1–3.4 kg/m² when grown in spring-summer crops in unheated film greenhouses and by 0.6–2.3 kg/m² when grown in summer. They are distinguished by uniform large fruits on all inflorescences regardless of their location on the main stem of the plant, have short internodes, frequent inflorescence arrangement, and are resistant to the most common tomato diseases. These heterotic F_1 hybrids of tomato have been tested in control and competition nurseries, where they have shown stable expression of the main economically valuable traits. They are characterized by high pollen resistance to low temperatures under natural conditions (15-20°C). This ensures high fruit setting (78.6...89.4%) when growing these plants in early the spring-summer period. They can be recommended for cultivation in unheated film-covered soil greenhouses in the ecological conditions of the Republic of Moldova.

CONCLUSIONS

It has been shown that heterosis is a valuable biological property of tomatoes, the use of which makes it possible to tap into additional reserves of the plant, increasing its yield, product quality, and resistance to temperature stress factors.

The heterosis effect is most often and clearly manifested in crossbreeding combinations with special and correct selection of parent pairs. The main principle in selecting pairs for crossbreeding is the presence of valuable recessive genes in the initial forms, the combination of which in a single F_1 hybrid genotype gives the expected heterosis effect.

New tomato varieties and F_1 heterotic hybrids have been created with an optimal ratio of morphological structures, high overall and marketable yields, combining resistance to high and low temperature stress factors and stable expression of these traits in three different years of research, which can be recommended for early cultivation in unheated plastic greenhouses and high-tech greenhouses in the Republic of Moldova.

ACKNOLEDGMENTS

The research was carried of the Proiect in the field of science and innovation **25.80012.5107.15SE, "Genetic diversity of mutant marker genes of tomato (*Solanum lycopersicum* L.) as a source of new germplasm for the creation of varieties and heterotic hybrids capable of realizing the productivity potential under climate change"**, financed by the Ministry of Education and Research.

REFERENCES

Ettore Pacini, Rudi Dolferus, 2016 - Recent advances and future perspectives. In book: *Abiotic and Biotic Stess in Plants.* DOI: 10.5772/61671.

Botnari V., Cebotari V.*, 2013 -* *Legumicultura*: Starea actual şi perspective dezvoltării. Analiza Sectorului Agricol, CAMIB, 48 p. www.camib.com.

Daskalov, Hr., 1987 - *Heterosis and its use in tomato cultivation*. Sofia: Bulgarian Academy of Sciences, 179 p.

Catalogul Soiurilor de Plante al Republicii Moldova, Chișinău (2024 – 2025). https://cstsp.md/uploads/files/Catalog%202024.pdf https://cstsp.md/uploads/files/Ordinul%20Nr_%2098%20A%20din%206%20noiembrie%202024.PDF

Dowker B.D., Driscoll C.J., Gordin G.H., 1987 - *Heterosis*: Translation. M.: Agropromizdat. 347 p.

Kang M.S. Breeding: Genotype-by-environment Interaction. *Encyclopedia of Plant and Crop Science*. New York: Marcel-Dekker; 2004. pp. 218-221. ISBN: 0491334386.

Khotyleva L.V., Kilchevsky A.V., Shapturenko M.N., 2016 - Theoretical aspects of heterosis. *Vavilov Journal of Genetics and Breeding*. 20(4):.482-492

Makovei M.D., 2018 - *Selection of tomatoes for resistance to abiotic stress factors using gamete technologies*. Sprint "Print-Caro", Chisinau, 473p. ISBN: 978-9975-56-565-3 (in Russ).

Makovei M.D., **2022 -** *The potential of mutant forms of tomato for selection and genetic studies*. Sprint "Print-Caro", Chisinau, 208 p. ISBN 978-9975-165 -22-8 (in Russ).

Orzan V.,Ionescu C., 1989 - *Metodica și Tehnica Experimentala pentru incercarea soiurilor de legume de câmp.* București, 1989. 268 p.

Tomato - Upov (*Solanum lycopersicum* L.) V 20120007 , TG/44/11 Rev. Geneva.

ENSURING SEED QUALITY: A MULTIDISCIPLINARY PERSPECTIVE ON LABORATORY TESTING

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Abstract

Seeds are fundamental to plant production. The seed industry and its representatives, at global, regional, and national levels, require analytical methods to meet trade requirements and manage quality-related risks. Standardized interpretation and reporting of laboratory test results are essential. Laboratory seed quality testing provides a rapid assessment of a seed lot's biological potential, specifically its cultural and utilization value. This comprehensive evaluation encompasses multiple parameters including physical purity, germination capacity, vigor assessment, and thousand seed weight determination. The aim of this paper is to describe and provide a multidisciplinary perspective on the most important seed quality indicators and the standardized tests required for commercial sowing seeds.

Keywords: methods, seeds, quality, testing

Seed is the most important input for increasing plant production. Whether intended for consumption or sowing, seeds are a fundamental input with a special place in optimizing yields and investments (Păcurar, 2007). When evaluating seed quality, clarifying the term 'seed' is essential, because seed testing deals with the devisions of seed plants only. Botanically, a seed (or sperma) is a higher plant organ derived from the fertilized egg, exhibiting varied shapes and sizes, consistent at the species level.

A true seed comprises an embryonic plant, stored food (rarely absent), and a protective coat. However, Kozlowski (1972) notes that 'seed' in seed testing is often used functionally as a unit of dissemination or a disseminule, embracing dry, one-seeded (or few-seeded) fruits as well as true seeds.

Specialized legislation (European Commission, 2020) defines 'seed' more broadly as reproductive material, including seeds and vegetative propagating material, which must belong to a high-yielding variety adapted to specific environments, possessing biological purity, high productivity, superior quality traits, physiological properties, physical purity, germination, and health. This description encompasses a broad range of seed types, including agricultural species (forage grasses, cereals, small-seeded legumes, large-seeded legumes, and other agricultural species such as Beta, Brassica, Helianthus, etc.), vegetables, herbs, flowers, spices, and medicinal plants.

Given this diversity, the review focuses on laboratory testing methods for seed quality that are both reproducible under field conditions and provide a reliable indication of expected seed lot performance. The discussion will emphasize rapid and effective techniques relevant across these diverse plant categories.

THE SEED QUALITY SYSTEM IMPORTANCE

Seed certification relies heavily on seed testing. Seed certification is a system designed to maintain and make available to the public sources of high-quality seed of superior crop varieties, ensuring their genetic identity and purity. Seed testing is the scientific process used to assess seed quality against pre-defined standards. Without seed testing, it would be impossible to verify that seed meets the standards required for certification.

Certification programs set specific standards for various seed quality parameters, such as: genetic purity - ensuring the seed represents the claimed variety, physical purity - absence of weed seeds, other crop seeds, and inert matter,

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germination - the percentage of seeds that are capable of producing normal seedlings etc.

Seed testing provides the data that confirms whether a seed lot meets these certification standards and enables informed decisions in the certification process. The results of seed tests can determine if a seed lot is eligible for certification, if it requires further processing or treatment, or if it should be rejected altogether.

A country's seed delivery system is best conceived as a value chain composed of interrelated components – from the development of well-adapted and nutritious crop varieties and their adoption by farmers, through the production and distribution, including sales, of quality seeds and planting materials, to on-farm utilisation of these inputs by farmers. The effective functioning of the value chain, enabled by the applicable national seed laws, policies, strategies, action plans and regulations, depends largely on the extent to which the stakeholders are able to put into practical use the relevant knowledge and skills required for producing quality seeds and planting materials.

Obtaining seeds with special qualitative properties is conditioned by the scientific substantiation of all activities which consist, on the one hand, in knowing the theoretical bases of genetics, breeding and seed production, and on the other hand, in the in-depth knowledge and application in this activity of modern methods and techniques standardized and regulated at national and international level (FAO, 2018a).

Benech – Ardold and Sánchez (2004) describe seeds as the beginning and the end of most agricultural practices and the way in which seeds function: their physiology, biochemistry, molecular biology, and genetics are critically important for agricultural success.

There are four basic parameters to classify the seed quality attributes: physical qualities - referring mostly to the seed lot, physiological qualities describing aspects of performance of the seed, genetic quality - relates to specific genetic characteristics of seed variety. When seed has good physical, physiological, seed health and genetic qualities, farmers have greater prospects of producing a healthy crop with improved yields. High quality seed is a major factor in obtaining a good crop stand and rapid plant development even under adverse conditions, although other factors such as rainfall, agronomic practices, soil fertility and pest control are also crucial (FAO, 2018c).

Seed is a living product and must be grown, harvested and processed correctly to maximize its viability and subsequent crop productivity (Rahman, 2016). Good seed quality can increase yield significantly.

Seed quality depends on the health, physiology, germinability and physical attributes of seeds, including the presence or absence of disease, chemical composition, insect infestation, and the presence or absence of weed seeds or other plant varieties. Quality of seeds and their products is directly or indirectly related to human health; nevertheless, the evaluation of seed quality parameters is a time-consuming process (Huang *et al.,* 2015, Rahman *et al.,* 2016).

According to FAO (2018b) the organization of seed certification requires the following steps: institute a seed certification agency – independent from the industry, establish a minimum seed certification standards and devise procedures for field inspection, processing, sampling, testing and labelling.

A seed law without some provisions for unbiased seed testing basis is meaningless and seed testing laboratories which are not properly integrated into a seed certification and seed control programme have questionable value (Seed Testing Manual, 2021). In industrialized countries, the existence of methods for verifying seed quality has always been an important support for the seed industry and for governments in seed production programs. In developing countries, where seed production is insufficient, the availability of internationally recognized methods represents a first step in initiating national seed production schemes: it facilitates the development of regulatory standards, such as seed certification (Léchappé, 2009).

THE SEED SAMPLING

Sampling is the first step and one of the most important when assessing the quality of a seed lot. In the second edition of the ISTA Handbook on Seed Sampling, Dr. Michael Kruse, Professor for Seed Science and Technology, quotes Arne Wold in the foreword: 'Sampling of seed is considered an important part of seed quality control. Correct sampling is a prerequisite for the reliable estimation of the quality of the seed lot. Accurate description and detailed information of the sampling procedures are therefore necessary. Uniformity in sampling seed lots as well as in drawing working samples is as important as uniformity in test methods in order to obtain accurate and reproducible results. Incorrect sampling may lead to misleading test results, discarding seed lots of high quality or to approval of seed lots of low quality which may reduce crop yield or even result in complete failure'.

According to International Seed Testing Association Rules (2024a) the object of sampling

is to obtain a sample of a size suitable for tests, in which the probability of a constituent being present is determined only by its level of occurrence in the seed lot which is a specified quantity of seed that is physically and uniquely identifiable. A good sample for seed testing must be representative of the lot (Bányai & Barabás, 2002).
The qualification of seed lots should be evaluated on the basis of their characteristics which can be examined on small representative samples drawn from them. Data collected on such small samples can then be useful for the entire lot following the application of appropriate mathematical statistical methods (Bányai & Barabás, 2002).

The reliability of the inference made about the quality of the seed lot depends primarily on two components: the accuracy with which the sample represents the lot and the accuracy and precision of laboratory tests (Kruse, 2004). For instance, the size of the purity tolerance depends on the size of the seed lot and on the number of bags from which sample cores are taken. Estimates of the quality of various attributes of seed in a lot are made from samples and these are subjected to error because of variation in the seed, in methods and in apparatus (Milles, 1963).

After sampling has been carried out according to standard requirements and the seed samples have been accepted and received in the seed testing laboratories, they enter the specific seed testing workflow, with the first test performed being usually the purity analysis.

THE PURITY ANALYSIS

Purity is an expression of how ‘clean’ the seed lot is. Physical purity is a critical factor affecting the value of seed. It indicates the proportion of ‘Pure Seed’, ‘Inert Matter’ and ‘Other Seeds’ within a seed sample. Testing for seed purity it’s important for ensuring that seed lot doesn’t devalue due to the presence of unwanted seeds or specific amounts of inert matter. According to International Rules for Seed Testing (2024b) the purity is referring to the percentage composition by weight of the sample being tested and by inference the composition of the seed lot and to identification of the various species of seeds and inert particles constituting the sample.

The pure seed fraction must refer to the species stated by the applicant or found to predominate in the test and must include all botanical varieties and cultivars of that species. Will be included structures like intact seed units and commonly found dispersal units i. e. achenes and similar fruits, schizocarps, florets with an obvious caryopsis containing endosperm, free caryopses and pieces of seed units larger than one-half their original size. In this fraction will be also included the structures which are immature, undersized, shrivelled, diseased or germinated, providing they can be identified as of that species, unless transformed into partially or fully ergotised visible fungal sclerotia, smut balls or nematode galls.

Mureşan, Pană and Cseresnyes (1986) consider the determination of physical purity the first of the two essential objectives pursued in seed quality control. The second essential objective is to determine the germination from the pure seed fraction separated at the purity analysis. The purity analysis provides information about the gravimetric composition of the working sample and by this about the whole seed lot, about the determination of the identity of different seeds and inert particles found in the working sample. The purity analysis is done on a working sample with a specific weight depending on species performing the following successive operations: dividing the sample in pure seed fraction, other seeds and inert matter, identifying the other seed species and type of inert matter and then weight them with specific decimal places.

Short history of Purity Test. Before the International Seed Testing Association was founded in 1924, according to Jensen (2008), two methods were used for Purity analysis in Europe: the Continental method or the Stronger method, and the Irish method also called the English method. By the Continental method, all seeds were examined first by the naked eye or using magnification, and then under reflected light. It required that the seeds, classified as pure seed, did not have any damage on vital parts of the seed. Undamaged seeds were, accordingly, considered to be able to germinate. The Quicker method, which was a modified form of the Irish Method, was based on the assumption that all pieces of seeds of the species tested, with a size of more than half the original size, should be classified as pure seed. The evaluation of whether the seeds were able to germinate was supposed to be determined in the germination test. The same author mentioned that the subject of what method to be used was intensively discussed during the ISTA Congresses at Copenhagen - 1921, Cambridge - 1924 and Rome - 1928. During the Congress at Wageningen - 1931 it was not possible to obtain an agreement about a preferred method, and both the Stronger method and the Quicker method were included in the first ISTA Rules of 1931. In time, those two methods for purity testing became an increasing inconvenience for the seed trade, and the Russian delegation in the International Organisation for

Standardisation - ISO raised the question whether ISO should go into standardisation of seed testing and that they should begin with the purity. This question was submitted via ISTA member countries standardisation organisations to the ISTA laboratories and to the ISTA Secretariat. It was taken as a serious warning that decisions on formulation of the Rules could move to other organisations, and the ISTA Congress in 1950 finally decided that the stronger method should be deleted and the quicker method should be the only method for purity analysis in the ISTA Rules.

THE THOUSAND SEED WEIGHT (TSW)

The object of the test is to determinte the weight of 1000 pure seeds from the submitted sample, either by counting the entire fraction or by counting in replicates (International Seed Testing Association Rules, 2024d). In general, the pure seed fraction must refer to the species stated by the applicant, or found to predominate in the test, and must include all botanical varieties and cultivars of that species including structures like intact seed units and pieces of seeds units larges than one-half their original size International Seed Testing Association Rules, 2024b). It varies from species to species, and within the same species from one cultivar to another. TSW provides an indirect measure of seed size and uniformity. A higher TSW generally indicates larger seeds, while a consistent TSW across samples from the same lot suggests greater uniformity. In contrast a low TSW can indicate that seeds were not fully mature at harvest or that they experienced stress during development, leading to poor "fill" (i.e., not being completely full of reserves). Immature or poorly filled seeds often have reduced germination and vigor.

Thousand seed weight is an important parameter for the evaluation of any variety being not only directly related to the grain yield and milling quality of grain, but also has an impact on the seedling vigour and growth indirectly affecting the wheat (*Triticum aestivum* L. subsp. *aestivum*) yield (Botwright *et al.,* 2002). TSW was also found to be closely associated with kernel size traits as well, such as kernel length, kernel width, kernel thickness, and the kernel length/width ratio (Dholakia *et al.,* 2003). For rice (*Oryza sativa* L.), thousand seed weight is frequently used in crop research as a measurement indicator (Li *et. al.,* 2004). TSW along with spike number per m^2 and kernel number per spike are the three main components determining wheat (*Triticum aestivum* L. subsp. *aestivum*) yield. Zhang *et al,* (2021) describe this trait is controlled by multiple genes being affected by environment as well as genetic background and positively correlated with kernel length and kernel width.

In hybrid broccoli, plants from large seeds had higher vegetative yields than plants from medium or small seeds (Heather & Sieczka 1991). In some *Brassica rapa* L. cultivars, plants from large seeds had more pods, larger pods, heavier seeds and higher seed yields than plants from small seeds (Ahmed & Zuberi, 1973).

Seed size is correlated with factors like seedling vigor and establishment. TSW helps characterize and differentiate seed lots. It allows for the comparison of seed quality between different varieties, production years, or geographical origins. This information is valuable for seed producers, breeders, and farmers in making informed decisions about seed selection.

In the same time TSW is not a standalone indicator: it should be used in conjunction with other seed quality parameters, such as germination percentage, purity, and vigor tests, to get a complete picture of seed quality.

THE GERMINATION

Theoretical Considerations. Seed germination is a critical process in the life cycle of higher plants. As stated by Mayer and Poljakoff-Mayber (2014), the germination of the seed of the higher plant may be regarded as that consecutive number of steps which causes a quiescent seed, with a low water content, to show a rise in its general metabolic activity and to initiate the formation of a seedling from the embryo.

Physiologically, seed germination is a multi-stage process where an embryo transforms into a seedling. It starts with water imbibition, which softens the seed coat and activates enzymes. A lag phase follows, during which food reserves (carbohydrates, fats/oils, and proteins) are mobilized by enzymes. Germination then occurs with the rupture of the seed coat and radicle emergence. Early growth relies on water uptake for cell elongation, consuming the storage tissues. Seedling growth patterns are classified as either hypogeal (cotyledons remain underground) or epigeal (cotyledons emerge above ground).

Germination is an energy-demanding process that requires functioning mitochondria. One of the earliest events of seed germination is progressive development of structurally simple and metabolically quiescent mitochondria into fully active ones, known as mitochondrial biogenesis. This is a complex and tightly regulated process, which is accompanied by sequential and dynamic gene expression, protein synthesis, and posttranslational modifications (Czarna *et al.,* 2016). The data highlight diverse regulatory and metabolic mechanisms upon seed germination, including induction of environmental factor-responsive signaling pathways, seed storage reserve mobilization and utilization, enhancement of DNA repair and modification, regulation of gene expression and protein synthesis, modulation of cell structure, and cell defense (Tan *et al.,* 2013).

While the summarized process outlines the general physiological stages of germination, it's important to note that these stages are not universal. Each species has unique germination characteristics, influenced by various factors.

These factors influencing the germination are: water availability, temperature, oxygen, dormancy mechanisms, light requirements and even storage based on the seed tolerance to desiccation. These factors can modify or even dictate the specific steps of germination for a given species.

Some plant species may require specific light conditions; usually, plants need the presence of light to germinate, but there are species, e.g., *Phacelia tanacetifolia* (ISTA Rules, 2024c) that germinate better in darkness. Other factors influencing the germination are dormancy, chemical deficiency, weather conditions during seed development, immaturity, mechanical damage, phytotoxicity caused by some chemicals, insects and mites, plant pathogens and longevity. The germination will not occur above or below the critical temperatures. Each species has a minimum, an optimum, and a maximum temperature for seed germination. Critical moisture levels vary among crop seeds. Most starchy seeds (monocots) will begin germination when they have a moisture content of approximately 30 percent. Most oily seeds (dicots), however, will not begin germination until they have a moisture content of at least 50 percent. Lack of oxygen is not usually a limiting factor for germination. However, wet or soggy substrate may not contain enough oxygen for germination to begin. Seeds planted in such conditions will absorb water quickly and will have the tendency to decay.

Very strongly connected to germination potential is the seed vigour which is a concept describing several seed performance associated characteristics, and not a single property (Perry, 1981). Seeds which are able to produce a seedling, respectively to achieve germination from a botanical point of view, will not necessarily have the vigour to produce a plant in field conditions.

Practical Considerations. The purpose of the germination test is to determine the germinative capacity of a seed lot, a determination that can subsequently be used both to compare different lots and to estimate the sowing value for cultivation in the field. The germination test reports the percentage of normal seedlings, abnormal seedlings and dead or ungerminable seeds in a seed lot.

Standard germination determined in the laboratory and expressed as a percentage involves an estimate of the potential of a seed lot for germination and emergence under favorable environmental conditions. When maximum viability is reached, a seed lot should theoretically have a germination of nearly 100%, providing dormancy is not a factor. Loss on viability from this point on results from the deterioration processes involved with seed ageing. However, performing the test under field conditions is normally unsatisfactory because the results cannot be reliably repeated. Therefore, laboratory methods have been developed in which external conditions are controlled to ensure the most homogeneous, rapid, and complete germination for most samples of a given species (International Seed Testing Association Rules, 2024c).

Germination tests are successful in two aspects (Matthews, 1981): they are repeatable, and they provide information about the potential of a seed lot to germinate under optimum conditions.

Other species have dormant seeds, meaning that seeds are viable but in a non-germination state. When testing, this situation might be solved by exposing the seeds to specific actions like removing or breaking seed coverings, cold, light, time, or hormones. The major limitation of the germination test as an assessment of seed lot potential performance is its inability to detect quality differences among high germinating seed lots (Roberts, 1984).

To improve germination, modern techniques are taken into consideration: seed priming and exposure to specific magnetic fields. According to Vashisth and Nagarajan (2010), treatment of sunflower seeds in static magnetic fields of strength from 0 to 250 mT in steps of 50 mT for 1–4 h in steps of 1 h increased the speed of germination, seedling length and seedling dry weight under laboratory germination tests. The treated seeds planted in soil resulted in statistically higher seedling dry weight, root length, root surface area and root volume in 1-month-old seedlings and in germinating seeds, enzyme activities of a-amylase, dehydrogenase and protease were significantly higher in contrast to controls. In a research experiment, Afzal et al. (2012) showed the positive impact of magnetism at 100 mT on improving early growth, germination rate and biochemical parameters on seeds of French marigolds (*Tagetes patula* L.). This was because the seeds after exposure to magnetic field lines showed higher levels of α-amylase activity which improved germination. According to Dotto and Silva (2017), the physiological priming of beet seeds with water or salicylic or gibberellic acids, respectively, alters seed germination and vigour potential and the response varies according to the cultivar used and the type of conditioning adopted. Germination of beet seeds is promoted at 1−2 mM ascorbic, gibberellic or salicylic acids, respectively, while at 1−3 mM, the growth of roots and shoot of beet seedlings are promoted.

While laboratory germination tests provide valuable information about a seed lot's potential, they are limited by their artificial environment and inability to fully capture complex factors like seed vigor and dormancy.

THE SEED VIGOUR

The subject of seed vigour is complex (Hampton & TeKrony, 1995) because it is not a single measurable property, like germination, but a concept describing several characteristics associated with various aspects of the seed, both in the field (Perry, 1978, 1981) and in storage (Hampton & Colbear, 1990). Seed vigour consists of those attributes that determine the potential for rapid, uniform development of seedlings under variable field conditions (Al-Amery *et al,* 2018, Marcos-Filho, 2015). Therefore, seed vigour is often a better indicator of stand establishment in the field (Saux *et al.,* 2020, Al-Amery *et al.,* 2018, Torres & Marcos-Filho, 2005, TeKrony & Egli, 1993).

In the acceptance of the International Seed Testing Association (2024e), 'Seed vigour is the sum of those properties that determine the activity and performance of seed lots of acceptable germination in a wide range of environmental conditions. Seed vigour is not a single measurable property, but a concept describing several characteristics associated with the following aspects of seed lot performance: rate and uniformity of seed germination and seedling growth, emergence ability of seeds under unfavourable environmental conditions and performance after storage, particularly the retention of the ability to germinate'. A vigorous seed lot is one that is potentially able to perform well even under environmental conditions which are not optimal for the species (Hampton & TeKrony, 1995). Results of vigour tests can be used in deciding whether the seed lots can be sown earlier in the season, when the occurrence of stressful conditions is possible, or it should be sown later, when the soil is warmer, and the conditions become more favourable for germination and seedling growth (Milošević & Zlokolica, 1996).

Seed vigour tests fall roughly into three general categories (Al-Amery et al, 2018):

1. Stress-Imposition Tests: Measure standard germination percentage after a pre-germination stress imposition. Examples include accelerated ageing, controlled deterioration, and cold test.
2. Indirect Measurement Tests: Indirectly measure germination potential utilizing an accepted physiological or biochemical aspect of germination. The most utilized indirect method uses electrolyte leakage (Marcos-Filho, 2015). Measurement of the electrical conductivity of leachates provides an assessment of the extent of electrolyte leakage from plant tissues. Conductivity measurement of the soak water in which a bulk sample of seeds has been steeped gives an estimate of seed vigour. Seed lots with high electrolyte leakage, i. e. high leachate conductivity, are considered to have low vigour, whilst those with low leakage (low conductivity) are considered to have high vigour (International Rules for Seed Testing, 2021e). The conductivity test was first recognized for seeds of several crop species by Hibbard & Miller in 1928 and later developed into a routine vigour test to predict field emergence of garden pea (*Pisum sativum* L.) (Matthews & Bradnock, 1967).
3. Visual Post-Germination Analysis: Uses visual assessment of seedlings after germination.

Accelerated Ageing Test: The accelerated ageing stress test exposes seeds for short periods to high temperature and high relative humidity (≈ 95 %). During the test, the seeds absorb moisture from the humid environment and the raised seed moisture content, along with the high temperature, causes rapid seed ageing. High vigour seed lots will withstand these extreme stress conditions and age more slowly than low vigour seed lots. Thus, after testing, high vigour lots retain a high germination, whilst that of low vigour lots is reduced (International Rules for Seed Testing, 2021e).

This test was initially developed as a test to estimate the longevity of seed in commercial storage (Delouche & Baskin, 1973) and has been used to predict the lifespan of a number of different species. It was correlated with the field emergence for the following species: *Arachis hypogaea* L., *Brassica oleracea* L. var. *capitata*, *Brassica rapa* L., *Capsicum* spp., *Glycine max* L., *Gossypium hirsutum* L., *Helianthus annuus* L., *Lolium perenne* L., *Phaseolus mungo* L., *Phaseolus vulgaris* L., *Sorghum bicolor* (L.)

Moench subsp. *bicolor*, *Trifolium incarnatum* L., *Trifolium pratense* L., *Triticum aestivum* L. subsp. *aestivum* and *Zea mays* L. and with storage conditions for: *Allium cepa* L., *Bromus willdenowii* Kunth., *Citrullus lanatus* Thunb. var. *caffer*, *Cynosurus cristatus* L., *Festuca arundinacea* L., *Glycine max* L., *Raphanus sativus* L., *Sorghum bicolor* (L.) Moench subsp. *bicolor*, *Trifolium incarnatum* L., *Trifolium pratense* L., *Triticum aestivum* L. subsp. *aestivum* and *Zea mays* L.

According to Zhang *et al.* (2021), high relative humidity and high temperature are two factors that accelerate seed deterioration. As seeds age, frequently observed changes include membrane damage and the destruction of organelle structure, an increase in the loss of seed leachate, decreases of respiratory rates and ATP production, and a loss of enzymatic activity. These phenomena could be interrelated and reflect the general breakdown in cellular organization. Many processes can result in seed ageing; it is likely that oxidative damage caused by free radicals and reactive oxygen species which can have vital interactions with any macromolecule of biological interest that result in damage to various cellular components caused by protein damage, lipid peroxidation, chromosomal abnormalities, and DNA lesions.

Controlled Deterioration Test: This test was developed for detecting seed lots of small-seeded vegetable species (carrot, onion, lettuce, brassicas) with poor field performance potential (Hampton & TeKrony, 1995, Powell & Matthews, 1981), and storage potential (Hampton & TeKrony, 1995, Powell & Matthews, 1984a). The test can consistently identify low and high vigour seed lots (Powell *et. al,* 1984b). The basis of the test is an ageing technique similar in principle to the accelerated ageing test i.e., seeds are exposed to the two most important environmental variables which influence seed deterioration: high temperature (40-45°C) and high seed moisture for a short period of time (24 - 48 hours depending on the species). The initial seed moisture content is raised to the same level for all lots prior to the period of deterioration at high temperature. Thus, the test provides a constant seed moisture content during the deterioration period, in contrast to accelerated ageing test where seed moisture is variable (TeKrony, 2003). The test can be run in a standardized manner for the following species: *Brassica* spp., *Daucus carota* L., *Lactuca sativa* L., *Beta vulgaris* var. *altissima* Doll., *Allium cepa* L., *Pisum sativum* L., *Trifolium pratense* L., *Medicago sativa* L., *Lolium perenne* L. and *Festuca arundinacea* Schreb. (Hampton & TeKrony, 1995).

Cold Test: This vigour test developed to simulate adverse field conditions like high soil moisture, low temperatures and soilborne fungi usually occurring in early spring. The test was first developed for maize, soybean and sorghum. Beyond the assessment of field performance, The Association of Official Seed Analysts (AOSA, 1983) lists several uses for the results of this test: evaluating fungicide efficacy, selecting genetic material demonstrating an ability to germinate in cold wet soil, evaluating physiological deterioration resulting from prolonged or adverse storage, freezing injury, immaturity, injury from drying and other causes, measuring the effect of mechanical damage on germination in cold, wet soil, selecting seed lots for early spring planting and providing a basis for adjusting planting rates for individual seed lots.

The cold test exposes seeds to cold temperatures (10°C, 7 days) in non-sterile field soil at approximately 60-70% of water holding capacity prior to a 4-7day growth period in ideal conditions (25°C). The ability of seeds to germinate and emerge in cold wet soil is affected by genotype, seed quality (both physical and physiological), pathogens and seed treatment. Because the test requires the use of soil, which is a variable material both physically and biologically, it cannot be readily standardized between laboratories.

Seed vigour testing provides valuable insights into a seed lot's ability to perform under a wide range of conditions, supplementing the information obtained from standard germination tests. However, it's essential to recognize that vigour tests, due to their inherent complexity and sensitivity to environmental factors, necessitate highly skilled and experienced analysts.

The subjectivity involved in some vigour assessments, as well as the need for precise execution of the test procedures, emphasizes the importance of well-trained professionals in order to obtain reliable and reproducible results. In other words, vigour tests require highly skilled professionals due to their inherent complexity and sensitivity to environmental factors.

CONCLUSIONS

The laboratory seed quality testing serves as a cornerstone for a thriving and sustainable seed system, moving far beyond mere academic exercise. Standardized methods, rigorously applied, provide the data-driven insights essential for mitigating risk, fostering trust, and driving economic prosperity across the seed value chain. This review has highlighted the diverse range of methods employed to assess seed purity, germination, vigor, and overall health, demonstrating how each contributes to a comprehensive understanding of seed lot potential.

The economic impact of accurate seed testing cannot be overstated. From enabling farmers to make informed decisions about sowing rates and pre-planting treatments, to facilitating international trade and protecting the value of plant breeding innovation, reliable seed quality data underpins the stability and competitiveness of the seed market.

By reducing the risk of crop failure and promoting efficient resource utilization, high-quality seed, assured by rigorous testing, contributes directly to increased agricultural productivity and food security.

While the existing arsenal of seed testing methods is robust, there remains scope for further refinement and innovation.

Future research should focus on developing rapid, non-destructive techniques for assessing seed vigor and health, as well as exploring the potential of molecular markers and other advanced technologies to enhance the accuracy and precision of seed quality assessment. Furthermore, continued harmonization and standardization of seed testing methods at the international level are crucial for facilitating global seed trade and ensuring that farmers worldwide have access to high-quality seed.

Investing in robust seed testing infrastructure, adhering to internationally recognized standards, and fostering collaboration among seed scientists, regulators, and industry stakeholders are essential for maintaining a vibrant and resilient seed system that supports sustainable agriculture and meets the growing demand for food in a changing world.

REFERENCES

Afzal, I., Mukhtar, K., Qasim, M., Basra, S., Shahid, M., Haq, Z. (2012). *Magnetic stimulation of marigold seed.* International Agrophysics, 26(4), 335–339. https://doi.org/10.2478/v10247-012-0047-1.

Ahmed, S.U., Zuberi, M.I. (1973). Effects of seed size on yield and some of its components in rapeseed, Brassica campestris L. var. Toria. Crop Science, 13, 119–120.

Al-Amery, M., Geneve, R., Sanches, M., Armstrong, P., Maghirang, E., Lee, C., Hildebrand, D. (2018). *Near-infrared spectroscopy used to predict soybean seed germination and vigour.* Seed Science Research, 28(3), 245-252. doi:10.1017/S0962508518000119.

Bányai, J., Barabás, J. (2002). *Handbook on Statistics in Seed Testing.* International Seed Testing Association, Zurich, Switzerland.

Benech-Arnold, R.L., Sánchez, R.A. (2004). *Handbook of seed physiology: applications to agriculture,* The Haworth Press, NY, USA, ISBN: 1-56022-928-4.

Botwright, T.L., Condon, A.G., Rebetzke, G.J., Richards. (2002). *Field evaluation of early vigour for genetic improvement of grain yield in wheat.* Australian Journal of Agricultural Research, 53, 1137–1145.

Czarna, M., Kolodziejczak, M., Janska, H. (2016). *Mitochondrial Proteome Studies in Seeds during Germination.* Proteomes, Volume 4, Number 2, 19-19(1). Directory of Open Access Journals. DOI: https://doi.org/10.3390/proteomes4020019.

Delouche, J.C., Baskin, C.C. (1973). *Accelerated ageing technique for predicting the relative storability of seed lots,* Seed Science and Technology, 1, 427-452. International Seed Testing Association. Zurich. Switzerland.

Dholakia, B.B., Ammiraju, J.S.S., Singh, H., Lagu, M.D., Röder, M.S., Rao, V.S., Dhaliwal, H.S., Ranjekar, P.K., Gupta, V.S., Weber, W.E. (2003). *Molecular marker analysis of kernel size and shape in bread wheat.* Plant Breeding, 122(5), 392–395. Retrieved from: https://doi.org/10.1046/j.1439-0523.2003.00896.x.

Dotto, L., Silva, V.N. (2017). *Beet seed priming with growth regulators.* Semina: Ciências Agrárias, 38(4), 1785. https://doi.org/10.5433/1679-0359.2017v38n4p1785.

European Commission. (2020). *Study on the Union's options to update the existing legislation on the production and marketing of plant reproductive material,* Brussels.

Food and Agriculture Organisation of the United Nations. (2018a). Seeds Toolkit. Module 1: Development of small-scale seed enterprises. The Food and Agriculture Organization of the United Nations and Africa Seeds. Rome. Italy.

Food and Agriculture Organisation of the United Nations. (2018b). Seeds Toolkit. Module 2: Seed processing: principles, equipment, and practice. The Food and Agriculture Organization of the United Nations and Africa Seeds. Rome. Italy.

Food and Agriculture Organisation of the United Nations. (2018c). *Seeds Toolkit. Module 3: Seed quality assurance.* The Food and Agriculture Organization of the United Nations and Africa Seeds. Rome. Italy.

Government of India, Ministry of Agriculture & Farmers Welfare. (2021, November 9). *Seed Testing Manual, Chapter 18: The role of seed testing laboratories under the seed law*, Retrieved from: https://seednet.gov.in/CMS/QualityControl/Seed_Testing_Manual/CHAPTER-18.pdf.

Government of India, Ministry of Agriculture & Farmers Welfare. (2021, November 9). *Seed Testing Manual,* Chapter 4: Seed testing procedures in brief, Retrieved from: https://seednet.gov.in/CMS/QualityControl/Seed_Testing_Manual/CHAPTER-4.pdf.

Hampton, J.G., Colbear, P. (1990). *Potential versus actual seed performance - can vigour testing provide an answer?* Seed Science and Technology, 18, 215-228.

Hampton, J.G., TeKrony, D.M. (1995). *Handbook of Vigor Test Methods,* 3rd Edition, International Seed Testing Association. Zurich. Switzerland.

Heather, D.W., Sieczka, J.B. (1991). *Effect of seed size and cultivar on emergence and stand* *establishment of broccoli in crusted soil*. Journal of the American Society for Horticultural Science 116: 946–949.

Hibbard, R.P., Miller, E.V. (1928). *Biochemical studies on seed viability.* Measurements of conductance and reduction. Plant Physiology, 3, 335-352.

International Rules for Seed Testing. (2024a). *Chapter 2: Sampling.* International Seed Testing Association. Zurich. Switzerland.

International Rules for Seed Testing. (2024b). *Chapter 3: The Purity Analysis, Chapter 4: Other Seeds by number.* International Seed Testing Association. Zurich. Switzerland.

International Rules for Seed Testing. (2024c). *Chapter 5: The germination test.* International Seed Testing Association. Zurich. Switzerland.

International Rules for Seed Testing. (2024d). *Chapter 10: Thousand-seed weight (TSW) determination.* International Seed Testing Association. Zurich. Switzerland.

International Rules for Seed Testing. (2024e). *Chapter 15: The vigour test.* International Seed Testing Association. Zurich. Switzerland.

Jensen, H.A. (2008). *Development of ISTA Purity Analysis and Determination of Other Seeds by Number from 1924 to 2006, Historical Report from the Purity Committee,* International Seed Testing Association, Zurich, Switzerland.

Kozlowski, T.T. (1972). *Seed Biology: Importance, Development, and Germination,* Volume 1, Academic Press, New York, USA.

Kruse, M. (2004). *ISTA Handbook on Seed Sampling, 2nd Edition,* International Seed Testing Association. Zurich, Switzerland.

Léchappé, J. (2009). *Harmonization of seed testing for the facilitation of trade. In Responding to the challenges of a changing world: The role of new plant varieties and high quality seed in agriculture:* Proceedings of the Second World Seed Conference, Session 5 (UPOV Publication No. 354(E)). International Union for the Protection of New Varieties of Plants.

Li, J., Thomson, M., McCouch, S.R. (2004). *Fine Mapping of a Grain-Weight Quantitative Trait* Locus in the Pericentromeric Region of Rice Chromosome 3. Genetics, 168(4), 2187–2195. https://doi.org/10.1534/genetics.104.034165

Marcos-Filho, J. (2015). *Seed vigor testing: an overview of the past, present and future perspective.* Scientia Agricola 72, 363–374.

Matthews, S. (1981). *Evaluation of techniques for germination and vigour studies*. Seed Science and Technology, 9, 543-551.

**Matthews, S., Bradnock, W.T. (1967*). The detection of seed samples of wrinkled-seeded peas (Pisum sativum L.) of potentially low planting value.* Proceedings of the International Seed Testing Association, 32, 553-563.

Mayer, A.M., Poljakoff-Mayber, A. (2014). *The Germination of Seeds,* Elsevier Science, Pergamon Press, England. Retrieved from: https://www.scribd.com/book/282590253/The-Germination-of-Seeds.

Milles, S.R. (1963). *Handbook of Tolerances and of Measures of Precision for Seed Testing.* Proceedings of the International Testing Association, vol. 28, no 3, International Seed Testing Association. Zurich. Switzerland.

Mureșan, T., Pană, N.P., Cseresnyes, Zoia. (1986). *Producerea şi controlul calităţii seminţelor agricole,* Editura Ceres, Bucureşti, România.

Păcurar, I. (2007). *Producerea seminţelor de cereale, leguminoase pentru boabe şi plante tehnice,* Editura Phoenix, Braşov, România.

Perry, D.A. (1978). *Report of vigour Test Committee 1974-1977.* Seed Science and Technology, 6, 159-181, Zurich, Switzerland.

Perry, D.A. (1981). *Introduction in: Handbook of vigour Test Methods.* International Seed Testing Association. Zurich, Switzerland.

Powell, A.A., Matthews, S. (1981). *Evaluation of controlled deterioration, a new vigour test for small seeded vegetables.* Seed Science and Technology, 9, 633-640.

**Powell, A.A., Matthews, S. (1984a*). Prediction of the storage potential of onion seed under commercial storage conditions*. Seed Science and Technology, 12, 641-647.

Powell, A.A., Matthews, S. (1984b). *Application of the controlled deterioration vigour test to detect seed lots of Brussels sprouts with low potential for storage under commercial conditions.* Seed Science and Technology, 12, 647-657.

Roberts, E.H. (1984). *The control of seed quality and its relationship to crop productivity.* Proceedings of the Australian Seed Research Conference, 11-25.

Saux, M., Bleys, B., Thierry, A., Bailly, C., El-Maarouf-Bouteau, H. (2020). *A Correlative Study of Sunflower Seed Vigor Components as Related to Genetic Background.* Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7154842/, USA.

Tan, L., Chen, S., Wang, T., Dai, S. (2013). *Proteomic insights into seed germination in response to environmental factors.* PROTEOMICS, Volume 13, Numbers 12-13, 1 June 2013, pp. 1850-1870(21). Wiley-Blackwell. Retrieved from: https://doi.org/10.1002/pmic.201200394.

TeKrony, D.M. (2003). *Precision is an essential component in seed vigour testing*. Seed Science and Technology, 31, 435-447, International Seed Testing Association, Zurich, Switzerland.

TeKrony, Y.R., Egli, D.B. (1993). *Relationship of seed vigour to crop yield: A review.* Crop Science, 31, 819-822.

The Association of Official Seed Analysts (AOSA). (1983). *Seed vigour testing handbook.* Contribution No. 32 to the Handbook on Seed Testing, Association of Official Seed Analysts. Las Cruces, NM, USA.

Torres, S.B., Marcos-Filho, J. (2005). Physiological potential evaluation in melon seeds (*Cucumis melo* L.), Seed Science and Technology, Volume 33, 341–350, Switzerland.

Vashisth, A., Nagarajan, S. (2010). *Effect on germination and early growth characteristics in sunflower (Helianthus annuus) seeds exposed to static magnetic field,* Journal of Plant Physiology 167, 149–156.

Zhang, K., Zhang, Y., Sung, J., Meng, J., Tao, J. (2021). *Deterioration of orthodox seeds during ageing: Influencing factors, physiological alterations and the role of reactive oxygen species,* Plant Physiology and Biochemistry 158, 475–485.

X-RAY DOSE EFFECTS ON SEEDS GERMINATION AND SEEDLING PERFORMANCE OF EUROPEAN BEECH

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Abstract

The aim of the study was to assess germination dynamics and post-germination adaptation in two populations of European beech (*Fagus sylvatica* L.) seeds collected in autumn 2023 in the 'Plaiul Fagului' State Nature Reserve, Republic of Moldova with contrasting initial viability levels ($PF\text{-}23_{high}$ – 97% and $PF\text{-}23_{low}$ – 57%) under X-ray exposure at doses ranging from 25 to 300 Gy. Germination parameters, including total germination, mean daily germination (MDG), mean germination time (MGT), and germination rate index (GRI), were recorded alongside seedling development under solarium conditions. $PF\text{-}23_{high}$ exhibited a more enhanced response: exposure to 25–125 Gy stimulated earlier and more intense germination (MDG up to 1.55; GRI up to 2.00), with a peak germination of 77.33% at 125 Gy and a 21-day advancement relative to the control. In contrast, $PF\text{-}23_{low}$ showed only moderate stimulation at 25 Gy (germination 65.67%, 13 days earlier than control), and was markedly more sensitive to doses ≥100 Gy, with reduced germination and delayed dynamics (MGT up to 122 days; MDG and GRI consistently lower across treatments). At high doses (200–300 Gy) both populations demonstrated a pronounced decline in germination parameters. Seedling survival under solarium conditions revealed a uniformly negative impact of irradiation: both $PF\text{-}23_{low}$ and $PF\text{-}23_{high}$ showed rapid post-germination mortality, particularly between weeks 6 and 10 at doses ≥50 Gy. Despite the initially higher physiological resilience of $PF\text{-}23_{high}$, neither population exhibited stable adaptation under prolonged post-irradiation stress. These findings may suggest a high level of radiosensitivity in European beech during early ontogenetic development, regardless of initial seed viability.

Keywords: *Fagus sylvatica* seeds, high-viability, low-viability, X-ray irradiation, germination traits

Fagus sylvatica L. (Fagaceae) is one of the key tree species in natural forests of Central Europe, characterized by a moderate lifespan of approximately 300 years and a comparatively late entry into the reproductive phase – at the age of 30-50 years (Packham J.R. *et al*., 2012). The onset of fruiting in European beech varies from 20 to 80 years depending on ecological conditions and growth form – solitary, in stands, or in dense forests (Bonner F.T., Leak W.B., 2008). Stable and abundant fruiting in beech depends on climatic factors and yield cyclicity (Bonner F.T., Leak W.B., 2008; Gavranović Markić A. *et al*., 2024).

Studies conducted across various European regions show that seed yield in *F. sylvatica* is mainly characterized by binary cycles, as well as 3- to 5-year cycles under the influence of various factors (Drobyshev I. *et al*., 2014; Lebourgeois F. *et al*., 2018; Chiavetta U., Marzini S., 2021; Gavranović Markić A. *et al*., 2024). At the same time, the periodicity of mast years varies by region and historical period and may reach 5-7 or even 15-20-year cycles (Piovesan G., Adams J. M., 2001; Drobyshev I. *et al*., 2014; Ascoli D. *et al*., 2017; Brumme R. *et al*., 2021; Hacket-Pain A. *et al*., 2022). Significant changes in mast periodicity are associated with climatic factors such as extreme summer temperatures, drought, and frost during flowering (Nussbaumer A. *et al*., 2020).

Contemporary climate dynamics are increasingly constraining the capacity for natural regeneration of *F.sylvatica* in several parts of its distribution area, particularly in southeastern marginal zones, where elevated heat and drought stress are becoming more prevalent (Bolte A. *et al*., 2016; Muffler L. *et al*., 2021).

Among various approaches to enhancing genetic diversity in plants, radiation-induced mutagenesis remains one of the most reliable and efficient techniques (Ma L. *et al*., 2021). X-rays and gamma radiation are the primary tools in mutation breeding programs, offering promising outcomes for woody species including *F. sylvatica*, which are genetically rich yet have not been subject to intensive selection efforts (Kornienko V.O., Netsvetov M.V., 2016; Holonets R. *et al*., 2021). For example, Holonets et al.)2021) found that gamma irradiation (γ-rays) at a dose of 2 Gy

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significantly increased the germination of *Quercus petraea* acorns to 86.67%. Long-term effects of gamma irradiation on the morphology of *Quercus robur* were also studied (Kornienko V.O., Netsvetov M.V., 2016). Comparable research involving radiation treatments has been extensively carried out on conventional agricultural crops as well as plant species cultivated under *in vitro* conditions (Reznik N. *et al.*, 2021).

Ionizing radiation, including both X-rays and γ-rays, has been actively explored in seed science for its potential to stimulate germination processes in seeds characterized by low physiological quality (Akshatha S. *et al.*, 2013; Holonets R. *et al.*, 2021; Flores-López L.Y. *et al.*, 2022; Beyaz R., Macadam J.W., 2023). When applied at low intensities (10–100 Gy), such irradiation can trigger a cascade of beneficial responses, including enhanced metabolic activity, increased permeability of the seed coat, activation of antioxidant defenses, and initiation of DNA repair, ultimately resulting in improved and accelerated germination (Akshatha S. *et al.*, 2013; Beyaz R., Macadam J.W., 2023). Such effects have been observed in the seeds of certain oak species (*Q.robur* and *Q. petraea*), which belong to the Fagaceae family and share close physiological and ecological traits with *F. sylvatica* (Kornienko V.O., Netsvetov M.V., 2016; Holonets R. *et al.*, 2021). Recent studies conducted on two genotypes of okra (*Hibiscus esculentus* L.) showed that low doses of X-ray irradiation (up to 5 Gy) stimulated seed germination, seedling growth, and antioxidant activity, while higher doses caused oxidative stress and suppressed plant development (Rezk A.A., *et al.*, 2019). Studies on *Rhynchostylis retusa* orchid seeds have shown that low doses of X-ray irradiation (up to 4 rad) enhance seed germination and seedling morphological development, including shoot, root, and leaf growth (Paul M. *et al.*, 2021). These findings highlight the potential of X-rays specifically for stimulating physiological processes and improving germination, which is particularly important for species with low seed viability.

Nevertheless, specific data concerning the response of *F. sylvatica* seeds to X-ray irradiation are scarce in the current literature. This gap is especially important in the context of poor mast years, when beech seeds often display reduced viability due to incomplete physiological development, embryonic abnormalities, or unfavorable storage conditions. Under these conditions, conventional pre-sowing treatments such as stratification and scarification frequently prove ineffective in improving germination outcomes (Ratajczak E. *et al.*, 2015; Małecka A. *et al.*, 2021).

As a result, applying low-dose X-ray irradiation may serve as a valuable alternative for improving germination rates in physiologically weak or dormant beech seeds, particularly under circumstances of limited high-quality seed stock. This strategy holds both practical relevance for seedling production and forest regeneration initiatives, and scientific value for exploring the radiotolerance of tree seeds.

The aim of this study is to evaluate how varying doses of X-ray exposure influence the germination performance of *Fagus sylvatica* seeds with differing levels of viability, and to assess the potential applicability of this method for enhancing seedling adaptation during early stages of development.

MATERIAL AND METHOD

The experiments were carried out in the laboratory Natural Bioregulators, in solarium of the Institute of Genetics, Physiology and Plant Protection, Moldova State University during 2024-2025. The seeds of *F. sylvatica* collected in autumn 2023 from the “Plaiul Fagului” Nature Reserve, Republic of Moldova (hereafter referred to as population PF-23) with different initial viability levels (high – 97%, PF-23_{high}, and low – 57%, PF-23_{low}) were used in the study.

The viability of seeds was determined by test using the 2.3.5-triphenyltetrazolium chloride (TTC) solution (França-Neto J.B., Krzyzanowski F.C., 2019).

X-ray irradiation of beech seeds were carried out following the Protocol for X-ray mutagenesis of plant material using an RS-2400 X-ray device, with doses ranging from 25 to 300 Gy (Protocol for X-ray mutagenesis of plant material: seeds, 2010; FAO/IAEA, 2018; Reznik N. *et al.,* 2021; Chanim A.M.A., 2024). Each variant of irradiation consisted of three replicates of 100 seeds each. The control variant included seeds that were not exposed to irradiation. After X-ray irradiation, the seeds were germinated during cold stratification at +4±1°C. Monitoring of seed germination was carried out each 7 days for the period of 150 days of stratification. The total germination percentage (TGP), mean daily germination (MDG), mean germination time (MGT) and germination rate index (GRI) were calculated using formulas described by F. Al-Ansari and T. Ksiksi (2016).

Root length of the germinated beech seeds was measured using a VOREL digital caliper with a resolution 0.1mm and an accuracy of ±0.2 mm.

Beech seedling emergence studies were carried out by planting in substrate under solarium conditions (unheated greenhouse) with regulated humidity. The experiment was conducted in a randomized design with three replicates per variant.

Statistical analysis. The results were analyzed using Statgraphics Plus 5.0 software, applying standard statistical procedures including one-way ANOVA and Multiple Range Tests at a significance level of $p \leq 0.05$ (Tukey's HSD — Honestly Significant Difference and LSD – Least Significant Difference).

RESULTS AND DISCUSSIONS

A comparative analysis of seed germination in European beech (*F. sylvatica*) from populations with low ($PF\text{-}23_{low}$) and high ($PF\text{-}23_{high}$) initial viability revealed that the total germination percentage of control seeds on the 150th day of stratification differed insignificantly between the two populations and averaged 63.33% and 67.33%, respectively, for $PF\text{-}23_{low}$ and $PF\text{-}23_{high}$. Although germination in both populations started at approximately the same time (on the 63rd day of stratification), their germination dynamics differed markedly. By the 80th day of stratification, germination in the $PF\text{-}23_{low}$ population was observed only in the 25 and 75 Gy treatments (0.33–0.67%). In contrast, in the $PF\text{-}23_{high}$ population, germination occurred in the control and in all irradiated treatments (0.33–2.33%), except at the highest dose of 300 Gy (*figure 1*).

In $PF\text{-}23_{high}$, germination progressed at a faster rate compared to $PF\text{-}23_{low}$ – more than 20% of seeds had germinated by the 105th day, particularly in the 25 and 50 Gy doses (28.0–30.0%). The majority of seeds in $PF\text{-}23_{high}$ germinated by the 120th day, which was 15 days earlier than in $PF\text{-}23_{low}$, where peak germination occurred only by the 135th day. This indicates higher metabolic activity and a faster response to stimulatory exposure in the more viable $PF\text{-}23_{high}$ population.

Irradiation with the lowest dose of 25 Gy had a stimulatory effect on both populations, though to different extents: an increase of 6.67% in $PF\text{-}23_{high}$ and 2.34% in $PF\text{-}23_{low}$ compared to the control. With increasing doses (50–100 Gy), the proportion of germinated seeds in $PF\text{-}23_{low}$ decreased compared to both the control and the 25 Gy treatment (down to 56.33–59.67%), while in $PF\text{-}23_{high}$ a high germination level was maintained (71.33–72.67%) (*figure 1*).

At 125 Gy, a marked divergence was observed: $PF\text{-}23_{low}$ showed suppression (46.33%), whereas $PF\text{-}23_{high}$ exhibited the strongest stimulatory effect (77.33%). At high irradiation doses (200–300 Gy), $PF\text{-}23_{low}$ displayed pronounced inhibition of germination, while $PF\text{-}23_{high}$ retained high viability (58.67–59.00%) (*figure 1*). It was found that in $PF\text{-}23_{high}$, irradiation at 25–125 Gy resulted in earlier germination compared to the control, while in $PF\text{-}23_{low}$ only the 25 Gy dose provided a moderately higher germination rate than the control (*figure 1*).

Statistical analysis (Multiple Range Tests, $p \leq 0.05$, Tukey's HSD and LSD) revealed that although the mean germination values in the 50, 75, and 100 Gy treatments for $PF\text{-}23_{low}$ were lower than those in the control and the 25 Gy treatment, these differences were not statistically significant ($p \leq 0.05$) (*figure 2*). Similarly, no statistically significant differences were found between the 25–125 Gy treatments and the control in the $PF\text{-}23_{high}$ population (*figure 2*).

At the same time, for $PF\text{-}23_{low}$, germination in the high-dose treatments (200–300 Gy) was significantly lower than in the control, whereas in $PF\text{-}23_{high}$, germination in these variants was at the level of the control and significantly lower than at 25, 100, and 125 Gy (*figure 2*).

Statistical analysis confirmed that for $PF\text{-}23_{low}$, only the control and the 25 Gy treatment provided significantly higher germination compared to the 200 and 300 Gy treatments (*figure 2*).

An analysis of Mean Daily Germination (MDG), Mean Germination Time (MGT), and Germination Rate Index (GRI) supported the differences in seed germination between populations of different initial viability: $PF\text{-}23_{high}$ showed higher MDG and GRI values and shorter MGT across all treatments (*table 1*).

In $PF\text{-}23_{high}$, irradiation at 25 Gy produced a slight stimulatory effect, with minor increases in MDG and GRI and a slight reduction in MGT. However, starting from 50 Gy, there was a gradual decline in MDG and GRI along with increased MGT, indicating the onset of stress response. At 200 and 300 Gy, values dropped sharply: MDG decreased to 0.50–0.70, GRI to 0.63–0.84, and MGT reached its maximum, indicating a strong inhibitory effect of high doses (*table 1*).

In contrast, the $PF\text{-}23_{high}$ population exhibited a positive response to irradiation at 25–125 Gy: MDG and GRI increased progressively, peaking at 125 Gy (1.55 and 2.00, respectively), while MGT remained in the range of 112.95–117.67 days – significantly lower than in $PF\text{-}23_{low}$, including its control (121.91). At high doses (200–300 Gy), $PF\text{-}23_{high}$ values also declined, but remained higher than those of $PF\text{-}23_{low}$ at comparable doses and were similar to the control values of the less viable population (*table 1*). This indicates higher resistance to X-ray irradiation and an enhanced capacity to compensate for radiation-induced stress in $PF\text{-}23_{high}$.

Overall, the results confirm that physiological responses to irradiation were strongly dependent on the initial viability of seeds. While PF-23_{low} demonstrated pronounced sensitivity and reduced germination rates even at moderate doses, PF-23_{high} exhibited stable adaptive responses, including accelerated germination and enhanced intensity under stimulatory exposures.

Thus, the reaction to irradiation directly depended on the initial viability of seeds. The PF-23_{high} population maintained a consistently high germination rate across the entire dose range up to 125 Gy and showed particular sensitivity to the 125 Gy dose (peak stimulatory effect). Even at 300 Gy, germination remained high (>50%). PF-23_{low} exhibited only a slight increase in germination at 25 Gy and, starting from 100 Gy, seed germination declined relative to the control. At doses ≥125 Gy, germination of beech seeds in PF-23_{low} was significantly lower than in PF-23_{high}.

The PF-23_{high} population demonstrated greater tolerance to X-ray irradiation during stratification. In contrast, PF-23_{low} showed high sensitivity to doses ≥100 Gy and no statistically significant positive response to low irradiation doses.

An analysis of beech seedling survival under solarium conditions showed that irradiation had a pronounced negative effect on seedling adaptation regardless of the initial viability of the population. Both populations – PF-23_{low} and PF-23_{high} exhibited a sharp decline in the number of viable seedlings within 3–6 weeks post-germination (*figure 3 a, b*).

At early stages (1–2 weeks post-germination), seedling survival was relatively high in the 25 Gy and control treatments, especially in PF-23_{high}. However, this effect proved temporary. By the 6th and especially the 10th week, almost all seedlings derived from seeds irradiated at 50 Gy and above had died. Even in the control, there was a noticeable reduction in the number of viable seedlings, particularly in the PF-23_{low} population, indicating generally low resistance (*figure 3 a, b*).

Therefore, irradiation adversely affected not only initial seed germination but also further adaptation and survival of beech plants under solarium conditions. Neither population showed a stable adaptive response to increasing doses, suggesting high sensitivity of beech to X-ray irradiation during the early stages of ontogenesis.

Our findings on the radiosensitivity of European beech during early ontogenetic stages are consistent with several studies on the effects of ionizing radiation on seed germination in other species. For example, Hong M.J., et al. (2018) reported that low doses of gamma radiation up to 10 Gy stimulate germination and seedling growth in wheat, resembling the hormetic responses we observed in *F. sylvatica* under X-ray exposure (i.e., enhanced germination in the PF-23 high population at 25–125 Gy) (Hong M.J. *et al.*, 2018).

Similarly, recent studies on European beech seeds from the same nature reserve (Plaiul Fagului State Nature Reserve, Republic of Moldova) indicate that X-ray doses ranging from 50 to 300 Gy reduce viability by approximately 40–50%, supporting our conclusions regarding the significant population decline in PF-23low under higher doses (Elisovetcaia D. *et al.*, 2024).

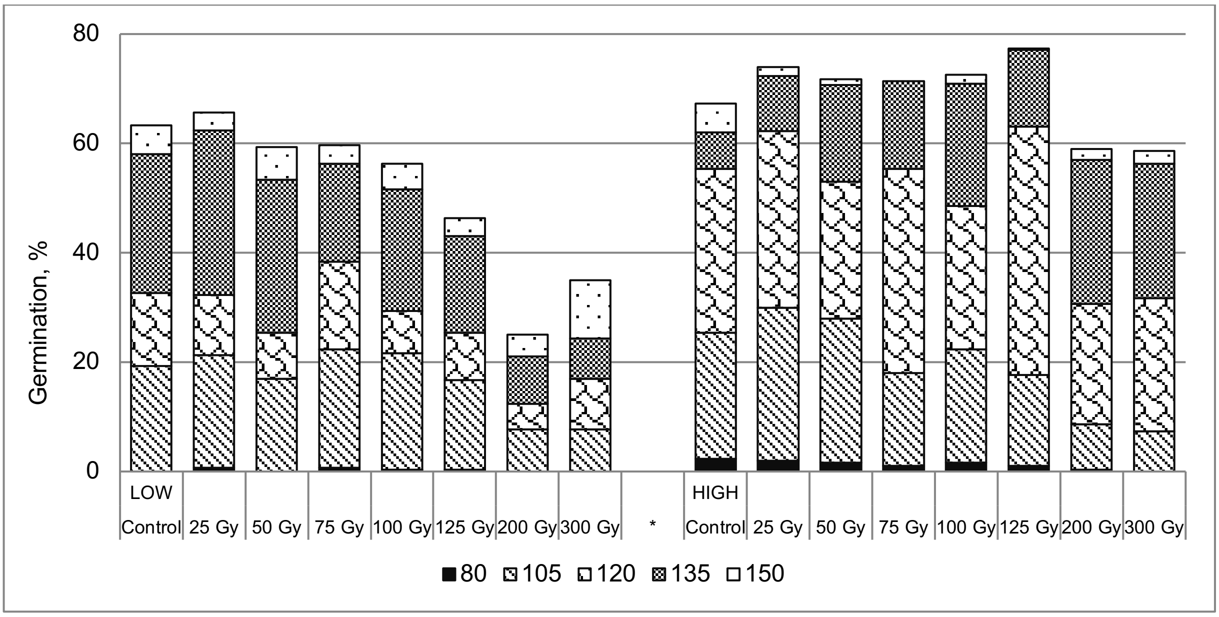


Figure 1 **Germination dynamics of beech seeds from the Plaiul Fagului-23 populations with low and high initial viability exposed to different X-ray irradiation doses during stratification under controlled laboratory conditions**

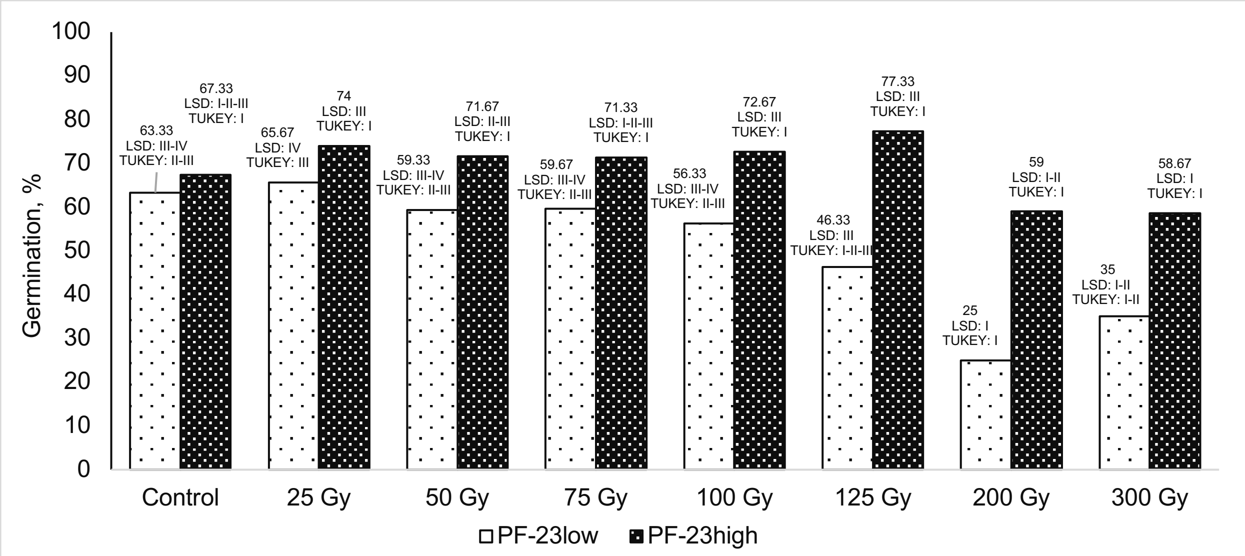
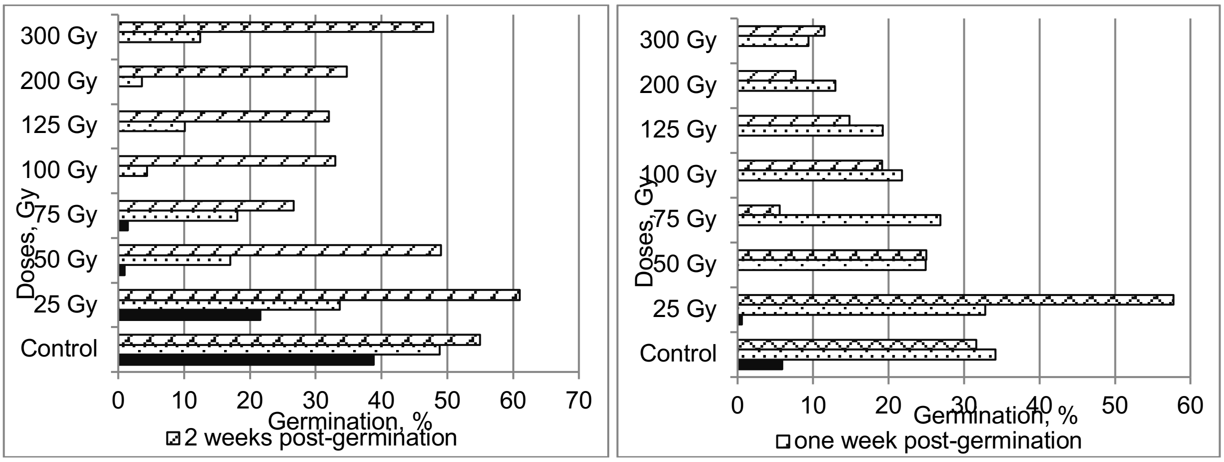


Figure 2 **Significance of differences in total germination percentage of beech seeds from the Plaiul Fagului-23 population with low and high initial viability exposed to different irradiation doses assessed using Multiple Range Tests (LSD and Tukey HSD)**

Table 1

Germination indices of beech seeds from the Plaiul Fagului-23 population with low and high initial viability exposed to different doses on the 150th day of stratification

Dose of irradiation	$PF\text{-}23_{low}$			$PF\text{-}23_{high}$		
	Mean daily germination (MDG)	Mean germination time (MGT)	Germination rate index (GRI)	Mean daily germination (MDG)	Mean germination time (MGT)	Germination rate index (GRI)
Control	1.27	121.91	1.60	1.35	114.19	1.80
25 Gy	1.31	120.90	1.68	1.48	112.95	1.99
50 Gy	1.19	123.80	1.48	1.43	115.48	1.89
75 Gy	1.19	118.38	1.56	1.43	116.14	1.86
100 Gy	1.13	119.66	1.46	1.45	117.67	1.88
125 Gy	0.93	120.00	1.19	1.55	116.95	2.00
200 Gy	0.50	123.37	0.63	1.18	122.93	1.46
300 Gy	0.70	127.68	0.84	1.17	124.26	1.43



a b

Figure 3 **The effect of X-ray radiation doses on the germination dynamics and plant adaptation of Plaiul Fagului-23 populations with low (a) and high (b) initial viability under solarium conditions**

Overall, the comparisons indicate that low to moderate irradiation doses may lead to a slight stimulatory effect, particularly in populations with higher initial viability. However, this effect remains limited and does not persist under higher or prolonged exposures. These observations contribute to the general knowledge of radiosensitivity in beech seeds during early developmental stages and can serve as a basis for further studies on stress resilience and adaptive potential.

CONCLUSIONS

The study demonstrated that the physiological response of European beech (*Fagus sylvatica* L.) seeds and seedlings to X-ray irradiation is strongly influenced by the initial viability of the seed population. The high-viability population ($PF\text{-}23_{high}$) showed enhanced germination performance and greater tolerance to irradiation up to 125 Gy, including earlier and more uniform germination. In contrast, the low-viability population ($PF\text{-}23_{low}$) exhibited lower total germination percentage and was more sensitive to increasing doses, especially ≥100 Gy. Despite these differences, both populations experienced severe post-germination seedling mortality under solarium conditions, particularly at doses of 50 Gy and above. These findings may suggest a generally high radiosensitivity of European beech during early ontogenetic development, with limited adaptive capacity under combined radiation and environmental stress.

ACKNOWLEGMENTS

This study was supported by the Ministry of Education and Research of the Republic of Moldova within the Subprogram 011101 “Genetic and biotechnological approaches to agroecosystem management under climate change conditions” for 2024-2027 and in the project in flame of bilateral cooperation between the Republic of Moldova and the Slovak Republic for academic year 2023-2024, supported by the Ministry of Education, Science, Research and Sports of the Slovak Republic.

REFERENCES

Akshatha S., Chandrashekar K.R., Somashekarappa H.M., Souframanien J., 2013 – *Effect of gamma irradiation on germination, growth, and biochemical parameters of Terminalia arjuna Roxb.* Radiation Protection and Environment, 36(1):38-44. Available at: https://doi.org/10.4103/0972-0464.121826

Al-Ansari F., Ksiksi T., 2016 - A quantitative assessment of germination parameters: the case of *Crotalaria persica* and *Tephrosia apollinea*. The Open Ecology Journal, 9:13-21. Available at: https://doi.org/10.2174/1874213001609010013.

Ascoli D., Maringer J., Hacket-Pain A., et al., 2017 – *Two centuries of masting data for European beech and Norway spruce across the European continent.* Ecology, 98(5):1473. Available at: https://doi.org/10.1002/ecy.1785.

Beyaz R., Macadam J. W., 2023 – *X-radiation of Lotus corniculatus L. seeds improves germination and initial seedling growth.* International Journal of Radiation Biology, 99(5):1-18. Available at: https://doi.org/10.1080/09553002.2023.2204961

Bolte A, Czajkowski T, Cocozza C., et al., 2016 – *Desiccation and Mortality Dynamics in Seedlings of Different European Beech (Fagus sylvatica L.) Populations under Extreme Drought Conditions.* Front. Plant Sci. 7:751. Available at: https://doi.org/10.3389/fpls.2016.00751

Bonner F.T., Leak W.B., 2008 – *Fagaceae – Beech family. Fagus L. beech. In: The Woody Plant Seed Manual. United States Department of Agriculture, Forest Service*, Agriculture Handbook No. 727. Eds. Bonner F. T., Karrfalt R.P., ed. Coord. Nisley R.G. Washington, USDA Forest Service. pp. 520-524. Available at: https://www.fs.usda.gov/rm/pubs_series/wo/wo_ah727.pdf.

Brumme R., Ahrends B., Block J., et al., 2021 – *Cycling and retention of nitrogen in European beech (Fagus sylvatica L.) ecosystems under elevated fructification frequency*. Biogeosciences, 18(12):3763–3779. Available at: https://doi.org/10.5194/bg-18-3763-2021.

Chiavetta U., Marzini S., 2021 – *foreMast: an R package for predicting beech (Fagus sylvatica L.) masting events in European countries*. Annals of Forest Science, 78:93. Available at: https://doi.org/10.1007/s13595-021-01109-5.

Drobyshev I., Niklaussona M., Mazerolle M.J., Bergeron Y., 2014 – *Reconstruction of a 253-year long mast record of European beech reveals its association with large scale temperature variability and no long-term trend in mast frequencies*. Agricultural and Forest Meteorology, 192-193: 9-17. Available at: https://core.ac.uk/download/pdf/323908747.pdf

Elisovetcaia D., Ivanova R., Fedorenco E., 2024 – Effect of x-ray radiation on the viability of European beech seeds. *Materials Proceedings of the VIIIth International Scientific Conference “Genetics, Physiology and Plant Breeding”, 07–08 October 2024, Chisinau*. Chişinău: S.n., pp. 348–354. ISBN 978-9975-62-766-5. Available at: https://doi.org/10.53040/gppb8.2024.60

FAO/IAEA, 2018 - *Manual on Mutation Breeding – Third edition*. In: Spencer-Lopes, M.M., Forster, B.P. and Jankuloski, L. (eds.), *Food and Agriculture Organization of the United Nations*. Rome, Italy. 301 pp. ISBN 978-92-5-130526-3

Flores-López L. Y., Iglesias-Andreu L. G., Palaox-Chávez M. L., 2022 – *Radiohormetic effect on the germination of Pinus pseudostrobus Lindl. seeds irradiated with linear accelerator*. Preprint. Available at: https://doi.org/10.21203/rs.3.rs-2002227/v1.

França-Neto J.B., Krzyzanowski F.C., 2019 – *Tetrazolium: an important test for physiological seed quality evaluation.* Journal of Seed Science, 41(3):359-366. Available at: https://doi.org/10.1590/2317-1545v41n3223104

Gavranović Markić A., Vujnović Z., Kičić M., Ivanković M., 2024 – *Seed Quantity and Quality Variation in European Beech (Fagus sylvatica L.): A Comparative Analysis of Different Crop Years*. South-East European Forestry *(SEEFOR)*, 15(1):1-12. Available at: https://doi.org/10.15177/seefor.24-03.

Ghanim A.M.A., 2024 – *Physical Mutagenesis in Cereal Crops*. In: Ghanim, A.M.A., Sivasankar, S., Rich, P.J. (eds) *Mutation Breeding and Efficiency Enhancing Technologies for Resistance to Striga in Cereals. Springer*, Berlin, Heidelberg. Available at: https://doi.org/10.1007/978-3-662-68181-7_2

Hacket-Pain A., Foest J.J., Pearse I.S., et al., 2022 – *MASTREE+: Time-series of plant reproductive effort from six continents*. Global Change Biology, 28(9): 3066–3082. Available at: https://doi.org/10.1111/gcb.16130

Holonec R., Viman O., Morar I.M., et al. 2021 – *Non-chemical treatments to improve the seeds germination and plantlets growth of sessile oak*. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 49(3):12401, https://doi.org/10.15835/nbha49312401

Hong M.J., Kim D.Y., Ahn J.W., Kang S.Y., Seo Y.W., Kim J.B., 2018 – *Comparison of radiosensitivity response to acute and chronic gamma irradiation in colored wheat.* Genetics and Molecular Biology, 41(3):611–623. Available at: https://doi.org/10.1590/1678-4685-GMB-2017-0189

Kornienko V. O., Netsvetov M. V., 2016 – *The effect of radiation exposure on the architecture of the aerial part of pedunculate oak (*Quercus robur *L.).* Scientific Bulletin of the National Forestry University of Ukraine, 3: 93–99. Available at: https://cyberleninka.ru/article/n/vliyanie-radiatsionnogo-oblucheniya-na-arhitektoniku-nadzemnoy-chasti-duba-chereshchatogo-quercus-robur-l

Lebourgeois F., Delpierre N., Dufrêne E., Cecchini S., Macé S., Croisé L., Nicolas M., 2018 – *Assessing the roles of temperature, carbon inputs and airborne pollen as drivers of fructification in European temperate deciduous forests*. European Journal of Forest Research, 137(3):27. Available at: https://doi.org/10.1007/s10342-018-1108-1

Ma L., Kong F., Sun K., Wang T., Guo T., 2021 – *From Classical Radiation to Modern Radiation: Past, Present, and Future of Radiation Mutation Breeding*. Front. Public Health, 9: 768071. Available at: https://doi.org/10.3389/fpubh.2021.768071

Małecka A., Ciszewska L., Staszak A., Ratajczak E., 2021 – *Relationship between mitochondrial changes and seed aging as a limitation of viability for the storage of beech seed (*Fagus sylvatica *L.).* PeerJ, 9:e10569. Available at: https://doi.org/10.7717/peerj.10569

Muffler L., Schmeddes J., Weigel R., Barbeta A. et al., 2021 – *High plasticity in germination and establishment success in the dominant forest tree Fagus sylvatica across Europe*. Global Ecology and Biogeography, 30(8): 1583-1596. Available at: https://doi.org/10.1111/geb.13320

Nedealcov M., Apostol L., Donica A., Grigoraș N., 2020 – *Climatic and ecological constraints in the distribution of European beech (Fagus sylvatica) at the eastern limit (Scientific Reserve "Plaiul Fagului")*. Academic Journal Present Environment and Sustainable Development, 14(1):255–263. Available at: https://doi.org/10.15551/pesd2020141020

Nussbaumer A., Meusburger K., Schmitt M., et al., 2020 – *Extreme Summer Heat and Drought Lead to Early Fruit Abortion in European Beech (Fagus sylvatica L.).* Scientific Reports, 10(1). Available at: https://doi.org/10.1038/s41598-020-62073-0.

Packham J.R., Thomas P.A., Atkinson M.D., Degen T., 2012 – *Biological Flora of the British Isles: Fagus sylvatica*. In: Journal of Ecology, 100(6):1557–1608. Available at: https://doi.org/10.1111/j.1365-2745.2012.02017.x.

Paul M., Kropi M., Gogoi P., Basumataty N., Penna S., Bora R.K., 2021 – *X-Ray irradiation induced effects on Seed Germination and Growth characteristics of Rhynchostylis retusa (L) Bl.* In: Wild Edible Bioresources of North East India. EBH Publishers (India), Guwahati. ISBN 978-93-904-34-58-9 Available on: https://www.researchgate.net/publication/376184091_X-Ray_irradiation_induced_effects_on_Seed_Germination_and_Growth_characteristics_of_Rhynchostylis_retusa_L_Bl

Piovesan G., Adams J. M., 2001 – *Masting behavior in beech: Linking reproduction and climate variability*. New Phytologist, 149(3):431-439. Available at: https://doi.org/10.1046/j.1469-8137.2001.00034.x

Protocol for X-ray mutagenesis of plant material: seed, 2010 – *Joint FAO/IAEA Centre of Nuclear Techniques in Food and Agriculture*. Available at: https://www.iaea.org/sites/default/files/21/07/nafa-pbg-manual-protocol-x-ray-mutagenesis-plants.pdf

Ratajczak E., Małecka A., Bagniewska-Zadworna A., Kalemba E.M., 2015 – *The production, localization and spreading of reactive oxygen species contributes to the low vitality of long-term stored common beech (*Fagus sylvatica *L.) seeds.* Journal of Plant Physiology, 174: 147–156. Available at: https://doi.org/10.1016/j.jplph.2014.08.021

Rezk A.A., Al-Khayri J.M., Al-Bahrany A.M., El-Beltagi H.S.; Mohamed H.I., 2019 – X-*ray irradiation changes germination and biochemical analysis of two genotypes of okra (Hibiscus esculentus L.).* Functional Plant Science and Biotechnology, 13(1):35–42. Available at: https://doi.org/10.1080/16878507.2019.1680188

Reznik N., Subedi B.S., Weizman S., et al., 2021 – *Use of X-ray Mutagenesis to Increase Genetic Diversity of Zantedeschia aethiopica for Early Flowering, Improved Tolerance to Bacterial Soft Rot, and Higher Yield*. Agronomy, 11:2537. Available at: https://doi.org/10.3390/agronomy11122537

LEARNING RESILIENCE FROM RESURRECTION PLANTS – A BOTANICAL, LITERARY AND PSYCHOLOGICAL APPROACH TO POEMS FROM AMERICAN, AUSTRALIAN AND GERMAN LITERATURE

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Abstract

The concept of resilience is constantly making the headlines with regard to every aspect of life spanning from the environmental and economic areas to the fundamentally social and personal spheres of our existence. It becomes even more striking when it is represented by plants, the Resurrection plants, and becomes the core muse for poetry – the public artistic manifestation of the inner workings of the hearts and minds of people pondering on relationships and life issues. The present study aims at pinpointing the essential traits of these plants from the botanical perspective, reflected in several American, Australian and German poems and echoing in the much desired emotional intelligence competences that people need to acquire nowadays. The conclusion that can be drawn is that the environment plays a crucial role both in ensuring the survival conditions of plants and humans as well as in facilitating the acquisition of essential adaptive mechanisms and the mastery of resilience which culminates in the preservation of life and hope.

Keywords: Resurrection plants, plant poems, resilience, adaptive mechanisms, emotional intelligence competences

In all spheres of life there has been a constant emphasis on the concept of resilience and the necessity of acquiring and enhancing this competence as a desirable strategy for survival. The American Psychological Association (APA) defines resilience as “The process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioral flexibility and adjustment to external and internal demands.” Furthermore, among the factors mentioned by the association as contributors to the good adaptation to adversities, the most notable are: “the availability and quality of social resources” and the “specific coping strategies” (APA, 2022, https://www.apa.org/topics/resilience), factors that hold true with regard to the world of plants as well.

Advocating a return to nature means recognizing that people need to develop an actively nourished awareness of the traits the natural world possesses and of the lessons we can extract from observing these traits. All things in nature have been designed with an amazing internal capacity to withstand adversity and regenerate. There is a strong connection between the background of one’s existence and the fostering of resilience both in the case of people and plants. For humans, the background is represented by the social connections and the cultural context, supplied by the internal resources that have been nurtured over time, such as self-awareness, self-esteem and self-efficacy. On the other hand, the background factors that influence the resilience and adaptive mechanisms of plants comprise soil, the availability of water and nutrients as well as the proximity to other plants.

A paradox in the world of plants is the existence of the so-called Resurrection plants, which seem to furnish relevant lessons for survival and arouse hope regarding the continuation of life. Pondering on the death of plants with a keener consideration of the Australian poet John Kinsella’s work, John C. Ryan highlights “the uncanny aptitude” of Resurrection plants, which represent “a small grouping of species that occur globally and can survive complete desiccation”, to resume “normal physiological function when rehydrated”, being thus able “to return from the brink of ordinarily death-dealing conditions, specifically drought and dehydration” (Ryan. J. C., 2016). Although the precise mechanism of reverting the metabolic arrest is still a mystery, “a subset of resurrection plants, characterized as poikilochlorophyllous” make use of “protein-mediated biochemical pathways to disassemble their chloroplasts and degrade their chlorophyll, which are then resynthesized during rewetting” (Ryan. J. C., 2016). Belonging to this subset is the particular plant called the Rose of Jericho which

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"retains its singular property of expansion by the absorption of water, and of contraction when dried for a long course of years" (Millar J. M. D., 1821). While there are many stories and superstitions connected to the Rose of Jericho, this particular plant was also distinguished "in later botanical works" by the name "Anastatica, derived from its property of reviving in water" (Millar J. M. D., 1821). While the true Rose of Jericho "scientifically known as Anastatic hierochuntica, is a desert plant native to the Middle East near the Dead Sea in Israel" (Jericho R.O., 2023) and "the only species of the genus Anastatica of the mustard family (Brassicaceae)" (Britannica Editors, 1998), the "false rose of Jericho or resurrection fern (Selaginella lepidophylla), is native to the Chihuahuan Desert of the United States and Mexico and is a member of the spike moss family (Selaginellaceae)" (Britannica Editors, 1998). Another Resurrection plant native to Western Australia is "the pincushion lily (Borya nitida)" (Ryan. J. C., 2016) around which Kinsella's poem *Resurrection Plants at Nookaminnie Rock* is woven. What unites these plants is their "courting death by paring down—then resuscitating—physiological processes in correspondence to fluctuating ecological circumstances" (Ryan. J. C., 2016). J. C. Ryan goes as far as to see in plant-death the "immanent, embodied expression of vegetative ensoulment" and - meditating on the Aristotelian entelechy - he asserts that "The latent potential for aliveness inheres within the potential for death, and the reverse is true." (Ryan. J. C., 2016).

The vivid awareness of the natural cycles plants follow and the biogenic or anthropogenic factors that may intervene have found expression in the works of many authors that may or may not have been native to the areas where these plants grow. In this study we are considering the works of the American poets: Harriet McEwen Kimball and Mollie Evelyn Moore Davis (both of them living through most of the 19th century), as well as those of Laura Sobbott Ross and Cindy Veach (contemporary poets). For a diverse perspective, John Kinsella's poem from the contemporary Australian background and Ferdinand Brunold's work from the German area (19th century) have been selected. The choice of these poems is grounded in the potential of Resurrection plants – either the true or the false Rose of Jericho, or the pincushion lily native to Australia – to bring to light the physical traits and the physiological characteristics of these plants masterfully depictive of the psychological competences humans should strive to master.

MATERIAL AND METHOD

In this study we approached six poems from the botanical, literary and psychological perspective in order to see how poets have perceived the specific plants and have highlighted the traits of the plant that are revelatory with regard to the psychological lessons one can infer. The purpose was to see whether the poems preserve the keenness of the scientific description of the traits and the life cycles of these plants.

The two poems from the 19th century depict either the Rose of Jericho – in Harriet McEwen Kimball's poem – and most likely "the resurrection moss, S. lepidophylla inhabiting the southern United States as a tumbleweed" (Ryan J. C., 2017) in Mollie Evelyn Moore Davis's poem. What these two poems have in common is the religious reverence with which the two plants are perceived and described and the eternal lessons inscribed in their particularly surprising life cycles. Harriet McEwen Kimball's poem contextualizes the plant in Joseph's and Mary's times when they fled to Egypt in order to preserve the life of baby Jesus:

"As through the desert wild they went
By angels led and undismayed,
A flower sprang up of sweetest scent
Where'er the Virgin's steps were stayed.

'T is fabled that this flower since then
Blooms only on some feast-day high,
And chiefly when comes round again
The Feast of Christ's Nativity."

The thoughts of the poet revolve only in the transcendental realm of meaning and her verses hint directly at the lesson one can learn from the Rose of Jericho:

"*When through life's desert places led*
By holy angels unaware,
Intent on mercy's deeds you tread
And make God's needy ones your care,

If in your arms the Christ Child dear
You carry wheresoe'er you go,
In every place earth's wilds to cheer
Will spring the Rose of Jericho."

(Kimball H. M., *The Rose of Jericho*)

The reader discovers thus that the Rose of Jericho thrives even in desert places, which turns resilience into a core symbol. The imagery created is that of the dry tumbleweed that may travel driven by the wind in a state of closely intertwined branches which may resemble human arms holding closely something precious in this constrained embrace.

Mollie Evelyn Moore Davis's poem *The Resurrection Plant* accurately describes the Resurrection plant in its state of life arrest: *"The useless thing was cast aside/ A mesh of black and withered roots"* which had nothing that promised beauty of life: *"The unsightly thing/ Lay rotting in the garden there"* (Moore M. E., 1872). The poet sees the human intervention as a rescuing force:

"Till one with youth upon her lips
And golden ripples in her hair,

Outspread it in a crystal dish
And showered pure water on its breast,
And placed it where the blossoms bloomed;
When lo! this plant outshone the rest!

The wonder of the resurrection of the dead plant is accompanied by a fair description of its traits when revived:

"Dainty and daintier emerald leaves
That all their crystal prison spanned,
And still more emerald heart that glowed!
The fairest thing in all the land!"

The lesson the poet offers brims with hope for those who may be experiencing a forlorn, desperate state of lifelessness, and names precisely the reviving factor of such plants which is water:

"Therefore, oh fainting hearts, take heart,
For God is patient: He can wait
The budding and the leafing-time;
He never cries "Unclean! Too late!"
…
I think He dips His pitying hand
In that fair River's waves, that flows
Fast by His Throne, upon whose banks
The never-fading Lily grows…" (Moore M. E., 1872)

The contemporary poets Laura Sobbott Ross and Cindy Veach move the focus on these plants as gifts that carry a certain deep meaning. Ross's poem unveils the poet's wonder at being offered a plant that possesses a rather uncomely aspect:

"Frills so startled by the atmosphere,
they faint, go brown with introspection.
Verdant sounds like a crushed succulence—
humid and emerald, not like these
ferns he's unstitched from hundred-year-old
live oaks whisper chipped into submission.
…
What makes a living thing mutate its genes
so it could appear dead for a hundred years
and revive after a single soaking?" (Ross L. S., 2012)

The rhetorical question on which the poet ponders invites researches to unveil the mystery behind the resurrection power of this plant which possesses a "persistent green heart" (Ross L.S., 2012) highlighting the existence of life in death, the hope of revival and the unexpected transition from being "brown with introspection" to "verdant", emerald succulence.

Cindy Veach's poem is even more rooted in the reality of our days: *"I'm not sure about this gift. This tangle/ of dried roots curled into a fist. This gnarl/ I've let sit for weeks beside the toaster/ and cookbooks on a bed of speckled granite."* (Veach C., 2003) Projected on a very domestic background, this plant sends the poet wondering about its miraculous effects praised by many but which she refuses to acknowledge, testifying that she doesn't believe in omens. The deprecatory description of the plant adds to the little if any significance that she is ready to attach to it: *"This still fist/ of possibility all wrapped up in itself.", "Dormant."* However, an inch of water sprinkled on it *"out of curiosity"* is meant to stir the surprise of a soul dormant in disbelief. What follows is a description of the stages in which this plant comes to life as well as of the poet's refusal to attach any deeper, religious interpretation to this form of resurrection:

"out of curiosity, I awakened
the soul of Jericho. Limb by limb it unfolded

and turned moss green. It reminded me
of the northwest, its lush undergrowth,

how twice despite the leaden clouds,
the rain, I found happiness there.

From tumbleweed to lush fern flower,
reversible, repeatable." (Veach C., 2003)

Surprising is the manner in which the poet has conceived her verses in couplets. These are pierced by punctuation marks which obstruct the flow of a poem that lacks the expected fluidity usually given by rhyming verses. This braking rhythm may be suggestive of the short, unexpected phases involved in awakening the life that has been arrested in this plant for a rather long time. The whole imagery of the poem seems to be constructed like a puzzle under the confused eyes of a reader who is unable to anticipate what will follow or where each piece will fit. The choice of words – "reversible" and "repeatable" – shows that behind a lack of faith in the revival of a dead organism there lies the unequivocal evidence of life in death which brings the poet to an ecological commitment to sustain life.

The contemporary Australian poet John Kinsella brings the topic of Resurrection plants into the knowledgeable sphere of a fervent supporter of indigenous treasures. His poem *Resurrection Plants at Nookaminnie Rock* flows like a narrative sparingly interrupted by punctuation marks which summon the readers to pauses of reflection:

"They're full-blown in their early spring
rush – pin cushions a fakir's bed of nails
so soft to tread on, so easy to make false
comparisons by, and all the baggage that carries –
rest-break on a granite slab looking out over
the island sea of scrub shaded with formations
beneath a green lagoon's surface. It's what we
bring to the apogee before the drying-off,
dead crunch beneath our feet as rock-
dragons wake to the heat, and emphatic

belief that the dead will stay dead
and there will be no lift, no rebirth,
wherever you come from, whatever
you believe. Step carefully around these
wreaths hooked into granite sheen,
holdalls
for a soil-less ecology, a carpet you know
would say so much more if your boots
were off and skin touched life brought
back, restored, gifted, bristling with death
because death is the most alive district
to inhabit. We could say so much more
if only we had the time." (Kinsella J., 2013)

The flow of the description of these plants and their environment is arrested by a profound thought that awakens the reader from any dormant slumber of faith: *"emphatic/ belief that the dead will stay dead/ and there will be no lift, no rebirth,/ wherever you come from, whatever/ you believe".* The solution is offered at the end of the poem: *"life brought/ back, restored, gifted, bristling with death/ because death is the most alive district/ to inhabit".*

John Oxenford's translation of the German poem written by Ferdinand Brunold (19th century) brings into the limelight two exceptionally powerful images – that of an old man on the brink of death intertwined with that of a Rose of Jericho from the Holy Land:

"His hands are dry and wither'd; a single rose they bear –
A rose that long has faded,-upon it falls the tear.
Yet o'er those pallid features a smile of pleasure creeps;
Unwillingly and slowly, thus speak his aged lips:— "

He holds in his old hands - which closely resemble the dry leaves of the Resurrection plant - a Rose of Jericho given to him by a lady as a token of truth, love, and of the enduring promise to meet again. Approaching his own death, the man does a last promised gesture of throwing the dry rose into wine:

"Behold! the wine is sparkling-the rose a perfume gives.
And more and more expanded are swelling forth its leaves.
Fix'd on the rose and goblet the old man's eye is gleaming
It is hope's joyous lustre that in his eye is beaming.

And fuller, ever fuller, the fragant rose-leaves blow;
And gladder, and still gladder, the old man's features glow." (Oxenford J., 1842)

The revival of the dead plant under his weary eyes is a reassuring promise of a life beyond death in a realm where all things shall be made new.

RESULTS AND DISCUSSIONS

Approaching various poems from different geographical areas and two distinct historical time spans from a botanical, psychological and literary perspective reveals two different modes of perception. The romantic inclination toward sublime images and feelings of the 19th century poets: Harriet McEwen Kimball, Mollie Evelyn Moore Davis and Ferdinand Brunold masterfully translated by John Oxenford, testify to a heartbeat-like rhythm - loosely iambic - given by the flow of the rhyming verses (either embraced or paired in couplets) which abound in deep thinking and longing for true hope and love. This perspective is counterbalanced by the contemporary writers: Laura Sobbott Ross, Cindy Veach and John Kinsella, whose poems take the forms of narratives in blank verse which render the train of thoughts either in flowing verses or lines sharply interrupted by punctuation marks. These contemporary poets offer a perspective deeply rooted in the actuality of things – or even human relations – approaching an ecological decay that human beings alone are called to withstand and if possible to revert, just like the Resurrection plants hold in them the power to be restored to life in the right environment.

Psychologists agree on the fact that resilience is acquired by being faced with "aversive circumstances" even from a young age and that learning to process emotions in various contexts leads to improvements in social competence, resilience and adaptation (Bar-On *et al.,* 2007). Whenever situational backgrounds highjack our amygdala which will determine our reactions and actions, the key to resilience "lies in how quickly we recover from that hijacked state" (Review, Goleman, Langer, *et al.,* 2017), and this competence of recovery is trained in the harshest environment by resorting to inner resources and a discourse that connects words to reality and hope.

Adaptive Mechanisms: Anabiosis and Metabolic Suspension in Resurrection Plants

A central physiological strategy employed by resurrection plants is anabiosis, defined as the reversible suspension of metabolic activity in response to extreme desiccation. During this phase, cellular processes are drastically reduced or halted, enabling the plant to persist in a dormant state for extended periods. This condition is characterized by the retention of structural integrity despite the near absence of water (Costa *et al.,* 2017). Importantly, anabiosis is not a passive state; it involves active regulation of gene expression, membrane stabilization, and the accumulation of protective molecules that mitigate irreversible damage.

Building upon the concept of anabiosis, another key mechanism supporting survival under desiccation is the preservation of the photosynthetic apparatus – a strategy known as homoiochlorophylly. Unlike poikilochlorophyllous species, which degrade chlorophyll and reconstruct photosynthetic structures upon rehydration, homoiochlorophyllous plants maintain thylakoid integrity and pigment stability, allowing for rapid resumption of photosynthesis.

Although effective, homoiochlorophylly increases the risk of reactive oxygen species (ROS) formation, necessitating the simultaneous activation of complex antioxidant defenses. In parallel, Costa *et al.* (2017) proposed that resurrection plants re-engage genetic programs analogous to those found in orthodox seeds, where desiccation tolerance is an ancestral trait.

Protective Compounds and Antioxidant Systems

Following the preservation of the photosynthetic machinery, the survival of resurrection plants under extreme drought conditions depends on the accumulation of protective compounds that stabilize cellular structures and mitigate oxidative damage. Among the most critical are soluble sugars (glucose, fructose, trehalose, sucrose), which act as vitrifying agents, forming an amorphous matrix that shields proteins and membranes in the absence of water (Hoekstra *et al.,* 2001; Oliver *et al.,* 2000). Proline, an osmoprotective amino acid, is also intensely accumulated during dehydration, aiding in the maintenance of osmotic potential and protecting enzymes from denaturation (Smirnoff & Cumbes, 1989). In addition to these compounds, resurrection plants activate a broad spectrum of antioxidants which neutralize free radicals generated during desiccation and rehydration (Kranner *et al.,* 2002; Farrant & Moore, 2011). These biochemical systems are essential for preventing oxidative stress and preserving cellular viability.

Collectively, the accumulation of protective compounds and the activation of antioxidant defenses reflect a highly coordinated metabolic strategy that enables resurrection plants to endure prolonged desiccation and resume physiological function upon rehydration.

Antioxidant Enzymes

During dehydration and subsequent rehydration, resurrection plants are exposed to elevated levels of oxidative stress due to the formation of reactive oxygen species (ROS), which can damage proteins, lipids, and nucleic acids. To mitigate these effects, they activate a complex antioxidant defense system composed of key enzymes essential for maintaining cellular integrity. Kranner *et al.,* (2002) conducted a comparative analysis across multiple resurrection species, showing that antioxidant system efficiency is closely linked to the rate of rehydration and the restoration of photosynthetic function. Furthermore, Farrant and Moore (2011) emphasized that these enzymes operate synergistically with non-enzymatic antioxidants such as reduced glutathione and ascorbic acid, forming a tightly regulated redox network.

Thus, the activation of antioxidant enzymes constitutes a fundamental component of desiccation tolerance, enabling resurrection plants to withstand extreme environmental stress without incurring irreversible cellular damage.

Symbiosis and Rhizospheric Interactions

In addition to intrinsic physiological adaptations, resurrection plants benefit from symbiotic interactions with drought-adapted microorganisms in the rhizosphere. These microbial communities contribute to plant resilience by inducing systemic resistance, synthesizing phytohormones, and enhancing nutrient acquisition (Lozo *et al.,* 2023). Furthermore, these microorganisms produce indole-3-acetic acid (IAA) and salicylic acid, which regulate hormonal balance and stress responses under drought conditions (Vurukonda *et al.,* 2016). Collectively, the rhizosphere functions as an auxiliary ecological system, supporting metabolic reactivation and contributing to the long-term survival and ecological stability of resurrection plants in arid and extreme environments.

CONCLUSIONS

A targeted approach of the world of plants through the eyes of poets and scientists can open the path of discovering deeper meaning regarding life, its end and the possibility of life emerging when hope fades. John C. Ryan's conclusion regarding Kinsella's poetic subtexts and the power of his poem *Resurrection plants at Nookaminnie Rock* to textualize "vegetal death and near-death, principally, as a process of embodied, ecological Jericho marvel and, secondly, as suggestive of the possibility of ecosystemic renewal" (Ryan J. C., 2016) is a herald of hope that needs to be sustained through active engagement with a nature that generously offers life lessons to humans. The adaptive mechanisms and the activation of resilience in times of lack of abundant resources can be learned from nature and may lead to the renewal of the hope that life does not cease with death.

The lessons the Resurrection plants offer are inscribed in their very structure and resilience mechanisms. When the contexts of life become adverse, the organism should stabilize and accumulate protective sources so that it may withstand any life threatening conditions. The anabiosis may outwardly appear as passive while it is actually an active inner regulation of emotions and activation of protective mechanisms and responses. In this state people may be selective as to the sources they may resort to in order to maintain stability, hope and life. In the apparent state of demise resilience is forged through storing inner strength and accumulating resources that will help neutralize further damaging stimuli. By retaining the structural integrity and stability, a resilient person will enhance the acquisition of the proper psychological nourishment needed for survival and further living.

While the poems approached in this study offered a slightly romanticized perspective on Resurrection plants which carry the promise of the revival of deep feelings such as love and of the body after death, the botanical insights testify to the fact that living organisms hold in themselves the potential for resilience and of a full restoration to life after temporary life arrest.

REFERENCES

APA, **2022 -** https://www.apa.org/topics/resilience

Bar-On, R., Maree, K., & Elias, M. J., 2007 - *Educating people to be emotionally intelligent*. In Praeger eBooks. https://doi.org/10.5040/9798400643897

Britannica Editors, 1998 - *Rose of Jericho | Definition, Plant, Types, & Facts*. Encyclopedia Britannica, available on-line at: https://www.britannica.com/plant/rose-of-Jericho

Costa, M.-C., Cooper, K., Hilhorst, H. W. M., & Farrant, J. M. , 2017 - *Orthodox seeds and resurrection plants: Two of a kind?* Plant Physiology, 175(2), 589–599. https://doi.org/10.1104/pp.17.01011

Farrant, J. M., & Moore, J. P., 2011 - *Programming desiccation-tolerance: From plants to seeds to resurrection.* Plant Science, 180(3), 322–331. https://doi.org/10.1016/j.plantsci.2010.11.014

Hoekstra, F. A., Golovina, E. A., & Buitink, J., 2001 - *Mechanisms of plant desiccation tolerance*. Trends in Plant Science, 6(9), 431–438. https://doi.org/10.1016/S1360-1385(01)02052-0

Jericho, R. O., 2023 - *The origin of the true Real Rose of Jericho*. Rose of Jericho, available on-line at: https://jericho-rose.org/the-origin-of-the-true-real-rose-of-jericho/

Kimball, H. McEwen - *The Rose of Jericho*. https://www.poetrynook.com/poem/rose-jericho

Kinsella, J., 2013 - *Poem* | John Kinsella - Overland literary journal. Overland Literary Journal, available on-line at: https://overland.org.au/previous-issues/issue-199/poem-john-kinsella-2/

Kranner, I., Beckett, R. P., Wornik, S., Zorn, M., & Pfeifhofer, H. W., 2002 - *Revival of a resurrection plant correlates with its antioxidant status*. The Plant Journal, 31(3), 403–415. https://doi.org/10.1046/j.1365-313x.2002.01329.x

Lozo, J., Ristović, N., Kungulovski, G., Jovanović, Ž., Rakić, T., Stanković, S., & Radović, S., 2023 - *Rhizosphere microbiomes of resurrection plants Ramonda serbica and R. nathaliae: Comparative analysis and search for bacteria mitigating drought stress in wheat* (*Triticum aestivum* L.). World Journal of Microbiology and Biotechnology, 39, 256. https://doi.org/10.1007/s11274-023-03702-4

Millar, James M.D., 1821 - *LXXV. Observations and experiments on the Rose of Jericho; with brief notices of its history*. Philosophical Magazine Series 1, 58:283, 360-363, DOI: 10.1080/14786442108652640

Moore, M. E., 1872 - *Poems.* Houston, Texas: E. H. Cushing.

Oliver, M. J., Tuba, Z., & Mishler, B. D., 2000 - *The evolution of vegetative desiccation tolerance in land plants.* Plant Ecology, 151(1), 85–100. https://doi.org/10.1023/A:1026556109680

Oxenford, J., 1842 - *The Mirror of literature, amusement, and instruction*, Nov. 1822-June 1847; London Vol. 2, Iss. 3, pp. 45-46.

Review, H. B., Goleman, D., Langer, E., David, S., & Congleton, C., 2017 - *Mindfulness* (HBR Emotional Intelligence Series). Harvard Business Press.

Ross, Laura Sobbott, 2012 - *He brings me resurrection Ferns* - Deep South magazine. https://deepsouthmag.com/2012/02/14/he-brings-me-resurrection-ferns/

Ryan, J. C., 2017 - *A comparative history of resurrection plants*. CLCWeb Comparative Literature and Culture, 19(2). https://doi.org/10.7771/1481-4374.3010

Ryan, J. C., 2016 - *On the Death of Plants: John Kinsella's Radical Pastoralism and the Weight of Botanical Melancholia // Sobre la muerte de las plantas: El pastoreo radical de John Kinsella y el peso de la melancolía botánica*. Ecozon European Journal of Literature Culture and Environment, 7(2), 113–133. https://doi.org/10.37536/ecozona.2016.7.2.1004

Smirnoff, N., & Cumbes, Q. J., **1989** - *Hydroxyl radical scavenging activity of compatible solutes*. Phytochemistry, 28(4), 1057–1060. https://doi.org/10.1016/S0031-9422(00)95294-3

Veach, C., 2003 - *Rose of Jericho*. Poets.org. https://poets.org/poem/rosejericho#:~:text=Add%20to%20anthology,the%20Academy%20of%20American%20Poets

Vurukonda, S. S. K. P., Vardharajula, S., Shrivastava, M., & SkZ, A., 2016 - Enhancement of drought stress tolerance in crops by plant growth promoting rhizobacteria. *Microbiological Research*, 184, 13–24. https://doi.org/10.1016/j.micres.2015.12.003

ARTIFICIAL INTELLIGENCE IN HIGHER EDUCATION AND TEACHER TRAINING: RESPONSIBLE INTEGRATION AND IMPACT

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Abstract

This paper aims to investigate the impact of artificial intelligence (AI) on higher education and teacher training with a focus on responsible integration and ethical implications. The study was conducted at the university level and combined the application of a questionnaire to a sample of respondents: students, doctoral students, Department for Teacher Training students, teachers and case studies (Ali Z*., et al.,* 2025*;* Brezuleanu M-M. *et al.,* 2025). This study showed that AI is mainly perceived as a tool to support documentation, personalization of learning and data analysis, but there are also challenges such as lack of staff training, digital dependency and reduced critical thinking (Castillo-Martínez I. M. *et al.,* 2024; Wang *S., et al*., 2024). The results highlight both the perceived advantages (quick access to resources, personalization, research support) and the main barriers (insufficient resources, cultural reluctance, ethical issues). At the same time, the analysis highlights the importance of respecting the principles of digital ethics and promoting good academic practices as essential benchmarks for the responsible integration of AI. The conclusions emphasize that AI can contribute significantly to the modernization of the educational process and the training of future teachers, provided that it is integrated in an ethical, equitable and didactically guided manner, in support of smart agriculture and sustainable development.

Keywords: artificial intelligence, teacher training, digital ethics, good university practices, smart agriculture

Introduction. Political, economic, social and cultural transformations in recent decades have led the Romanian education system into a continuous process of reform and innovation. In this context, technological progress, particularly the development of artificial intelligence (AI), exerts a major influence on how universities design their curricula and educate future specialists. At the European level, strategic documents such as Education and Training 2020 and the Digital Agenda for Europe underscore the need to modernize educational processes by integrating digital competences, fostering innovation and preparing young people for a labor market in constant flux (European Commission, 2020a; European Commission, 2020b).

In the context of accelerated digital transition, universities are called upon to redefine educational paradigms to meet both the needs of students and the demands of a knowledge-based labor market. According to the Organisation for Economic Co-operation and Development OECD *(2024)*, more than 65% of emerging occupations require advanced digital competences and AI integration is becoming a catalyst for pedagogical innovation. Likewise*,* UNESCO (2024) stresses that AI should be understood not merely as a technology but as a socio-technical ecosystem influencing values, ethics and educational equity. Therefore, responsible integration requires a dual approach: developing the digital competences of teachers and fostering the critical thinking of students to enable reflective interaction with AI.

AI may be defined as a set of technologies and methods that simulate human cognitive processes—learning, reasoning, and decision-making—and that can be applied across multiple domains of knowledge. In education, AI is manifested through tools that support personalized learning, adaptive assessment, automated feedback systems, interactive resources, and digital platforms that promote the active engagement of students, doctoral candidates and Department for Teacher Training participants.

In higher agricultural and technical education, AI offers unique opportunities for modeling decision-making processes, simulating agricultural ecosystems and analyzing

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experimental data, thus fostering evidence-based learning. Moreover, integrating these technologies into Department for Teacher Training programs contributes to developing transversal competences - creativity, collaboration and ethical responsibility - that are essential for 21st-century education.

At IULS, AI is relevant not only for students in agronomy, horticulture, animal science, and veterinary medicine, but also for doctoral candidates engaged in research and for Department for Teacher Training participants preparing for teaching careers. The agriculture of the future and modern teacher education can no longer be conceived without the use of digital technologies: crop monitoring via sensors and drones, disease diagnosis through visual algorithms, as well as the use of AI to develop lesson plans, provide rapid feedback, and build pedagogical competences (Miller T., *et al.,* 2025).

Thus, AI plays a multifaceted role in the work of students, doctoral candidates, and Department for Teacher Training participants at IULS: from supporting independent study and research to strengthening teacher education and professional formation (Liang J., *et al.,* 2025; Tan, L. Y., *et al.,* 2025). The responsible integration of these tools, under the guidance of academic staff, can contribute to preparing specialists and teachers capable of meeting the challenges of smart agriculture and digital education (*USV Iași, 2024*).

MATERIAL AND METHOD

The study examined how students, doctoral candidates and Department for Teacher Training participants at IULS perceive and use AI in their academic, practical, and pedagogical activities. Two main directions were investigated: an analysis of curricular documents and an exploration of participants' direct experiences.

Methods employed included:

- administering questionnaires to a sample of 120 respondents (students, doctoral candidates, and Department for Teacher Training participants);

- case studies on the application of AI in practical and pedagogical activities (visual applications, adaptive platforms, machine-learning algorithms).

The methodological design followed a mixed-methods research model, combining quantitative questionnaire analysis with a qualitative approach based on case studies and reflective observations. The sample included participants from four faculties, allowing for significant inter-field comparisons. The qualitative components (semi-structured interviews) explored dimensions such as perceptions of AI ethics, trust in algorithms, and the role of AI in creating interactive educational resources.

The data were interpreted using descriptive statistical methods and by correlating questionnaire results with information obtained from academic staff. On this basis, recommendations were formulated for expanding and diversifying educational activities through the responsible and creative integration of AI.

RESULTS AND DISCUSSIONS
3.1. GENERAL ANALYSIS

The analysis of questionnaires, interviews, and case studies revealed distinct trends among students, doctoral candidates, and Department for Teacher Training participants. The overall level of familiarity with AI ranges from moderate to low, with clear differences between participant categories. The perceived usefulness of AI also varies: students view it primarily as a tool for rapid information retrieval, doctoral candidates employ it for data analysis, while Department for Teacher Training participants use it for lesson preparation and the simulation of teaching scenarios.

The results showed that 72% of participants use AI weekly, mainly for documentation and academic writing. However, only 28% reported having received formal training on the ethical use of these tools. This discrepancy highlights the need for critical digital literacy - a point also emphasized by Wang *et al.* (2024), who noted that "technological familiarity without ethical awareness amplifies the risks of dependency and cognitive superficiality."

The distribution of AI familiarity levels is presented in (*figure 1*).

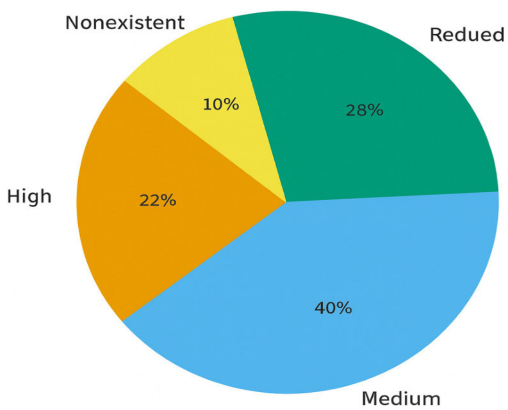

Figure 1 **Level of familiarity with AI among respondents**

The perceived advantages are shown in (*figure 2*), confirming the importance of rapid access to information and personalized learning.

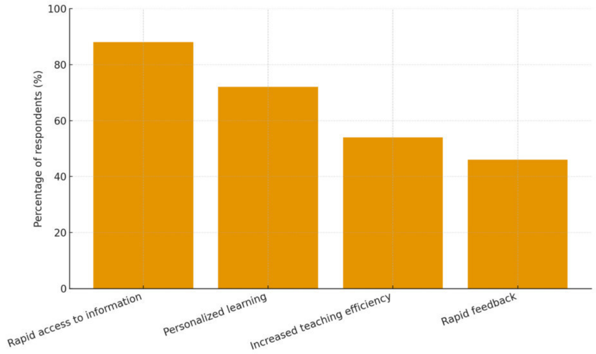

Figure 2 **Perceived benefits of using AI in education**

The identified challenges are summarized in Figure 3, which highlights insufficient teacher training and the risk of digital dependency as the primary concerns.

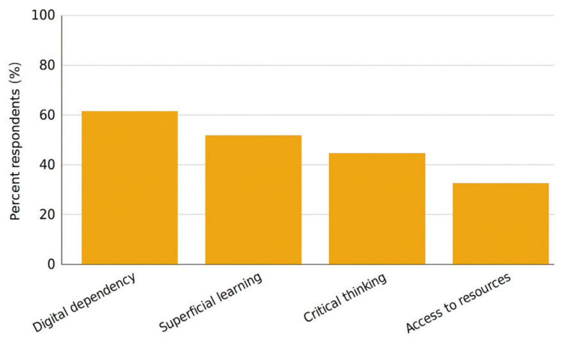

Figure 3 **Perceived challenges in integrating AI into education**

3.2. THE ROLE OF AI IN TEACHER EDUCATION

The use of AI in teacher education enables the personalization of the educational process, the generation of differentiated instructional scenarios, and the simulation of complex classroom situations. Machine learning algorithms support the analysis of learners' performance, highlighting strengths and areas in need of development. In this way, AI contributes to the development of both digital and pedagogical competences among future teachers.

AI-based learning models, such as ChatGPT, DeepL, or Consensus, facilitate the creation of personalized teaching scenarios and adaptive feedback. Through AI-powered learning analytics platforms, educators can anticipate learners' difficulties and adjust learning content in real time. Moreover, AI supports assisted pedagogical reflection — a concept introduced by (Liang *et al.* 2025) — involving the automated analysis of teaching strategies through natural language processing algorithms. This leads to more efficient training, oriented toward measurable outcomes and personalized learning experiences.

3.3. ETHICAL CONSIDERATIONS

The integration of AI raises major ethical issues, including algorithmic transparency, the protection of personal data, equity of access, and the risk of replacing the human dimension of education. Universities must ensure an inclusive framework in which AI is employed as a complementary tool, not a substitute for human interaction.

Digital ethics in education requires ensuring algorithmic transparency, equitable access and shared responsibility between the user, the institution, and technology developers. According to the UNESCO Recommendation on the Ethics of Artificial Intelligence (2023), higher education institutions are obliged to establish codes of conduct regarding AI use, particularly in student assessment and academic research. Therefore, it is recommended to implement a university-level AI governance framework based on the FAIR principles (Findable, Accessible, Interoperable, Reusable) for managing educational data responsibly.

3.4. EXAMPLES OF GOOD PRACTICES AT IULS

Examples of good practices include the integration of AI into Department for Teacher Training modules, interdisciplinary projects, digital ethics workshops, support for teaching practice through automated analysis, and international partnerships (Erasmus+, Horizon Europe).

IULS aligns with European trends through the integration of AI Literacy modules within Department for Teacher Training and participation in Erasmus+ projects focused on developing digital competences among teachers. Additionally, the use of computer vision–based visual applications in agricultural practice demonstrates the interdisciplinary transfer of AI between education and applied research.

3.5. PRELIMINARY CONCLUSIONS FROM THE QUESTIONNAIRE

The questionnaire results confirm both the participants' interest in and openness toward AI, as well as the need for a cautious approach. The still modest level of familiarity highlights the importance of digital literacy and teacher training. The main advantages identified are learning personalization and rapid access to resources, while the main challenges concern digital dependency, critical thinking, and access barriers. Thus, AI can become a valuable tool for the modernization of education—provided that its integration is ethical and pedagogically guided.

ACKNOWLEDGMENTS

The authors express their gratitude to the academic staff of "Ion Ionescu de la Brad" University of Life Sciences - IULS and the Department for Teacher Training for their support. We also thank the students, doctoral candidates, and participants who contributed valuable insights through questionnaires and interviews.

CONCLUSIONS

1. The integration of AI has a significant impact on students, doctoral candidates and Department for Teacher Training participants, providing support for information gathering, learning and research.

2. Practical uses differ: students turn to AI for study, doctoral candidates for research and Department for Teacher Training participants for preparing teaching activities.

3. Academic staff and mentors endorse AI integration but emphasize the need for appropriate digital and ethical training.

4. The identified risks (dependency, superficiality and diminished critical thinking) underscore the importance of balanced use.

5. The case studies demonstrated AI's applicability in agriculture, research and teacher preparation.

6. AI integration should be a cross-cutting process designed to prepare future specialists and teachers for the challenges of smart agriculture and digital education.

These findings confirm that integrating AI into higher education is no longer optional but a strategic necessity. However, the added value of AI depends on the human dimension of education - critical thinking, empathy and social responsibility must be cultivated alongside digital skills. For the future, it is recommended to:

- develop a transversal digital ethics curriculum within Department for Teacher Training;
- establish university centers for AI-assisted educational innovation;
- and promote a culture of transparency and ethical evaluation in the use of emerging technologies.

REFERENCES

Ali, Z., *et al.*, 2025 - Artificial intelligence for sustainable agriculture: A systematic review (2010–2023). Sustainability, 17(5), 2281. https://doi.org/10.3390/su17052281

Brezuleanu, M.-M., Ungureanu, E., Zaharia, R.-S., & Brezuleanu, C.-O., 2025, *Studies on the sustainable impact of artificial intelligence in technical and agricultural university education: Benefits, challenge and future directions.* Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 25(1).

Castillo-Martínez, I. M., & Fernández-Martínez, C., 2024 - *AI in higher education: A systematic literature review*. Frontiers in Education. https://doi.org/10.3389/feduc.2024.1391485

Espinel, R., *et al.*, 2024 - *Artificial intelligence in agricultural mapping: A review*. Agriculture, 14(7), 1071.https://doi.org/10.3390/agriculture14071071

European Commission, 2020a-*Education and training monitor 2020: Teaching and learning in a digital age.* Publications Office of the European Union. https://op.europa.eu/en/publication-detail/-/publication/92c621ce-2494-11eb-9d7e-01aa75ed71a1

European Commission, 2020b - *European education area communication* (COM (2020) 625). https://education.ec.europa.eu/sites/default/files/document-library-docs/eea-communication-sept2020_en.pdf

Létourneau, A., *et al.*, 2025 - *A systematic review of AI-driven intelligent tutoring systems in K–12 education.* Education Sciences. https://doi.org/10.3390/educsciXXXXXX

Liang, J., *et al.*, 2025 - *A systematic review of the early impact of AI in higher education*. Frontiers in Education.https://doi.org/10.3389/feduc.2025.1522841

Miller, T., *et al.*, 2025 - *The IoT and AI in agriculture: The time is now—A review focused on arable crops and grasslands.* Sensors, 25(12), 3583. https://doi.org/10.3390/s250X03583

OECD, 2024 -*Digital Economy Outlook 2024 (Vol. 1)*. OECD Publishing. https://doi.org/10.1787/d30a04c9-en

Tan, L. Y., *et al.*, 2025 - *Artificial intelligence-enabled adaptive learning platforms: A systematic review.* npj Science of Learning. https://doi.org/10.1016/j.npjsol.2025.100123

UNESCO, 2024 - *Artificial Intelligence in Education: A guidance framework. UNESCO.* https://www.unesco.org/en/digital-education/artificial-intelligence

USV Iași, 2024 - *Soluții digitale în agricultura inteligentă la USV Iași.* https://iuls.ro/comunicat-de-presa/solutii-digitale-in-agricultura-inteligenta-la-usv-iasi/

Wang, S., *et al.*, 2024 - *Artificial intelligence in education: A systematic literature review.* Expert Systems with Applications, 239, 125123. https://doi.org/10.1016/j.eswa.2024.125123

BENEFITS AND CHALLENGES OF WOMEN'S INVOLVEMENT IN AGRITOURISM ENTREPRENEURSHIP

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Abstract

Agritourism is one of the strategies available to farmers to improve their livelihoods, with women play an essential role in maintaining, developing and innovating agritourism businesses. The study aims to identify, based on a systematic analysis of academic literature, the impact of rural women's involvement in agritourism, both at the individual and rural community level. At the same time, various restrictions and challenges they face as farmers, entrepreneurs and professional women are highlighted. Agritourism entrepreneurship provides many benefits to rural women, appearing as a catalyst for their socio-cultural and economic empowerment: achieving financial independence, improving visibility and social status, new entrepreneurial opportunities and skills, personal development, etc. The findings indicate that the constraints they encounter are determined by the political-institutional and socio-cultural contexts in which operate. In addition to individual and tourism industry-related factors (which traditionally influences the business potential of all farmers), gender inequality is the most limiting factor for women's empowerment and their entrepreneurial performance. Four main factors are influencing female's empowerment: women's entrepreneurship, education, human capital and social capital. Subjected to discrimination not only from other male farmers, but also from customers and suppliers, women farmers have limited access to essential resources (capital, credit, land, technology), vocational training, education and business networks. They often deal with insufficient decision-making power and struggle to find a balance between managing agritourism operations and domestic responsibilities. Overcoming these barriers and challenges requires policies to promote gender equality, specific support programs and facilitating access to markets and technology.

Keywords: agritourism, women, empowerment, benefits, challenges

All over the world, agritourism is asserting itself as a means of promoting sustainable agriculture, diversifying farm incomes and revitalizing the rural economy (Brandth B and Haugen M.S., 2011). Agritourism encompasses a variety of farm-based activities for educational or recreational purposes (Gil Arroyo C. *et al,* 2013), women making a crucial contribution in maintaining and developing agritourism businesses (McGehee N.G. *et al*, 2007). However, agricultural production management is typically considered a male domain, with most farms being owned by men. (Vuciterna R. *et al*, 2024). Scholars works highlight women's propensity for innovation and their tendency to develop new agricultural businesses (Bock B.B., 2004) and to lead non-agricultural entrepreneurial activities (Gasson R. and Winter M., 1992). For many years, tourism has been perceived as a sector conducive to entrepreneurial initiatives (Nikraftar T. and Hosseini E., 2016) and as a generator of opportunities specifically for women entrepreneurs (Haugen M.S. and Vik J., 2008). The strategy of farm diversification through tourism provides women with opportunities for socio-cultural and economic empowerment and advancement (Dong H. and Khan M.S., 2023). Women's empowerment is a complex process of changing their abilities to make strategic choices in life, with considerable effects on their well-being (Dewi A.C. *et al*, 2025). The motivation behind the decision to participate in agritourism entrepreneurship depends on the potential benefits and the effort required by rural women to obtain them. Due to the complexity of the agricultural industry and the versatility of tourism activities, numerous barriers and challenges arise, affecting the performance of women entrepreneurs in agritourism. Various studies conducted in different rural regions around the world have highlighted that women's empowerment through agritourism is a path towards inclusive and sustainable development. (Arintyas A. *et al*, 2024; Pécot M. *et al*, 2024; Vujko *et al*, 2024). As agritourism continues to

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expand, understanding its contributions to improving the lives of rural women and the well-being of local communities is increasingly relevant.

MATERIAL AND METHOD

This paper uses an analysis of existing research in the academic literature to investigate the most important and frequently mentioned opportunities and challenges that accompany women's participation in managing agritourism businesses. The analysis includes studies on the emancipation of women farmers through agritourism, on the barriers and challenges encountered, as well as on the positive impact on their lives and rural communities. To capture a broader and more relevant range of these aspects, studies conducted over the last 25 years in rural areas of countries with different cultures, norms and levels of economic development, were included. The present paper draws on research findings from over fifteen countries across four continents (Asia, Africa, North America and Europe). In this way, heterogeneous socio-economic, cultural and regulatory contexts surrounding agritourism farms were taken into account.

RESULTS AND DISCUSSIONS

Findings from the analysis of academic literature support the fact that agritourism can generate various benefits for women involved in agritourism management, although they face several challenges and restrictions. Women's roles in agritourism are multiple and complex (*figure 1*). In agriculture, they range from farming and processing agricultural produce to marketing, while in the tourism sector, women's contribution goes far beyond simply providing of various services (Tristanti T. *et al*, 2022).

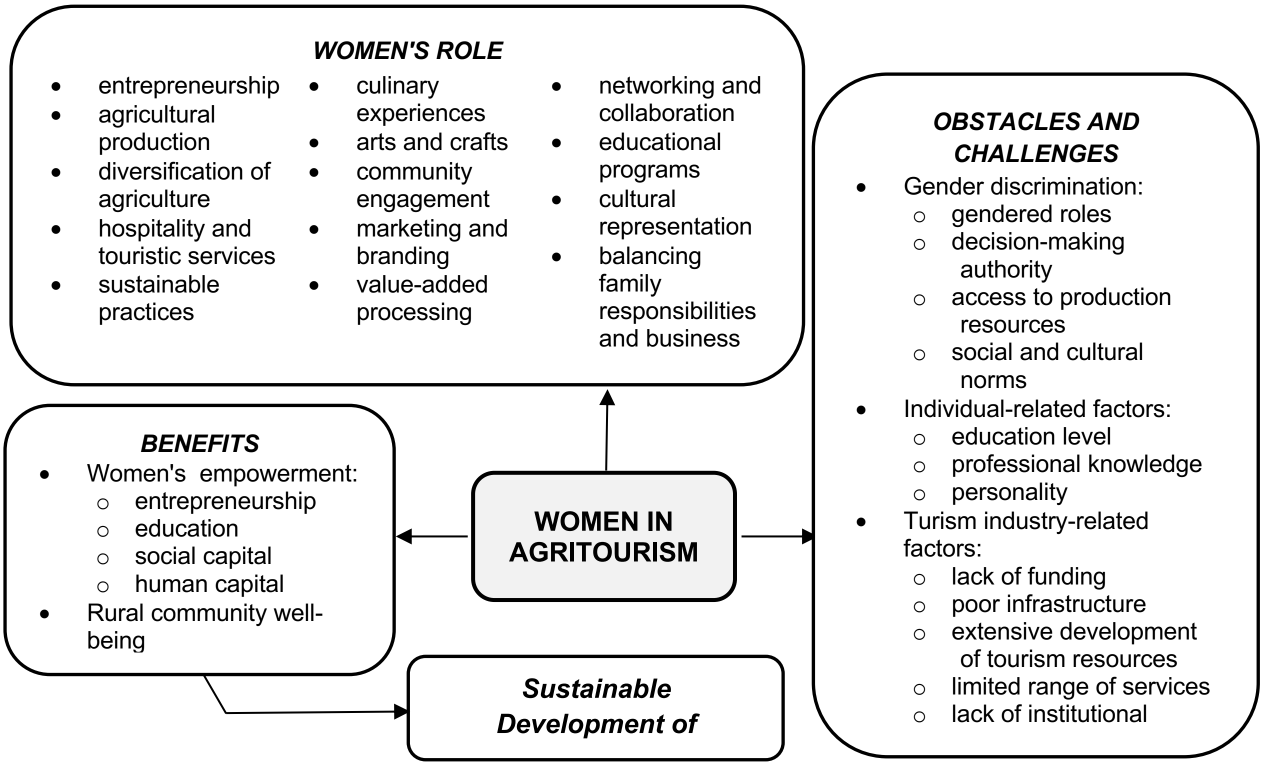

Figure 1: Women's involvement in agritourism

Studies conducted by some scholars indicate that women farmers willingly choose to participate in agritourism, which predominantly involves production and sale of local food, beverages, souvenirs and activities related to hospitality and touristic services (Tristanti T. *et al*, 2022; Vuković D. *et al,* 2023; Vujko A. *et al*, 2024). Women entrepreneurs in agritourism have important roles in protecting cultural heritage, safeguarding rural life and original rurality, sharing agricultural knowledge and traditions with tourists (Annes A. and Wright W., 2015), conserving natural resources and promoting sustainable practices (Rakočević L. *et al*, 2025).

- **Benefits for women and local community.** Agritourism has the potential to achieve the emancipation and empowerment of rural women through entrepreneurial initiatives (Gil Arroyo C. *et al*, 2019; Vuković D. *et al*., 2023). Studies show that female farmers tend to have a greater openness to agritourism than most male operators (Brandth B. and Haugen M.S., 2011; Giraud C., 2011) and a different way of farming (Annes A. and Wright W, 2015). There are also differences in the perception of success in agritourism entrepreneurship: while women usually prioritize holistic benefits (such as personal satisfaction, preservation of rural cultural heritage, increased decision-making power, etc.), men are more interested in maximizing revenue and profit (Halim M.F. *et al*, 2020). In less developed countries, and especially in rural areas, women lack financial independence (Alemu A. *et al*, 2022), with agritourism creating a good opportunity to achieve this goal (Alavion J. and Taghdisi A., 2021). Agritourism enables women to set up and run small rural businesses (craft shops, homestays, guided tours, food services), ensuring greater recognition of their contributions and skills in local cuisine, sale of agricultural products and handicrafts (Rakočević L. *et al*, 2025). Thus, in addition to revenue from traditional agricultural work, they obtain new and diversified income streams, which boosts their *financial independence* (Gil Arroyo C. *et al*, 2019). This could lead to *increased decision-making power* for women (Sulaj A. and Themelko H., 2024) and substantial changes in their lives and those of their families, as well as in the local communities (Vujko A. *et al*, 2024; Dewi A.C. *et al*, 2025).

The involvement of women in agritourism can lead to *challenging traditional gender norms* and promoting greater social equity. In many rural areas, female entrepreneurs in agritourism benefit from *a recognition of their contribution* to the life of the rural community, enjoying an *improvement in their visibility and status,* as well as a *more equitable distribution of responsibilities and opportunities* (Vujko A. *et al*, 2024). Similar conclusions were formulated by Sharpley R. and Vass A. (2006) based on research conducted in the north-east of England, where rural women are motivated to initiate tourism activities on farms by feelings of *independence* and *professional satisfaction,* gaining *social visibility* by assuming roles and responsibilities that could lead to personal empowerment. Cánoves G. *et al* (2004) argue that the involvement of Spanish women farmers in tourism promises *personal empowerment* by overcoming the limitations imposed by domestic roles and escaping the status of social invisibility. At the same time, women entrepreneurs in agritourism *create businesses and jobs locally*, increasing female participation in the workforce, which contributes to greater social well-being of their communities and economic stability in rural areas (Gil Arroyo C. *et al*, 2019).

By providing economic and socio-cultural empowerment, agritourism promotes a *better self-perception and identity* for rural women (Vujko A. *et al*., 2024). It can also lead to improved household well-being and children's education, while promoting local community development (Bhatta K. and Ohe Y., 2020).

The study conducted in rural China by Dong H. and Khan M.S. (2023) identified four main factors influencing women's empowerment: women's entrepreneurship, education, human capital and social capital (*figure 1*). They emphasize that promoting *female entrepreneurship* and women's empowerment by improving their access to education and resources have a positive impact on the sustainable development of farm turism and local economy (Halim M. *et al*, 2016). Female entrepreneurship in agritourism facilitates financial independence, reasonable distribution of benefits and social harmony. Rural women are strongly attached to the rural environment and possess a deeper understanding of local issues, integrating better into the community and possessing suitable skills for rural tourism-related businesses (Annes A. and Wright W., 2015).

The most important determinant of the economic and social progress of women in rural areas is *education*, the level of which directly influences the quantity and quality of women in the labor force, the expansion of rural tourism and the development of rural communities (Dong H. and Khan M.S., 2023). Many female farmers running agritourism businesses do not have studies in essential fields, such as marketing and hospitality (Artinya A.L. *et al*., 2024). Education enables women to overcome political and institutional barriers and cultivate self-awareness (Sulaj A. and Themelko H., 2024).

The basis of the *social capital* of women entrepreneurs is the social support provided by family and society, which is conducive to promoting female employment at the local level (Dong H. and Khan M.S., 2023). Essential for starting and running an agritourism business is also *human capital*, which relies on developing women's own advantages. Human capital challenges are represented by the lack of education, tourism-related skills and business knowledge, which reduce women's empowerment. Qualities such as flexibility, attentiveness, patience, willingness to put their knowledge into practice and women's natural affinity for tourism, contribute to amplifying their entrepreneurial potential (Vuković D. *et al*, 2023).

- **Obstacles and challenges.** Often, women agritourism entrepreneurs face numerous barriers and challenges in conducting their businesses, which manifests itself in each of the three roles she fulfills: farmer, entrepreneur and professional women (Halim M. *et al*, 2016). The constraints they encountered are determined by the political-institutional and socio-cultural contexts in which operate (Bui H.T.M. *et al*, 2018). Regardless of gender, the business potential of farmers depends on *personal factors* (such as education level, professional knowledge, personality, etc.) and *tourism industry-related factors* (lack of funding and institutional support, poor infrastructure, extensive development of tourism resources, limited range of services, etc.) (Nikraftar T. and Hosseini E., 2016).

Although *financial capital* is a frequently mentioned constraint for women entrepreneurs in agritourism, it is not the most common (Dewi A.C. *et al*, 2025). The most numerous and complex challenges are those associated with *gender inequality*. In this regard, it is important to mention the observation of Winn J. (2005): "in many transition economies, gender-biased privatisation processes have led to redistribution in favour of men, leaving women with insufficient collateral to secure financial resources". Traditional *gender discrimination* restricts women's ability to start an agritourism business. In many cases, women farmers are not being perceived and accepted as real farmers (Halim M. *et al*, 2016). Due to the lack of innate farming knowledge and physical strength necessary for agricultural work, they are seen rather as "incomplete farmers" (Saugeres L., 2002). Despite the fact that women have long been involved in agricultural production, their participation in farming has always been characterized by *invisibility* (Arintyas A. *et al*, 2024). In the traditional rural society, their positioning is influenced by a patriarchal culture and an agrarian ideology that still persists in many regions, as evidenced by research conducted in rural southern France by Annes A. and Wright W (2015). Another study carried out in France by Giraud C. (2011) concluded that the involvement of women farmers in tourism allowed them to obtain, in addition to extra income and a better expression and capitalization of their skills, a certain degree of autonomy, but this is dependent, however, on the consent of their husbands. Therefore, there is *limited independence* and women find themselves in a disadvantageous position that restricts their entrepreneurial potential. In many rural regions, women do not have adequate *decision-making authority* within the household and are less vocal than men regarding family affairs and the allocation of available resources. (Al-Dajani H. and Marlow S., 2013). The patriarchal structure of agriculture subjects women entrepreneurs to discrimination from both business partners and associates, as well as customers. (Godwin *et al*, 2006).

Cultural norms and legal systems can influence women's involvement and success in agritourism. Khazami N. *et al* (2023) found that Tunisian rural women show a strong desire to get involved in agritourism entrepreneurship, but social and cultural norms constitute a significant obstacle. The persistence of stereotypes and predetermined *gender roles* in Tunisian society determines their under-representation in the tourism industry of this country (Alavion J. and Taghdisi A., 2021). The situation is different in most South American countries, where the tourism industry has a higher proportion of female entrepreneurs than other sectors (Surangi H., 2022).

Compared to their male counterparts, women entrepreneurs involved in agritourism have *limited access to main resources* like capital (Bruni A. *et al,* 2004), land, tools and technology (Meinzen-Dick R. *et al*, 2011), which prevents them from increasing their production, improving economic performance (Ragasa C., 2012) and developing their businesses (Still L.V. and Walker E.A., 2006). Women entrepreneurs appear to suffer from a *lack of credibility* among male farmers (Gundry L.K. *et al*, 2002), often encountering difficulties in collaborating with them and accessing business networks (Halim M. *et al*, 2016). Furthermore, this limits their access to information, professional training and opportunities to enter new markets and establish strategic partnerships (Still L.V. and Walker E.A., 2006). In this regard, Barbieri C. and Mshenga P.M. (2008) showed that the economic performance of American agritourism farms managed by women is, in general, lower than those managed by men. This statement is consistent with the results of Permani R. (2021), which highlights that Indonesian female farmers typically earn over 33% less than men in similar roles. Anthopoulou T. (2010) argues that this situation is generally valid for the entire agricultural sector, being the result of significant gender inequality in terms of access to technology, inputs, land, human and social capital, property rights and decision-making power (Pehu E. *et al*, 2009).

Unequal land rights are, also, an important obstacle for women farmers in countries governed by legal systems permissive with gender inequality. (Ogunlela Y.I. and Mukhtar A.A., 2009). Even though the law allows women to inherit agricultural land, there is a tendency for farmers to leave their inheritance preferentially to male descendants, as Salamon S. (1995) concluded after a study conducted in the USA.

Barriers to rural women's agritourism career opportunities may include not only limited education, socio-cultural norms and restricted access to vocational training, but also *physical constraints* and *language limitations*, as observed by Tristanti T. *et al.* (2022) in Indonesia.

In addition to these aspects frequently mentioned in the literature, Halim M. *et al.* (2016) identified that women farmers who provide agritourism in North Carolina (USA) are particularly concerned about: *lack of reliable staff*; *lack of institutional support*; *optimizing business development* while maintaining the desired quality; *keeping the farm in the family* and continuing the agritourism business by descendants.

As professional women, another challenge for female farmers engaged in tourism activities is to achieve a *balance between professional activity and traditional family duties*. Many times, rural women are subjected to pressure from family members, especially their husbands, to prioritize family obligations and household work over professional activity (Bruni A. *et al*, 2004).

Globally, studies have emphasised that women's participation in agritourism business is hindered by significant challenges. In order to promote the empowerment of women and their success in agritourism entrepreneurship, a multidirectional approach to these challenges is needed. By providing financial support, educational programs and initiatives for increasing women's access to resources and their role in decision-making, a favorable framework can be ensured, in which women can fully exploit their potential and available skills.

CONCLUSIONS

Agritourism entrepreneurship provides many benefits to rural women, appearing as a catalyst for their socio-cultural and economic empowerment. The constraints and challenges they encounter are determined by the political-institutional and socio-cultural contexts in which operate. These are manifested in each of the roles that rural women fulfill: farmer, entrepreneur and professional woman. Key benefits include achieving financial autonomy, increasing decision-making power, challenging traditional gender norms, improving livelihoods and social status, gaining new entrepreneurial opportunities and skills, personal development, contribution to rural sustainable development. Gender discrimination is the most restrictive factor for women's empowerment and their entrepreneurial performance. This generates a series of shortcomings and inconveniences such as: limited independence; inadequate decision-making authority; limited access to resources, information, training and markets; unequal land rights; lack of credibility, etc. Overcoming these barriers and challenges can enhance agritourism's impact on rural development. That requires policies to promote gender equality, specific support programs and facilitating access to markets and technology.

REFERENCES

Alavion J., Taghdisi A., 2021 - *Rural E-marketing in Iran; modeling villagers' intention and clustering rural regions*. Information Processing in Agriculture, 8(1): 105–133.

Al-Dajani H., Marlow S., 2013 - *Empowerment and entrepreneurship: A theoretical framework.* The International Journal of Entrepreneurial Behavior & Research, 19: 503–524.

Alemu A., Woltamo T., Abuto A., 2022 - *Determinants of women participation in income generating activities: Evidence from Ethiopia*. Journal of Innovation and Entrepreneurship, 11(1): 1–17.

Annes A., Wright W, 2015 - *"Creating a room of one's own": French farm women, agritourism and the pursuit of empowerment*. Women's Studies International Forum, 53: 1 - 11.

Anthopoulou T., 2010 - *Rural women in local agrofood production: Between entrepreneurial initiatives and family strategies. A case study in Greece*. Journal Rural Studies, 26: 394–403.

Arintyas A. *et al*, 2024 - *Women, agriculture, and villages: A community of empowerment study to achieve wellbeing and sustainable development*. Journal of Agrosociology and Sustainability, 2(1): 1–16.

Barbieri C., Mshenga P.M., 2008 - *The role of the firm and owner characteristics on the performance of agritourism farms*. Sociologia Ruralis, 48: 166–183.

Bhatta K., Ohe Y., 2020 - *A review of quantitative studies in agritourism: The implications for developing countries.* Tourism and Hospitality, 1(1): 23–40.

Bock B.B., 2004 - *Fitting in and multi-tasking: dutch farm women's strategies in rural entrepreneurship*. Sociol Ruralis, 44:245–260.

Brandth B., Haugen M.S., 2011 - *Farm diversification into tourism – implications for social identity? Journal of Rural Studies,* 27: 35-44.

Bruni A., Gherardi S., Poggio.B.,2004 - Entrepreneur-mentality, gender and the study of women entrepreneurs.*Journal of Organizational Change Management,* 17(3): 256-268.

Bui H.T.M., Kuan A., Chu T.T., 2018 - *Female entrepreneurship in patriarchal society: motivation and challenges*. Journal of Small Business and Entrepreneurship, 30(4):325-343.

Cánoves G., Villarino M., Priestley G.K., Blanco A., 2004 - *Rural tourism in Spain: An analysis of recent evolution.* Geoforum, 35(6): 755-69.

Dewi A.C., Loch A., Akzar R., O'Connor P., 2025 - Empowering women in Indonesian agritourism: a systematic literature review. *Asia Pacific Journal of Tourism Research*, 10: 2556204.

Dong H., Khan M.S., 2023 - *Exploring the Role of Female Empowerment in Sustainable Rural Tourism Development: an Exploratory Sequential*

Mixed-Method Study. International Journal of Professional Business Review, 4: 1-28.

Gasson R, Winter M., 1992 - *Gender relations and farm household pluriactivity.* Journal of Rural Studies, 8:387–397.

Gil Arroyo C., Barbieri C., Sotomayor S., Knollenberg, W., 2019 - *Cultivating women's empowerment through agritourism: Evidence from Andean communities.* Sustainability, 11(11): 3058.

Gil Arroyo, C., Barbieri, C., & Rozier Rich, S. (2013). *Defining agritourism: A comparative study of stakeholders' perceptions in Missouri and North Carolina. Tourism Management*, *37*, 39–47.

Giraud C., 2011 - *Les voies de l'autonomie féminine*. In Gilles Ferréol (Ed.), *Femmes et agriculture,* Bruxelles-Fernelmont: EME & InterCommunications. pp. 89-100.

Godwin L.N., Stevens C.E., Brenner N.L., 2006 - *Forced to play by the rules? Theorizing how mixed-sex founding teams benefit women entrepreneurs in male dominated contexts.* Entrepreneurship Theory and Practice, 30(5): 623-642.

Gundry L.K., Ben-Yoseph M., Posig M., 2002 - *Contemporary perspectives on women's entrepreneurship: A review and strategic recommendations*. Journal of Enterprising Culture 10(1): 67-86.

Halim M.F., Barbieri C., Morais D.B., Jakes S., Seekamp E., **2020** - *Beyond Economic Earnings: The Holistic Meaning of Success for Women in Agritourism.* Sustainability, 12(12): 4907.

Halim M.F., Morais F., Duarte B., Barbieri C., Jakes S., Zering K., 2016 - *Challenges Faced by Women Entrepreneurs Involved in Agritourism*. Travel and Tourism Research Association: Advancing Tourism Research Globall,. 10.

Haugen M.S., Vik J., 2008 - *Farmers as entrepreneurs: the case of farm-based tourism.* International Journal of Entrepreneurship and Small Business, 6(3): 321–336.

Khazami N., Nefzi A., Yahyaoui A., 2023 - *Role of rural women on the agritourism entrepreneurial behavior in Tunisia.* Cogent Business & Management, 11(1): 2292313

McGehee N.G., Kim K., Jennings G.R., 2007 - *Gender and motivation for agri-tourism entrepreneurship*. Tourism Management, 28(1), 280–289.

Meinzen-Dick R. *et al,* 2011 - *Engendering Agricultural Research, Development and Extension*; International Food Policy Research Institute: Washington, DC, USA, Volume 176.

Nikraftar T., Hosseini E., 2016 - *Factors affecting entrepreneurial opportunities recognition in tourism small and medium sized enterprises*. Tourism Review, 71(1): 6–17.

Ogunlela Y.I., Mukhtar A.A., 2009 - *Gender issues in agriculture and rural development in Nigeria: The role of women.* Humanity & Social Sciences Journal 4(1): 19-30.

Pécot M. *et al*, 2024 - *From empowering women to being empowered by women: A gendered social innovation framework for tourism-led development initiatives*. Tourism Management, 102: 104883.

Pehu E., Lambrou Y., Hartl M., 2009, *Gender in Agriculture Sourcebook*; The World Bank: Washington, DC, USA; FAO: Rome, Italy; IFAD: Rome, Italy.

Permani R., 2021 - *Rethinking women's roles in Indonesian agriculture*. The Jakarta Post; available online at: https://www.thejakartapost.com/academia/2021/10/24/rethinking-womens-rolesin-indonesian-agriculture.html (accesed on 14.08.2025).

Ragasa C., 2012 - *Gender and institutional dimensions of agricultural technology adoption: a review of literature and synthesis of 35 case studies*. In *2012 Conference*, International Association of Agricultural Economists Foz do Iguacu, Brazil, pp. 18-24.

Rakočević L., Knežević M., Vujko A., 2025 - *Empowering women in rural Montenegro: A pathway to sustainable rural tourism development.* Geojournal of Tourism and Geosites, 59(2): 920–929.

Saugeres L., 2002 - *The cultural representation of farming landscape: Masculinity, power and nature.* Journal of Rural Studies, 18: 373-384.

Salamon S., 1995 - *Cultural dimensions of land tenure in the United States*. Land Tenure Center, University of Wisconsin-Madison, USA.

Sharpley R., Vass A., 2006 - *Tourism, farming and diversification: An attitudinal study*. Tourism Management, 27: 1040-1052.

Still L.V., Walker E.A., 2006 - T*he self-employed woman owner and her business: An Australian profile.* Women in Management Review, 21(4): 294-310.

Sulaj A., Themelko H., 2024 - *Agritourism as A Pathway to Women's Empowerment: Insights From Rural Albania.* European Countryside, 16(4): 628-646.

Surangi H., 2022 - *A critical analysis of the networking experiences of female entrepreneurs: A study based on the small business tourism sector in Sri Lanka*. Journal of Innovation and Entrepreneurship, 11(1): 1–16.

Tristanti T., Nurhaeni I.D.A., Mulyanto M., Sakuntalawati, R.D., 2022 - *The role of women in tourism: a systematic literature review*. *KnE Social Sciences*, pp. 545-554.

Vuciterna R., Ruggeri G., Mazzocchi C., Manzella S., Corsi S. *2024* *- Women's entrepreneurial journey in developed and developing countries: a bibliometric review* Agricultural and Food Economics, 12:36.

Vuković, D., Petrović M.D., Maiti M., Vujko A., 2023 - *Tourism development, entrepreneurship and wome's empowerment– Focus on Serbian countryside.* Journal of Tourism Futures, 9: 417–437.

Vujko A., Karabašević D., Cvijanović D., Vukotić S., Mirčetić V., Brzaković P., 2024 - *Women's Empowerment in Rural Tourism as Key to Sustainable Communities' Transformation.* Sustainability, 16: 10412.

Winn J., 2005 - *Women entrepreneurs: can we remove the barriers?* The International Entrepreneurship and Management Journal, 1(3): 381–397.

THE LIVING EPISTEME: PRELIMINARY CONCEPTUAL FRAMEWORK

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Abstract

This research responds to deep social needs of reconnecting knowledge with lived meaning, human relationship, and authentic transformation of life – both individually and collectively. Its aim was the formulation of an epistemological framework based on relation and becoming. The research methodology integrated conceptual analysis, autoethnography, validation through resonance, and dialectical confrontation, within a transdisciplinary approach. The results included: (1) the formulation of a new epistemological framework – the Living Epistema – which proposes a balance between scientific rigor and human, ethical and reflexive engagement; (2) the configuration of 8 principles of this episteme which reflect the values: dignity, contextualization of truth, relation as a way of knowing, validation through practice and transformation through learning. The originality of the approach lies in the way it interweaves traditional perspectives into a relational, contextualized and transformative vision.

Keywords: reflexive qualitative research, relational epistemology, theoretical autoethnography, reflexive validation, transdisciplinary education

The understanding of the nature of knowledge has evolved from modernity's view of it as a static set of objective truths, to contemporary thinking which sees it as a dynamic, context-dependent process. This shift shaped the need for an integrative conceptual framework that could connect diverse perspectives on the genesis, transmission, and renewal of knowledge. In this context, the concept of the Living Epistema emerges as a response to the complex and dynamic character of contemporary knowledge.

Thomas Kuhn showed that science progresses through paradigmatic shifts that deeply restructure the vision of the scientific community, undermining the idea of an absolute and immutable truth (Kuhn T.S., 1962). Furthermore, Michael Polanyi emphasized that people always know more than they can express explicitly, and that knowledge is never fully explicit, being significantly embedded in personal experience, practical skills, and individual intuition. The socio-historical context and the subject's personal involvement are integral to the process of generating knowledge (Polanyi M., 1966).

According to the theory of the social construction of reality, everyday reality and knowledge itself are social constructs, resulting from institutionalized human interactions. Knowledge takes the form shaped by the social and historical context. Language, values, and practices of a community give form to accepted truth (Berger P.L. and Luckmann T., 1966).

In pedagogy, there has been a shift from authoritarian transmission of information to a participatory and emancipatory approach, from students as passive receivers to their involvement as active subjects in the co-creation of knowledge. Thus, the act of knowing cannot be separated from the human context, enhancing the ethical and transformative dimension of education (Freire P., 2000). It has also been argued that the act of knowing is a fundamental trait of living entities, a perspective which blurs the boundary between life and knowledge, integrating knowledge into the living phenomenon (Maturana H.R. and Varela F.J., 1987).

Today's global issues have highlighted the need for concepts such as transdisciplinarity, as a unifying vision between the sciences of nature, society and culture (Nicolescu B., 2002), and for epistemological pluralism, in which diverse cultures are valued in a global dialogue rather than subjected to a universal set of rules (Santos B. de S., 2014).

The aim of the research presented here was to propose a preliminary conceptual framework for an emerging epistemology – the Living Epistema – which sustains a lived, relational, contextual, and transformative knowledge. The derived objectives are: (1) to clarify the term "living" as a distinct

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epistemological stance; (2) to compare the Living Epistema with other paradigms in order to shape its uniqueness; (3) to outline the principles that ground it. The publication of this research is an act of repositioning and balancing the logic of efficiency with the ethics of lived experience.

MATERIAL AND METHOD

The methodology used reflects the epistemological nature of the proposed concept: the Living Epistema. It involves a reflexive, relational, and shared experiential approach, in which the researcher is part of the knowledge process. In the spirit of interpretative qualitative research (Denzin N.K. and Lincoln Y.S., 2011; Stake, 1995), this study combined four essential methodological dimensions:

1. Reflexive conceptual analysis, through which the central terms – "episteme" and "living" – were investigated starting from existing theoretical frameworks (Kuhn, 1962; Polanyi, 1966; Varela F.J. *et al.,* 1991), and confronted with the researcher's experience in scientific contexts.
2. Theoretical autoethnography, which combined personal narrative with theoretical reflection (Ellis C. and Bochner A.P., 2000; Adams, Holman Jones S., and Ellis C., 2015), to integrate the author's own epistemological becoming as part of the conceptual construction.
3. Dialogical resonance was used for epistemological validation, replacing classical criteria of objectivity or replicability. Thus, the proposed ideas were calibrated through their transformative effect on dialogue partners and on the researcher himself (Freire, 2000; Biesta, 2006).
4. Epistemological dialectical analysis, through which each principle was subjected to reflexive confrontation between divergent theoretical positions (pro and con) identified from current scientific literature. This analysis enabled the articulation of the principles in a critical and justified manner.

The research design is aligned with recent initiatives in transdisciplinary research proposing contextual, situated, and responsible knowledge (Haraway, 1988; Santos, 2014), in dialogue with a digital conversational agent calibrated for epistemological research and integrated in a human reflexive process. The Living Epistema remains deliberately in progress because it offers an open methodological positioning, in line with its principles of relationality and transformation.

RESULTS AND DISCUSSIONS

1. The central terms "episteme" and "living" between existing theoretical frameworks and the researcher's experience

1.1. The term "episteme" was consecrated by Michel Foucault (1966) as the set of conditions of possibility for knowledge in a given historical era. The episteme is a deep structure that shapes what is known, how, and what can be known.

The reflexive critical approach leads to the idea that these definitions maintain a structuralist, even impersonal, view of knowledge. Lacking is the ethically responsible subjectivity, the researcher's own reflection, and epistemic awareness in methodological choices. For example, in a project dedicated to identifying barriers to rural youth entrepreneurship (World Bank 7200142/08.04.2021), an integrated methodology was applied: semi-structured interviews, focus groups, and questionnaires. This approach succeeded in capturing external barriers: lack of funding, bureaucracy, poor infrastructure. The epistemological approach was assumed, positioned, and contextualized.

1.2. The concept of "living" is usually associated with biology or with humanistic metaphors, with some relevant exceptions: enactivism proposed by Varela F.J. (1991) as an emergent, embodied, interactive process; process philosophy; or relational epistemologies (Bateson G., 1979) that recognize the dynamism of experience as an epistemic source. Typically, "living" appears as a decorative metaphor, and lived knowledge is considered subjective and excluded from scientific methodology. From this, the need emerged for it to be understood epistemologically as a condition in which knowledge is: relational; emergent (not fixed); transformed through presence; contextual and embodied (not abstractly universalizable). Thus, it becomes a term of epistemological positioning, comparable to "situated" (Haraway D., 1988), "tacit" (Polanyi M., 1966), or "embodied" (Varela F.J. et al., 1991), but proposed as a distinct and foundational term. For example, in the same research, without being explicitly stated, young people also experienced internal barriers: fear of failure, lack of confidence, absence of curiosity, or inability to imagine another life. These internal barriers were captured through tone, hesitation, and gestures, noticed through the researcher's affective attention and relational intuition. Here, the episteme became living because it recognizes the value of knowledge lived in relationship, accepts the affective dimension as legitimate, and embraces the transformation of both the researched object and the researching subject.

2. The epistemological transformation of the author as part of the conceptual construction highlighted by theoretical autoethnography. Reflexive dialogue, as a space of epistemic co-creation where dialogue becomes a research tool if it is also a framework for relational transformation, implies a double commitment: of affective presence and shared critical thinking. This approach explored: the way reflexive dialogue produces emergent meanings; the nature of the researcher–participant relationship; and the forms of validation that appear in the process.

The application scenario is from the same research: the interviewee, a young man who had returned to his now-empty parental home after several years, said: “When I left the country, I had trust that people here knew what was good, what was bad, that there was a kind of common foundation. Now, after I came back, I feel like something has broken. I no longer have the same trust — neither in others, nor in myself as someone from this village. And I wonder: can we do something to rebuild that trust? Or was it just a youthful illusion?”

At that moment, I felt it was not the time to ask for explanations. I asked nothing. That shared silence was a form of respect for a wound spoken aloud for the first time. It was a living silence, which marked the beginning of a new relationship based on shared vulnerability. It was also a question for me: what does it mean to be worthy of someone’s trust, in a world where trust falls apart so easily?

The emerging analysis highlights the fact that trust is also an epistemic element. Without trust, mutual knowledge becomes fragile, and shared meanings unstable. The participant’s insight emerges in the form of an emotional question: “Can we still rebuild trust?” It is a question about the possibility of reconnection. The researcher’s silence is not a lack of reaction. It is the acknowledgment of spoken vulnerability. In this space, trust is rebuilt through ethical presence. Validation appears in the fact that the participant hears himself and accepts the rupture.

This example shows how the relationship of trust becomes a source of meaning. Reflexive dialogue produces data, transforms the researcher’s positioning, and opens a space for shared epistemic construction.

3. Calibration of proposed ideas through their transformative effect on dialogue partners – dialogical resonance

The focus group conducted within the project Cooperation for Holistic Agricultural Innovation Incubators in Sub-Saharan Africa (1010822963-ERASMUS-EDU-2022-CBHE) was a relational space where emergent forms of knowledge arose through dialogue and collective interaction (Kamberelis G. & Dimitriadis G., 2005; Brumă *et al.,* 2022). This type of focus group emphasizes the pedagogical and reflexive dimension of the meeting (Buber M., 1971). The research aimed to understand the perceptions and challenges faced by rural youth in Kenya in starting a business. The discussion group consisted of 24 participants from the Kisumu region, Kenya, distributed into 3 groups representing the diversity of the agricultural ecosystem: researchers, farmers, consumers, entrepreneurs, investors, NGO representatives, public authorities, and cultural/religious institutions. The facilitator’s role was to observe the emergence of moments of resonance and rupture (Freire P., 2000; Lincoln Y.S. & Guba E.G., 1985).

Representative dialogical fragment (thematized): Participant 1: “The business idea sounds good, but we have no capital, and the bank asks for guarantees we don’t have.” Participant 2: “Maybe the bank isn’t the only solution. Maybe we could make a cooperative.” (collective pause) Participant 3: “That way, we could support one another. We wouldn’t have to wait for help from outside anymore.” At that moment, the group moved from data collection to a relational framework of collective initiation. A new vision emerged – the local cooperative as a viable alternative – through horizontal co-reflection. This became an epistemic scene.

Through this method, participation becomes a practice of thinking together; knowledge is co-created when participants recognize their own experience in the voice of the other; transformation emerges through emotional and conceptual resonance, and relationality is multiplied among participants, researchers, and community. Thus, the transformative focus group becomes a living tool for the genesis, transmission, and renewal of knowledge.

4. Epistemological analysis of the principles of the Living Epistema was structured around epistemological questions that challenge each principle in terms of the validity of knowledge, as well as an analysis of major positions in the literature, both opposing and supporting.

Principle 1 (P1): Human dignity is the cardinal value – To what extent should the recognition of human dignity as a cardinal value determine knowledge? How does respecting the dignity of those involved influence the necessity, validity, and legitimacy of the knowledge obtained?

The researcher has the right to full intellectual freedom even if there is no immediate practical application. (Polanyi M., 1962) argued for the autonomy of research as a premise for authentic discoveries. According to classical positivism, knowledge is conceived as axiologically neutral, based on facts (Weber M., 1919), and ethics is seen as a source of bias. Hence, participants are treated as means to obtain data, with no concern for their dignity (Merton R.K., 1942). In contrast, humanist traditions recognize knowledge as authentic only if it respects dignity. The human being must be treated as an end in itself; knowledge gains meaning when it contributes to the improvement of the human condition (Dewey J., 1938); learning is a humanizing cognitive and educational process (Freire P., 2000); and the neglect of marginalized voices constitutes epistemic injustice (Fricker M., 2007).

P2: Truth is contextual – Is truth univocal and absolute, or does it depend on the context of the knower? How does context affect interpretation and the validity of truth?

In classical epistemology, truth is absolute and universal. In the realist perspective, truth corresponds to objective reality, regardless of the observer or context. Hence, hypothesis testing uses universally valid criteria, independent of socio-cultural circumstances (Popper K., 1963). Contextualist approaches, on the other hand, reject absolute truth and tie it to the dominant scientific paradigm (Kuhn T., 1962). In social sciences, truth is socially constructed (Berger P.L. & Luckmann T., 1966); meanings depend on local cultural context (Geertz C., 1973); regimes of truth are shaped by power and discourse (Foucault M., 1980); and no truth is complete independent of the observer's position (Haraway D., 1988).

P3: Knowledge has a transformative role – What is the relationship between knowledge and transformation? Is knowledge a neutral endeavor of describing reality, or one that generates personal and social change?

The traditional-positivist perspective sees knowledge as descriptive and neutral, a way of explaining the world. A transformative mission is seen as ideological contamination. Michel Foucault (1975) warned that knowledge can become a tool for power and control or for legitimizing hidden interests (Lyotard J.F., 1979). However, critical thinking ties authentic knowledge to usefulness and transformation. Philosophy must change the world (Marx K., 1845); in consciousness-raising pedagogy, learning is an act of liberation (Freire P., 2000); it creates space for critical freedom (Habermas J., 1971); and according to transformative learning theory, critical reflection leads to shifts in one's frame of reference. The epistemic value of research increases when it contributes to social, personal, or community transformation (Lewin K., 1946).

P4: Knowledge is multimodal – Are there more legitimate ways of knowing than through scientific concepts and data? Are storytelling, art, metaphor, dialogue, and personal reflection valid in knowledge?

The classical positivist model validates only knowledge that is logically or empirically verifiable. Logical empiricism accepts only empirically tested statements. Scientism and reductionist views deem narrative, artistic, or intuitive contributions epistemically illegitimate (Wilson E.O., 1998). In contrast, an expanded epistemology is proposed that includes experiential, symbolic, conceptual, and practical modes (Heron J. & Reason P., 1997). A distinction is made between narrative and paradigmatic thinking (Bruner J., 1986); the concept of tacit, lived knowledge becomes fundamental (Polanyi M., 1966); and cultural anthropology and indigenous epistemologies include myth, ritual, art, and relationship as part of authentic knowing (Smith L.T., 1999).

P5: The researcher is transformed in the process – Is the researcher an objective and unchanged observer, or does he evolve with the research process? How does involvement transform the researcher?

According to classical positivism, the researcher is a neutral, uninvolved observer, unaffected by emotional or personal interference (Durkheim E., 1895). Researcher influence must be minimized because transformation is seen as a source of bias. However, qualitative, reflexive, and interpretive research asserts that the researcher is deeply influenced and that transformation is an epistemic resource. Autoethnography values experience, interaction with subjects, and the fieldwork that brings emotional, cognitive, and spiritual changes (Ellis C. & Bochner A.P., 2000). In naturalistic research, transparency about personal transformation becomes part of scientific rigor (Lincoln & Guba, 1985); the researcher must examine their own position, values, and influences (Bourdieu P., 2004).

P6: Knowledge is relational – Is knowledge independent of others or born in dialogue? Is it indifferent to or shaped by social interactions?

In objectivist tradition, knowledge is rational and solitary. Beginning from certain truths obtained independently from others (Descartes R., 1641), the modern model of science promoted controlled experiments, standardized methods, and the principle of universalism (Merton R.K., 1942). In contrast, constructivist and relational perspectives claim that research arises from life and returns to it (Boyer E., 1996); social reality is built and sustained through interaction (Berger P. & Luckmann T., 1966); cognitive development begins in the relational space (Vygotsky L.S., 1978); and true understanding emerges in dialogue, as an encounter of perspectives (Gadamer H.-G., 1960). Indigenous epistemologies affirm the studied reality as a relationship between researcher and subject (Wilson S., 2008). In this light, knowledge cannot be built without authentic human participation. Living research is a form of accompaniment — an act of epistemic, ethical, and communal sharing. Truth arises in dialogue, presence, and mutual transformation (Lewin K., 1946; Smith L.T., 1999; Wilson S., 2008).

P7: The value of knowledge also lies in the way it is acquired – How much does the method by which we reach knowledge matter compared to the result? Is a conclusion valuable regardless of how it was obtained?

From a consequentialist perspective, if a statement is true and verified, the way it was obtained becomes secondary. Thus, methods that were ethically questionable have sometimes been accepted because the results saved lives. Any method seems valid if it leads to knowledge (Feyerabend, 1975). However, especially due to inhumane deviations, the scientific community has established, for example through the Nuremberg Code, that no result justifies the violation of human rights. We cannot sacrifice integrity for progress (Jonas H., 1969), and true knowledge implies a process guided by honesty, rigor, and responsibility (Zagzebski L., 1996).

P8: Learning is grounded in active accompaniment and shared reflection – Is authentic learning a one-way transmission of information or shared reflection in a learning community? What is the role of cooperation in assimilating knowledge?

In classical educational tradition, learning is often the transfer of information from expert to beginner, with clear structures, sequencing, and individual effort. Collaboration or introspection are seen as inefficient (Kirschner P.A. *et al.,* 2006). The classical behaviorist model reinforces learning through repetition and feedback. In contrast, contemporary learning theories support knowledge as a deeply social and relational process. Collaboration among students is important (Vygotsky L.S., 1978), as are activities in communities of practice, informally guided by experienced members (Lave J. & Wenger E., 1991). Teacher and student are equals in the search for meaning, and shared reflection and inquiry into lived experience are sources of transformation (Freire P., 2000; Dewey J., 1916).

Thus, in the logic of the Living Epistema, human dignity is a condition of epistemic validation. Knowledge is legitimate if it also means recognition. It becomes a space for healing, wisdom, and the shared creation of meaning that transforms both individually and collectively. It includes the logical-empirical register, but also story, symbol, metaphor, spiritual reflection, practice, and dialogue—necessary to understand the complexity of human life. It sees truth as an open, relational construct anchored in experience. It is built in and through relationship, and truth becomes visible in dialogue, empathy, and mutual contextualization.

Valuable research is grounded in and validated by applicability—when it concretely supports the lives of those involved. And its value lies in the result, but also in the method, relationship, intention, and integrity with which it was obtained. The researcher participates with presence, empathy, and responsibility. They are consciously transformed—spiritually, socially, emotionally, cognitively—and learning comes alive through active accompaniment and shared reflection.

CONCLUSIONS

The Living Epistema is an epistemological proposal that responds to the need to rethink knowledge beyond objectivist and efficiency-driven paradigms. It has been shown that the act of knowing is inseparable from the human, relational, and affective context, and that values such as dignity, reflection, and transformation become epistemic sources. Within this framework, the researcher is an involved participant, and their positioning, relationships, and personal transformation strengthen the meaning and validity of the knowledge produced.

This work proposes an open and evolving framework that invites epistemological dialogue and co-creation. It is a starting point for future research in fields such as education, economics, sociology, and rural development.

ACKNOWLEGMENTS

Project funded by the World Bank 7200142/08.04.2021 – Study of family farms in Romania – Support for programming the Common Agricultural Policy (CAP) – P173505

ERASMUS MOBILITIES PROJECT 1010822963-ERASMUS-EDU-2022-CBHE – Cooperation for Holistic Agriculture Innovation Nests in Sub-Saharan Africa.

REFERENCES

Adams T.E., Holman Jones S., Ellis C., 2015 – *Autoethnography: Understanding Qualitative Research*. Oxford University Press.

Bateson G., 1979 – *Mind and Nature: A Necessary Unity*. Dutton, New York.

Berger P.L., Luckmann T., 1966 – *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*. Anchor Books.

Biesta G., 2006 – *Beyond Learning: Democratic Education for a Human Future*. Paradigm Publishers.

Bourdieu P., 2004 – *Science of Science and Reflexivity*. University of Chicago Press.

Boyer E.L., 1996 – The Scholarship of Engagement. *Journal of Public Service & Outreach*, 1(1), 11–20.

Brumă S., et al., 2022 – *Short Food Supply Chains and Local Development in Rural Eastern Europe*. Springer.

Bruner J., 1986 – *Actual Minds, Possible Worlds*. Harvard University Press.

Buber M., 1971 – *I and Thou*. Touchstone.

Denzin N.K., Lincoln Y.S. (Eds.), 2011 – *The Sage Handbook of Qualitative Research* (4th ed.). Sage Publications.

Descartes R., 1641 – *Meditationes de Prima Philosophia* (Romanian edition: *Meditații despre filosofia primă*, 1992).

Dewey J., 1916 – *Democracy and Education: An Introduction to the Philosophy of Education*. MacMillan.

Dewey J., 1938 – *Experience and Education*. Kappa Delta Pi.

Durkheim E., 1895 – *Les Règles de la Méthode Sociologique* (Romanian edition: *Regulile metodei sociologice*, Editura Științifică, 1993).

Ellis C., Bochner A.P., 2000 – Autoethnography, Personal Narrative, Reflexivity. In Denzin N. & Lincoln Y. (Eds.), *Handbook of Qualitative Research* (2nd ed.). Sage Publications.

Feyerabend P.K., 1975 – *Against Method: Outline of an Anarchistic Theory of Knowledge*. New Left Books, London.

Foucault M., 1966 – *Les Mots et les choses*. Gallimard, Paris.

Foucault M., 1975 – *Surveiller et punir. Naissance de la prison* (Romanian edition: *A supraveghea și a pedepsi*, Editura Humanitas, 1997).

Foucault M., 1980 – *Power/Knowledge: Selected Interviews and Other Writings 1972–1977*. Pantheon Books.

Freire P., 2000 – *Pedagogy of the Oppressed*. Bloomsbury.

Fricker M., 2007 – *Epistemic Injustice: Power and the Ethics of Knowing*. Oxford University Press.

Gadamer H.-G., 1960 – *Wahrheit und Methode* (Romanian edition: *Adevăr și metodă*, Editura Teora, 2001).

Geertz C., 1973 – *The Interpretation of Cultures*. Basic Books.

Habermas J., 1971 – *Knowledge and Human Interests*. Beacon Press (Romanian edition: *Cunoaștere și interes*, Editura Politică, 1983).

Haraway D., 1988 – Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. *Feminist Studies*, 14(3), 575–599.

Heron J., Reason P., 1997 – A Participatory Inquiry Paradigm. *Qualitative Inquiry*, 3(3), 274–294.

Jonas H., 1969 – Philosophical Reflections on Experimenting with Human Subjects. *Daedalus*, 98(2), 219–247.

Kamberelis G., Dimitriadis G., 2005 – Focus Groups: Strategic Articulations of Pedagogy, Politics, and Inquiry. In Denzin N.K. & Lincoln Y.S. (Eds.), *The Sage Handbook of Qualitative Research*.

Kirschner P.A., Sweller J., Clark R.E., 2006 – Why Minimal Guidance During Instruction Does Not Work. *Educational Psychologist*, 41(2), 75–86.

Kuhn T.S., 1962 – *The Structure of Scientific Revolutions*. University of Chicago Press.

Lave J., Wenger E., 1991 – *Situated Learning: Legitimate Peripheral Participation*. Cambridge University Press.

Lewin K., 1946 – Action Research and Minority Problems. *Journal of Social Issues*, 2(4), 34–46.

Lincoln Y.S., Guba E.G., 1985 – *Naturalistic Inquiry*. Sage Publications.

Lyotard J.-F., 1979 – *La Condition Postmoderne: Rapport sur le savoir* (Romanian edition: *Condiția postmodernă*, Editura Babel, 1993).

Marx K., 1845 – Teze despre Feuerbach (published in: *Marx & Engels – Opere alese*, ESPLA, 1960).

Maturana H.R., Varela F.J., 1987 – *The Tree of Knowledge: The Biological Roots of Human Understanding*. Shambhala, Boston.

Merton R.K., 1942 – The Normative Structure of Science. In: *The Sociology of Science: Theoretical and Empirical Investigations*, University of Chicago Press, 1973.

Nicolescu B., 2002 – *Manifesto of Transdisciplinarity*. State University of New York Press, Albany.

Polanyi M., 1962 – The Republic of Science: Its Political and Economic Theory. *Minerva*, 1(1), 54–73.

Polanyi M., 1966 – *The Tacit Dimension*. Doubleday & Co., Garden City, NY.

Popper K., 1963 – *Conjectures and Refutations: The Growth of Scientific Knowledge*. Routledge & Kegan Paul.

Santos B. de S., 2014 – *Epistemologies of the South: Justice Against Epistemicide*. Paradigm Publishers, Boulder.

Smith L.T., 1999 – *Decolonizing Methodologies: Research and Indigenous Peoples*. Zed Books.

Stake R.E., 1995 – *The Art of Case Study Research*. Sage Publications.

Varela F.J., Thompson E., Rosch E., 1991 – *The Embodied Mind: Cognitive Science and Human Experience*. MIT Press.

Vygotsky L.S., 1978 – *Mind in Society: The Development of Higher Psychological Processes*. Harvard University Press.

Weber M., 1919 – Wissenschaft als Beruf (Romanian edition: *Știința ca vocație*, in *Știința și politica*, Editura Anima, 1992).

Wilson S., 2008 – *Research is Ceremony: Indigenous Research Methods*. Fernwood Publishing.

Zagzebski L., 1996 – *Virtues of the Mind: An Inquiry into the Nature of Virtue and the Ethical Foundations of Knowledge*. Cambridge University Press.

THE CONCEPT OF CARBON CREDITS IN AGRICULTURE: A REVIEW OF LITERATURE

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Abstract

One of the major concerns of the 21st century is climate change, which has a significant impact on sustainable development strategies and the global economy. In this regard, the carbon credit market has become a key tool in efforts to reduce greenhouse gas emissions and accelerate the shift towards a low-carbon economy.
This work presents a literature study that emphasizes the discrepancies in the current understanding of carbon credits in agriculture. The approach will focus on a detailed analysis of the relevant terms and concepts, highlighting the connections and interdependencies among them and emphasizing their importance within the carbon market framework. Thus, carbon credits are primarily intended to provide businesses with a financial motivation to implement strategies to reduce greenhouse gas (GHG) emissions and to switch to environmentally friendly and more sustainable operations in industries like manufacturing and agriculture.
The paper's findings highlight the three key areas of study for experts in the field of carbon credits: carbon trading, carbon markets, and carbon sequestration.

Keywords: GES, carbon sequestration, carbon credits, regenerative agriculture

As global warming intensifies, climate change mitigation has transitioned from a prospective necessity to an immediate imperative. The rise in anthropogenic CO_2 emissions represents a primary driver of global warming, thereby prompting increased scholarly and policy attention toward the pursuit of carbon neutrality.

Agriculture, as a sector essential to food security, makes a significant contribution to global greenhouse gas (GHG) emissions, thereby necessitating the establishment of robust methodologies for the estimation and monitoring of these emissions, along with efficient and transparent reporting systems (Ken EG, *et al.,* 2021).

The growing awareness of climate change and global warming acknowledges CO_2 emissions and other greenhouse gases as potential drivers contributing to climate change, which poses significant risks to individuals, economies, and livelihoods. The Paris Agreement, in force since 2016, aims to limit global warming to 1.5 degrees Celsius in order to achieve a climate-neutral world by the middle of the century.

Agriculture is the economic sector capable of sequestering greenhouse gases from the environment while simultaneously maintaining productivity. Within agriculture, conditions can be created that foster synergies between mitigation and adaptation strategies. (Vershuuren J., 2018)

Within the suite of financial instruments designed to reduce carbon emissions—including credits, bonds, insurance schemes, and trading mechanisms—carbon trading emerges as the most pivotal in terms of investment and financing. In the landscape of the construction and functioning of the global carbon market, the European Union (EU) carbon market stands out as the most successful in terms of institutionalization, the development of mechanisms, and the achievement of multiple objectives, including the monitoring of performance in reducing carbon emissions. Its experience in efficient operation and governance constitutes a benchmark and reference framework for other jurisdictions and organizations engaged in climate change mitigation efforts. (Z. Rui, 2017)

In 1968, the American economist J.H. Dales outlined the concept of emission rights in his monograph *Pollution, Property and Prices*, building upon Ronald Coase's theory of property rights. This proposal emerged as the outcome of an in-depth theoretical exploration. The fundamental idea expressed in this work asserts that the government, as the representative of public

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interests and custodian of environmental resources, may trade emission rights for certain pollutants, such as stocks, to the highest interested bidder. This approach is grounded in the principle that the efficient allocation of emission rights can establish a market mechanism that incentivizes pollution reduction and fosters a more efficient use of natural resources, in line with the principles of a market economy. (J.H. Dales, 2002)

The relationship between climate change and carbon credits is fundamental to understanding how this global challenge is addressed. Carbon credits constitute a powerful instrument for incentivizing the reduction of greenhouse gas emissions and for financing sustainable development initiatives.

As early as 2012, Ștefan G. emphasized in his article that the economy was at the outset of a stage of structural transformations, a development that gave rise to the emergence of new economic theories. (Stefan, 2012)

Accelerated economic development, unprecedented population growth, and rapid industrialization have exerted significant pressure on the global ecosystem through the depletion of limited renewable resources and the introduction of inadequate, toxic, and non-recyclable products, thereby undermining the environment's capacity to sustain the ecological balance essential for the survival of species, including humans.

Addressing climate change, driven by the accumulation of atmospheric pollutants, is an essential endeavor that requires translating global policy imperatives into applicable solutions across all economic sectors. (N. Lokuge, 2022)

CARBON CREDITS AND MECHANISMS OF IMPLEMENTATION IN AGRICULTURE

The justification for a carbon certificate is straightforward. A company that is unable to halt its CO_2 emissions, yet wishes or needs to continue its activities, must purchase carbon certificates from the carbon market, thereby enabling another entity (a project developer) to undertake CO_2 emission reductions. In this scenario, although a company continues to emit CO_2, the overall global concentration of carbon in the atmosphere decreases.

Speculative investors, such as brokers, dealers, and exchanges, participate in the carbon market by acquiring carbon emission certificates as intermediaries. Final buyers may obtain carbon permits either directly from them or from project developers. The revenues generated from the sale of certificates provide financial support to the projects that produce them, thereby fostering new emission reduction initiatives.

Consequently, they are essential to climate change mitigation initiatives, providing economic incentives for emission reductions and facilitating the transition toward a low-carbon economy. They are frequently employed by businesses and nations to meet emission reduction targets, comply with regulations, or demonstrate environmental responsibility.

By promoting the reduction of greenhouse gas emissions in an economically viable manner, carbon credits play a pivotal role in the global transition toward a low-carbon economy, while at the same time providing a flexible and adaptable framework for companies and governments in their efforts to combat climate change.

THE EXTENT OF CARBON SEQUESTRATION THROUGH SUSTAINABLE AGRICULTURAL TECHNOLOGIES

The most accurate method for determining changes in soil carbon content within a given area is the collection of physical samples and the quantification of carbon levels before and after the change in practice.

Financial intermediaries employ mathematical models to forecast the amount of soil organic carbon generated by specific changes in agricultural land management practices. The predictive capabilities of these models are still in the testing phase. Thus, the scientific literature highlights the relationships between agricultural systems and the amount of carbon sequestered in soils (*table 1, table 2, table 3, and table 4).*

Tabel 1

Algorithms for quantifying practices across three tillage systems in wheat crop

Indicator	What does it represent?	Intervals		
		Conventional Tillage System	Minimum Tillage System	No-Tillage System
Dry matter fraction of the product	Proportion of the product (seeds/grains) without water	0.85 – 0.90	0.85 – 0.90	0.85 – 0.90
Harvest index	Proportion of grains/seeds in the total aboveground biomass	0.40 – 0.50	0.40 – 0.50	0.40 – 0.50
Root-to-shoot ratio	Root mass relative to aboveground mass at harvest	0.18 – 0.23	0.18 – 0.23	0.18 – 0.23

Carbon fraction of the product	%C in the dry mass of seeds/grains	0.42 – 0.47	0.42 – 0.47	0.42 – 0.47
Carbon fraction of aboveground residues	%C in the dry mass of straw/stover/stems	0.42 – 0.45	0.42 – 0.45	0.42 – 0.45
Carbon fraction of roots	%C in the dry mass of roots	0.38 – 0.45	0.38 – 0.45	0.38 – 0.45
Fraction of residues retained on the field	Portion of residues left in the field (not removed/burned)	0.50 – 0.90	0.80 – 1.00	0.90 – 1.00
Stabilized fraction of C from residues	Proportion of residue-derived C retained long-term in soil	0.11 – 0.15	0.13 – 0.17	0.15 – 0.18
Stabilized fraction of C from roots + rhizosphere	Proportion of root-derived C retained long-term in soil	0.20 – 0.24	0.23 – 0.29	0.26 – 0.32

Tabel 2

Algorithms for quantifying practices across three tillage systems in maize crop

Indicator	What does it represent?	Intervals		
		Conventional Tillage System	Minimum Tillage System	No-Tillage System
Dry matter fraction of the product	Proportion of the product (seeds/grains) without water	0.85 – 0.88	0.85 – 0.88	0.85 – 0.88
Harvest index	Proportion of grains/seeds in the total aboveground biomass	0.48 – 0.58	0.48 – 0.58	0.48 – 0.58
Root-to-shoot ratio	Root mass relative to aboveground mass at harvest	0.15 – 0.22	0.15 – 0.22	0.15 – 0.22
Carbon fraction of the product	%C in the dry mass of seeds/grains	0.42 – 0.47	0.42 – 0.47	0.42 – 0.47
Carbon fraction of aboveground residues	%C in the dry mass of straw/stover/stems	0.42 – 0.45	0.42 – 0.45	0.42 – 0.45
Carbon fraction of roots	%C in the dry mass of roots	0.38 – 0.45	0.38 – 0.45	0.38 – 0.45
Fraction of residues retained on the field	Portion of residues left in the field (not removed/burned)	0.50 – 0.90	0.80 – 1.00	0.90 – 1.00
Stabilized fraction of C from residues	Proportion of residue-derived C retained long-term in soil	0.11 – 0.15	0.13 – 0.17	0.15 – 0.18
Stabilized fraction of C from roots + rhizosphere	Proportion of root-derived C retained long-term in soil	0.20 – 0.24	0.23 – 0.29	0.26 – 0.32

Tabel 3

Algorithms for quantifying practices across three tillage systems in sunflower crop

Indicator	What does it represent?	Intervals		
		Conventional Tillage System	Minimum Tillage System	No-Tillage System
Dry matter fraction of the product	Proportion of the product (seeds/grains) without water	0.90 – 0.92	0.90 – 0.92	0.90 – 0.92
Harvest index	Proportion of grains/seeds in the total aboveground biomass	0.25 – 0.35	0.25 – 0.35	0.25 – 0.35
Root-to-shoot ratio	Root mass relative to aboveground mass at harvest	0.05 – 0.08	0.05 – 0.08	0.05 – 0.08
Carbon fraction of the product	%C in the dry mass of seeds/grains	0.42 – 0.47	0.42 – 0.47	0.42 – 0.47
Carbon fraction of aboveground residues	%C in the dry mass of straw/stover/stems	0.42 – 0.45	0.42 – 0.45	0.42 – 0.45
Carbon fraction of roots	%C in the dry mass of roots	0.38 – 0.45	0.38 – 0.45	0.38 – 0.45
Fraction of residues retained on the field	Portion of residues left in the field (not removed/burned)	0.50 – 0.90	0.80 – 1.00	0.90 – 1.00
Stabilized fraction of C from residues	Proportion of residue-derived C retained long-term in soil	0.11 – 0.15	0.13 – 0.17	0.15 – 0.18
Stabilized fraction of C from roots + rhizosphere	Proportion of root-derived C retained long-term in soil	0.20 – 0.24	0.23 – 0.29	0.26 – 0.32

Tabel 4

Algorithms for quantifying practices across three tillage systems in rapeseed crop

Indicator	What does it represent?	Intervals		
		Conventional Tillage System	Minimum Tillage System	No-Tillage System
Dry matter fraction of the product	Proportion of the product (seeds/grains) without water	0.90 – 0.92	0.90 – 0.92	0.90 – 0.92

Harvest index	Proportion of grains/seeds in the total aboveground biomass	0.28 – 0.40	0.28 – 0.40	0.28 – 0.40
Root-to-shoot ratio	Root mass relative to aboveground mass at harvest	0.20 – 0.28	0.20 – 0.28	0.20 – 0.28
Carbon fraction of the product	%C in the dry mass of seeds/grains	0.42 – 0.47	0.42 – 0.47	0.42 – 0.47
Carbon fraction of aboveground residues	%C in the dry mass of straw/stover/stems	0.42 – 0.45	0.42 – 0.45	0.42 – 0.45
Carbon fraction of roots	%C in the dry mass of roots	0.38 – 0.45	0.38 – 0.45	0.38 – 0.45
Fraction of residues retained on the field	Portion of residues left in the field (not removed/burned)	0.50 – 0.90	0.80 – 1.00	0.90 – 1.00
Stabilized fraction of C from residues	Proportion of residue-derived C retained long-term in soil	0.12 – 0.15	0.14 – 0.17	0.16 – 0.18
Stabilized fraction of C from roots + rhizosphere	Proportion of root-derived C retained long-term in soil	0.20 – 0.24	0.23 – 0.29	0.24 – 0.30

The tables above present the calculation algorithms of sequestered carbon according to the soil tillage system (conventional, minimum tillage, and no tillage) for the following crops: wheat, maize, sunflower, and rapeseed.

Since the specialized literature primarily employs metric tons of CO_2 (carbon dioxide equivalent) to discuss carbon sequestration quantities, all measurements were converted into this unit of measure.

The reduction of greenhouse gas emissions, the adaptation of production methods to climate change, and the steep increase in global food demand driven by population growth are the three interconnected challenges facing the agricultural sector.

Research indicates that greenhouse gas (GHG) emissions from agricultural activities are minimal compared to industrial emissions. Globally, the energy and industrial sectors represent the main source of GHG emissions, contributing approximately 73% of the total.

In comparison, agriculture, forestry, and other land uses (AFOLU) account for approximately 18–22% of global emissions, of which agriculture alone (excluding land-use change) contributes 10–12% of the total (IPCC, 2021; FAO, 2021). In the European Union, the structure is similar: the agricultural sector is responsible for about 11% of total emissions, while energy and industry together exceed 70% (EEA, 2022).

Therefore, carbon credit systems in the agricultural sector have attracted considerable global attention with respect to achieving climate neutrality.

Table 5 presents the main measures and their impact on emissions. Financial incentives are needed to promote the adoption of these solutions by rewarding efforts to improve soil management, enhance fertilizer use efficiency, and implement effective irrigation practices.

Tabel 5

Agricultural Greenhouse Gas Mitigation Measures

Measure	Examples	Effects on emissions		
		CO_2	CH_4	N_2O
Cropland management	Fertilization	+		+
	Soil tillage	+		+/-
	Irrigation/Drainage	+/-		+
	Land-use change (set-aside/fallow)	+	+	+
Grassland management	Grazing intensity	+/-	+/-	+/-
	Fertilization	+		+/-
	Introduction of new species	+		+/-
Management of organic soils	Avoidance of wetland drainage	+	-	+/-
Restoration of degraded lands	Erosion control, organic amendments, fertilization	+		+/-
Livestock management	Improved feeding practices		+	+
	Additives and agents		+	
Manure management	Improved storage and handling		+	+/-
	Anaerobic digestion		+	+/-
Bioenergy	Energy crops	+	+/-	+/-

ECONOMIC AND ENVIRONMENTAL BENEFITS OF CARBON CREDIT SYSTEMS

The integration of carbon credits into agricultural practices presents significant economic opportunities for farmers. By adopting practices that sequester carbon, farmers can generate additional income through the sale of carbon credits. This financial incentive could drive the broader adoption of sustainable agricultural practices.

In addition to financial benefits, carbon credit systems may also promote secondary environmental gains, such as improved soil health, enhanced biodiversity, and better water management. However, the extent to which these benefits are realized depends on the specific practices adopted and the context in which they are implemented.

The advantages and disadvantages of the carbon credit system are essential for understanding the complexity and effectiveness of this environmental policy instrument in combating climate change. *Tables 6* and *7* present the identified advantages and disadvantages.

Tabel 6

Benefits of carbon credit systems

ADVANTAGES	JUSTIFICATION
Incentivizing Emission Reductions	Carbon credits encourage entities to reduce their GHG emissions, motivating them not only to adopt cleaner technologies in the short term but also to plan long-term sustainability strategies. This can lead to significant innovations in emission reduction technologies and the adoption of sustainable business practices.
Promoting Global Sustainability	By facilitating investments in environmental projects such as reforestation or renewable energy, carbon credits contribute to fostering sustainability at the global level. They represent a mechanism through which companies can play an active role in combating climate change.
Flexibility for Companies	The system provides companies facing difficulties in directly reducing their emissions with the option to purchase carbon credits. This mechanism offers flexibility and enables enterprises to comply with environmental regulations in a cost-effective manner.
International Cooperation	The trading of carbon credits can facilitate cooperation between industries and nations, bringing together a wide range of actors in the joint effort to reduce global GHG emissions.

Tabel 7

Challenges and limitations of carbon credit systems

CHALLENGES AND LIMITATIONS	JUSTIFICATION
Ethical Concerns and Effectiveness	There are ethical concerns regarding the actual effectiveness of offsetting emissions through the purchase of carbon credits. Critics argue that this system allows companies to evade responsibility for implementing real and lasting changes in their operations by effectively buying their way into compliance.
Risk of Greenwashing	Companies may use the purchase of carbon credits as a marketing strategy to enhance their public image without making significant investments in actual emission reductions. This can lead to misleading perceptions regarding the companies' genuine commitment to sustainability.
Economic Inequalities	The carbon credit market may favor larger and more profitable companies that can afford to purchase credits rather than invest in emission reductions. This dynamic can create inequalities among companies and hinder progress toward a low-carbon economy.
Implementation and Monitoring	The effective implementation and monitoring of the carbon credit system are significant challenges, requiring rigorous verification and reporting mechanisms to ensure the integrity and transparency of the process.

CONCLUSIONS

1. With agriculture responsible for 10–12% of global GHG emissions (~11% in the EU), carbon credit markets in this sector are justified.

2. The European Union carbon market, responsible for managing over 70% of emissions from energy and industry, represents an opportunity for farmers to increase their income through the sale of sequestered carbon.

3. Conservation tillage practices (minimum and no-tillage) significantly enhance soil carbon sequestration. Under these systems, residue retention on the field reaches 90–100% (as opposed to 50–90% in conventional tillage), while the stabilized fraction of root-derived carbon increases to 26–32% (compared with 20–24%)."

4. Measures such as set-aside, irrigation /drainage, and grassland management simultaneously reduce CO_2, CH_4, and N_2O emissions, thereby contributing to climate neutrality.

5. Carbon credits generate additional income for farmers while delivering environmental benefits such as improved soil health, enhanced biodiversity, and a cleaner environment."

6. The system entails the risk of greenwashing (where polluters merely purchase carbon credits to offset their own emissions without making significant investments in clean technologies), as well as economic inequalities between small farms (which face scale-related barriers to accessing the carbon market) and large farms (which have easier access to the market).

ACKNOWLEGMENTS

This work was carried out within PNRR-DTEClimate/VeBDisease project no. 760008/30.12.2022.

REFERENCES

Dales J.H., a. 2002 - *Polluation, Property& Prices – An essay in policy-making and economics, printed and bound in Great Britain by Bookcraft (Bath*) Ltd., ISBN 1 84064 842 2

Hoffmann M.P., Jacobs A., Whitbread A.M., a. 2015, *Crop modelling based analysis of site-specific production limitations of winter oilseed rape in northern Germany*, Field Crops Research Volume 178, July 2015, Pages 49-62

Ken E.G., Renske H., Jens A.A., James S., a. 2021 - *Regenerative agriculture: an agronomic perspective*, SageJournals, Volume 50, https://doi.org/10.1177/00307270219980

Lokuge N., Anders S., a. 2022 - *Carbon-Credit Systems in Agriculture: A Review of Literature*, The School of Public Policy Publications, Volume 15:12

Raziel A. O., Sotirios V. A., Rafael M.-F., Jerry L. H., Emily E. W., Michael J. C., a. 2020, *Root to shoot and carbon to nitrogen ratios of maize and soybean crops in the US Midwest*, European Journal of Agronomy, Volume 120, 126130

Rui Z., a. 2017 - Building a national unified carbon market requires institutional innovation[N], China Financial News

Sanz-Sáez Á., Erice G., Aguirreolea J., Muñoz F., Sánchez-Diaz M., Irigoyen J.J., a. 2012 - *Alfalfa forage digestibility, quality and yield under future climate change scenarios vary with Sinorhizobium meliloti strain*. Journal of Plant Physiology, 169:782-788.

Stefan G., a. 2012, *Considerations on the theory of economic growth and development, Proceedings of World Conference on Business, Economics and Management (BEM-2012), vol 62, pp. 280-284, DOI10.1016/j.sbspro.2012.09.045*

Trepos R., Champolivier L., Dejoux J.-F., Al Bitar A., Casadebaig P., Debaeke P., a. 2020, *Forecasting Sunflower Grain Yield by Assimilating Leaf Area Index into a Crop Model*, Remote sensing

Verschuuren, J., a. 2018 - *Towards an EU regulatory framework for climate-smart agriculture: The example of soil carbon sequestration*, Transnational Environmental Law, 7 (2): 301-322

*** **Departament of Primary Industries, a. 2011** - Canola growth & development

*** **European Environment Agency, a. 2022 -** Annual European Union greenhouse gas inventory 1990–2020 and inventory report 2022. European Environment Agency, Report No 8/2022.

*** F**ood and Agriculture Organization, a. 2021 -** FAOSTAT Emissions Database. Food and Agriculture Organization of the United Nations.

*** **Intergovernmental Panel on Climate Change, a. 2006** - 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 Agriculture, Forestry and Other Land Use, Cap. 4 Forest Land, pag. 4.48-4.49

*** **Intergovernmental Panel on Climate Change, a. 2021 -** Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

*** **Ministerul Mediului, a. 2021 -** *"Evoluția emisiilor de gaze cu efect de seră în perioada 2007-2020"*.

*** **U.S. Department of Agriculture**, **a. 2024** - Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: METHODS FOR ENTITY-SCALE INVENTORY, Cap. 3 Quantifying Greenhouse Gas Sources and Sinks in Cropland and Grazing Land Systems, pag. 3-16 – 3-17

AN INTEGRATED APPROACH TO EVALUATING THE FINANCIAL PERFORMANCE OF AGRICULTURAL ENTITIES: A COMPOSITE SCORING MODEL

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Abstract

The economic performance of agricultural entities has recently been analyzed in the context of increasing pressures caused by economic instability, climate change, and sustainability requirements promoted by the European Union, international organizations, and financial institutions. Financial assessment can no longer be limited to traditional indicators, requiring an approach that combines financial soundness with resource-use efficiency.
This paper proposes an analytical model based on the construction of a composite financial performance index. The main objective is to provide a simple yet useful tool for understanding the overall performance of agricultural enterprises.
Although numerous financial indicators are commonly used to assess agricultural performance, they are typically analyzed individually, and aggregation into a unified score is rarely applied in Romania's agricultural sector.
Indicators such as return on assets, return on equity, current ratio, debt ratio, and asset turnover were included. A sub-index of economic sustainability was calculated based on profit per hectare and income per employee. All values were normalized and combined into a general score, scaled from 0 to 100.
The model was applied to a sample of five agricultural farms, using data for the year 2024. The results were graphically represented, allowing for an intuitive interpretation of the scores. The findings confirm the relevance of a synthetic evaluation method that is easy to apply and adaptable to various agricultural contexts.

Keywords: Agribusiness, Financial performance, Composite indicators, Financial scoring

In recent years, agriculture has been increasingly exposed to pressures driven by economic instability, climate change, and sustainability requirements imposed at both European and international levels. In this context, the financial performance of farms can no longer be assessed through traditional analysis based solely on isolated indicators. A more comprehensive approach is needed—one that captures the complexity of modern agricultural activity and reflects both financial soundness and the efficiency of resource utilization (Gómez-Limón & Riesgo, 2009).

The literature offers a wide range of financial indicators for performance analysis; however, they are often considered independently, without an integrated aggregation method (Hedman Jansson & Lagerqvist, 2013). In Romania, synthetic evaluations—such as scoring models—are rarely applied in the agricultural sector, despite their potential to provide a clearer and more interpretable overview (Herman & Zsidó, 2023).

This paper proposes a composite scoring model designed to integrate key financial indicators—profitability, liquidity, indebtedness, and efficiency—alongside a sub-index reflecting economic sustainability. The latter is calculated based on the ratio of profit to farmed area and total income per employee, in line with recent recommendations on sustainable and efficient performance (Sinisterra-Solís *et al.,* 2024).

The main objective is to develop and apply a user-friendly assessment tool that enables comparative analysis between agricultural entities and facilitates performance monitoring over time. The model is tested on a sample of Romanian farms using real data for the year 2024. The results provide a starting point for discussions on economic efficiency in agriculture and potential directions for optimization.

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MATERIAL AND METHOD

The study was conducted using a sample of five crop-focused agricultural entities selected from the North-East Region of Romania. The selection criteria were based on the availability of detailed financial data reported for the year 2024 and classification within the same business size category, determined by turnover and number of employees. The analyzed entities were anonymized and labeled generically as E1–E5.

The data used in the analysis were extracted from official public sources and included the following financial indicators: turnover, total revenues, total expenses, gross profit, net profit, number of employees, fixed assets, current assets, inventories, receivables, cash and bank accounts, equity, share capital, total liabilities, and deferred revenues.

Based on these data, the following key performance indicators were calculated: Return on Assets (ROA), Return on Equity (ROE), Current Ratio, Debt Ratio, and Asset Turnover.

To account for the economic sustainability component, an additional indicator—revenue per employee—was introduced. This was calculated as the ratio of total revenues to the number of employees, reflecting the efficiency of human resource utilization and the economic potential for remuneration—an increasingly relevant aspect given labor market pressures and the need for long-term profitability in agriculture.

In order to ensure comparability between indicators expressed in different units and to construct a unified score, all six indicators were normalized to a scale from 0 to 100 using the min-max method. The resulting score ranges from 0 to 100, with 100 representing the best performance.

The formula applied was:

Normalized score = $(X_i - X_{min})/(X_{max} – X_{min}) * 100$, where:

X_i = the value of the indicator for the analyzed entity,

X_{min} și X_{max} = the minimum and maximum values of the indicator across the sample.

For the debt ratio—a negative-impact indicator—a reverse formula was used:

Negative score = $(X_{max} – X_i)/(X_{max} – X_{min}) * 100$.

This adjustment ensures that a lower debt value translates into a higher score, reflecting superior performance.

The indicators were grouped into two main components: financial performance (based on the five financial indicators) and economic sustainability (based on revenue per employee). These two components were then aggregated into a final composite score.

For each entity, a financial performance sub-score (arithmetic mean of the five financial indicators) and an economic sustainability sub-score (normalized score for revenue per employee) were calculated.

Finally, the composite score was computed as the arithmetic mean of the two sub-scores:

Composite Score = (Financial Sub-score + Sustainability Sub-score) / 2

The results were graphically represented using a radar chart, allowing for a comparative visualization of each entity's performance across all analyzed dimensions.

RESULTS AND DISCUSSIONS

The proposed model was applied by normalizing six key indicators: ROA, ROE, Current Ratio, Debt Ratio, Asset Turnover, and Revenue per Employee. Each indicator was converted to a scale from 0 to 100, enabling comparability across entities. The normalized values reveal significant differences between the entities analyzed.

Table 1

Normalized Scores and Composite Scores

	E1	E2	E3	E4	E5
Normalized ROA	100,00	0,00	2,55	19,79	14,95
Normalized ROE	100,00	0,00	11,51	67,33	24,45
Normalized Current ratio	100,00	11,28	25,84	0,00	26,44
Normalized Debt ratio	100,00	54,40	0,00	6,41	68,03
Normalized Asset Turnover	0,00	100,00	90,56	30,64	29,46
Normalized Revenue/Employee	80,14	54,60	0,00	100,00	93,47
Composite Scores	80,07	43,87	13,05	62,42	63,07

Entity E1 recorded a composite score of 80.07, ranking first among the five. It achieved maximum values for profitability (ROA, ROE), liquidity, and financial autonomy, indicating a stable and well-capitalized position. The only weak point is asset turnover, suggesting inefficient use of invested resources. Additionally, revenue per employee shows above-average labor efficiency. E1 appears to be a mature and financially balanced farm, but with room to improve operational efficiency.

Entity E2 obtained a composite score of 43.87, reflecting high activity but a lack of profitability. It stands out for excellent asset turnover (100) and a moderate level of debt (54.40). However, the complete absence of profitability (ROA and ROE = 0) is concerning, especially in the context of low liquidity (11.28). Revenue per employee (54.60) is moderate, indicating an acceptable productivity level. E2 seems to operate efficiently, but it struggles to generate value, which may suggest an unsustainable cost structure or low selling prices.

Entity E3 scored 13.05, revealing a vulnerable financial profile. Profitability (ROA 2.55 and ROE 11.51) is extremely low, and both liquidity (25.84) and financial autonomy (debt ratio 0) suggest short-term financial imbalances. Despite a high asset turnover (90.56), the revenue per employee (0) points to severe weaknesses in economic sustainability. E3 appears to be a structurally challenged farm requiring urgent measures to improve efficiency and profitability.

Entity E4 has a final score of 62.42. Its main strengths include a high ROE (67.33) and maximum revenue per employee (100), reflecting strong productivity. In contrast, its liquidity is zero, which may indicate blocked funds in low-liquidity assets or poor cash flow management. Additionally, its asset turnover (30.64) and low debt ratio (6.41) suggest a cautious approach with room for growth. E4 is efficient in human resource use but requires financial consolidation to become more resilient.

Entity E5, with a score of 63.07, represents a generally balanced profile. It performs well in revenue per employee (93.47) and debt ratio (68.03), but shows weaknesses in asset turnover (29.46) and liquidity (26.44). Profitability is moderate (ROA 14.95 and ROE 24.45), indicating a functional farm without strong capacity to rapidly scale performance. E5 is a solid model with moderate potential for improvement through investments in efficiency and working capital.

The composite scoring model proposed in this study provides strong analytical value by transforming a set of fragmented financial indicators into a single, easily interpretable outcome. Through normalized aggregation of key metrics, the model enables a global performance assessment without losing sight of the individual dimensions—profitability, liquidity, financial risk, operational efficiency, and economic sustainability. This approach supports comparative analysis between entities, highlights structural imbalances, and provides a relevant overview for diagnosis and decision-making.

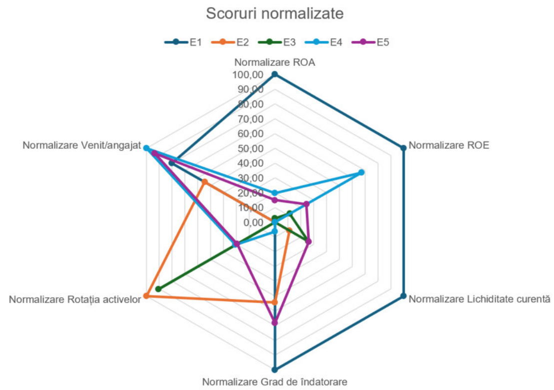

Figure 1 – **Normalized scores**

The individual scores for each indicator were illustrated using a radar chart, allowing an intuitive visualization of each entity's performance profile. The charts highlight significant internal imbalances (e.g., maximum scores in some indicators and minimum in others), emphasizing the usefulness of an integrated and synthetic approach in performance assessment.

The results demonstrate the added value of the proposed composite score as a synthetic tool for evaluating financial performance. In a sector marked by high variability and dependence on external factors, such as agriculture, the isolated evaluation of financial indicators provides a fragmented and often insufficient perspective for making strategic decisions. The composite scoring model enables the coherent integration of essential performance dimensions—profitability, liquidity, operational efficiency, financial leverage, and economic sustainability—into a single reference value.

This approach enhances comparability among entities with different financial profiles and facilitates the rapid identification of strengths and weaknesses. Moreover, the associated graphical representation (radar chart) amplifies the practical utility of the model, offering clear and intuitive visual support. Thus, the composite score not only simplifies the evaluation process but transforms it into a decision-making tool applicable in various contexts—from internal managerial analysis to external reporting, funding applications, or sectoral benchmarking.

Table 2

Composite Score and Regional Variations

Entity	Conty	Composite Score
E1	Iași	80,07
E2	Vaslui	43,87
E3	Neamț	13,05
E4	Botoșani	62,42
E5	Iași	63,07

Although the sample size is limited (5 entities), a positive correlation can be observed between the composite score and counties with a more developed economic profile (e.g., Iași), while less developed counties (e.g., Vaslui, Neamț) are associated with lower scores.

This observation suggests that the financial performance of farms is not exclusively influenced by internal factors, but also by the economic and institutional characteristics of the region in which they operate. Infrastructure, access to advisory support, logistics connectivity, and the local educational environment can all influence the ability of agricultural entities to achieve sustainable performance.

To validate the consistency of the composite score, pearson correlation coefficients were calculated between the final score and two key financial indicators: net profit and turnover. The results indicate a strong correlation between the composite score and net profit (r = 0.74), confirming that the proposed score is a relevant reflection of the financial performance of the entities. The correlation with turnover was weaker (r = 0.3), suggesting that the volume of sales alone is not sufficient to characterize overall performance without considering resource efficiency and financial structure.

CONCLUSIONS

This study proposed an integrated approach to evaluating the financial performance of agricultural entities, by constructing a composite score that combines key indicators of profitability, liquidity, operational efficiency, debt, and economic sustainability. The model was applied to a sample of five crop-based entities from the North-East Region of Romania, using financial data reported for the year 2024.

The results revealed significant differences between entities in terms of their financial performance structure. Entity E1 stood out with a strong and balanced financial profile, achieving high or maximum scores across most indicators. In contrast, entities such as E3 recorded low scores, reflecting structural problems in resource management and operational efficiency.

The practical relevance of the model lies in its ability to synthesize performance in a comparable way, offering a useful diagnostic tool for managers, investors, and financing institutions. Moreover, the analysis suggested a potential correlation between the level of financial performance and geographical location, with more economically developed counties hosting entities with higher scores.

Although the proposed model has some limitations—such as the small sample size and equal weighting of indicators - it provides a valuable synthetic evaluation tool. The composite score is easy to calculate, interpretable, and replicable, making it suitable for both academic research and practical application in the agricultural sector. From this perspective, it can be considered a robust scoring model, with the potential to be improved and expanded in future studies.

Farmers, financial consultants, and agricultural managers can use this model as a quick self-assessment tool, for year-over-year comparisons or in the process of accessing funding. The overall score and visual analysis can support the identification of critical points and inform investment or financial optimization decisions.

REFERENCES

Coca O. & Ștefan G., 2023 – *Navigând prin Analiza Economico – Financiară: Ghid practice pentru studenți și profesioniști.*

Gómez-Limón, J. A., & Sanchez-Fernandez, G., 2010 - *Empirical evaluation of agricultural sustainability using composite indicators.*

Gómez-Limón, J. A., & Riesgo, L., 2009 - *Alternative approaches to the construction of a composite indicator of agricultural sustainability: An application to irrigated agriculture in the Duero basin in Spain.*

Hedman Jansson, K., & Lagerqvist, C., 2013 - *Performance Indicators in Agricultural Financial Markets*.

Herman, E., & Zsidó, K., 2023 – *Mathematics.*

Magrini, A., & Giambona, F, 2022 - *A Composite Indicator to Assess Sustainability of Agriculture in European Union Countries*.

Sinisterra-Solís, N. K., et al., 2024 - *Developing a composite indicator to assess agricultural sustainability: Influence of some critical choices.*

RESEARCH TRENDS AND DIRECTIONS ON AGRICULTURAL HOLDINGS IN ROMANIA: A BOBLIOMETRIC APPROACH

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Abstract

The present study aims to identify and analyze the main trends and research directions in the agricultural economics sector, with a particular focus on agricultural holdings in Romania. To achieve this objective, a research methodology based on bibliometric analysis was used, an increasingly common tool used to map the structure and evolution of scientific research in a given field. The bibliometric analysis was carried out on a sample of 176 scientific publications indexed in the Web of Science (WoS) database, selected based on the topic criterion containing the terms "agricultural holding" and "Romania". The results of the analysis highlighted a constant increase in the interest of the scientific community in Romania, but also at international level, in topics aimed at the sustainable development of agricultural holdings, especially in the context of their adaptation to the environmental, social and economic requirements imposed by European policies. A significant share of publications focuses on the analysis of the impact of the Common Agricultural Policy (CAP) on Romanian farmers, in particular on access to subsidies, economic efficiency and the process of alignment with European standards. Another topic frequently addressed in the specialized literature is the fragmentation of agricultural land, a major structural problem with historical roots, which continues to affect the competitiveness and performance of Romanian farms. Also, in recent years, there has been an increase in interest in the digitalization of agriculture, reflected in publications dealing with topics such as precision agriculture, the use of drones, IoT sensors and farm management systems based on artificial intelligence. These trends indicate a growing openness of researchers and research institutions towards innovation and technology, in response to contemporary challenges in the agricultural sector.

Keywords: agricultural holdings, Romania, bibliometric analysis, trends, agricultural policies.

The agricultural holding is an organizational form specific to the agricultural sector, consisting of all units intended for carrying out agricultural activities and under the management of a farmer (Dumitru *et al*, 2020).

Both national legislation and specialized literature define and classify agricultural holdings according to a series of relevant factors, such as physical size, object of activity, economic size, land ownership regime, human resources structure, production destination, as well as other legal and economic factors (Alecu *et al*, 2001).

In the context of agriculture in Romania, the predominant form of organization is represented by the family farm, which plays an essential role in the rural social structure, having the ability to capitalize on both available land and family labor. From an economic perspective, however, these holdings are not distinguished by a high level of profitability, since a large part of the agricultural production obtained is intended for self-consumption. This situation is particularly specific to very small farms, namely those with an area of less than two hectares (Burja & Burja, 2010; Ionescu *et al*, 2021; Tachianu *et al*, 2022).

However, statistical data highlight the fact that the majority of agricultural farms in Romania fall into the category of those with areas between two and five hectares. Within this segment, the agricultural production obtained exceeds the household's own consumption needs, which leads farmers to market the surplus products, thus generating additional income (Popescu, 2010; Crecană & Crecană, 2019).

MATERIAL AND METHOD

The research comprehensively analyzes the studies in the existing specialized literature, paying special attention to studies that address the analysis of agricultural holdings in Romania.

The research method used was the analytical method and synthesis of information found in the specialized literature. The selected articles and studies were identified in specialized journals, WOS. The search was carried out using the keywords "agricultural holding" and "Romania". With the help of the VOSviewer software, an

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analysis of the frequency of keywords used in the literature and of co-authorship networks was carried out, thus highlighting the main thematic clusters and the evolution of scientific interest in the analyzed subject over time, as well as the degree of cooperation in the elaboration of scientific research.

RESULTS AND DISCUSSIONS

Starting with 1997 (1 publication) the concept of agricultural holding has been increasingly used in scientific works, which suggests an increase in interest for researchers in the agronomic field. The data in figure 1 illustrate a positive dynamic in terms of the number of documents indexed in WoS under the topic "agricultural holding" and "Romania". Starting with 2008 (2 publications) the number of publications has increased steadily, reaching 15 publications in 2016. This increase can be attributed to Romania's accession to the European Union, which brought about a series of important changes in the structure of agricultural holdings. The maximum number of publications was recorded in 2018, namely 20 publications.

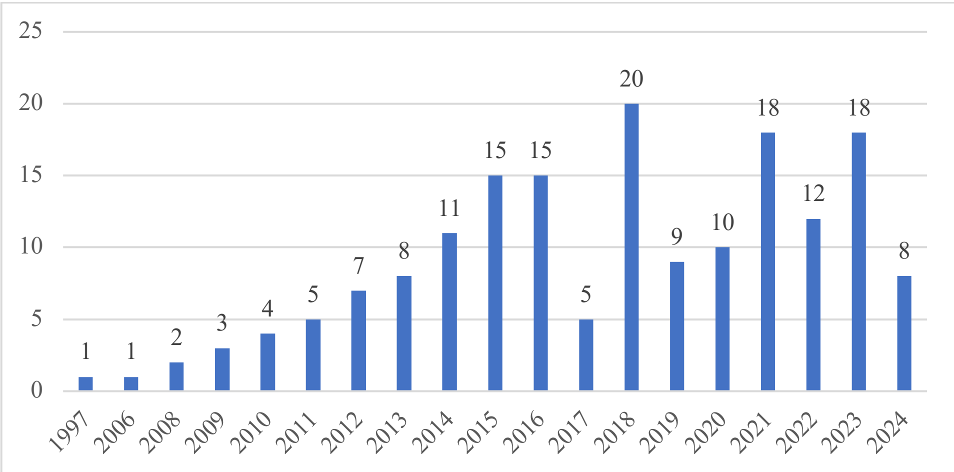

Figure 1 **Evolution of published works on the topic of "agricultural holding in Romania" in WoS (number of documents/year)**
Source: own data processing using the WoS database, accessed on 05.08.2025.

Regarding the WoS categories, most of the publications indexed in this database are part of the Agricultural Economics Policy category, namely 75 publications, representing approx. 43% of the total publications identified by the analyzed topic. Also, the Economics category stands out for a substantial number of publications, more precisely 25 publications, representing approx. 14% of the total publications analyzed.

Table 1

Top five Web of Science Categories by number of publications

Web of Science Categories	Record Count	% of 176
Agricultural Economics Policy	75	42,61%
Economics	25	14,21%
Management	17	9,66%
Business	16	9,09%
Agronomy	10	5,68%

Source: WoS database, accessed on 05.08.2025.

Regarding the titles of publications in WoS, Scientific Papers Series Management Economic Engineering in Agriculture and Rural Development is the publication with the most registered documents, representing approx. 38% of the total publications identified in WoS by topic, followed by International Multidisciplinary Scientific Geoconference Sgem with documents, representing 3.41% of the total.

Table 2

Top five Publication Titles s by number of publications

Publication Titles	**Record Count**	**% of 176**
SCIENTIFIC PAPERS SERIES MANAGEMENT ECONOMIC ENGINEERING IN AGRICULTURE AND RURAL DEVELOPMENT	67	38,07%
INTERNATIONAL MULTIDISCIPLINARY SCIENTIFIC GEOCONFERENCE SGEM	6	3,41%
SUSTAINABILITY	5	2,84%
VISION 2020 SUSTAINABLE ECONOMIC DEVELOPMENT AND APPLICATION OF INNOVATION MANAGEMENT	5	2,84%
EKONOMIKA POLJOPRIVREDA ECONOMICS OF AGRICULTURE	4	2,27%

Source: WoS database, accessed on 05.08.2025.

By classifying the publications in WoS according to our topic, it is observed that most publications were written in Romania, namely 155 (88% of the total publications identified in the WoS database according to the selected topic). Poland and Serbia each recorded 6 publications (totaling 6.82% of the total publications). The data may suggest that Romania has close ties with these countries when it comes to agricultural research (Table 3).

Table 3

Top five Countries by number of publications

Countries/Regions	**Record Count**	**% of 176**
ROMANIA	155	88,07%
POLAND	6	3,41%
SERBIA	6	3,41%
FRANCE	5	2,84%
GERMANY	4	2,27%

Source: WoS database, accessed on 05.08.2025.

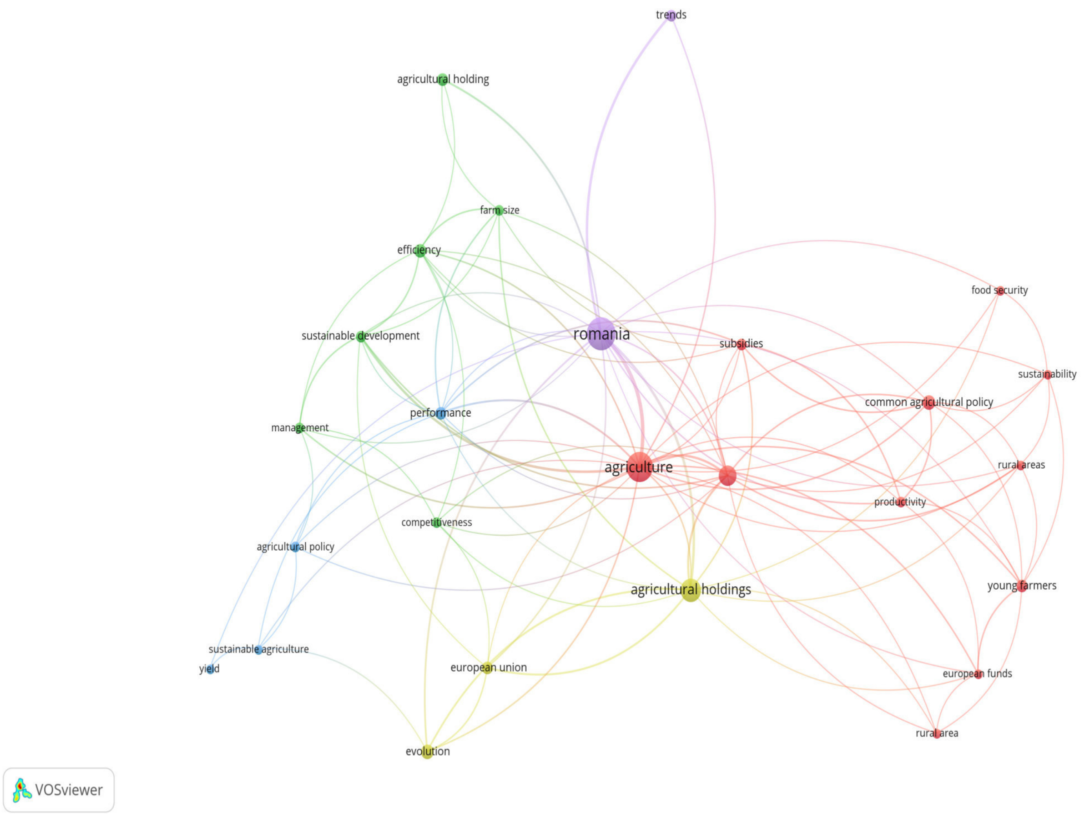

Figure 2 Correlation map of the terms "agricultural holding" and "Romania"
Source: own processing of data from the WoS database in VOSviewer , accessed on 05.08.2025

1. Romanian Agriculture in the Context of the Common Agricultural Policy (Red Cluster)

Romania’s integration into the European Union in 2007 represented a high point for the national agricultural economy, especially in terms of adapting to the requirements of the CAP. Terms such as agriculture, common agricultural policy, European funds, food security, productivity, rural development, subsidies and young farmers are frequently used in the specialized literature analyzing the impact of accession on agricultural holdings (Ionita et al., 2018). Studies indicate that, in the post-accession period, considerable pressure was exerted on agricultural holdings in Romania to align with European standards, especially in sensitive regions such as Oltenia.

A major challenge is the excessive fragmentation of holdings: in 2020, 90% of farms were under 5 ha, and 54% even under 1 ha. Despite a slight increase in the average farm size (from 3.45 ha in 2010 to 4.42 ha in 2020), chronic undercapitalization continues to limit the performance of the agri-food sector (Colf et al., 2024).

Another crucial aspect is the difficulties encountered by small producers in effectively capitalizing on agricultural production, especially in the vegetable sector. Research conducted by Ghibășeanu et al. (2022), through the application of a national questionnaire, reveals thatthe rejuvenation of the active population in agriculture is encouraged through support instruments within the Rural Development Programs, with promising results.

2.Farm size and economic efficiency (Green Cluster)

The comparative analysis of the size and efficiency of agricultural holdings, using terms such as: agricultural holding, competitiveness, efficiency, farm size, management and sustainable development, shows significant differences between the development regions of Romania. In the South-Muntenia and South-East regions, for example, holdings differ visibly in size and economic efficiency. In 2020, the average holding area in South-Muntenia was 4.4 ha, close to the national average, while in the South-East it was 6.7 ha (Tachianu et al., 2023).

Case studies, such as the one conducted in Dâmbovița County, highlight a persistent gap compared to the European Union average, where agricultural holdings are of the order of tens or even hundreds of hectares (Tachianu *et al*, 2022). These structural differences affect the competitiveness of the sector, and research supports the need to reorganize the Romanian farm to increase the efficiency of the use of production factors (Burja and Burja, 2016).

3.Agricultural policies and sustainability (Blue Cluster)

The third conceptual cluster revolves around agricultural policies and sustainable performance (agricultural policy, performance, sustainable agriculture, yield). According to research by (Stanciu, 2017), Romania has the largest number of agricultural holdings in the EU, but this figure is influenced by the unclear methodology applied in defining agricultural units eligible for censuses, which makes real comparisons with other Member States difficult.

In the context of sustainable agriculture, small peasant households play an essential role through environmentally friendly agricultural practices. They use traditional methods, consume locally and apply technologies with low environmental impact, which makes them relevant for sustainable agricultural models promoted within the EU (Marunelu, 2020).

4.Structural evolution of Romanian agriculture (Yellow Cluster)

The terms agricultural holdings, European Union and evolution reflect researchers' concern for the structural changes generated by Romania's accession to the EU. According to Bularca and (Toma, 2018), between 2002 and 2016, the total number of farms decreased, while large farms (0.5% of the total) came to manage over 50% of the utilized agricultural area.

An important aspect is represented by investments in the modernization of agricultural holdings, supported by European funds, which are becoming increasingly dependent on the size of the farm and its capacity to attract direct payments. The study conducted by (Curea *et al*, 2022) reveals that access to funded projects depends not only on the number of farms and their size, but also on regional economic needs, analyzed based on Eurostat and FADN data.

5.General trends in Romanian agriculture (Purple Cluster)

The least represented cluster, composed of the terms Romania and trends, reflects the interest in outlining the general directions of evolution of Romanian agriculture. This segment can cover topics such as post-accession transformations, the digitalization of agriculture, the ecological transition or adaptation to climate change. Although this cluster is less present in the analyzed literature, it is essential for understanding macroeconomic trends and the strategic perspective on Romanian agriculture in the context of European and global policies.

CONCLUSIONS

The analysis of publications in the WoS database highlighted an increased interest in the topic of "agricultural holding" and "Romania". The research themes identified were diverse, but all focused around the same concept: "agricultural holding". The results of these researches showed that excessive fragmentation of holdings, chronic undercapitalization, and difficulties in valorizing production are recurring problems in the studies analyzed. However, notable progress is noted in consolidating farms, encouraging young farmers and absorbing European funds. Thus, we can consider that the sustainable development of Romanian agriculture requires an integrated approach, in which the economic dimension, environmental sustainability and adaptation to the requirements of the CAP must work synergistically.

The correlation of the keywords highlighted strong connections of the keyword „agricultural holding'' with other words such as: „agriculture'', „Romania'', „European Union'', „European funds'', „farm size'', „competitiveness'', and „performance'', all of these words being found in the vocabulary used in the agriculture and rural development sector. The study of the specialized literature showed how these words are connected to each other. Thus, for a sustainable development of agricultural holdings in Romania, there is an urgent need for political and implicit economic support. The European Union supports the sustainable development of Romanian agricultural holdings through a series of policies, financing and regulations aimed at the balance between economic development, environmental protection and social cohesion in the agricultural sector, the CAP being the main instrument through which the EU supports the Member States.

ACKNOWLEGMENTS

The present research is part of the Project ADER 22.1.1. The design of technical-economic models for the analysis of the resilience and sustainability capacity of the agricultural sector and the optimization of production processes, of the Research Institute for Agricultural Economics and Rural Development (ICEADR Bucharest).

REFERENCES

Alecu, I. et al., 2001. *Managementul exploatațiilor agricole*. București: Editura Ceres. ISBN/Cod: 973-40-0499-0.

Bularca, E., & Toma, E. 2018. *Structural change in the Romanian agriculture: implications for the farming sector.* Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development 18(2), 59-66.

Burja, C., & Burja, V. 2016. *Farms size and efficiency of the production factors in Romanian agriculture*. Ekonomika poljoprivrede, 63(2), 361-374.

Burja, C., and Burja, V., 2010. *Financial analysis of the agricultural holdings viability in Romania in the european context*. Annales Universitatis Apulensis-Series Oeconomica. 12(1), 63-71.

Colf, I., Mateoc Sîrb, N., & Iancu, T. 2024. *The "Nădlac farmer" agricultural cooperative–a model of good practices for small farmers, Romania*. Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 24(2).

Crecană, D.N., and Crecană, C.D., 2019. *Increasing the Performance of Agricultural Holdings in Romania-an Imperative for their Management*. Revista de Management Comparat International. 20(2), 112-121.

Curea, I. C., Franzutti, R., & Fîntîneru, G. 2022. Incentives for agricultural holdings in accessing investment funds for their modernisation through cap measures. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development Vol. 22(2), 239-248.

Dumitru, E.A., Bădan, D.N., Petre, I.L., and Brătulescu, A.M., 2020. *Analysis of agricultural holdings in Romania in terms of size*. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development. 20(1), 193-198. PRINT ISSN 2284-7995, E-ISSN 2285-3952.

Gimbășanu, G. F., Micu, R. A., Fîntîneru, A., Postamentel, M., & Tudor, V. C. 2022. *Research regarding the methods of valorization of vegetable production at the level of agricultural holdings in Romania*. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development Vol. 22(2), 353-360.

Ionescu, R.V., Zlati, M.L., Antohi, V.M., Florea, A.M., Bercu, F., and Buhociu, F.M., 2021. *Agricultural holdings' impact on the rural development. Case study: Romania.* Agronomy. 11(11), 2231. DOI: https://doi.org/10.3390/agronomy11112231.

Ioniță, N., Mărcuță, L., & Mărcuță, A. G. 2018. *The evolution of agricultural holdings in macroregion four (south west-Oltenia) after Romania's integration into the European Union*. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development Vol. 18(2), 255-258.

Mărunțelu, I. 2020. *Research on the small peasant individual households in Romania within the framework of sustainable agriculture.* Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development Vol. 20(1), 341-346.

Popescu, G.A., Ciobanu, L., and Maţoschi, O., 2010. *Componentele subzistenţei pentru p olitica agricolă comună*. Contabilitate. 27, 135-141.

Stanciu, S. 2017. *The Farm Structure Surveys in the European Union-2010 Romanian Agricultural Holdings between the European Definition and Its National Interpretation*. SUSTAINABLE ECONOMIC GROWTH, EDUCATION EXCELLENCE, AND INNOVATION MANAGEMENT THROUGH VISION 2020, VOLS I-VII, 3994-4001.

Tachianu, A. V., Marcuta, L., & Marcuta, A. 2023. *Comparative study on the evolution of the number of agricultural farms, the average size and agricultural production in the South-Muntenia and south-east regions of Romania.* Scientific Papers Series Management, Economic Engineering in Agriculture & Rural Development, 23(1).

Tachianu, A.V., Marcuta, A., and Marcuta, L., 2022. *Study on the evolution of the size of agricultural holdings in Romania and the UE in the period 2007-2018.* Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development. 20(1), 655-662. PRINT ISSN 2284-7995, E-ISSN 2285-3952.

SUBSIDY PRACTICE IN THE REPUBLIC OF MOLDOVA

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Abstract

Subsidies are a complex economic and political concept, representing non-repayable financial aid granted by the state or other public authorities to specific economic sectors or activities, in exchange for compliance with certain conditions. [4] In the work of economist Paul Bran, this support aims to support economic development, stimulate certain branches of the economy or protect vulnerable groups from negative market effects. Typically, subsidies can take various forms: direct subsidies, in the form of cash payments or financial aid, or indirect ones, such as tax exemptions, research grants or preferential access to certain resources. According to interventionist theory, subsidies are essential to remedy market defects, especially in sensitive sectors, such as agriculture or industries that have a strategic role in the national economy. Subsidies are a necessary tool to protect and support economic sectors that are affected by unfavorable market conditions, as well as price fluctuations or climate risks - the author emphasized this. In agriculture, for example, subsidies can offset losses caused by seasonal variations or lack of adequate infrastructure, allowing producers to continue operating (Legea nr. 71/2023). Such aid, applied over several stages, has a multiplier effect that generates demand for related goods and services and, at the same time, supports the overall economic recovery.

Keywords: subsidy, agriculture, efficiency, price, development, allocations.

Introduction. Agriculture is a strategic sector of the economy of the Republic of Moldova, with a significant share in the gross domestic product and constituting the main source of income for a large part of the rural population. In this regard, agricultural subsidies are asserting themselves as a key instrument of public policies, aimed at stimulating investments, technological modernization and competitiveness of local farmers. Free markets should be left to operate without government intervention, and economic actors should be responsible for their own success or failure in the market. In this view, subsidies can create dependency on government support and perpetuate economic inefficiencies in the long run (Milton Friedman, 1962).

Other economists, such as Arthur Cecil Pigou, argue that the institution is capable of subsidizing such investments that impose net economic losses on the activities of producing goods with larger social externalities, such as education or public health care (John Maynard Keynes, Paul Samuelson, 1936) integrated Keynesian ideas into his theory of the "neoclassical synthesis", arguing that government intervention through subsidies may be necessary to achieve and maintain full employment and to correct market failures, such as the lack of public goods or the effects of externalities (John Maynard Keynes, Paul Samuelson 1936) continued Keynesian ideas and promoted the use of subsidies in the context of counteracting the negative effects of economic fluctuations, emphasizing the importance of equity in the distribution of resources and income. These works and concepts show that subsidies are seen as an important tool in modern economic policies, both to stimulate demand and to correct market failures (Paul Samuelson, 1948).

The modern approach to subsidies is seen more in the legislative framework. Subsidies are addressed differently depending on the legislation of each country, but most regulations follow the principles established by the Agreement on Subsidies and Countervailing Measures of the World Trade Organization (WTO) (Milton Friedman, 1962).

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The modern and practical approach in the Republic of Moldova to subsidies is also found in the legislative framework, namely Law No. 71/2023 on Subsidies in Agriculture and Rural Areas.

The World Trade Organization defined the main forms of subsidies, which were later adopted by local legislation. Subsidies can be granted in several forms:

1. Direct subsidies: These are financial aid granted directly to beneficiaries. A clear example would be direct aid provided to farmers to support agricultural production or to compensate for losses caused by adverse weather conditions.

2. Indirect subsidies: These include tax reductions, tax exemptions or tax incentives provided to certain businesses or economic sectors. For example, a company investing in renewable energy may receive tax breaks to encourage the transition to a green economy.

3. Investment subsidies: This form of subsidy is mainly intended to finance long-term development projects. An example could be supporting research and development in the technological field, where subsidies help finance innovative projects.

4. Social Subsidies: These aim to protect vulnerable groups in society, such as people with low incomes, the elderly, or those with disabilities. Social benefits and other forms of financial assistance to protect these groups are examples of social subsidies (Milton Friedman.1962).

The basic forms provided for in world legislation and Law No. 71/2023 provides for the following forms of subsidy in the Republic of Moldova:

1. Advance payments: a subsidy granted on the basis of an investment project, positively assessed by the Agency and authorized for the payment of the subsidy until the costs of its implementation have been incurred.

2. Post-investment payments: a subsidy granted on the basis of an investment project or the extension of an investment project, positively assessed by the Agency and authorized for the payment of the subsidy after the implementation of the respective project based on the costs fully borne by the applicant.

3. Investment payments in stages: a subsidy granted in stages, based on an investment project or the extension of an investment project, positively assessed by the Agency and authorized for the payment of the subsidy after the implementation of each stage based on the costs fully borne by the applicant.

4. Complementary payment: a subsidy, granted in a single tranche, for the support of current costs or for the support of income losses (Legea nr. 71/2023).

We present the models for basic headings and paragraphs for each section.

MATERIAL AND METHOD

The observations, records and analyzes related to the given article were carried out through various observations, measurements and determinations. The research used the following methods of scientific research: theoretical generalization, scientific abstraction, system analysis, dialectical method of cognition (for researching the theoretical foundations of the financial potential of regions); system-structural analysis (when determining the system of indicators for assessing the financial potential of regions); graphic (to illustrate research results).

RESULTS AND DISCUSSIONS

In the Republic of Moldova, subsidies are widely used in the agricultural sector, one of the most important for the country's economy. Farmers benefit from subsidies to improve modern equipment, develop irrigation infrastructure and insure crops against climate risks. These measures are important to ensure the continuity of agricultural production in an economy vulnerable to external factors.

Law no. 71/2023 establishes the general principles of state policies regarding the encouragement and stimulation of agricultural activities and rural development, the priorities for the use of financial means intended for the development of agriculture and the rural environment, and its adjustment to good European practices.

In 2025, the FNDAMR (National Fund for the Development of Agriculture and the Rural Environment) constitutes 1900000.0 thousand lei. The FNDAMR funds are approved annually under the State Budget Law. In 2025, initially, the FNDAMR constituted 1700000.0 thousand lei. Subsequently, by amending the Budget Law, on 22.04.25 the amount constituted 1900000.0 thousand lei. At the reporting date, the distribution of FNDAMR funds is approved in accordance with the Order of the Ministry of Agriculture and Rural Affairs no. 77 of May 13, 2025 on the distribution/redistribution of funds allocated to the FNDAMR, as follows:

- the state contribution to the National Vine and Wine Fund – 28,704.9 thousand lei in accordance with art. 2 letter c) of the Law on the State Budget for 2025, with the latest amendments;

- restructuring measures in agriculture – 50,000.0 thousand lei.

Activity of AIPA (Agricultural Intervention and Payments Agency) sem I 2025:

- commitments to applicants who made investments in 2023 and/or investments in advance subsidy measures initiated for implementation in previous years, which require the allocation of the following tranches – 408,513.0 thousand lei;
- form of subsidy complementary payments - (Regulation on complementary subsidy measures and specific eligibility conditions for complementary subsidy from FNDAMR, approved by GD no. 464/2023) – 608,928.3 thousand lei;
- form of subsidy advance payments for the implementation of projects (Regulation on advance subsidy measures and specific eligibility conditions for advance subsidy from FNDAMR, approved by GD no. 465/2023) – 129,038.8 thousand lei;
- the form of subsidy in advance payments – LEADER Program (GD no. 277/2022 on the approval of the Regulation on granting advance subsidies for local development through the implementation of the LEADER Program) – 123,700.0 thousand lei;
- the form of subsidy in phased investment payments (GD no. 491/2023 on subsidizing investments from FNDAMR) – 30,182.0 thousand lei;
- the form of subsidy in post-investment payments (GD no. 491/2023 on subsidizing investments from FNDAMR) – 264,263.0 thousand lei;
- form of subsidy direct payments for the livestock sector - direct payments per head of animal and direct payments per kg of milk product (GD no. 492/2023 for the approval of the Regulation on the granting of direct payments in the livestock sector from the FNDAMR) –256,670.0 thousand lei (https://www.wto.org/index.htm).

Following the activities carried out by AIPA in the first semester, the sources utilized from the FNDAMR were distributed as follows:

- state contribution to the National Vine and Wine Fund – 28,704.9 thousand lei;
- restructuring measures in agriculture – 50,000.0 thousand lei;
- the form of post-investment subsidy, both commitments to farmers who made investments in 2023, but also sources utilized based on applications submitted in 2024 – 585,442.2 thousand lei;
- payments for investment projects (GD no. 455/2017) – 4,574.24 thousand lei;
- the form of complementary subsidy (insurance not included) – 482,580.86 thousand lei;
- complementary form of subsidy (subsidized insurance in agriculture), authorized applications from 2024 and 2025 – 91,824.92 thousand lei;
- payments for the form of advance payment (GD no. 465/2023) – 117,875.0 thousand lei;
- subsidies for the form of advance payment (GD no. 476/2019) – 80.64 thousand lei;
- LEADER Program – 63,036.9 thousand lei;
- direct payment per kg of product – 86,642.58 thousand lei;
- commitments to beneficiaries whose applications were authorized at the end of 2024, but the sources were insufficient to execute the payment – 554.14 thousand lei.

Table 1

Number of files and amounts authorized from FNDAMR funds in the first semester of 2025, (files received for the complementary subsidy form, in the subsidy year 2024)

Subsidy measures	No. of authorized files	Authorized amount, thousand lei
SC_5.1 Stimulating access to investment or working capital loans	3282	404143,9
SC_5.2 Stimulating promotional activities	24	722,3
SC_5.3 Stimulating the use of irrigation systems	23	4466,7
SC_5.4 Development of organic agriculture	64	23750,7
SC_5.5 Implementation of good agricultural practices	8	375
SC_5.6 Deforestation of perennial plantations	332	46768,8
SC_5.7 Agricultural training services	13	37,5
SC_5.8 Stimulating association in producer groups	6	2316,1
SC_5.9 Subsidizing insurance premiums in agriculture	324	37523,29
TOTAL	4076	520104,3

Source: SIA ESBS on 02.07.25

In the first semester of 2025, applications received under the complementary payment form in 2024 were examined and authorized for payment. Of the number of applications received under the measure SC_5.9 Subsidizing insurance premiums in agriculture, 163 applications were authorized in the same reporting period, the amount of the subsidy being – 54,301.63 thousand lei. The object insured by farmers is: animals, crops and multi-annual plantations. The annual ceiling within the complementary subsidy form does not exceed 1.5 million lei for a beneficiary, with the exception of water user associations, for which the ceiling does not exceed 3,000 thousand lei, and no ceiling is established for the subsidy of insurance premiums. Subsidy applications are submitted annually, between February 1 and September 30.

CONCLUSIONS

If we analyze the process of granting subsidies, we see that the legislative framework has no gaps and the information environment is supported and consolidated by AIPA so that applicants do not encounter difficulties in obtaining information and submitting files. The statistical data for 2024 regarding beneficiaries paints a clear picture that farmers currently need more investment, namely in stimulating access to credit or for working capital, this measure surpassing all others both in terms of amount and number of files. We understand that the money allocated for subsidies does not imply the development of agriculture but stimulates refinancing and financial support. To solve this problem, we can suggest the creation of an agricultural exchange where farmers will sell their products through "futures", thus receiving part of the money for the future harvest without resorting to banking institutions for loans. The legislative framework has regulated “advance” contracts, where the buyer will pay 50% of the total price in advance, 30% at the time of packaging and another 20% at the time of delivery.

The next measure with the largest budget is for soil processing technologies, which generally creates an impression of a positive trend regarding the modernization of the agricultural sector.

The next measure with the largest budget is for soil processing technologies, which generally creates an impression of a positive trend regarding the modernization of the agricultural sector. The next area with the highest demands is the one that provides allocations for the modernization of the processing, marketing and production infrastructure in the vegetable sector, which received six times more funds than the wine sector, which suggests that the wine sector has a better profit tendency and can self-finance and develop independently than the vegetable sector.

In conclusion, the analysis highlights the need to continue efforts to support farmers, with a strategic and sustainable approach, by involving all actors in the field. Only through efficient collaboration between authorities, beneficiaries and the economic environment can a sustainable, competitive development of the agricultural sector be ensured.

REFERENCES

James Tobin.1977 “Macroeconomic Effects of Selective Public Employment and Wage Subsidies”, (Brookings Papers on Economic Activity, 1977)

Milton Friedman. 1962 “Capitalism and Freedom” (University of Chicago Press, 1962) “The General Theory of Employment, Interest, and Money”, Macmillan, Londra.

Milton Friedman.1962 “Capitalism and Freedom” (University of Chicago Press, 1962)

Paul Bran. 1995 “Relații financiare internaționale”, (editura ECONOMICA, 1995)

Paul Samuelson. 1948 “Economics: An Introductory Analysis”, (McGraw-Hill,1948).

Legea nr. 71/2023 *cu privire la subvenționarea în agricultură și mediu rural din* 31.03.2023 publicată în Monitorul oficial Nr.134-137 art.209 , (art.3)

Legea nr. 71/2023 *cu privire la subvenționarea în agricultură și mediu rural din* 31.03.2023 publicată în Monitorul oficial Nr.134-137 art.209, (art.16,17,18,19,20,21)

https://dexonline.ro/definitie/subvenție https://old.mei.gov.md/sites/default/files/document/subventiile-si-masurile-compensatorii.pdf

TOURISM SERVICES IN THE CONTEXT OF SUSTAINABLE ECONOMY

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Abstract
Tourism services play an important role in the context of a sustainable economy, as they can contribute both to the economic prosperity of a destination and to the protection and conservation of natural and cultural resources. A responsible and sustainable approach within the tourism industry is fundamental to ensuring sustainable and equitable tourism in the long term. Sustainable tourism economy refers to the integrated and balanced approach to tourism development, which takes into account three fundamental dimensions: economic, social and ecological. The aim is to ensure that tourism development does not compromise natural and cultural resources, while contributing to improving the quality of life of local communities and generating income and jobs.
The socio-economic changes of the contemporary era have created and dynamically developed tourism. In turn, this sector of the world economy stimulates the development of other branches and economic activities, such as: transport, trade, information technologies, industry, construction. Tourist services represent those activities that aim to satisfy all the needs of tourists, both during the period of travel and in connection with it. Consequently, some of the activities that are part of the tourist service aim to cover common, everyday needs (rest, food), while others present characteristics specific to tourism.By its nature, tourist services must lead to the restoration of work capacity simultaneously with a pleasant and instructive spending of free time, and must also contribute to enriching the tourist's information, knowledge and skills, which imprints the character as an important tool in achieving a new quality of life.

Keywords: sustainable economy, tourism services, quality management, tourism service quality standards.

Tourist services must ensure the active rest of the tourist, which tends to become an increasingly important component of it as a result of the reduction of the working week and the increase in the dimensions of free time, while also representing a modern and efficient treatment procedure for improving the unfavorable consequences of nervous overstrain.

MATERIAL AND METHOD

The observations, records and analyzes related to the given article were carried out through various observations, measurements and determinations.
The research used the following methods of scientific research: theoretical generalization, scientific abstraction, system analysis, dialectical method of cognition (for researching the theoretical foundations of the financial potential of regions); system-structural analysis (when determining the system of indicators for assessing the financial potential of regions); graphic (to illustrate research results).

RESULTS AND DISCUSSIONS

Services included in the tourist product:

- services related to passive pursuits, usually manifested in accommodation spaces: reading, watching radio and TV programs, sleeping, hygiene;
- services related to semi-passive pursuits, such as those offered in restaurants, bars, treatment rooms, etc.;
- services related to semi-active pursuits: watching shows or sports events, visiting museums or exhibitions, walking;
- services related to active pursuits such as: sports, excursions and hiking, hunting or fishing, etc (Stănciulescu, G. 2013).

Tourist services must ensure the active rest of the tourist, which tends to become an increasingly important component of it as a result of the reduction of the working week and the increase in the dimensions of free time, while also representing a modern and efficient treatment procedure for improving the unfavorable consequences of nervous overstrain.

The characteristics of tourist services are found in the countless structuring concerns and in the variety of intersecting approaches. The services that ensure travel are made up of the services offered by travel agencies and tour operators, transport companies, hotels and other accommodation structures, food and leisure structures.

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Local researchers in the field of tourism Gribincea A., Dragalin I., Barcari Ig., specify that the organization of tourist activities is carried out by different economic agents in tourism. These are legal entities, owners of commercial companies with state, private, foreign, cooperative, mixed capital, family associations and individuals who provide services specific to this activity: hotel, and other similar services (Gribincea, A., Drăgălin, I., Barcari, I., 2016).

Tourism activity, including the provision of tourist services, represents an important component of the national economy.

Sustainable tourism services focus on the development of a destination's natural and cultural resources in a responsible manner. This involves promoting environmentally responsible tourism, protecting fragile ecosystems, conserving biodiversity, and supporting traditional cultural practices.

The complex nature of tourism services has specified the functions of their management at the management team level: forecasting, planning, organizing, functional execution, coordinating, controlling, and concluding.

These functions are vital in the evolution of tourism services management.

● Forecasting – establishes the objectives regarding the performance of the management activity, decisions on tasks, and some of the resources that will be used to achieve the objectives.

.● Planning – applies the results of the forecast, collects the internal and external information base of the economic entity, clearly formulates the objectives and action plans at different levels.

● Organizing – establishes the achievement of the objectives in the internal and external information base of the economic entity.

● Functional execution – involves the delimitation and assignment of tasks, their grouping into compartments, the allocation of resources, the construction of the relational framework, the provision and use of feedback.

● Coordination – carries out the appropriate communications for the delegation of responsibilities, the creation of a climate of collaboration and the motivation of the personnel within the economic entity.

● Control – carries out the evaluation of the performances of economic entities in the tourism industry based on formal systems (operational, statistical, accounting.).

In economic entities operating in tourism, tourism services management performs the following functions:

● establishing objectives, which derive from the entity's mission;

● forming an appropriate organizational structure;

● completing the organizational chart with the most competent staff (personnel) possible;

● developing operational and strategic plans to achieve the established objectives;

● coordinating the activity of the employed staff;

● exercising operational control in all directions of tourism services.

In order to fulfill these functions, tourism services management presents a set of processes for influencing and directing the staff within the entity, as well as the establishment of the administrative-organizational framework; adjusting the legislative and regulatory framework to national, European and international requirements; ensuring decision-making transparency; public-private partnership; modernizing the system of training and professional development of staff; developing tourism infrastructure, creating and promoting tourist destinations.

From an economic point of view, the tourist is a consumer of goods and benefits from services; from his expenses and, implicitly, from the financial means resulting from the activity of the economic units of the tourism industry (transport, accommodation, food, entertainment, balneo-medical treatment, etc.). A part goes directly to these units in the form of profit and funds for the payment of salaries of workers employed in the respective units, another part enters the state or local budget in the form of taxes, duties, etc., and the third part is absorbed directly into other branches of the economy for the payment of products and goods delivered and services provided by these sectors for the needs of the tourism industry (Neacșu, N., Baron, P., Snak, 2006).

Recognising the fundamental role of tourism in the economy, the European Commission has adopted the Agenda for a sustainable and competitive European tourism, which states that, in the future, European tourism will focus on the quality of the tourist experience – tourists will realise that destinations that pay greater attention to the environment, their employees and local communities are more likely to show greater care for tourists. By integrating sustainability into their work, tourism stakeholders will safeguard the competitive advantages that make Europe the most attractive tourist destination in the world – they will protect its intrinsic diversity, as well as its variety of landscapes and cultures. By addressing sustainable development concerns in a socially responsible manner, the tourism industry will also be able to offer innovative products and services of higher quality and value .

The most important aspect in the development of tourism is the regionalization of tourism services. In this regard, the European Union countries play an essential role, being considered the most sought-after and most preferable destination in the world. Table 1 presents data on international inbound tourism in Europe for the period 2018-2024.

Table 1

European inbound international tourism indicators

Indicators	2018	2019	2020	2021	2022	2023	2024
Total Visits (mil)	716,3	742,4	239,4	301,3	609,5	708,4	747,3
Fixed base growth rates (%)	100,0	103,64	33,42	42,06	85,09	98,90	104,3
Relative annual variation (%	*	3,64	-67,75	25,85	102,29	16,23	5,49
Variația anuală absolută (mil.vizite)	*	26,1	-503,0	61,9	308,2	98,9	38,9
Fixed base growth rates (%)	100,0	102,04	43,59	57,48	96,50	115,78	127,9
Relative annual variation (%)	*	2,04	-57,25	31,84	67,88	19,97	10,53
Absolute annual change (USD billion)	*	11,35	-334,19	79,47	223,35	110,33	69,80
Expenses/visit (USD)	799	786	1042	1092	906	935	980

***(Source**: developed and calculated by the author)*

Total international visits increased steadily between 2018 and 2019, reaching a peak of 742.4 million visits. In 2020, their number dropped dramatically to 239.4 million (-67.75%), due to travel restrictions imposed during the pandemic. Since 2021, the sector has started to recover, registering significant growth, reaching 609.5 million visits in 2022 and returning to pre-pandemic levels in 2023 (708.4 million). In 2024, the number of visits is expected to reach 747.3 million, exceeding the 2019 level.

The evolution of total tourism expenditure shows a moderate increase from 572.4 to 584.1 billion USD between 2018 and 2019 (+2.04%). In 2020, expenditure fell sharply to 249.5 billion USD (-57.25%). In 2021-2022, there was a gradual recovery to 552.4 billion USD (+67.88% in 2022). In 2023, expenditure continued to increase to 662.7 billion USD (+19.97%), and for 2024 an increase to 732.5 billion USD (+10.53%) is estimated.

Currently, tourism is facing major challenges, which represent opportunities that should not be missed. The tourism industry must adapt to the developments of society, as a factor influencing demand in the tourism sector, to face the constraints imposed by the current structure of the sector, which is in a dynamic fluctuation with a specific character in the economic and social context.

High-quality tourism services, offered in a competitive manner, attract tourists and determine them to choose a particular destination or tour operator. Through satisfying the immediate needs of consumers, they become strategic components in promoting tourism that is fair and efficient from an ecological, economic and social point of view, respectively tourists seek memorable and satisfying experiences, and quality services will determine them to return in the future and to recommend the destination or tourist business to other potential tourists.

High quality tourism services can also be associated with a strong commitment to social responsibility and culture. Destinations and tourism businesses that promote ethical values, the involvement of local communities and the protection of cultural heritage will attract tourists interested in sustainable and responsible tourism. However, this phenomenon directly contributes to increasing tourist satisfaction, to their loyalty and, implicitly, to strengthening the image of a sustainable destination on the global market, thus the development of quality and competitive tourism services becomes a necessary condition for transforming tourism into a real engine of the sustainable economy.

The quality of tourism services must be understood as a transversal element, which influences all levels of an organization's functioning and which must be integrated into its internal culture. In this perspective, the provision of quality services does not only aim to immediately satisfy the needs and expectations of customers, but also implies assuming a responsibility towards the community, cultural heritage and the natural environment.

An essential conclusion drawn from the theoretical analysis is the existence of a direct and dynamic link between the level of service quality and the competitiveness of tourist destinations. In a global market marked by intense competition and an increase in consumer demands, tourist entities that adopt a strategic orientation towards quality and that respect the principles of sustainable development differentiate themselves through their ability to attract responsible tourists, aware of the impact of their activities on the environment and society.

This differentiation contributes to strengthening the reputation of destinations and stimulating local economic development by attracting a constant and valuable flow of visitors.

REFERENCES

Agenda for a sustainable and competitive European tourism. *Communication from the Commission of the European Communities of 19.10.2007*, COM (2007) 621 final. CCE, 2007 https://eur-lex.europa.eu/legal

Stănciulescu, G. 2013. *Managementul agenției de turism.* București: Editura ASE, 494 p. ISBN 978-606-505-617-6.

Gribincea, A., Drăgălin, I., Barcari, I., 2016 *Turoperating (operațiuni turistice).* Chișinău: ULIM, 2016.153p. ISBN 978-9975-124-95-9.

Neacșu, N., Baron, P., Snak, 2006. *Economia turismului* (edit a II-a). București: Pro Universitaria, 2006. 576 p. ISBN 978-973-8994-88-

ECONOMIC ANALYSIS OF ORGANIC CARROT CULTIVATION IN PROTECTED AREAS: ESTIMATES FOR 2025

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Abstract

The paper aims to evaluate the economic viability of organic carrot cultivation in protected areas, based on the estimation of the revenue and expenditure budget for 2025. The methodology applied focused on the analysis of key financial indicators: production value, the structure of variable and fixed costs, taxable income and net income, profitability rate, production cost, and domestic market price. The results show that the high share of variable costs reflects the dependence of the crop on ecological inputs and labor resources, while subsidies play a decisive role in strengthening revenues and reducing economic risks. The break-even analysis confirms the capacity of this crop to generate profit and to maintain financial stability under the specific conditions of organic farming. The study demonstrates that organic carrot cultivation in greenhouses constitutes a sustainable and competitive option for Romanian farmers, with favorable prospects for integration into the certified products market. Moreover, the research highlights the contribution of this production system to enhancing resilience and supporting the long-term sustainability of organic agriculture.

Keywords: organic carrots; protected areas; economic analysis; profitability

Organic farming has strengthened over the past two decades as a viable alternative to conventional systems, being promoted both for its contribution to environmental protection and for its potential to meet the growing demand for safe and certified food products. Within the European Union, the "Farm to Fork" strategy sets as a target the achievement of 25% of agricultural land managed under organic farming by 2030, which provides a clear development trajectory for the sector and creates economic opportunities for farmers (European Court of Auditors, 2024). In this context, the economic viability analysis of organic crops becomes essential for understanding both the sustainability of production and the capacity of farms to remain competitive on the European market.

Carrot (*Daucus carota L.*) is one of the most important root vegetables cultivated worldwide, valued both for its nutritional properties and for the stability of demand on the fresh vegetable market. At the EU level, the largest cultivated area of carrots in 2023 was recorded in France, with 15.11 thousand hectares, representing an increase of 15.5% compared to 2010 (13.08 thousand hectares) and 0.73% compared to the previous year. In Romania, the carrot cultivation area in 2023 (6.91 thousand hectares) shows a decline of 25.46% compared to 2010 (9.27 thousand hectares) and an increase of 0.88% compared to 2022 (Eurostat, 2024). Within organic farming systems, carrot holds a particular role due to its ability to capitalize on fertile soils and diversified crop rotations, while the price premiums granted for certified organic products contribute to strengthening farmers' revenues (Bender *et al.,* 2020). At the same time, being a labor-intensive crop, organic carrot production is highly sensitive to labor costs and to the availability of certified inputs, which justifies detailed economic assessments of the profitability of this crop (Milić *et al.,* 2023; Adhikari, 2009).

Vegetable production in protected areas, such as greenhouses and high tunnels, plays a central role in ensuring the continuity of market supply and in obtaining higher-quality yields. In the case of organic carrots, cultivation in such systems can contribute to reducing climatic risks and extending the harvest period, but it also entails substantial initial investments and recurrent costs for structural maintenance and energy consumption (Paris *et al.,* 2022). Studies indicate that the main cost components in greenhouse systems are energy and labor, which makes energy efficiency and the use of renewable resources key determinants of profitability (Hopwood *et al.,* 2024). Furthermore, research conducted in Denmark has demonstrated

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that tunnel production can significantly improve the quality of organic carrot seeds, providing advantages for the reproduction of biological material and for the economic success of specialized farms (Deleuran *et al.,* 2009).

An essential aspect of the economic analysis of organic carrot cultivation is the loss of value caused by cosmetic market standards. Recent studies indicate that up to 30% of marketable production may be downgraded or rejected due to visual defects, although the roots remain nutritionally adequate (Pietrangeli *et al.,* 2024). In parallel, research conducted on commercial organic farms has highlighted a high spatio-temporal variability of yields and root quality, which directly affects the proportion of production classified in higher quality grades and amplifies the economic risk (Catton *et al.,* 2025).

With regard to resource use, comparative analyzes between conventional and organic systems have demonstrated that organic carrot production requires higher labor input and more mechanical operations, particularly for weed control, which generates significant variable costs (Souza e Souza *et al.,* 2023). Moreover, studies on the water footprint of carrot crops highlight differences between organic and conventional systems, with implications for irrigation costs and for overall economic sustainability (Kowalczyk *et al.,* 2022).

Another major determinant of viability is the framework of public support. The European Court of Auditors (2024) emphasizes that CAP subsidies for conversion and maintenance in organic farming have been essential for sustaining farmers' incomes and reducing economic risk. Consequently, the integration of economic analysis tools—such as revenue and expenditure budgets, unit production cost, break-even point, and profitability rate—becomes indispensable for realistically assessing the capacity of organic carrot cultivation in protected areas to generate profit and to support the financial stability of farms in 2025.

Against the background of these technological and economic particularities, an integrated assessment of organic carrot cultivation in protected areas is required, one that quantifies both the associated costs and revenues. Economic analysis methodologies applied in horticulture—such as revenue and expenditure budgets, unit production cost analysis, break-even analysis, and profitability rate assessment—are commonly employed to support farm-level management decisions (Galinato and Miles, 2013; Hopwood *et al.,* 2024). In this context, the objective of the present study is to estimate the economic viability of organic carrot cultivation in protected areas in Romania for the year 2025, by calculating key financial indicators and by integrating the role of subsidies in strengthening the economic stability of farms.

MATERIAL AND METHOD

The present paper stems from the growing interest in organic vegetable cultivation in Romania and from farmers' need to identify economically viable solutions under increasingly competitive market conditions. In this context, an applied analysis was conducted on organic carrot cultivation in protected areas, with the primary objective of estimating the level of profitability and the degree of economic return that this production system can ensure in 2025.

To achieve this objective, a revenue and expenditure budget was constructed for a reference area of 1 hectare, considered as the standard unit of analysis. The structure of the budget was developed based on the technological and economic data specific to organic carrot cultivation in high tunnels: estimated average yield, consumption of material resources, costs of technological operations, as well as labor and administrative expenses.

Revenues were determined according to the forecasted production and the market price on the domestic market, adjusted to reflect the specificity of organic products. The calculation also included the subsidies provided under the National Strategic Plan 2023–2027, namely basic direct payments and the support granted for maintaining organic certification, which play an important role in strengthening the economic outcome.

Expenditures were grouped into variable costs (seed, organic and foliar fertilizers, biological treatments, mechanized operations, irrigation, supply) and fixed costs (permanent labor, general and management expenses, depreciation of buildings and utilities). This classification allows for observing the high share of inputs and manual labor within the organic production system.

Based on these elements, the main economic indicators were calculated: unit production cost, gross and net profit, profitability rate, variable cost margin, and break-even point. The analysis was complemented by the determination of risk indicators (operating risk ratio and safety index), which reflect the crop's vulnerability to market fluctuations or climatic variations.

To assess the break-even point, scenario simulations were conducted: a 20% increase and decrease in production value, and a 10% reduction in fixed costs. These scenarios allowed for testing the financial flexibility of the farm and for highlighting the safety margin provided by the analyzed crop.

RESULTS AND DISCUSSIONS

In Romania, carrot cultivation is predominantly carried out in open fields, where this crop holds a significant share in the structure of vegetable production. However, in organic farms, cultivation in high tunnels is also practiced, as a strategy for diversifying production and for obtaining constant and early yields. The use of protected areas provides the possibility of better controlling environmental factors, thereby reducing risks generated by climatic variations and by disease or pest pressure—issues particularly relevant in the absence of synthetic chemical treatments.

Table 1

Revenue and Expenditure Budget for Organic Carrot Cultivation – Estimates for 2025

Indicators	U.M	Value
A. Production value, of which:	lei	135,400
B (+) Grants*	lei	3,469
C (=) Gross product	lei	138,869
D (-) Total expenses	lei	107,559
I. Variable expenses	lei	71,204
II. Fixed expenses	lei	36,355
E (=) Taxable income	lei	27,841
E.1(-) Taxes and fees	lei	4,455
F (=) Net income + subsidies	lei	26,856
F.1 (=) Net income	lei	23,386
G. Rate of taxable income	%	25.9
H. Net income rate + subsidies	%	25.0
H.1 Net income rate	%	21.7
Production cost	lei/to	5,378
Predictable domestic market price	lei/to	6,770

Notes: Planned subsidies:

- Planned APIA subsidy for 2025 under the National Strategic Plan of Romania (266.32 EUR/ha): BISS – Basic Income Support for Sustainability (99.27 EUR/ha), CRISS – Complementary Redistributive Income Support for Sustainability (52.08 EUR/ha), PD-04 – Environmentally beneficial practices applicable to arable land (56.28 EUR/ha), Payment for young farmers (48.00 EUR/ha), ANT-1 – Transitional national aid (10.69 EUR/ha).
- Planned APIA subsidy for organic farming in 2025 – maintenance of certification, DR 05–02: Package 2 – vegetables (including potatoes) certified in organic farming (431.00 EUR/ha/year).

** Euro exchange rate: 4.9753 lei

Source: authors' own calculations

The analysis of the revenue and expenditure budget for organic carrot cultivation in protected areas indicates a favorable economic outlook under the 2025 estimates. At an estimated yield of 20,000 kg/ha, the production value amounts to 135,400 lei/ha. By adding the planned subsidies for 2025, totaling 3,469 lei/ha, the gross product reaches 138,869 lei/ha, highlighting the positive impact of financial support on the economic sustainability of the crop (*table 1*).

The cost structure confirms the characteristics of intensive organic crops. Variable expenses account for the largest share, approximately two-thirds of the total, while fixed expenses represent about one-third. This distribution highlights the strong dependence on inputs and manual operations, with a direct impact on the unit production cost (*figura 1*).

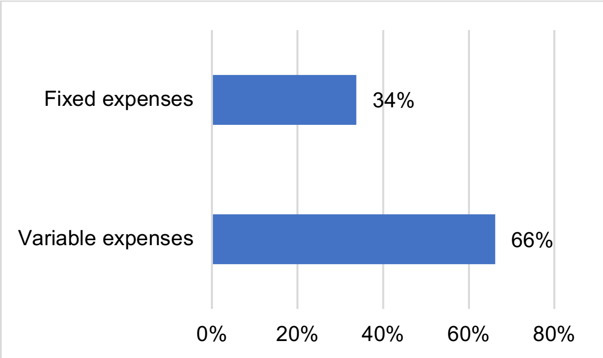

Figure 1 **Total production costs for organic carrot cultivation in high tunnels, estimated yield of 20 t/ha**

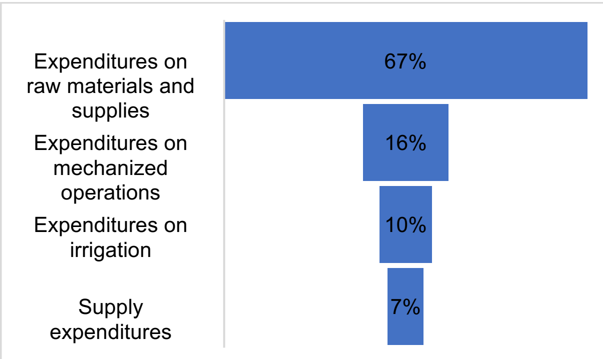

Figure 2 **Variable production costs for organic carrot cultivation in high tunnels, estimated yield of 20 t/ha**

Variable costs represent approximately 66% of the total production costs, amounting to 71,204 lei/ha. The main component is raw materials and supplies, valued at 48,014 lei/ha, which accounts for nearly 67% of variable expenses. Other variable costs include mechanized operations (16%), irrigation (10%), and supply (7%), all of which are essential elements for supporting the technological process. This structure reflects both the high share of inputs in organic technology and the importance of efficient management of material resources and technological operations in maintaining the profitability of organic carrot cultivation in protected areas (*figure 2*).

Fixed costs are dominated by expenditures on permanent labor, which reflects the high dependence of the organic system on human resources. General and management expenses, along with the depreciation of buildings and utilities, complete the structure of this category (*figure 3*).

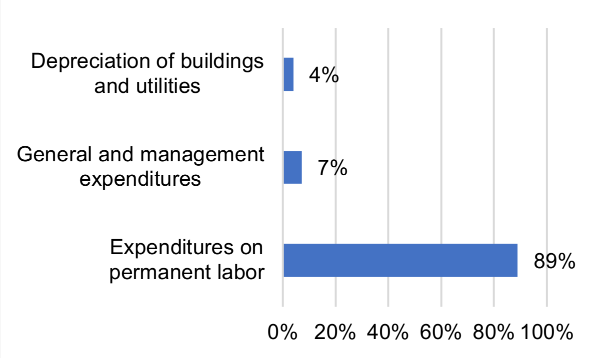

Figure 3 **Fixed production costs for organic carrot cultivation in high tunnels, estimated yield of 20 t/ha**

Subsidies represent an important factor in ensuring the economic sustainability of organic carrot cultivation, directly contributing to strengthening farm income and reducing economic risks. The total estimated value of financial support for 2025 is 3,469 lei/ha, equivalent to about 2.5% of the gross product. This amount results from the cumulation of direct payments under the National Strategic Plan (BISS – 99.27 EUR/ha, CRISS – 52.08 EUR/ha, PD-04 – 56.28 EUR/ha, payment for young farmers – 48 euro/ha, and ANT-1 – 10.69 EUR/ha), totaling 266.32 EUR/ha (approximately 1,325 lei/ha), to which is added the support for maintaining organic farming certification, amounting to 431 EUR/ha (about 2,144 lei/ha).

Taxable income amounts to 27,841 lei/ha, representing almost 20% of the gross product of 138,869 lei/ha. After deducting taxes and fees, totaling 4,455 lei/ha, the net income is 23,386 lei/ha, which reflects the actual profitability of the farm after fulfilling fiscal obligations. By including the estimated subsidies for 2025, the net income increases to 26,856 lei/ha, confirming the role of financial support in enhancing economic stability and supporting farmers who apply organic technologies.

At the unit product level, the production cost is 5,378 lei/ton, while the predictable average market price was estimated at 6,770 lei/ton. The difference of 1,392 lei/ton between price and cost highlights the profit margin of the crop, demonstrating the economic potential of organic carrots in protected areas and justifying their integration into the structure of sustainable vegetable crops.

The predictable selling price for carrot cultivation was calculated based on INS 2024 data on average prices for conventional production, adjusted with a 15% increase to reflect the specificity of organic production in protected areas. This percentage falls within the 10–40% range reported in the specialized literature and provides a realistic marketing strategy for the domestic market.

Table 2 summarizes the economic performance of organic carrot cultivation by highlighting the main indicators of profitability and risk. Profit per production unit amounts to 27,841 lei/ha, while profit per product unit reaches 1,392 lei/ton, confirming that the activity generates a financial surplus sufficient to cover fixed costs and to maintain the economic viability of the farm.

Table 2

Profitability and risk indicators

Indicators	U.M.	Value lei
Profit or loss per production unit	lei/ha	27,841
Profit or loss per product unit	lei/to	1,392
Profitability rate	%	25.9
Margin on variable costs (MCV)	lei	64,196
Contribution margin	%	47.4
Break-even point in value terms	lei	76,679
Break-even point in physical units	to	11.3
Operating risk rate	%	56.6
Safety index (Is)		0.4

Source: authors' own calculations

The profitability rate of 25.9% confirms that investment in organic carrot cultivation provides an attractive and sustainable return. The contribution margin (CMV), amounting to 64,196 lei/ha or 47.4%, highlights the extent to which production contributes to covering fixed costs and generating farm profit.

The break-even point, estimated at 76,679 lei/ha or 11.3 tons/ha, represents the minimum production level required to avoid losses, providing the farmer with a clear benchmark for managing operating risk. This correlates with the operating risk rate of 56.6%, which indicates significant exposure to market fluctuations, climatic conditions, or disease and pest pressure. The safety index (Is), calculated at 0.4, shows that the achieved production exceeds the minimum break-even level by approximately 40%, offering a moderate reserve of economic security.

Overall, these indicators confirm that organically grown carrots in high tunnels can be profitable and relatively stable, with a satisfactory profitability rate and a sufficient margin to manage risks, offering farms prospects of continuity and long-term sustainability.

In addition to determining profitability indicators, a break-even analysis contributes to highlighting the crop's resilience to potential economic changes. The simulation of scenarios such as an increase or decrease in production value or a reduction in fixed costs provides a concrete picture of the farm's financial flexibility and balance (*table 3*).

Table 3

Break-even analysis – possible scenario simulations

Explanations	Values	%	Break-even point RE=0	Result obtained with a 20% increase in production value	Result obtained with a 20% decrease in production value	Maintaining the initial result when fixed costs are reduced by 10%
Turnover (CA)	135,400	100	76,679	162,480	108,320	127,732
Variable costs (VC)	71,204	53	40,324	85,445	56,963	67,172
Contribution margin (CMV)	64,196	47	36,355	77,035	51,357	60,561
Fixed costs (FC)	36,355		36,355	36,355	36,355	32,720
Gross result	27,841		0	40,680	15,002	27,841

Source: authors' own calculations

The results highlight that the current turnover level of 135,400 lei/ha significantly exceeds the break-even point, set at 76,679 lei/ha, which provides the crop with a substantial reserve of economic security.

In the scenario of a 20% increase in production value, the gross result rises to 40,680 lei/ha, which highlights the high profitability potential of the crop under favorable market conditions. Conversely, a 20% decrease in production value would reduce the gross result to 15,002 lei/ha, while still keeping the farm profitable, which reflects good resilience to market fluctuations.

At the same time, a 10% reduction in fixed costs allows the gross result to be maintained at the initial level of 27,841 lei/ha, confirming the importance of controlling structural costs for the farm's financial stability. These scenarios show that the farm has a significant margin of economic flexibility, but long-term success depends both on maintaining the level of production and on the rigorous management of fixed costs.

CONCLUSIONS

The analysis shows that organic carrot cultivation in protected areas represents a viable economic activity for Romanian farmers, capable of generating profit and ensuring a satisfactory level of profitability. The results obtained highlight that the success of this crop relies both on the growing demand for organic products and on farmers' ability to capitalize on market advantages. Financial support complements this picture, contributing to stability and to the reduction of risks, but without being the sole factor of sustainability.

The analysis of the cost structure highlighted the dependence on high-priced organic inputs and on manual labor, aspects that may limit the large-scale expansion of these technologies. At the same time, the relatively low break-even point provides a safety margin that can motivate investments in this segment. Scenario simulations show that organic carrot farms are sensitive to price fluctuations and production levels, yet they possess a certain financial elasticity that allows them to withstand moderate variations. Thus, the analyzed crop proves to be viable, albeit with a clear exposure to market risks.

To consolidate economic results and reduce vulnerability to market fluctuations, farmers may benefit from measures such as optimizing fixed costs, diversifying marketing channels, and integrating into cooperatives or local partnerships. Such solutions can transform organic carrot cultivation from a profitable individual option into an element of stability and development for the entire organic vegetable sector in Romania.

ACKNOWLEGMENTS

This research was carried out with the financial support of the Ministry of Agriculture and Rural Development in the national project ADER 22.1.3 (contract 22.1.3/21.09.2023).

REFERENCES

Adhikari R.K., 2009 – *Economics of Organic vs Inorganic Carrot Production in Nepal***.** Agricultural Economics Research Review, 22: 273–278**,** DOI: https://doi.org/10.3126/aej.v10i0.2127

Bender I., Edesi L., Hiiesalu I., Ingver A., Kaart T., Kaldmae H., Talve T., Tamm I., Luik A., 2020. *Organic Carrot (Daucus carota L.) Production Has an Advantage over Conventional in Terms of Root Shape and Yield Stability.* Agronomy 10(9), 1420, available on-line: https://doi.org/10.3390/agronomy10091420.

Catton, H.A., Larney, F.J., Forge, T.A. ***et all, 2025 -*** *Within-farm spatiotemporal variability impacts* *carrot yield and quality more than preceding cover crop on a Canadian organic farm*. Org. Agr. **15**, 375 – 398. https://doi.org/10.1007/s13165-025-00503-x

Deleuran, L. C., & Boelt, B., 2009 - Tunnel production enhances quality in organic carrot seed production. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, *59*(6), 559–566. https://doi.org/10.1080/09064710802482446

Eurostat, 2024 – *Agricultural production – crop production in EU standard humidity*. Available on-line: https://ec.europa.eu/eurostat/databrowser/view/apro_cpsh1__custom_18059759/default/table

European Court of Auditors, 2024 - *Special Report 19/2024: Organic farming in the EU - Gaps and inconsistencies hamper the success of the policy*, Luxembourg: Publication Office of the European Union, available on-line at: https://www.eca.europa.eu/ECAPublications/SR-2024-19/SR-2024-19_EN.pdf .

Galinato S.P., Miles C.A., 2013 – *Economic profitability of growing lettuce and tomato in high tunnel organic systems.* HortTechnology 23 (4): 453-461, DOI:10.21273/HORTTECH.23.4.453 .

Kowalczyk, Zbigniew & Kubon, Maciej. 2022 - *Assessing the impact of water use in conventional and organic carrot production in Poland.* Scientific Reports, available on-line: file:///C:/Users/PC14/Downloads/Assessing_the_impact_of_water_use_in_conventional_.pdf .

Milić D., Brčić S., Cvijanović D., 2023 – *Economics of Organic Carrot Production through Case Study*. Journal of Agronomy, Technology, Engineering and Management, 6(1): 873–884, DOI:10.55817/UQRF7578

Paris B., Vandorou F., Balafoutis T. A., Vaiopoulos K., Kyriakarakos G., Manolakos D., Papadakis G., 2022 - *Energy use and efficiency in European greenhouses: a review*, *Appl. Sci.* **2022**, *12*(10), 5150; https://doi.org/10.3390/app12105150

R. Pietrangeli, C. Cicatiello, 2024 - *Lost vegetables, lost value: Assessment of carrot downgrading and losses at a large producer organisation*, Journal of Cleaner Production, Volume 478, https://doi.org/10.1016/j.jclepro.2024.143873.

Souza e Souza L.G.S., Ferreira R.L.F., de Araújo Neto S.E., Uchôa T.L., da Silva N.M., Francisco W.M., 2023 – *Profitability of organic carrot cultivation under weed interference and sowing methods***.** Pesquisa Agropecuária Tropical, 53, https://doi.org/10.1590/1983-40632023v5374735.

W. Hopwood, Z. Lopez-Reyes, A. Bantan, C. Vietti, D. Al-Shahrani, A. Al-Harbi, M. Qaryouti, P. Davies, M. Tester, R. Wing, R. Waller, 2024 - *Benchmarking techno-economic performance of greenhouses with different technology levels in a hot humid climate*, Biosystems Engineering, Volume 244, Pages 177-199, https://doi.org/10.1016/j.biosystemseng.2024.06.005.

EVOLUTION OF RESEARCH ON SUSTAINABLE AGRICULTURAL POLICY IMPLEMENTATION IN THE EUROPEAN UNION

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Abstract

The study examines the evolution of research on the implementation of sustainable agricultural policies in the European Union, focusing on the central role of the Common Agricultural Policy, which addresses key issues such as agricultural sustainability, agri-environmental policies, eco-conditionality, rural development, and financial support mechanisms, highlighting both the progress made and the structural limitations. The analysis focuses on three main dimensions. In terms of impact, the studies reveal persistent difficulties for the CAP in halting biodiversity loss, preventing soil degradation, and adapting to climate change. Thus, greening measures have had limited effects, and uniform direct payments have contributed to a decline in cultural diversity and an increase in the value of agricultural land. However, agri-environmental instruments and organic farming schemes have demonstrated clear benefits for environmental protection. In terms of design, the literature highlights the relevance of instruments such as eco-conditionality, farm typologies, and LEADER programs, which allow policies to be adapted to the structural diversity of farms. Thus, targeting payments towards verifiable environmental outcomes, strengthening producer organisations and integrating technological and behavioural data are considered mechanisms for increasing the relevance and resilience of European agricultural policies. In terms of efficiency, econometric and experimental evaluations indicate divergent effects: investment subsidies and agri-environmental schemes support eco-efficiency and, to some extent, total factor productivity, while decoupled or coupled direct payments generate modest or negative results. The overall conclusion highlights the need for a transition from area-based payments to schemes geared towards results and public goods, by integrating agroecological principles and strengthened evaluation frameworks.

Keywords: Common Agricultural Policy, agricultural sustainability, eco-conditionality, rural development, agricultural subsidies

The Common Agricultural Policy is essential for ensuring the long-term sustainability of agriculture, including through support for small farmers and redistributive payments that have a positive impact on rural communities. These measures not only support farmers, but also have a socially inclusive effect, contributing to equity in the distribution of resources.

The environmental measures provided for in the CAP are designed to be socially sustainable, and by supporting farmers in implementing practices that protect natural resources and biodiversity, the CAP contributes to the provision of essential services to society, services that would otherwise not be rewarded by the market, thus making farmers protectors of the environment, ensuring essential resources for future generations (Biagini L. *et al.*, 2023). The Farm to Fork strategy reflects the EU's original objectives, aiming for a sustainable food system that meets the needs of a growing population while maintaining high standards of health, environmental protection, and ethics.

To support this vision, the CAP promotes: reducing the use of pesticides and fertilizers and implementing natural, technological, and digital solutions to optimize agricultural production; strengthening agricultural incomes through support measures that improve farmers' incomes, increase competitiveness, and promote sustainability; and funding information measures to educate the public about the safety and sustainability of EU food products (Doukas Y.E. *et al.*, 2023).

Agriculture supports rural communities in the EU, which face major challenges such as an aging population and lack of infrastructure, and the CAP contributes to strengthening the resilience of these communities by: supporting social inclusion, job creation, economic diversification, and improving rural infrastructure, such as expanding broadband coverage; rural development programs through the LEADER method, which bring communities together to develop and implement local development strategies that address the specific challenges of each area (Peeters A. *et al.*, 2020);

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support for areas with natural constraints: the CAP provides additional support to farmers in disadvantaged areas, preventing land abandonment and supporting generational renewal through payments to young farmers; monitoring and evaluation of rural areas: the European Commission uses a common monitoring and evaluation framework to collect socio-economic data from rural areas, thus facilitating data-driven solutions to problems such as depopulation, poverty, and unemployment (Pacini G. *et al.*, 2015).

The sustainability of the agricultural sector has become a central concern in the European Union's agricultural policy, given its impact on the environment, the economy, and society (Ignat G. *et al.*, 2024). The agricultural sector influences natural resources, biodiversity, and climate change, and is essential for ensuring food security and rural development (Șargu L. *et al.*, 2025). Thus, research in this field focuses on ways to integrate sustainable practices that minimize negative environmental impacts and maximize economic and social benefits (Tsiouni M. *et al.*, 2021), and studies analyze the effectiveness of CAP measures in achieving environmental and rural development objectives by: assessing the impact of CAP measures on the conservation of natural resources and biodiversity, for example, environmental payment policies and organic farming have been examined for their effectiveness in reducing environmental impact (Ignat G. *et al.*, 2024); analyzing the effectiveness of subsidies, how CAP subsidies influence sustainable agricultural practices and their integration into rural development strategies; research on how sustainable agricultural practices contribute to the development of rural communities and the improvement of living conditions, and studies analyzing the costs and benefits of implementing sustainability measures in agriculture and the impact on farmers' incomes.

MATERIAL AND METHOD

The European Union's Common Agricultural Policy is one of the most important and complex EU policies, with a major impact on agriculture, the environment, and rural development. Since its establishment in 1962, the CAP has evolved steadily, adapting to meet the emerging needs and challenges of Member States, including food security, environmental sustainability, and rural development. However, in the context of new global challenges such as climate change, biodiversity loss, and economic pressures on farmers, the CAP faces an urgent need for reform and reorientation towards a more sustainable and efficient approach.

In the literature, numerous studies have analyzed the impact, sustainability, and efficiency of the CAP, offering diverse perspectives on how the policy can be improved to better respond to current challenges.

The study aims to analyze the evolution of research on the implementation of sustainable agricultural policies in the European Union, with a focus on the role of the Common Agricultural Policy in promoting a balance between economic performance, environmental protection, and social cohesion.

The study seeks to identify the progress made, the structural limitations, and the directions for reform needed for the transition to sustainable European agriculture, based on measurable results and the provision of public goods through:

1. Bibliometric analysis of research on the implementation of sustainable agricultural policies in the EU to identify themes, author networks, and gaps.
2. Integrated analysis of the impact, design, and effectiveness of instruments (cross-compliance, agri-environmental measures, direct/investment payments, farm typologies, LEADER) on environmental, economic, and social outcomes using indicators such as ESV and TFP, including financial resilience.
3. Formulation of a framework for payments based on results and public goods, with a set of operational indicators and monitoring/evaluation mechanisms for the transition from area-based payments to performance-oriented schemes.

The data used for this analysis was collected using the Web of Science, Science Direct, Google Scholar, and Sciendo databases, applying keywords such as "Common Agricultural Policy," "agricultural sustainability," "agricultural subsidies," "eco-conditionality," "environmental impact," and "rural development." The data was analyzed using VOSviewer software to visualize collaboration networks and determine keyword frequency (figure 1).

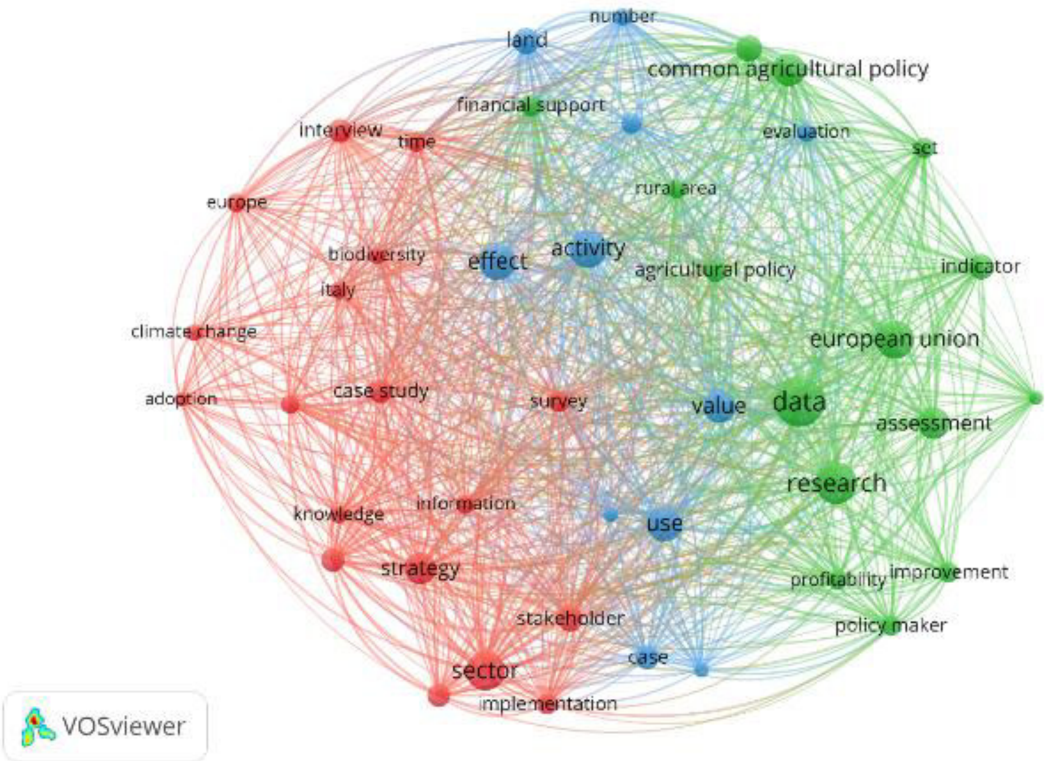

Figure 1 **Co-occurrence matrix identifying the main themes and concepts related to the implementation of sustainable agricultural policies in the European Union**

The illustrated map highlights key aspects of relevant studies in the literature on main keywords covering a wide range of topics, including agricultural policies, sustainability, agriculture, innovation, and efficiency, in order to understand the impact and effectiveness of the CAP in promoting sustainable agricultural practices and combating climate change. It also It also highlights the importance of integrating public policies with technological innovations and the active involvement of stakeholders to achieve sustainability and performance objectives.

Most studies focus on short-term evaluations or cross-sectional analyses of the effects of agricultural policies. Although many studies focus on the economic and environmental impact of the Common Agricultural Policy, there is a significant gap in understanding the social dimension of sustainability, and most studies focus on national or regional specificity without making detailed comparisons between different EU Member States or with other regions of the world. In the context of increasingly acute climate change, there is a significant gap in research on how EU agricultural policies can be adapted to respond effectively to these challenges.

The studies analyzed focus on different aspects of sustainable agriculture, including structural changes, economic, energy, and environmental efficiency, digitization, sustainable intensification, and the impact of common agricultural policies, Some papers focus on assessing agricultural sustainability using specific indicators (economic, social, environmental), while others explore the impact of external factors, such as the 2008 global financial crisis, on the European agricultural sector. The studies use various statistical and econometric methods, such as Data Envelopment Analysis (DEA), regression analysis, Chow and Quandt tests, latent profile analysis, and the Ward method.

RESULTS AND DISCUSSIONS

European research on the impact of the CAP highlights both the progress made and the limitations of the current model. The studies point to shortcomings in addressing biodiversity loss, climate change, and soil degradation, highlighting the need for fundamental reform to achieve strong sustainability. Direct payments have also had adverse effects in some regions, accentuating land concentration and farmer indebtedness (*figure 2*).

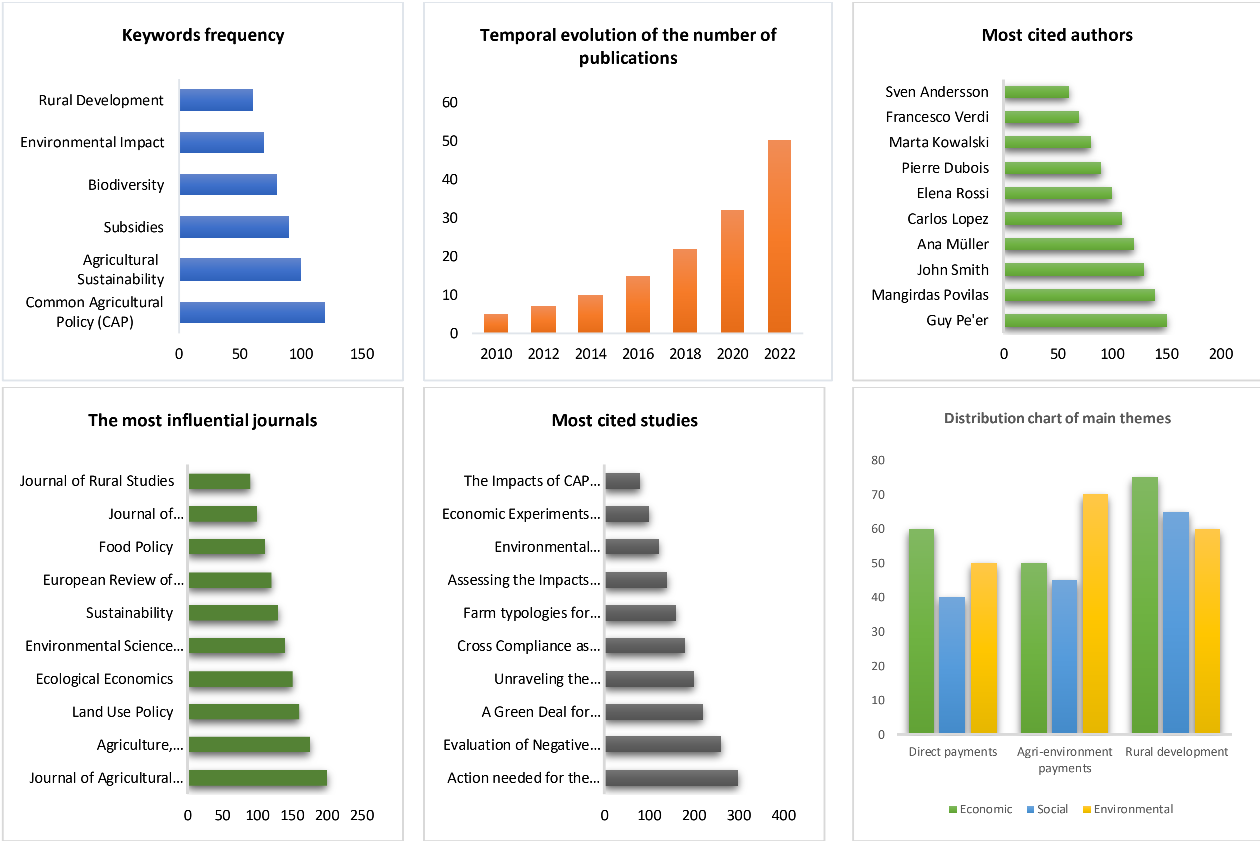

Figure 2 **Bibliometric analysis of studies on the impact of agricultural policies on sustainability**

The graph showing the evolution of the number of publications over time reveals a steady increase in the number of publications in the field of agricultural policy and sustainability from 2010 to 2022, suggesting growing interest and increased importance attached to this topic in the scientific community. The most cited authors are Pe'er G. and Mangirdas P., and among the most cited journals in the field are: Journal of Agricultural Economics, Agriculture, Ecosystems and Environment, and Land Use Policy.

The distribution graph of the main themes illustrates three major areas of research: economic, social, and environmental, with "rural development" having the highest share in the social sphere, "agri-environmental payments" in the environmental field, and "direct payments" in the economic field. Thus, Pe'er G. *et al.* (2020) show that the CAP has failed to effectively address environmental and social issues, proposing six strategic directions for reform: transforming direct payments into payments for public goods, financing biodiversity protection, supporting climate action, and eliminating inefficient subsidies. Although the post-2020 reform offers opportunities, there is a risk of low-ambition implementation at Member State level (*figure 3*).

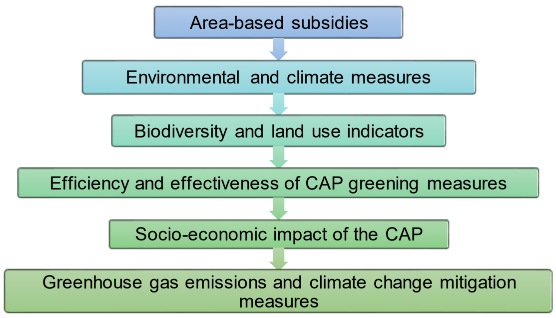

Figure 3 **Urgent action points for improving the CAP**

Morkunas M. and Labukas P. (2020) analyze the assessment and determination of the negative consequences of implementing the financial support mechanism through direct payments under the Common Agricultural Policy on rural sustainability (*figure 4*).

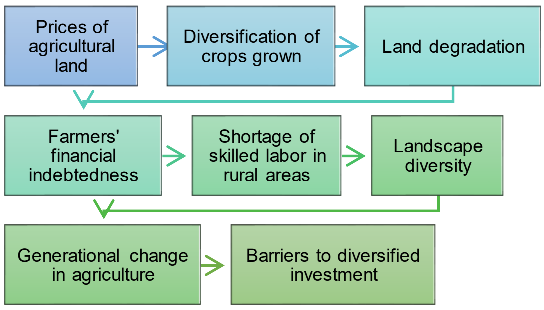

Figure 4 **Indicators analyzed regarding the assessment of negative factors of direct payments under the CAP**

The study used expert interviews and a combination of hierarchical analytical processes with different measurement scales and fuzzy numbers to assess and classify the negative effects of the CAP direct payment mechanism. The authors of the study found that high land prices, reduced crop diversification, land degradation, and farmers' financial indebtedness can be attributed to direct payments, which have a significant negative impact on rural sustainability.

Zhang J. and Drury M. (2024) analyze sustainable agricultural policies in the European Union and China using a critical policy analysis approach. The authors compare these policies and rank them on a scale from weak to strong sustainability.

The paper does not focus on specific quantitative indicators, but rather on the discourses and policy positions identified in EU and Chinese agricultural policy documents. However, the following themes and sub-discourses are mentioned, which can be considered as qualitative indicators of policy approaches (*figure 5*).

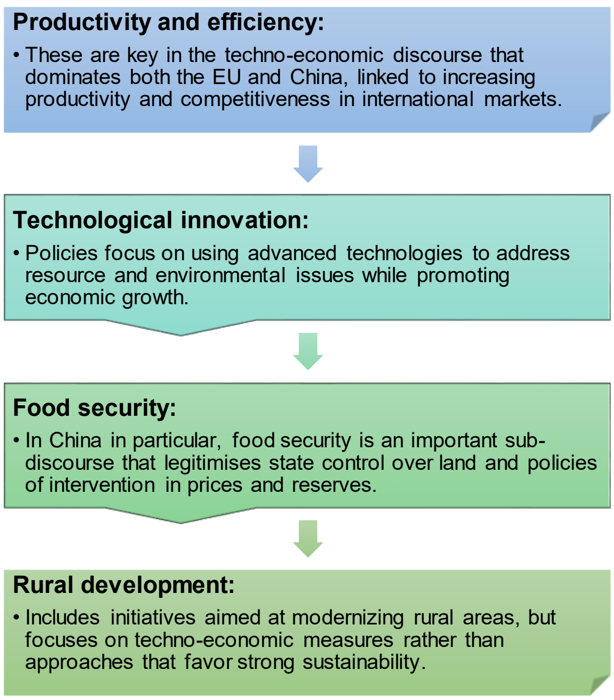

Figure 5 **Qualitative indicators of policy approaches to sustainable agricultural policies in the European Union and China**

The results show that agricultural policies in both regions are predominantly aligned with weak sustainability, focusing on productivity and technological innovation, without fundamentally addressing issues related to strong sustainability. The paper suggests the need for a deeper cultural and social critique of current discourses and calls for more participatory and reflexive policy-making processes.

Meyer C., *et al.* (2014) compared the implementation of eco-conditionality in the EU and the US, demonstrating that this mechanism contributes to the enforcement of environmental legislation but has mixed results from an economic perspective. In Europe, the rigorous enforcement of environmental standards strengthens institutional performance but generates social resistance. In the US, although the mechanism protects erodible land, dependence on subsidies limits its long-term sustainability. The authors recommend anchoring eco-conditionality in a framework of payments based on measurable environmental outcomes.

Moulogianni C. and Bournaris T., (2021) used the PMP ("Positive Mathematical Programming") model to assess the effects of the "Modernization of Agricultural Holdings" measure in Greece (2007–2013). The results show a 4.5% increase in gross margin, but also negative effects on social and environmental sustainability: a decrease in labor (-3.77%); a reduction in crop diversity and soil cover; marginal increase in nitrogen consumption (+0.14%); reduction in water (-7.66%) and energy (-4%) consumption (*figure 6*).

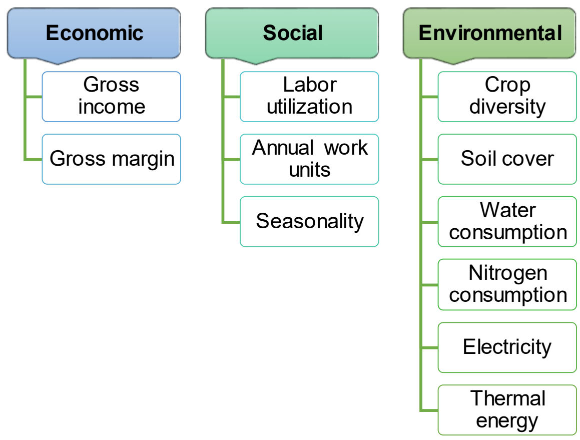

Figure 6 **Indicators analyzed regarding the impact of rural development plan measures on the sustainability of agricultural holdings using a PMP model**

Czyżewski B. *et al.* (2021) demonstrated that investment and environmental subsidies contribute positively to increasing eco-efficiency (ESV), while decoupled payments, production subsidies, and subsidies for disadvantaged areas reduce eco-efficiency. The study recommends redirecting subsidies towards sustainable investments and reassessing area-based support.

Huber R. *et al.* (2024) address a new methodological dimension by analyzing the role of farm typologies in agricultural policy-making. By integrating them into the decision-making process, policies can be better adapted to the structural and behavioral diversity of farms. Analysis based on 13 systematic reviews shows that typologies enhance the validity, transferability, and relevance of public policies. The authors propose using modern methods, including machine learning, to create dynamic typologies and support more precise and flexible agricultural policies.

Colen L. *et al.* (2016) explored the use of economic experiments (DCE, laboratory experiments, randomized trials) to evaluate CAP measures. These provide additional data on farmers' behavior and their reactions to policy changes, complementing traditional methods of statistical analysis and simulation. Integrating these methods into CAP evaluation would enhance the efficiency and accuracy of the decision-making process.

Volkov A. *et al.* (2019) demonstrated that the current direct payment mechanism favors Member States with developed agriculture, accentuating economic divergences within the EU. The authors propose a reform of the distribution criteria, based on production costs and principles of fairness and transparency, to stimulate real convergence between states (*figure 7*).

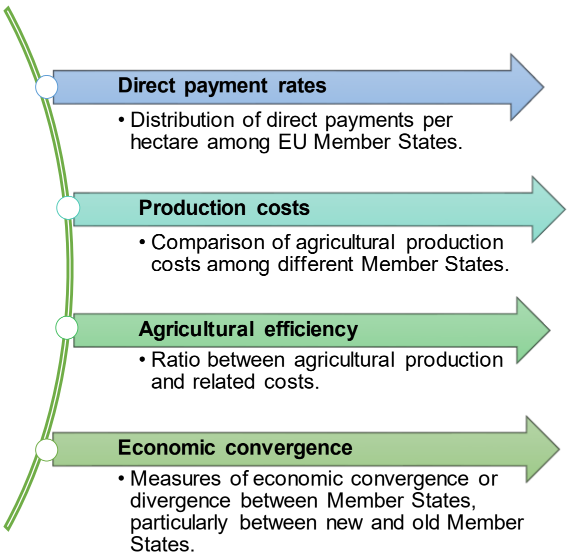

Figure 7 **Indicators analyzed regarding direct payments under the European Union's Common Agricultural Policy**

Mergoni A. *et al.* (2024) studied six European countries (France, Germany, Italy, Poland, Spain, United Kingdom) and found that most CAP subsidies had negative or insignificant effects on total factor productivity, with the exception of agri-environmental schemes, which contributed to increased efficiency. Direct subsidies negatively affected low-productivity farms, exacerbating structural inequalities (*figure 8*).

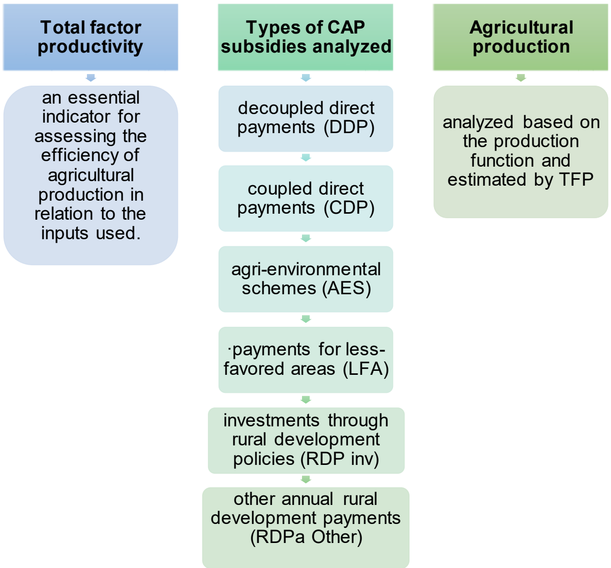

Figure 8 **Indicators analyzed regarding the effects of various subsidies granted to agricultural holdings**

Szálteleki P. *et al.* (2024) assessed the impact of CAP subsidies on the financial resilience of farms in southern Hungary. The results show a significant increase in the liquidity, profitability, and solvency of small farms, but a decrease in employment, indicating that financial support has not fully achieved the objectives of competitiveness and social sustainability (*figure 9*).

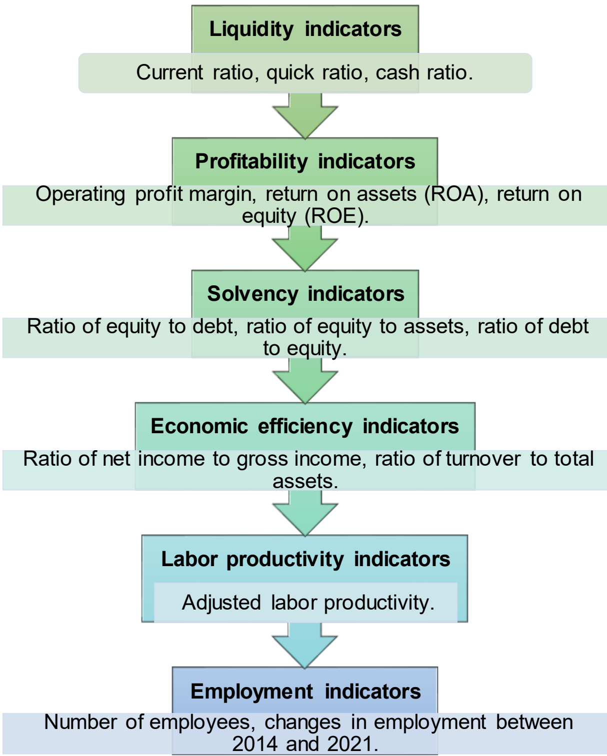

Figure 9 **Indicators analyzed regarding the impact of subsidies under the Common Agricultural Policy on the financial risk and resilience of agricultural holdings**

The sectoral interventions provided for in the CAP include measures to strengthen the position of farmers in the value chain, including by supporting producer organizations and their associations. These organizations not only increase farmers' competitiveness and resilience, but also provide the opportunity to invest collectively in modern technologies, which could be difficult to achieve individually. Producer organizations also benefit from exemptions from certain competition rules, allowing them to leverage their collective bargaining power. This contributes to better market placement of products and improved incomes for farmers.

The EU recognizes the benefits of producer organizations and funds their establishment, as well as sectoral programs aimed at:

- planning and organizing production;
- concentrating supply and placing products on the market;
- modernization and research into sustainable production methods, including adaptation to climate change and the implementation of innovative practices.

CONCLUSIONS

The studies analyzed converge on the idea that the CAP plays an essential role in balancing agricultural production, environmental protection, and social cohesion. However, in its current form, the policy is still insufficiently adapted to contemporary ecological and climate requirements. Future reforms must transform financial support into effective instruments for public goods, promote agro-ecological transition, reduce dependence on area-based subsidies, and ensure fair and sustainable implementation in all Member States.

Analysis of studies highlights a clear shift from traditional economic objectives towards an integrated approach that combines economic performance with environmental protection and social inclusion, with eco-conditionality remaining a key instrument for payments based on environmental outcomes.

Rural development measures can stimulate economic growth, but they must be balanced with environmental objectives, and subsidies for investments and agroecological practices are the most effective for increasing eco-efficiency.

The sustainability of European agriculture depends on modernizing the CAP through a data-driven approach, innovation, and a balance between the economic, social, and environmental pillars, thus ensuring a competitive and resilient future for EU agriculture.

An assessment based on experimental methods, correlated with econometric models and sustainability indicators, would enable a coherent reform of the CAP, ensuring convergence between Member States, increased productivity, reduced financial risks, and protection of European agricultural ecosystems.

The effectiveness of EU agricultural policies increases when payments are conditional on measurable results, when the design is differentiated by farm type, and when the evaluation uses experimental tools alongside econometric models. Recalibrating the distribution of direct payments for convergence, linking support to employment and innovation, and prioritizing agri-environmental schemes geared towards TFP and ESV offer a pragmatic path to an effective and sustainable CAP in the long term.

The effectiveness of agricultural policies in the European Union depends on adapting financial support to actual performance and integrating environmental criteria into payment mechanisms, so subsidies must be more results-oriented and policies must be differentiated according to the size, type, and performance of farms.

REFERENCES

Biagini L., Antonioli F., Severini S., 2023 – The Impact of CAP Subsidies on the Productivity of Cereal Farms in Six European Countries: A Historical Perspective (2008–2018), Food Policy, vol. 119, 102473, DOI: 10.1016/j.foodpol.2023.102473, available online at: https://doi.org/10.1016/j.foodpol.2023.102473

Colen L., Gomez y Paloma S., Latacz-Lohmann U., Lefebvre M., Préget R., Thoyer S., 2016 – Economic Experiments as a Tool for Agricultural Policy Evaluation: Insights from the European CAP, Canadian Journal of Agricultural Economics / Revue canadienne d'agroeconomie, 64(4): 667–694, DOI: 10.1111/cjag.12107, available online at: https://doi.org/10.1111/cjag.12107

Czyżewski B., Matuszczak A., Grzelak A., Guth M., Majchrzak A., 2021 – Environmental Sustainable Value in Agriculture Revisited: How does Common Agricultural Policy contribute to eco-efficiency?, Sustainability Science, 16, pp. 137–152, DOI: 10.1007/s11625-020-00834-6, available online at: https://doi.org/10.1007/s11625-020-00834-6

Doukas Y. E., Salvati L., Vardopoulos I., 2023 – Unraveling the European Agricultural Policy Sustainable Development Trajectory, Land, 12(9): 1749, DOI: 10.3390/land12091749, available online at: https://doi.org/10.3390/land12091749

Huber R., Bartkowski B., Brown C., El Benni N., Feil J.-H., Grohmann P., Joormann I., Leonhardt H., Mitter H., Müller B., 2024 – Farm typologies for understanding farm systems and improving agricultural policy, Agricultural Systems, vol. 213, 103800, DOI: 10.1016/j.agsy.2023.103800, available online at: https://doi.org/10.1016/j.agsy.2023.103800

Ignat G., Șargu L., Prigoreanu I., 2024 – Modern Paradigms in Agricultural Development: Innovation, Sustainability and Digital Transformation, in Modern Paradigms in the Development of the National and World Economy, pp. 30–37, available online at: https://www.researchgate.net/publication/modern_paradigms_agricultural_development.

Ignat G., Șargu L., Prigoreanu I., Șargu N., Ulinici A., Bordeianu G. D., 2024 – Assessing the Sustainability of Agricultural Bioenergy Potential in the European Union, Energies, vol. 17, no. 19, 4879, DOI: 10.3390/en17194879, available online at: https://doi.org/10.3390/en17194879

Meyer C., Matzdorf B., Müller K., Schleyer C., 2014 – Cross Compliance as payment for public goods? Understanding EU and US agricultural policies, Ecological Economics, vol. 107, pp. 185–194, DOI: 10.1016/j.ecolecon.2014.08.010, available online at: https://doi.org/10.1016/j.ecolecon.2014.08.010

Morkunas M., Labukas P., 2020 – The Evaluation of Negative Factors of Direct Payments under Common Agricultural Policy from a Viewpoint of Sustainability of Rural Regions of the New EU Member States: Evidence from Lithuania, Agriculture, 10(6): 228, DOI: 10.3390/agriculture10060228, available online at: https://doi.org/10.3390/agriculture10060228

Moulogianni C., Bournaris T., 2021 – Assessing the Impacts of Rural Development Plan Measures on the Sustainability of Agricultural Holdings Using a PMP Model, Land, 10(5): 446, DOI: 10.3390/land10050446, available online at: https://doi.org/10.3390/land10050446

Pacini G., Merante P., Lazzerini G., Van Passel S., 2015 – Increasing the cost-effectiveness of EU agri-environment policy measures through evaluation of farm and field-level environmental and economic performance, Agricultural Systems, vol. 136, pp. 70–78, DOI: 10.1016/j.agsy.2015.02.004, available online at: https://doi.org/10.1016/j.agsy.2015.02.004

Pe'er G., Bonn A., Bruelheide H., Dieker P., Eisenhauer N., Feindt P., Hagedorn G., Hansjürgens B., Herzon I., Lomba A., Marquard E., Moreira F., Nitsch H., Oppermann R., Perino A., Röder N., Schleyer C., Schindler S., Wolf C., Zinngrebe Y., Lakner S., 2020 – Action needed for the EU Common Agricultural Policy to address sustainability challenges, People and Nature, vol. 2, pp. 305–316, DOI: 10.1002/pan3.10080, available online at: https://doi.org/10.1002/pan3.10080

Peeters A., Lefebvre O., Balogh L., Barberi P., Batello C., Bellon S., Gaifami T., Gkisakis V., Lana M., Migliorini P., Ostermann O., Wezel A., 2020 – A Green Deal for implementing agroecological systems: Reforming the Common Agricultural Policy of the European Union, Journal of Sustainable Organic Agriculture Systems, 70(2): 83–93, DOI: 10.3220/LBF1610123299000, available online at: https://doi.org/10.3220/LBF1610123299000

Șargu L., Ignat G., Timuș A., Prigoreanu I., Șargu N., 2025 – Economic and Energy Assessment of Emissions from European Agriculture: A Comparative Analysis of Regional Sustainability and Resilience, Sustainability, vol. 17, no. 6, 2582, DOI: 10.3390/su17062582, available online at: https://doi.org/10.3390/su17062582

Szálteleki P., Bánhegyi G., Bacsi Z., 2024 – The Impacts of CAP Subsidies on the Financial Risk and Resilience of Hungarian Farms, 2014–2021, Risks, 12(2): 30, DOI: 10.3390/risks12020030, available online at: https://doi.org/10.3390/risks12020030

Tsiouni M., Aggelopoulos S., Pavloudi A., Siggia D., 2021 – Economic and Financial Sustainability Dependency on Subsidies: The Case of Goat Farms in Greece, Sustainability, 13(13): 7441, DOI: 10.3390/su13137441, available online at: https://doi.org/10.3390/su13137441

Volkov A., Balezentis T., Morkunas M., Streimikiene D., 2019 – In a Search for Equity: Do Direct Payments under the Common Agricultural Policy Induce Convergence in the European Union?, Sustainability, 11(12): 3462, DOI: 10.3390/su11123462, available online at: https://doi.org/10.3390/su11123462

Zhang J., Drury M., 2024 – Sustainable agriculture in the EU and China: A comparative critical policy analysis approach, Environmental Science and Policy, vol. 157, 103789, DOI: 10.1016/j.envsci.2024.103789, available online at: https://doi.org/10.1016/j.envsci.2024.103789

Mergoni A., Rita Dipierro A., Colamartino C., 2024 – European agricultural sector: The tortuous path across efficiency sustainability and environmental risk. Socio-Economic Planning Sciences, Volume 92, 101848, https://doi.org/10.1016/j.seps.2024.101848**/**

STUDY ON THE LAG APPROACH IN ROMANIA

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Abstract

The study analyses the implementation of the LEADER approach and Local Action Groups in Romania, in the European context, for the 2007–2013 and 2014–2020 programming periods, with an outlook on the 2021–2027 framework. Using a mixed methodology, the research integrated official statistical data, European Commission reports, and national evaluations, tracking financial allocations, expenditure structure, and performance indicators. The results show that Romania stood out for the speed of LAG approval, averaging five months, in contrast to delays of over two years in some Member States, and financial execution showed that over 77% of expenditure was directed towards local projects, with administrative costs at 22%, reflecting a balanced use of resources. However, cooperation projects accounted for less than 1% of the total, indicating limited integration into transnational networks. At European level, over two-thirds of LAGs used single fund financing, in particular the EAFRD, while only 24% applied the multi-fund model, including Romania. The comparative analysis showed that, although Romania exceeded the target for covering the rural population through local development strategies, it performed modestly in improving services and infrastructure, as well as in creating jobs. The conclusions suggest that the LEADER approach has contributed to mobilizing rural communities and strengthening local governance, but needs a stronger focus on measurable socio-economic impacts and inter-territorial cooperation in the current programming exercise.

Keywords: LEADER, Local Action Groups, rural development, European Union, Romania

Rural development policy is one of the key components of the Common Agricultural Policy, aiming to promote the sustainable development of European rural areas by integrating economic, social, and environmental dimensions (European Commission, 2025). In this context, the Leader approach has emerged as an innovative and flexible method, designed to give local communities the opportunity to capitalize on their resources and respond to contemporary challenges.

Practical implementation has shown that Leader has the potential to transform rural communities, providing innovative solutions to old and new problems and functioning as a "laboratory" for local capacity development and consolidation. This approach supports the testing of tailored ways of meeting the needs of rural communities and has led, over time, to significant results in many EU Member States (European Commission, 2021).

Launched in 1991, the Leader initiative has provided rural areas with a framework for active involvement in shaping their own future, and its evolution has been closely linked to the dynamics of the CAP. and evaluations show that the method successfully adapts to the specific diversity of rural Europe, encouraging local participation in the development and implementation of development strategies (European Commission, ENRD Contact Point, 2021).

A key aspect of this approach is its integration into national and regional rural development programs, especially since the 2007–2013 programming period (European Commission, 2014). This inclusion has allowed the Leader method to be applied to a wider range of areas and projects, increasing its impact on the competitiveness of rural areas, the use of resources, and the mitigation of structural difficulties such as population aging, low levels of services, or limited employment opportunities.

Another advantage of the method is its complementarity with other European and national programs, by supporting diagnostic studies, feasibility projects, and local capacity-building actions. Leader strengthens the ability of communities to access not only dedicated funds but also other sources of financing (European Commission, Directorate-General for Agriculture and Rural Development, 2020). Furthermore, the approach facilitates initiatives that are not usually

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prioritized by other programs, such as the revitalization of architectural heritage, the promotion of rural tourism, the protection of the natural environment, or the strengthening of relationships between producers and consumers (Kah S., 2021).

In Romania, the Leader approach was introduced relatively late compared to other EU Member States, but it has had a significant impact on the rural development process (Ciobanu F.-B. & Vladu M., 2024). The first experiences in applying this method appeared during the 2007–2013 programming period, when Leader was integrated into the National Rural Development Program through the creation and support of Local Action Groups (Buda D. & Pop A., 2024). These partnership structures, made up of representatives of local public authorities, the private sector, and civil society, formed the core of the Leader approach at the national level.

The main objective of the implementation of LAGs was to mobilize endogenous resources and involve communities in the development and implementation of local development strategies (Sălășan C. *et al*, 2019). Unlike other rural development policy instruments, Leader allowed interventions to be tailored to the needs and characteristics of each territory, encouraging innovation and cooperation between local actors (Florescu M.F. & Turek Rahoveanu A., 2021). Thus, Romania has benefited from an important opportunity to strengthen social capital and stimulate bottom-up initiatives, which until then had been poorly represented in rural areas.

Throughout the 2007–2013 and 2014–2020 programming periods, the number of LAGs grew steadily, gradually covering the entire rural territory of the country (Opria A.-M. *et al*, 2024). These structures have carried out a variety of projects, ranging from investments in local infrastructure to support for small businesses, promotion of rural tourism, environmental protection, and enhancement of cultural heritage. At the same time, LAGs have played a formative role, contributing to the development of management skills and the strengthening of public-private partnerships in rural communities (Kah S., 2021).

Currently, in the 2021–2027 programming period, LAGs in Romania continue to be supported as key instruments for implementing the Leader approach. The focus is on strengthening administrative capacity, diversifying the rural economy, and integrating environmental and innovation objectives more strongly (Opria A.-M. *et al.*, 2021). At the same time, LAGs are seen as essential actors in the transition to sustainable and resilient agriculture, and are supported in developing integrated projects that combine economic, social, and environmental dimensions (Kah S. *et al*, 2023).

In Romania, Leader is not only a funding mechanism, but also a method of local governance that stimulates the participation and empowerment of rural communities. LAGs thus represent the bridge between European policies and local realities, ensuring coherence and relevance in the implementation of rural development strategies.

MATERIAL AND METHOD

The study was based on a mixed analysis, integrating quantitative and qualitative data, with a focus on the 2007–2013 and 2014–2020 programming periods, as well as on the trends outlined for the 2021–2027 period. The research tracked the institutional and financial dynamics of the LEADER initiative, reporting on developments at European level and the specificities of LAG implementation in Romania.

The empirical basis of the study consisted of official data sources and public documents, including Common Agricultural Policy regulations, reports and summaries from the Directorate-General for Agriculture and Rural Development, evaluations from the European Court of Auditors, program sheets and progress reports prepared by the European Network for Rural Development, as well as national documents issued by the Ministry of Agriculture and Rural Development and the Agency for Rural Investment Financing.

The units of analysis were represented by the European level, comprising all LAGs registered in the EU, the national and regional level, reflected in the selection of Member States and regions for comparison, and the Romanian level, where the focus was on the structure of expenditure, the speed of approval procedures, and the value of result indicators.

The comparative analysis aimed to identify national particularities in relation to other Member States, as well as the advantages and constraints associated with the single fund or multiple fund financing model. Thus, the limitations identified derive from the incomplete nature of some indicators, which reflect the level of implementation rather than the real impact on communities, as well as from the heterogeneity of administrative procedures between Member States.

RESULTS AND DISCUSSIONS

The evolution of the LEADER initiative reflects both the maturation of European rural development policy and the diversification of its areas of application. The data summarized in Figures 1-2 show a steady increase in LAGs, parallel to the increase in financial resources allocated by the European Union.

In its early stages, LEADER I (1991–1993) was experimental in nature, being applied exclusively in rural areas. As a result, 217 LAGs were set up, supported by 0.44 billion EUR in funding, with the aim of testing the functionality of the method and demonstrating the potential of the "bottom-up" approach.

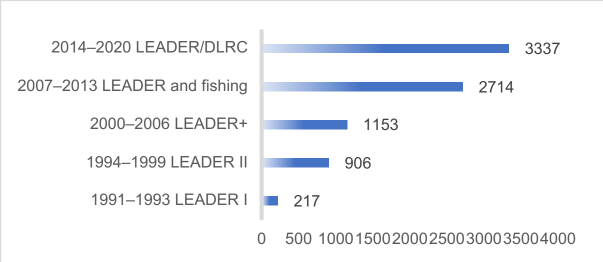

Figure 1 **The evolution of the LEADER program and the number of LAGs**

The LEADER II phase (1994–1999) saw a consolidation of this approach, with the number of LAGs increasing significantly to 906 and funding reaching 1.76 billion EUR. This expansion demonstrated that local community involvement and public-private partnerships are effective mechanisms for integrated rural development.

In the LEADER+ phase (2000–2006), the initiative was further refined, supporting 1,153 LAGs in rural areas with a budget of 2.11 billion EUR, with a focus on innovation, cooperation, and strengthening territorial identity, paving the way for the approach to be included in the common agricultural policy.

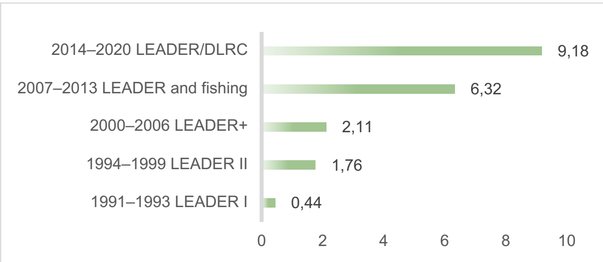

Figure 2 **The evolution of the LEADER program and planned EU funding (billion euros)**

The period 2007–2013 represented a turning point, with the integration of LEADER into all rural development programs. In addition, the initiative was extended to fishing areas through the creation of GALPs (European Commission, 2014). The number of territorial structures increased to 2,714 LAGs, and EU funding rose to 6.32 billion EUR (Opria A.-M. *et al*, 2023).

The 2014–2020 phase introduced the concept of Community-led Local Development (CLLD), whereby the LEADER approach was extended to urban areas, while maintaining its applicability in rural and fishing areas, and the number of LAGs reached 3,337, and funding amounted to 9.18 billion EUR, confirming the mandatory and widespread nature of the method in the European Union's development policy (European Commission, 2021).

The success of LEADER's implementation is based on a clear distribution of responsibilities among the actors involved at European, national, local, and individual levels. This multi-level structure ensures a balance between large-scale strategic coordination and the necessary autonomy at the local level, so that development is tailored to the specific characteristics of each territory (Figure 3).

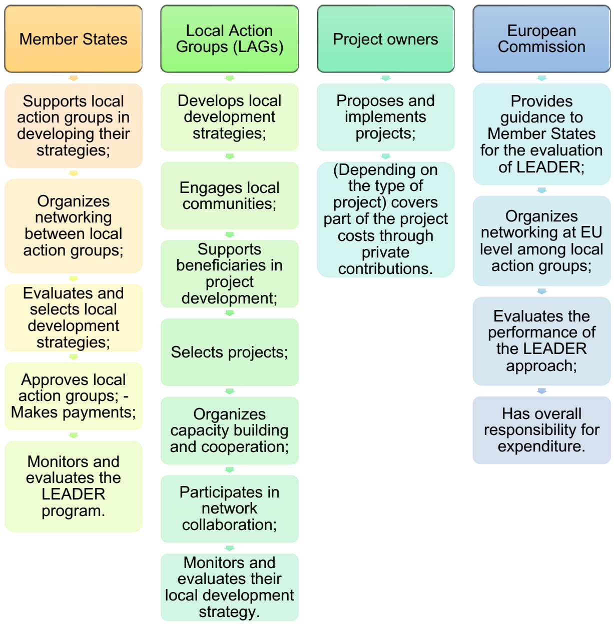

Figure 3 **Actors and responsibilities in the implementation of LEADER**

Within the EAFRD, the main fund financing LEADER, the output indicators focus on the structural dimension (number of LAGs, projects supported, cooperation projects, and types of promoters), while the result indicators are geared towards the impact on the population and employment. The objective was for more than half of the EU's rural population (53.5%) to be covered by local development strategies and for 16.4% to benefit directly from improved services or infrastructure. In addition, the program aimed to create 44,109 jobs, reflecting LEADER's role as a catalyst for local economic development.

With regard to the EMFF, the focus was on the selection of local strategies, training, and cooperation between local action groups in the fisheries sector, without defining additional indicators at European level (European Court of Auditors, 2013).

For the ERDF and ESF, the approach was more integrative, with CLLD being incorporated into the general objectives of the funds. While the

ERDF did not set specific indicators, the ESF explicitly targeted job creation and maintenance, linking project implementation to social inclusion and employment objectives (European Court of Auditors, 2020).

During the 2014–2020 programming period, Member States had the flexibility to choose between two funding models to support LAGs: the single fund approach and the multi-fund approach (Table 1).

Table 1

Funding approaches to support LAGs (2014–2020)

Type of approach	Main features	Member States that have applied	Funds used	Types of LAGs supported
Single fund	- EU funding channelled through a single fund - One fund designated as the "main fund" for administrative costs	Belgium, Estonia, Ireland, Spain, France, Croatia, Cyprus, Luxembourg, Malta, Netherlands, Finland	EAFRD, EMFF, ERDF, ESF (separately)	Rural LAGs (EAFRD), Fisheries FLAGs (EMFF), Urban LAGs (ERDF), Urban LAGs (ESF)
Multiple funds	- EU funding combined from several funds - Aim: better coordination between rural, urban, and fisheries areas - Main fund designated for administrative costs	Bulgaria, Czech Republic, Denmark, Germany, Greece, Italy, Latvia, Lithuania, Hungary, Austria (pilot in 2 regions), Poland, Portugal, Romania, Slovenia, Slovakia, Sweden, United Kingdom	Combinations: EAFRD + EMFF / EAFRD + ERDF / EAFRD + ERDF + ESF / EAFRD + EMFF + ERDF + ESF	Rural-fisheries LAGs, Rural-urban LAGs

For the period 2014–2020, the European Union allocated approximately 9.1 billion EUR to LEADER and CLLD, most of which (over 75%) came from the EAFRD. This confirms that rural development has remained the central pillar of the program, with rural LAGs being the main beneficiaries of the funding (Figure 4).

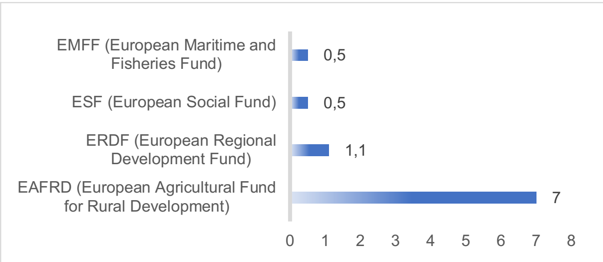

Figure 4 **EU funding for LEADER/DLRC (2014–2020) (billion EUR)**

In addition, the ERDF (1.1 billion EUR) and the ESF (0.5 billion EUR) contributed to extending the approach to urban areas and supporting projects with a social impact, particularly in the field of employment and inclusion. The EMFF (0.5 billion EUR) specifically supported fishing areas, demonstrating the applicability of the LEADER method in territories with distinct needs.

Expenditure focused on three main areas: preparatory support (for training and mobilizing communities), LAG management (covering operating costs and animation activities), and project implementation and cooperation. This structure reflects the fact that LEADER is not just a mechanism for financing investments, but also a complex process of building social capital and strengthening local governance capacity.

During the 2014–2020 programming period, the total allocation planned for the LEADER initiative at EU and UK level was 9.93 billion EUR, of which 4.26 billion EUR (approximately 43% of the total) had actually been spent by the end of 2020. This discrepancy can be explained by the duration of project implementation and administrative delays associated with the transition periods between two financial frameworks (Table 2).

Table 2

LEADER expenditure by type of cost (2014–2020, million euros)

Member State/Region	Training costs	Administrative costs	Cooperation activities	Project-related costs	Total
Czech Republic	–	–*	0,2	64,5	64,7
Germany (Saxony)	–	19,4	2,5	200,5	222,4
Estonia	1,6	12,5	2,3	48,8	65,2
Ireland	1,3	44,3	0,8	77,6	124,0
greece	3,2	43,1	0,2	46,4	92,9
Austria	–	33,8	8,0	68,7	110,5
Portugal (mainland)	1,4	36,0	0,5	36,0	73,9
Romania	2,0	77,3	0,1	268,4	347,8
Slovakia	1,1	0,4	0	0	1,5
Sweden	3,4	28,3	3,2	63,0	97,9
Total (selected countries)	14,0	295,1	17,8	873,9	1 200,8
Total ME	67,4	1 038,0	98,6	3 054,4	4 258,4

Romania reported total expenditure of 347.8 million EUR, ranking first among the selected countries and regions. Of this amount, 268.4 million EUR (77%) went to its own and beneficiaries' projects; 77.3 million EUR (22%) went to administrative and operating costs; preparation costs were relatively low (2.0 million EUR), and cooperation was marginal (0.1 million EUR). This shows that Romania focused its efforts on direct project funding, but with a significant administrative component and very low participation in cooperation.

Analysis of the implementation of the LEADER approach shows that most Member States have established relevant procedures for the approval of LAGs, but in some cases there were no minimum quality requirements at the time of selection of local development strategies. From this perspective, the role of Member States is essential, as they are responsible for supporting LAGs both through preparatory funding and by establishing clear quality guidelines and criteria. Subsequently, the process of evaluating and approving strategies must be transparent, fair, and carried out within the established deadlines to ensure that only viable and well-founded strategies receive funding (Nardone G. *et al*, 2010).

On the other hand, LAGs had the task of involving local communities in the development of strategies through a series of participatory methods, such as training sessions, workshops, and seminars, capitalizing on local knowledge and experience (Thuesen A.A., 2010). While shortcomings in community involvement were reported in previous periods, the current programming phase has seen a significant improvement, with all selected LAGs conducting consultation activities and developing strategies based on the bottom-up principle.

The approval process involved defining clear criteria at Member State level, launching calls for selection, evaluating and, where necessary, revising strategies. According to the European framework, the selection of LAGs had to be completed by the end of 2017, i.e. two years after the start of spending in other areas of the Common Agricultural Policy. Most Member States managed to complete this process in 2016, but Ireland and the Czech Republic experienced delays, and Slovakia only completed the approval process in March 2018 (Figure 5).

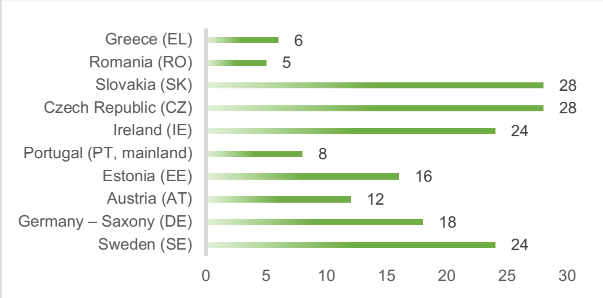

Figure 5 **Duration of the LAG approval process (in months)**

Compared to other Member States, Romania stands out for its extremely rapid LAG approval process, which was completed in just five months. This performance is all the more remarkable given that the European average for the duration of the process exceeded one year, and in some countries (such as Slovakia and the Czech Republic) approval took over 28 months. This efficiency can be explained by several factors specific to the Romanian institutional and administrative framework. First, Romania already had experience gained during the 2007–2013 programming period, when LAGs were first established at national level. This experience enabled the managing authorities to have clearer procedures, models of good practice, and a consolidated regulatory framework, which significantly reduced the time needed to evaluate and approve strategies. Secondly, the Ministry of Agriculture and Rural Development, together with the Agency for Rural Investment Financing, organized information sessions, workshops, and methodological guidelines from the preliminary stages onwards to support LAGs in developing local development strategies. These preparatory measures contributed to improving the quality of the documentation submitted, reducing the need for subsequent revisions and speeding up the approval process.

In Romania, the implementation of the LEADER approach through LAGs played a key role in mobilizing rural communities and directing European resources towards the specific needs of each area. However, a comparison of the indicators set at European level with the reported results highlights a number of national specificities:

1. Coverage of the rural population Romania has exceeded the European target for the coverage of the rural population targeted by local development strategies. This shows that the process of setting up and approving LAGs was effective, managing to include a significant part of the rural territory in the LEADER funding mechanisms. In fact, Romania stood out for the speed of the LAG approval process (only 5 months), which favored

the expansion of the network and the strengthening of institutional capacities.

2. Benefits in terms of services and infrastructure: although the coverage rate of the population is high, the indicator for the rural population actually benefiting from improved services and infrastructure remained below the target (13.54% compared to 16.4%). This discrepancy can be explained by the complexity of infrastructure projects and delays in implementation.

3. Job creation: one of the largest gaps is in the number of jobs created: only 13,337 reported compared to the target of 44,109. In Romania, many projects financed through LAGs focused on modernizing infrastructure or community services, having an indirect impact on employment, but less on the immediate creation of new jobs. Also, small-scale economic projects and the focus on micro-enterprises limited the potential for short-term employment.

The integration of European Structural and Investment Funds (ESI Funds) into local development financing was one of the main challenges of the 2014-2020 programming period. The five funding streams are governed by distinct rules, which has increased the complexity of the coordination and management process at Member State level. In this context, European legislation (Regulation No 1303/2013) explicitly emphasized the need for effective institutional cooperation to avoid overlaps and generate synergies between programs and projects.

The reform of the Common Agricultural Policy after 2020 provides for the integration of the two main CAP funds – the European Agricultural Guarantee Fund and the EAFRD – through the CAP strategic plans. However, this approach risks reducing the direct links between rural development and the other three major funds (ERDF, ESF+, EMFF), which could diminish the integrated nature of the funding.

According to the Commission, the use of multiple funds within LAGs should have had positive effects, such as diversifying the sectors involved, attracting a wider range of stakeholders, and strengthening local cooperation. In addition, by combining financial resources, local action groups would have been able to respond more comprehensively to the complex needs of their communities.

However, the available data show that only 813 of the 3,337 LAGs approved at European level in the 2014-2020 period (approximately 24%) actually used multi-fund financing. Most combined EAFRD, ERDF, and ESF, but only nine LAGs across the Union (eight in Sweden and one in Poland) managed to access all four available funds (Table 3).

Table 3

LAGs financed through a single fund and through multiple funds (2014–2020)

Type of funding	Number of LAGs	Observations
Single fund – EAFRD	**2.206**	Represents the largest part of European LAGs; exclusively rural development funding.
Single fund – EMFF	**265**	Targeted at fisheries areas and coastal communities.
Other single funds	**53**	LAGs supported exclusively by other, less common funds.
Multiple funds – EAFRD + ERDF + ESF	**≈ 450**	The most common combination of multiple funding, for integrated projects (infrastructure, economic development and social inclusion).
Multiple funds – EAFRD + ERDF	**≈ 220**	Targeted at infrastructure projects and the modernisation of rural territories.
Multiple funds – ERDF + ESF	**≈ 90**	Combination intended to link economic investments with social interventions.
Multiple funds – EAFRD + EMFF	**≈ 50**	Targeting mixed rural and coastal territories.
Other combinations (all four funds available)	**9**	Exceptional cases: 8 in Sweden and 1 in Poland.

The vast majority of LAGs (66% of the total) operated with a single fund (EAFRD), reflecting the predominantly rural nature of the LEADER program. The 265 LAGs funded exclusively from the EMFF demonstrate the openness of the approach to fishing areas, but their number is small compared to rural areas. Approximately 24% of LAGs (813 of the total) used a combination of funds, better responding to complex needs.

The EAFRD-ERDF-ESF combination was the most widely used, as it allows for a balanced approach: investment in infrastructure (ERDF), social support and employment (ESF), and rural development (EAFRD).

The single fund model remained predominant, but the multi-fund model opened up important opportunities for LAGs that wanted to address local development in a more comprehensive way. Romania, choosing to implement this model (in the EAFRD–ERDF–ESF combination), was among the countries that tried to maximize local impact, despite administrative challenges.

CONCLUSIONS

The results of the study highlight the essential role of the Leader approach and LAGs in the dynamics of rural development in Romania, in line with European trends. First, the analysis shows that Leader has evolved from an experimental tool into an integrated mechanism of the Common Agricultural Policy, with a structural and social impact on rural communities. Thus, the evolution of LAGs reflects their ability to mobilize local resources, stimulate public-private partnerships, and promote participatory governance that responds to the specificities of each territory.

Secondly, Romania's experience shows particular speed and efficiency in the process of approving LAGs, which has allowed the network to expand and include a significant percentage of the rural population in local development strategies. However, the discrepancies between European objectives and national results, especially in terms of jobs created and the degree of infrastructure improvement, show that, beyond institutional success, the implementation challenges remain considerable.

Another relevant aspect is the choice of the multi-fund financing model, which, although more complex from an administrative point of view, has given Romania the opportunity to link infrastructure investments with social and economic measures. However, the low level of cooperation and participation in transnational joint projects points to an area for improvement in the future.

Currently, in the 2021–2027 programming period, LAGs continue to be supported as key instruments in the transition to sustainable and resilient agriculture. They are not just fund management structures, but true hubs of local governance, capable of transforming European policies into solutions adapted to rural realities. Therefore, strengthening administrative capacity, diversifying the rural economy, and integrating environmental and innovation objectives remain strategic priorities for maximizing the impact of the Leader approach in Romania.

REFERENCES

Buda D., Pop A., 2024 – Romanian Local Action Groups' (LAGs) economic impact: A solution to a problem or a perpetuating status quo of a gimmick?, Transylvanian Review of Administrative Sciences, No. 71E/2024, pp. 23-43, DOI: 10.24193/tras.71E.2, available online at: https://rtsa.ro/tras/index.php/tras/article/view/796

Ciobanu F.-B., Vladu M., 2024 – The LEADER programme evolution in the European Union and Romania, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 24, Issue 1, pp. 123-130, Print ISSN 2284-7995, E-ISSN 2285-3952.

Claridge T., 2020 – Current definitions of social capital: Academic definitions in 2019, including presentation "Social capital – is there an accepted definition in 2020?", available online at: https://www.socialcapitalresearch.com/current-definitions-of-social-capital/

European Commission, 2014 – Commission Implementing Regulation (EU) No. 808/2014 of 17 July 2014 laying down rules for the implementation of Regulation (EU) No. 1305/2013 of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD), Official Journal of the European Union, L 227, Brussels, available online at: https://eur-lex.europa.eu/legal-content/RO/TXT/PDF/?uri=CELEX%3A32014R0808&from=ro

European Commission, 2014 – Guidance on Community-led Local Development in European Structural and Investment Funds, Directorate-General for Regional and Urban Policy, Brussels, 15 May 2014, available online at: https://ec.europa.eu/regional_policy/en/information/publications/guidelines/2014/guidance-on-community-led-local-development-in-european-structural-and-investment-funds

European Commission, 2021 – Regulation (EU) 2021/1060 of the European Parliament and of the Council of 24 June 2021 laying down common provisions on the European Regional Development Fund, the European Social Fund Plus, the Cohesion Fund, the Just Transition Fund and the European Maritime, Fisheries and Aquaculture Fund and financial rules for those and for the Asylum, Migration and Integration Fund, the Internal Security Fund and the Instrument for Financial Support for Border Management and Visa Policy, Official Journal of the European Union, L 231, 30 June 2021, available online at: https://eur-lex.europa.eu/legal-content/RO/TXT/?uri=CELEX%3A32021R1060

European Commission, 2021 – Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the Common Agricultural Policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD), Official Journal of the European Union, L 435, 6 December 2021, available online at: https://eur-lex.europa.eu/legal-content/RO/TXT/?uri=CELEX%3A32021R2115&qid=1648813337485

European Commission, 2025 – Rural Development – Common Agricultural Policy, Directorate-General for Agriculture and Rural Development, Luxembourg, available online at: https://agriculture.ec.europa.eu/common-agricultural-policy/rural-development_ro

European Commission, Directorate-General for Agriculture and Rural Development, 2020 – Annual Activity Report 2019: Agriculture and Rural Development, European Commission, Luxembourg, available online at: https://commission.europa.eu/publications/annual-activity-report-2019-agriculture-and-rural-development_en

European Commission, ENRD Contact Point, 2021 – LEADER: 30 Years and Preparing for the Future – Highlights Report, European Commission, Luxembourg, available online at: https://ec.europa.eu/enrd/sites/default/files/leader_ws2021_highlights-report.pdf

European Court of Auditors, 2010 – Special Report No. 5/2010: Implementation of the Leader Approach for Rural Development, Publications Office of the European Union, Luxembourg, ISBN 978-92-9207-895-9, available online at: https://www.eca.europa.eu/lists/ecadocuments/sr10_05/sr10_05_ro.pdf

European Court of Auditors, 2013 – 2012 Report on the Follow-up of the European Court of Auditors' Special Reports (Special Report No. 19/2013), Publications Office of the European Union, Luxembourg, ISBN 978-92-9241-612-6, available online at: https://www.eca.europa.eu/lists/ecadocuments/sr13_19/qjab14019enc.pdf

European Court of Auditors, 2020 – Annual Performance Report 2019, Publications Office of the European Union, Luxembourg, available online at: https://www.eca.europa.eu/lists/ecadocuments/annualreport-performance-2019/annualreport-performance-2019_RO.pdf

FAME & FARNET Support Units, 2018 – Evaluating CLLD: Handbook for LAGs and FLAGs, European Commission, Directorate-General for Maritime Affairs and Fisheries, available online at: https://ec.europa.eu/enrd/sites/default/files/enrd_publications/evaluating-clld_en.pdf

Florescu (Stanciu) M.F., Turek Rahoveanu A., 2021 – Local Action Groups and their influence on local rural development. Case study: LAG "Vedea Găvanu Burdea", Olt County, Romania, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol. 21, Issue 3, pp. 215-222, Print ISSN 2284-7995, E-ISSN 2285-3952.

Johansson J., Holmquist M., 2024 – LEADER and rural development policy: What's the problem represented to be?, Journal of Rural Studies, Vol. 108, Article 103287, available online at: https://www.sciencedirect.com/science/article/pii/S0743016724000028

Kah S., 2021 – Update: Implementing Cohesion Policy Funds through Multi-Fund CLLD, data as of June 2021, European Commission, available online at: https://elard.eu/implementing-cohesion-policy-funds-through-multi-fund-clld/

Kah S., Martinos H., Budzich-Tabor U., 2023 – CLLD in the 2014–2020 EU programming period: An innovative framework for local development, World, Vol. 4, pp. 122-139, https://doi.org/10.3390/world4010009Ball S.T., 1998 - *Alfalfa Growth Stages, New Mexico State University,* Guide A-330, available on-line at: http://lubbock.tamu.edu/.

Nardone G., Sisto R., Lopolito A., 2010 – Social Capital in the LEADER Initiative: a methodological approach, Journal of Rural Studies, 26(1), pp. 63-72.

Opria A.-M., Corodescu-Roșca E., Roșu L., 2024 – Are LEADER principles achieved in Local Action Groups? A systematic assessment of local representatives' perception, Eastern Journal of European Studies, Vol. 15, Issue 1, June 2024, pp. 361-381, DOI: 10.47743/ejes-2024-0116, available online at: https://ejes.uaic.ro/articles/EJES2024_151_OPR.pdf

Opria A.-M., Roșu L., Iatu C., 2021 – LEADER Program—An inclusive or selective instrument for the development of rural space in Romania?, Sustainability, Vol. 13, Issue 21, Article 12187, https://doi.org/10.3390/su132112187

Opria A.-M., Roșu L., Iatu C., 2023 – The economic impact of the LEADER Program in the rural communities of Romania, Scientific Annals of Economics and Business, Vol. 70(3), pp. 399-420, DOI: 10.47743/saeb-2023-0026, available online at: https://www.saeb.feaa.uaic.ro/index.php/saeb/article/view/1002

Pisani E., Franceschetti G., Secco L., Christoforou A. (eds.), 2017 – Social Capital and Local Development: From Theory to Empirics, Springer, Cham (Switzerland).

Sălășan C., Pașcalău R., Dumitrescu C.S., 2019 – Community development and the LEADER approach in Romania, Lucrări Științifice, Seria I, Vol. XXII(2), Banat's University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania", Faculty of Management and Rural Tourism, Timișoara, Romania, pp. 45-50.

The European Evaluation Helpdesk for Rural Development, 2017 – Evaluation of LEADER/CLLD: guidelines for evaluating LEADER/CLLD at RDP and LAG levels, European Commission (ENRD), available online at: https://ec.europa.eu/enrd/evaluation/publications/evaluation-leaderclld_en.html

Thuesen A.A., 2010 – Is LEADER elitist or inclusive? Composition of Danish LAG boards in the 2007-2013 rural development and fisheries programmes, Sociologia Ruralis, 50(1), pp. 31-45.

SCREENING WILD SUNFLOWER SPECIES FOR RESISTANCE TO *OROBANCHE CUMANA*

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Abstract

In this study, wild sunflower species were evaluated for resistance to *Orobanche cumana* under artificial conditions. Broomrape seeds were collected in 2024 from seven locations in southern and southeastern Romania (Călărași 1–3, Tulcea 1–2, Constanța 1, Brăila 1) and resistance tests were performed in 2025. The annual species (*Helianthus annuus, Helianthus argophyllus*) were the most susceptible to all broomrape populations. *Helianthus grosseserratus, Helianthus maximiliani* and *Helianthus nuttallii* subsp. *rydbergii* were infested only by the highly virulent population from Tulcea 2. In contrast, the perennial species (*Helianthus divaricatus, Helianthus giganteus, Helianthus mollis, Helianthus nuttallii subsp. nuttallii, Helianthus salicifolius, Helianthus californicus, Helianthus laetiflorus*) showed complete resistance to all tested populations. These results highlight the potential of perennial wild sunflowers as valuable genetic resources for breeding resistant cultivars and ensuring sustainable sunflower production.

Keywords: sunflower, *Orobanche cumana*, wild species, germplasm screening

Broomrape (*Orobanche cumana* Wallr) is a rots parasitic plant who infested sunflower ((*Helianthus annuus* L.) in many countries around the world and causes low seed yield. The most aggressive races of broomrape are localized in basin of Black Sea, in countries such as Romania, Moldova, Turkey, Bulgaria, Ukraine (Kiliç Y., Goksoy A.T., 2024; Duca M., Bivol I., 2022; Nenova N., 2023; Maklyak E. *et al*, 2018). In Romania was reported all races of broomrape, from A up to I (Anton F.G., 2023; Anton F.G. *et al*, 2023, Rîsnoveanu L. *et al*, 2016; Skoric D. *et al*, 2021). In Turkey are present races F, G, H and I of sunflower broomrape (Akar H., Kaya Y., 2021). In Ukraine, is present races G and H (Khablak S.H. *et al*, 2025).

In Russia where reported races E, F, G and H of sunflower broomrape (Antonova T. *et al*, 2020, 2022, 2023; Savichenko D. *et al*, 2023; Skoric D. *et al*, 2021). In Moldova where reported races G and H of broomrape (Clapco S., 2021, Clapco S. *et al*, 2020; Duca M. *et al*, 2020, 2022, 2024).

In Serbia is present race E of broomrape (Cvejić S. *et al*, 2020; Ivanović Z. *et a*l, 2021; Jocković J. *et al*, 2023). In Greece are present races of broomrape G and G+ (Kaundun S.S. *et al*, 2024).

In Spain, are present races of sunflower broomrape, F and G (Fernández-Aparicio M. *et al*, 2022; Fernández-Melero B. *et al*, 2024; Calderón-González Á., *et al*, 2024**)**. In China was reported races E, F, G and G+ (Duca M. *et al*, 2021; Shi B.X. *et al*, 2019; Shi B., Zhao J., 2020; Bao T.T. *et al*, 2023). In Morocco, in North Africa are present races E and G (Nabloussi A. *et al*, 2023).

Orobanche cumana Wallr was reported in Iran (Nosratti I. *et al*, 2020), Tunisia (Amri M. *et al*, 2012; Jebri M. *et al*, 2017; Khamassi K. *et al*, 2023), Portugal (González-Cantón E. *et al*, 2019), Bolivia (Barea G. *et al*, 2025), Kazakhstan (Antonova T., 2014), France (Jestin C. *et al*, 2014), Israel (Eizenberg H. *et al*, 2004), Hungary (Onișan E. *et al.*, 2023).

Wild *Helianthus* species represent a gene poll for sunflower breeding for parasite *Orobanche cumana* (Chabaud M. *et al,* 2022; Seiler G.J., Jan

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C.C., 2014; Jocković J. *et al*, 2023; Velasco L., Perez -Vich B., 2023).

MATERIAL AND METHOD

In year 2024, we collected broomrape seeds from seven locations from southern and southeastern Romania (Călărași 1–3, Tulcea 1–2, Constanța 1, Brăila 1) and in year 2025 we screening resistace/tolerance at *parasite Orobanche cumana*, of some wild species of genus *Helianthus* in artificial conditions, in Fundulea.

In buckets of 10 l with mixed soil:sand in percent of 3:1 and broomrape seeds from each location. In date of April 1 st, 2025, we sown more differential genotypes for determining broomrape races present in all seven locations and on date March 27 th, 2025, we sown annual species and perennial wild species (*table 1* and *2*).

Table 1

Sunflower differential genotypes for *Orobanche cumana* races

No.	Genotype	Gene *Or*	Race
1	KA41	*Or1*	A
2	J8281	*Or2*	B
3	Record	*Or3*	C
4	1002A	*Or4*	D
5	1003A	*Or5*	E
6	1093A	*Or6*	F
7	P96	*or6,or7*	F
8	1010B XA2DEB	*Or?*	G
9	0305CX P9MO	*Or Mol Or Mol*	H
10	Neagra De Cluj	*Or?*	G,H,I
11	Performer Sensitive Check	No Or	-
12	BR4	Or_6; Or_6,Or_7	F

Table 2

Sunflower annual and perennial wild species

Plant name	Wild species of genus *Helianthus*	Annual/ perennial	Chromosome number
CAL2383	*H. californicus*	Perennial	2n= 6x = 102 (hexaploid)
CAL2798	*H. californicus*	Perennial	2n= 6x = 102 (hexaploid)
APS/HD/ 2017/038/ 297	*H. divaricatus*	Perennial	(2n=2x=34) diploid
GIG2015	*H. gigantheus*	Perennial	(2n=2x=34) diploid
GIG- IRW	*H. gigantheus*	Perennial	(2n=2x=34) diploid
GRO2027	*H. grosseserratus*	Perennial	(2n=2x=34) diploid
MAX2049	*H. maximiliani*	Perennial	(2n=2x=34) diploid
MAX2284	*H. maximiliani*	Perennial	(2n=2x=34) diploid
MOL880	*H. mollis*	Perennial	(2n=2x=34) diploid
NUT2749	*H.nuttallii subsp.nuttallii*	Perennial	(2n=2x=34) diploid
NUT2286	*H. nuttallii subsp.rydbergii*	Perennial	(2n=2x=34) diploid
SAL2666	*H. salicifolius*	Perennial	(2n=2x=34) diploid
SMI2592	*H. smithii*	Perennial	(2n=2x=34) diploid
LAET2643	*Helianthus x laetiflorus*	Perennial	2n= 6x = 102 (hexaploid)
ANN 0340	*H. annuus*	Annual	(2n=2x=34) diploid
ANN 1526	*H. annuus*	Annual	(2n=2x=34) diploid
ARG 13	*H. argophyllus*	Annual	(2n=2x=34) diploid

In flowering time we note number of broomrape at sunflower differential genotypes and at sunflower wild species to establish resistance/tolerance at broomrape populations from all seven locations.

RESULTS AND DISCUSSIONS

In stage of flowering of differential sunflower genotypes, between June 10 - June 15 2025, we take of sunflower roots from soil and we noticed with Sensible if are underground tubercles and multiple shoots of broomrape and with Resistant if is not present.

Race A of broomrape is present in Romania, in year 2024 in locations Călărași 1 and 3, Tulcea 1 and 2, Constanța 1, Brăila 1 because genotype KA 41 was sensible, except location Calarasi 3 because genotype KA 41 (gene Or_1) was resistant (*table 3*).

Race B of broomrape is present in Romania, in year 2024 only in location Tulcea 1, because genotype J8281 (gene Or_2) was sensible.

Races C, D, E, F and G of broomrape is present in Romania, in year 2024 in all seven locations Călărași 1 -3, Tulcea 1 - 2, Constanța 1, Brăila 1, because genotypes Record (gene Or_3), 1002A (gene Or_4), 1003A (gene Or_5), 1093 A (gene Or_6), BR4 (genes Or_6; Or_6, Or_7) was sensible

Differential genotype P96 (*or6, or7)* resistant at race F from Spain according to Cvejić S. *et al* (2020), was resistant at Calarasi 1 broomrape population, but differential genotypes 1093 A and BR4 who is differential genotypes for race F of broomrape was sensible. That means is difference between race F from Romania and race F from Spain.

Differential genotype 1010BxA2De (gene *Or* ??) resistant at race G of broomrape, result from interspecific hybridization with annual wild specie

Helianthus debilis, in F10 generation*,* was sensible in all seven location.

Differential genotype 0305CxP9Mo (genes Or *Mol* Or *Mol*) resistant at race H of broomrape, result from interspecific hybridization with perennial wild specie *Helianthus mollis,* in F10 generation, was sensible in Calarasi 1 and 2, Tulcea 1 and 2, Constanta 1. Race H of broomrape was not present only in Calarasi 3 and Braila 1 in year 2024.

Old Romanian variety Neagra de Cluj (gene *Or*??), was resistant at broomrape populations from Calarasi 1 and 3, Tulcea 1 and Braila 1 in year 2024. Races of broomrape G, H and I are present in year 2024, in locations Calarasi 2, Tulcea 2 and Constanta 1.

Conventional sunflower hybrid Performer with no *Or* gene (sensitive check) was infested 100% in all seven locations.

Table 3

Behavior of differential genotypes of parasite *Orobanche cumana* in year 2024, in Romania, in seven locations

Genotype	Broomrape population						
	Calarasi 1	**Calarasi 2**	**Calarasi 3**	**Tulcea 1**	**Tulcea 2**	**Constanta 1**	**Braila 1**
KA41	Sensible	Sensible	**Resistant**	Sensible	Sensible	Sensible	Sensible
J8281	**Resistant**	**Resistant**	**Resistant**	Sensible	**Resistant**	**Resistant**	**Resistant**
Record	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
1002A	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
1003A	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
1093A	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
P96	**Resistant**	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
1010B XA2DEB	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
0305CX P9MO	Sensible	Sensible	**Resistant**	Sensible	Sensible	Sensible	**Resistant**
Neagra De Cluj	**Resistant**	Sensible	**Resistant**	**Resistant**	Sensible	Sensible	**Resistant**
Performer Sensitive Check	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
BR4	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible

In period June 13 – October 10, 2025, in flowering time, we observed shoot emergence on sunflower wild species and we noticed *sensible* if are underground tubercles and multiple shoots of broomrape and with *resistant* if is not present (*table 4* and *figure 1*).

Annual species *Helianthus annuus* (ANN 0340), *Helianthus annuus* (ANN 1526) and *Helianthus argophyllus* (A13) was sensible at all seven broomrape population from Romania in year 2024.

Table 4

Screening for resistance of wild species from genus *Helianthus* at parasite *Orobanche Cumana,* in year 2024, in Romania, in seven locations

Plant name	Wild species of genus *Helianthus*	Broomrape population						
		Calarasi 1	**Calarasi 2**	**Calarasi 3**	**Tulcea 1**	**Tulcea 2**	**Constanta 1**	**Braila 1**
CAL2383	***H. californicus***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
CAL2798	***H. californicus***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
APS/HD/ 2017/038/ 297	***H. divaricatus***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
GIG2015	***H. gigantheus***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
GIG- IRW	***H. gigantheus***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
GRO2027	*H. grosseserratus*	**Resistant**	**Resistant**	**Resistant**	**Resistant**	Sensible	**Resistant**	**Resistant**
MAX2049	***H. maximiliani***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
MAX2284	*H. maximiliani*	**Resistant**	**Resistant**	**Resistant**	**Resistant**	Sensible	**Resistant**	**Resistant**
MOL880	***H. mollis***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
NUT2749	***H.nuttallii subsp.nuttallii***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
NUT2286	*H. nuttallii subsp.rydbergii*	**Resistant**	**Resistant**	**Resistant**	**Resistant**	Sensible	**Resistant**	**Resistant**
SAL2666	***H. salicifolius***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**

LAET2643	***Helianthus x laetiflorus***	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**	**Resistant**
ANN 0340	*H. annuus*	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
ANN 1526	*H. annuus*	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible
ARG 13	*H. argophyllus*	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible	Sensible

Figure **1 Screening of wild species of genus *Helianthus* in artificial conditions for resistance at sunflower broomrape**

In location Tulcea 2, in Romania, in year 2024, there is the most virulent race of *Orobanche cumana* because perennial wild species *Helianthus grosseserratus* (GRO2027), *Helianthus maximiliani* (MAX2284), *Helianthus nuttallii subsp.rydbergii* (accesion NUT2286) and annual species *Helianthus annuu*s (ANN 0340), *Helianthus annuus* (ANN 1526), *Helianthus argophyllus* (A13) was sensible at broomrape population from this location.

Annual wild species *Helianthus anomalus* provide resistance at race G of broomrape by gene Or_{Anom1} (Fernández-Melero B. *et al*, 2024), *Helianthus debilis ssp. tardiflorus* by gene Or_{Deb2} (Velasco L. *et al*., 2012), *Helianthus praecox* by gene Or_{pra1} (Sayago A. *et al*, 2018).

Jocković J. *et al* (2023) find different degree of resistance at parasite *Orobanche cumana* in sunflower perennial wild species such as in *Helianthus grosseserratus, Helianthus tuberosus, Helianthus divaricatus, Helianthus mollis, Helianthus maximiliani, Helianthus niveus, Helianthus nuttalii* and in sunflower annual wild species *Helianthus petiolaris, Helianthus debilis, Helianthus deserticola, Helianthus neglectus, Helianthus argophyllus., Helianthus bolanderi, Helianthus praecox.*

CONCLUSIONS

In Romania, in year 2024, race A of broomrape is still present in six locations from seven, such as Calarasi 1 and 2, Tulcea 1 and 2, Constanta 1, Braila 1, excepting Calarasi 3. Race B of broomrape is still present only in location Tulcea 1 and races from C, up to G is present in all seven locations. Race H of broomrape is present in five locations such as Calarasi 1 and 2, Tulcea 1 and 2, Constanta 1, excepting Calarasi 3 and Braila 1. Race I of parasite *Orobanche cumana* is present in locations Calarasi 2, Tulcea 2 and Constanta 1 excepting locations Calarasi 1 and 3, Tulcea 1 and Braila 1.

Wild perennial species *Helianthus californicus* (CAL2383 accession Pl 664635, CAL2798 accession Pl 673295), *Helianthus divaricatus* (APS/HD/2017/038/297 accession Ames 34086)*, Helianthus gigantheus* (GIG2015 accession Pl 547177, GIG-IRW accession Pl 673312), *Helianthus maximiliani* (MAX2049 accession Pl 547206)*, Helianthus* mollis (MOL880 accession), *Helianthus nuttallii subsp.nuttallii* (NUT2749 accession Pl 673236), *Helianthus salicifolius* (SAL2666 accession Pl 664773) and *Helianthus x laetiflorus* (LAET2643 accession Pl 664747) from gene bank from Ames, Iowa, USA, Regional Plant Introduction Station, Iowa State University, North Central Regional Plant Station, represented a valuable source for resistance to most aggressive races of sunflower broomrape(*Orbanche cumana*) from Romania.

REFERENCES

Akar H., Kaya Y., 2021 - *The genetic characterization of wild sunflower species (Helianthus spp.) and interspecific hybrids based on broomrape resistance*. Proceedings of International Conference On Agricultural, Biological And Life Science, Edirne, Turkey, 1010-1025.

Amri M., Abbes Z., Ben Youssef, S., Bouhadida M., Ben Salah H., Kharrat M., 2012 - *Detection of the parasitic plant, Orobanche cumana on sunflower (Helianthus annuus L.) in Tunisia*. Afr. J. Biotechnol. 11:4163–4167,

Anton F.G., 2023 - *Races of broomrape present in south-eastern Romania*. Proceedings of 5th International Symposium on Broomrape in Sunflower 1-3 November 2023, Antalya, Turkey, 37.

Anton F.G., Contescu L., Risnoveanu L., Joita-Pacureanu M., Oprea D., Serban M., 2023 - *Sunflower genotypes in field infested with broomrape in Braila location, in year 2022.* Scientific Papers. Series A. Agronomy, Vol. LXVI, 1: 206-211.

Antonova T., 2014 - *The history of interconnected evolution of Orobanche cumana Wallr. and sunflower in the Russian Federation and Kazakhstan.* Proceedings of 3rd International Symposium on Broomrape (Orobanche spp.) in Sunflower. Córdoba, Spain, 3-6 June, 2014. Int. Sunflower Assoc., Paris, France, pp. 57–64.

Antonova T.S., Araslanova N.M., Pitinova J.V., 2020 - *Racial belonging of broomrape (Orobanche cumana Wallr.) seeds, collected on the fields of* *different regions of the Russian Federation in 2019.* Agrarian Sci. 339: 62–65,

Antonova T.S., Araslanova N.M., Iwebor M.V, Saukova S.V., 2022 - *To the morphophysiological co-evolution of the broomrape (Orobanche cumana) and sunflower.* Cyberleninka, 4(192), 12–19.

Antonova T., Araslanova N., Iwebo M., Saukova S., 2023 - *Evolution of Orobanche cumana Wallr. in intensive sunflower cultivation in regions of Russian Federation.* Proceedings of 5th International Symposium on Broomrape in Sunflower 1-3 November 2023, Antalya, Turkey, 49-58.

Bao T.T., Shı S. H., Yan N., Lıu Z.D., Yang J.L., Zhang W.B., Zhang J., Zhang Z.W., Zhao J., 2023 - *A preliminary study on the identification of different sunflower varieties with the level of resistance to race G minor species an* . Proceedings of 5th International Symposium on Broomrape in Sunflower 1-3 November 2023, Antalya, Turkey, 39.

Barea G., García-Carneros A.B., Baltazar L., Darwin C., Coimbra-Melgar M., Zankiz-Salvatierra, Zomeno P., Molinero-Ruiz L., 2025 - *First report of Orobanche cumana Wallr. (sunflower broomrape) in South America*.

Calderón-González Á., Fernández-Melero B., Del Moral L., Muños S., Velasco L., Pérez-Vich B., 2024 - *Mapping an avirulence gene in the sunflower parasitic weed Orobanche cumana and characterization of host selection based on virulence alleles.* BMC Plant Biol. 2024 Nov 29;24(1):1147.

Chabaud M., Auriac M.C., Boniface M.C., Delgrange S., Folletti T., Jardinaud M.F., Legendre A., Pérez-Vich B., Pouvreau J.B., Velasco L., Delavault P., Muños S., 2022 - *Wild Helianthus species: A reservoir of resistance genes for sustainable pyramidal resistance to Broomrape in sunflower.* Front Plant Sci. 2022; 13:1038684.

Clapco S., 2021 - *Virulence and aggressiveness of some sunflower broomrape populations belonging to different countries.* Scientific Papers. Series A. Agronomy, LXIV (1), 266–272.

Clapco S, Martea R, Duca M 2020 - *Relaţia dintre distanţa genetică şi distanţa geografică la unele populaţii de Orobanche cumana Wallr. din Republica Moldova. Relationship between genetic distance and geographical distance in some populations of Orobanche cumana Wallr. from Republic of Moldova*. Ştiinţa Agricolă 1:73-80.

Cvejić S., Radanović A., Dedić B., Jocković M., Jocić S., Miladinović D., 2020 - *Genetic and genomic tools in sunflower breeding for broomrape resistance.* Genes 11: 152: 17.

Duca M., Bivol I., 2022 - *The study of ISSR-markers polymorphism in broomrape populations from Bulgaria*. In: VIth International Symposium Advanced Biotechnologies – Achievements and Prospects, October 3-4, 2022, Chisinau, Republic of Moldova, 26-28.

Duca M., Clapco S., Joita-Pacureanu M., 2022 - *Racial status of Orobanche cumana Wallr. in some countries other the world.* Helia 45, 1–22.

Duca M., Bivol I., Mutu A., Port A., Clapco S., 2024 - *Analysis of genetic relationships between broomrape populations from different countries using ISSR markers.* Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 52(1):13590.

Duca M., Bivol I., Mutu A., Clapco S., Wang C., 2021 - Variabilitatea unor populatii de lupoaie originare din China. Genotiparea și determinarea polimofismului genetic (II). Academos 61: 61–69.

Duca M., Joiţa-Păcureanu M., Port A., Martea R., Boicu A., Rîşnoveanu L., Clapco S., 2020 - *Genetic diversity analysis of sunflower broomrape populations from Republic of Moldova using ISSR markers.* Romanian Agricultural Research 37:89-97.

Eizenberg H., Plakhine D., Landa T., Achdari G., Joel D., Hershenhorn J., 2004 - *First Report of a New Race of Sunflower Broomrape (Orobanche cumana) in Israel.* Plant Disease - PLANT DIS. 88: 1284-1284.

Fernández-Aparicio M., Del Moral L., Muños S., Velasco L., Pérez-Vich B., 2022 - *Genetic and physiological characterization of sunflower resistance provided by the wild-derived Or (Deb2) gene against highly virulent races of Orobanche Cumana Wallr.* Theor Appl Genet, 135:501–25.

Fernández-Melero B., del Moral L., Todesco M., Rieseberg L.H., Owens G.L., Carrère S., Chabaud M., Muños S., Velasco L., Pérez-Vich B., 2024 - *Development and characterization of a new sunflower source of resistance to race G of Orobanche Cumana Wallr. Derived from Helianthus anomalus.* Theor Appl Genet. 2024;137:56.

González-Cantón E., Velasco A., Velasco L., PérezVich B., Martín-Sanz A., 2019 - *First Report of Sunflower Broomrape (Orobanche cumana) in Portugal.* Plant Disease, 103(8).

Ivanović Ž., Marisavljević D., Marinković R., Mitrović P., Blagojević J., Nikolić I., Pavlović D., 2021 - *Genetic diversity of Orobanche cumana populations in Serbia*. Plant Pathol. J. 37:512–520.

Jestin C., Lecomte V., Duroueix F., 2014 - *Current situation of sunflower broomrape in France.* Proc. 3rd Int. Symp. on Broomrape (Orobanche spp.) in Sunflower, Córdoba, Spain. Int. Sunflower Assoc., Paris, France, 28–31.

Jebri M., Ben Khalifa, M., Fakhfakh H., Pérez-Vich B., Velasco L., 2017 - *Genetic diversity and race composition of sunflower broomrape populations from Tunisia.* Phytopathol. Mediterr. 56: 421–430,

Jocković J., Cvejić S., Radanović A., Jocković M., Jocić S. , Miladinović D. , Zorić L. , Luković J., 2023 - *Wild Helianthus species as a valuable breeding source for broomrape resistance of cultivated sunflower (Helianthus annuus L.)*. Proceedings of 5th International Symposium on Broomrape in Sunflower 1-3 November 2023, Antalya, Turkey, 33.

Khamassi K., Abbes Z., Tani E., Katsileros, A.; Guenni, K., Rouissi M., Khoufi S., Chaabane R., Chachalis D., Kharrat M., 2023 - Genetic structure and diversity analysis of Tunisian Orobanche spp. and Phelipanche spp. using molecular markers. Appl. Sci., 13: 11622.

Kaundun S.S., Martin-Sanz A., Rodríguez M., Serbanoiu T., Moreno J., Mcindoe E., le Goupil G., 2024 - *First case of evolved herbicide resistance in the holoparasite sunflower broomrape, Orobanche cumana Wallr.* Frontiers in Plant Science 15.

Khablak S.H., Bondareva L.M., Dolia M.M., Blume Y. B., Tymoshchuk T.M., Mrynskyi I.M., Hrytsiuk N.V., Spychak V.M., 2025. *Resistance of new sunflower hybrids to sunflower broomrape (Orobanche cumana) and the possibility of their use in the strategy of protection against the parasite*. Regulatory Mechanisms in Biosystems, 16(2), e25063. https://doi.org/10.15421/0225063

Kiliç Y., Goksoy A.T., 2024 - *Effect of an aggressive new race broomrape (Orobanche cumana L.) on agronomical and technological traits of the sunflower in mediterranean environments.* Avaible online at: *https://www.researchgate.net/publication/385428534_Effect_of_an_Aggressive_New_Race_Broomrape_Orobanche_Cumana_L_on_Agronomical_and_Technological_Traits_of_the_Sunflower_in_Mediterranean_Environments*

Khamassi, K.; Abbes, Z.; Tani, E.; Katsileros, A.; Guenni, K.; Rouissi, M.; Khoufi, S.; Chaabane, R.; Chachalis, D.; Kharrat, M., 2023 - *Genetic structure and diversity analysis of Tunisian Orobanche spp. and Phelipanche spp. using molecular markers.* Appl. Sci., 13:11622.

Maklyak E, Kyrychenko V.V., Pacureanu-Joita M., 2018 - *Race composition and phenology of sunflower broomrape (Orobanche cumana Wallr.) in Ukraine.* Proceedings of the 4th international symposium on broomrape (Orobanche spp.) in sunflower. Bucharest, Romania, 67–78.

Nabloussi A., Pérez-Vich B., Velasco L., 2023 - *Virulence, genetic diversity, and putative geographical origin of sunflower broomrape populations in Morocco.* Phytopathol. Mediterr., vol. 62, no. 1, pp. 65–72.

Nenova N., 2023 - *Krasela- the first bulgarian sunflower hybrid, resistant to broomrape (rac deveda e h) and stable yield potential under limited moisture conditions*. Proceedings of 5th International Symposium on broomrape in sunflower, 1-3 November 2023, Antalya, Turkey, 10-16.

Nosratti I., Mobli A., Mohammadi G., Yousefi A.R., Sabeti P., Chauhan B.S., 2020 - *The problem of Orobanche spp. and Phelipanche spp. and their management in Iran. Weed Science*, 68(6):555-564. doi:10.1017/wsc.2020.61

Onișan E., Sărac I., Petrescu I., Botău D., 2023 - *Assessment of the aggressiveness of the Orobanche cumana breeds from Hungary in the Szeged region.* JOURNAL of Horticulture, Forestry and Biotechnology Volume 27(2): 18-22, https://journal-hfb.usab-tm.ro

Rîşnoveanu L., Joiţa-Păcureanu M., Anton F.G. 2016 - *The virulence of broomrape (Orobanche cumana Wallr.) in sunflower crop in Braila Area, in Romania.* Helia, 39(65), 189–196.

Sayago A., Perez-Vich B., Fernandez-Martinez J.M., Velasco L., 2018 - *A new source of posthaustorial resistance to sunflower broomrape derived from Helianthus praecox*. Proceedings of the 4th International Symposium on Broomrape in Sunflower; Bucharest, Romania. 2–4 July 2018, 147.

Savichenko D., Guchetl S., Demurin Y., Chebanova Y., Rubanova O., 2023 - *DNA marker for marker-assisted selection for sunflower resistance to race G of broomrape.* Proceedings of 5th International Symposium on Broomrape in Sunflower 1-3 November 2023, Antalya, Turkey, 27.

Seiler G.J., Jan C.C., 2014 -. *Wild Sunflower Species as a Genetic Resource for Resistance to Sunflower Broomrape (Orobanche cumana Wallr.). Helia*, 37, 61:129-139.

Shi, B., Zhao J., 2020 - *Recent progress on sunflower broomrape research in China*. OCL, 27(30):1-9.

Shi B.X., Zhang J., Gu Y.G., Lai C.X., Lei Z.H., Sha H., Zhao J., 2019 - *Application of ISSR markers to reveal the genetic diversity of sunflower broomrape in China.* Chinese Journal of Oil Crop Sciences 41(4):629-637.

Skoric D., Joita-Pacureanu M., Gorbachenko F., Gorbachenko O., Masirević S., 2021 - *Dynamics of change in broomrape populations (Orobanche cumana Wallr.) in Romania and Russia (Black Sea area*). Helia 44, 1–14. doi: 10.1515/helia-2020-0025.

Velasco L., Pérez-Vich B., 2023- *Broomrape resistance from wild species*. Proceedings of 5th International Symposium on Broomrape in Sunflower 1-3 November 2023, Antalya, Turkey, 63.

Velasco L., PérezVich B., Yassein A.M.,Jan C.C.,Fernández-Martínez J.M., 2012 - *Inheritance of resistance to broomrape (Orobanche cumana Wallr.) in an interspecific cross between Helianthus annuus and Helianthus debilis ssp. tardiflorus.* Plant Breeding131: 220–221.

THE WEEDS CONTROL IN WHEAT CROP UNDER THE PEDOCLIMATIC CONDITIONS FROM NARDI FUNDULEA

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Abstract

Wheat is an important crop affected by many weeds which, fortunately, can be effectively controlled by specific applications of herbicides.This paper present the results obtained at National Agricultural Research and Development Institute Fundulea, during 2023-2024, according to the herbicide treatments: Floramix (70.8 g/kg piroxsulam + 14.2 g/kg florasulam + 70.8 g/kg cloquintocet-mexil - safener) + Dasoil 26-2 N (Adjuvant); Pallas (7.5% piroxsulam + 75% cloquintocet-mexil safener) + Adjuvant; Omnera + Foxtrot 69 EW (135 g/l fluroxypyr + 30 g/l thifensulfuron metil + 5 g/l metsulfuron metil 69 g/l fenoxaprop-P-etil + 34.5 g/l cloquintocet mexil - safener), postemergently (BBCH -31) applied for the weeds controlling .

The herbicides must be correlated with the infestation degree of weed, the spectrum and dominance of weeds, the time of application, the technical potential for efficacy, the local climatic conditions.

Keywords: weeds, herbicides, time of application, dose, selectivity and efficacy.

Wheat cultivation is one of the oldest and most important agricultural practices, playing a crucial role in feeding the world and developing society. Wheat is the second largest crop in the world after corn, among the types of large crops, being the most important plant cultivated in over 100 countries. Wheat and its derivatives are part of the current diet, establishing themselves as a staple food, present in daily meals in various forms.

The crop's weed flora is very diverse and numerous, both in terms of the numerical ratio of weed species present, and especially in terms of the numerous combinations between the various biological groups. This variety is explained by the diversity of pedoclimatic conditions existing in the areas where this crop is cultivated (Anghel *et al.,* 1972).

The presence of weeds in field crops is a reality in all areas where they are grown. The damage caused by weeds can be diverse and often leads to reduced yields, increased production costs, deterioration of product quality, ideal hosts for pathogens and pests, etc. (Mortensen *et al.,* 2000; Roman and Lăzureanu, 2012).

In the field of weed control in field crops, the main objective is to permanently eliminate weed competition below the damage threshold throughout the growing season, in order to reduce water and nutrient consumption by them, so that plants continue to grow. culture to have a normal development, which will lead, in the end, to obtaining high yields, qualitative and at the level of the biological potential of cultivated varieties (Popescu A., 2007).

Weeds have the greatest negative impact, around 37%, compared to insects (18%), fungi and bacteria (16%) and viruses (2%) (Oerke, 2006).

The magnitude of the loss is related to the composition of the weed flora, weed emergence timing in relationship to the crop, weed density, intensity, and crop development stage in relation to the period of competition (Singh *et al.,* 2016).

The aim of the research was to identify technological solutions to control the weeds present in the crop by using the herbicide treatments, aiming to broaden the control spectrum, synergism, persistence and without negative impact on the environment.

The main objective of this paper focused on the study of selectivity and effectiveness of the application of herbicide treatments in the control of weeds in the wheat crop.

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Table 1

The herbicide treatments applied in the wheat crop. Experimental variants

No var	Herbicides treatments	Active ingredient	Dose g,l /ha	Time of application
1	Untreated	-	-	-
2	Floramix + Dasoil 26-2 N (Adj)	70.8 g/kg piroxsulam + 14.2 g/kg florasulam + 70.8 g/kg cloquintocet-mexil (safener)	260 g/ha + 0,6 l/ha	
3	Pallas 75WG + Adj.	7.5% piroxsulam + 7.5% cloquintocet-mexil safener	250g+ 0.5 l/ha	Postem BBCH 31
4	Omnera + Foxtrot 69 EW	135 g/l fluroxypyr + 30 g/l thifensulfuron metil + 5 g/l metsulfuron metil 69 g/l fenoxaprop-P-etil + 34.5 g/l cloquintocet mexil (safener)	1.0 l/ha + 1.0 l/ha	

Table 2

Monthly average temperature (°C)

Temperature (°C)	Mar	Apr	May	Jun	Jul	Aug	Sep	OCT
2023	8.2	10.8	16.9	22.3	26.1	26.1	21.7	16.1
2024	8.5	15.0	16.4	26.1	27.7	26.3	20.0	12.7

Table 3

Monthly sum of precipitation (mm)

Precipitation (mm)	Mar	Apr	May	Jun	Jul	Aug	Sep	OCT
2023	10.0	77.2	32.4	40.2	43.8	6.6	4.2	29.0
2024	38.6	62.4	34.2	15.6	45.4	18.0	62.0	7.8

MATERIAL AND METHOD

The research was carried out in the period 2023-2024, at the National Institute for Agricultural Research and Development - Fundulea, being studied the application of new herbicide treatments at the wheat crop. The research was carried out in the experimental field, the experiment being located on a soil of cambic chernozem type (3.2% organic matter, 37% clay, 6.5 pH), using the Pitar wheat variety created by the institute from Fundulea.

The organization of the experiment was done according to the method of randomized blocks, with a plot area of 25 m^2, in 4 replications, the amount of water used was 300 l/hectare. In this experiment, we observed the degree of selectivity of plants and the degree of control of weeds by applying herbicide treatments *(table 1*): Floramix + Dasoil 26-2 N (Adj); Pallas 75WG + Adj.and Omnera +Foxtrot 69 EW. The herbicide treatments were applied in the post-emergence (BBCH-31). After the application of herbicide treatments, observations of selectivity (%) of plants were made at different intervals (7 - 14 - 21 days after the application of treatments) and the degree of control (%) of weeds at different intervals 14 - 21 days from the application of treatments).

During the years 2023 and 2024, the climatic conditions (*table.2, table.3*) recorded at Fundulea were differentiated. The amount of precipitation recorded in 2023 was 423.4 mm and in 2024 it was 437.0 mm. The difference between the two years in terms of precipitation was only 13.6 mm.

RESULTS AND DISCUSSIONS

The experience of wheat realized in the experimental field showed an infestation degree of 75%, in the culture being present the weeds extremely diversified, depending on: the pre-emergent plant, the local pedo-climatic conditions.

The most representative weed species were: *Anthemis arvensis-ANTAR, Matricaria inodora - MATIN, Galium aparine-GALAP, Papaver rhoeas-PAPRH, Veronica hederifolia-VERHE and Avena fatua -AVEFA.*

Figure 1 **The infestation degree (%) with weeds from the untreated plots.**

Anthemis arvensis, also known as field chamomile, is an annual plant in the Asteraceae family, known for its erect and branched stem, reaching up to 50 cm, and for flowers with white petals at the base and a yellow center, which appear in summer. This species reproduces by seeds, germinates from autumn to spring and can be found in crops and pastures, but also for phytotherapeutic purposes.

Matricaria inodora is a annual plant, frequently found in agricultural crops, where it makes the harvest difficult. It is considered a difficult weed because it can grow very strongly, having a taproot, while the stem can reach 50-100 cm in height. The inflorescence has white ligules, with yellow flowers and a full calatidium inside. A single Matricaria plant can produce up to 5.000 seeds. Germination period: autumn - spring, superficial germination, especially on wet and marshy soils. Flowering period: May - August.

Studies on the competition between M. inodora and various autumn grasses have been carried out more recently (Schlichting, 1986; Ionescu & Ionescu, 2013). Such research falls within one of the new fields of theoretical and applied herbology, namely weed ecology, with the help of which some answers could be found in substantiating the application of the complex of control measures - Integrated Control Management (ICM) of the respective species (Labrada, 1995; Sokal & Rolf, 1981)

A field infested with M. inodora turns golden-white (from the flowers) when the plants have sprouted. From this point until maturity, the infestation is very obvious, as the weed surpasses the crop plants in height.

Galium aparine is considered one of the most harmful weeds. Galium is an annual seed-bearing plant, with a stem covered with clinging hairs, which can reach a height of 2 meters. Gallic acid is rough to the touch and sticky. It prefers fertile soils, rich in humus, but can also be found on moist clay soils. Gallic acid seeds can germinate for over 8 years, and a single plant can produce between 100 and 500 seeds. Germination period: autumn - spring.

Papaver rhoeas is a annual weed with a taproot. A single poppy plant can produce an impressive amount of seeds (10.000-20.000) that retain their germination for up to 20 years. The poppy can reach a height of one meter. It is perhaps the most easily recognizable weed, with solitary, long-pedunculated flowers, usually red, with white, pink or purple variations. The fruits are globose capsules. The poppy belongs to the group of weeds that can overwinter. Germination period: autumn or very early spring. Flowering periods: spring - summer.

Veronica hederifolia- a weed that can survive over winter, rarely annual, light-loving. It prefers light (skeletal) soils, rich in nutrients, sandy-loamy to loamy, rich in calcium.

Avena fatua - Paniculate grass very similar to cultivated oats. It prefers heavy, calcium-rich, cool to moist, clay and loamy soils. Germination period Spring. Germination depth up to 20 cm.

In the experimental field, all the selectivity observations made for the cultivated variety-Pitar, not recorded phytotoxic phenomena (EWRS scale = 0).

In the wheat crop, the herbicide treatments applied post-emergence (BBCH 31) had a good control effect, highlighting their effectiveness through a single application. By applying the treatments with herbicides, good results were obtained regarding the effect of combating weeds, depending on: the climatic conditions, the degree of infestation, the spectrum and the dominance of the species present in this crop.

Figure 2 shows the average effectiveness results recorded after the post-emergence application of the treatment with Floramix +Dasoil 26-2 N (Adj). In the version treated with Floramix + Dasoil 26-2 N (70.8 g/kg piroxsulam + 14.2 g/kg florasulam + 70.8 g/kg cloquintocet-mexil - safener), it is a new systemic herbicide, with post-emergence application (BBCH 31).

The efficacy results obtained after the application of the treatment show a good control effect (94–100%) for the annual dicotyledons: *Anthemis arvensis, Matricaria inodora, Galium aparine, Papaver sp.,* and *Veronica hederifolia*. The species *Avena fatua* showed a control effect of 94%.

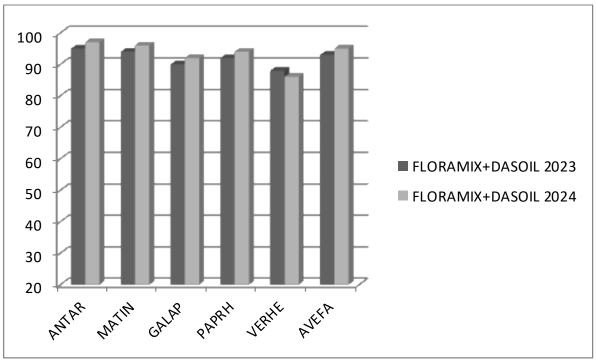

Figure 2 **The efficacy (%) of the Floramix +Dasoil 26-2 N on weeds control from the wheat crop (Fundulea, 2023-2024)**

The next variant treated was with the Pallas 75WG + Adj, is a systemic herbicide, with post-emergence application, intended for the control of grass and broadleaf weeds in wheat crops. Experiments carried out in several countries have not shown any damage to subsequent crops, on different soil types.

Control is influenced by the stage of weed development, with young stages of development being more easily controlled.

The efficacy results (Figure 3) obtained after the application of the treatment show a good control effect (92-97%) for the weeds: *Anthemis arvensis, Matricaria inodora Avena fatua and Veronica hederifolia* -81 %.

The species *Gallium aparine* had a efficacy of 73% and the weed *Papaver sp.,* showed a moderate control – 55%.

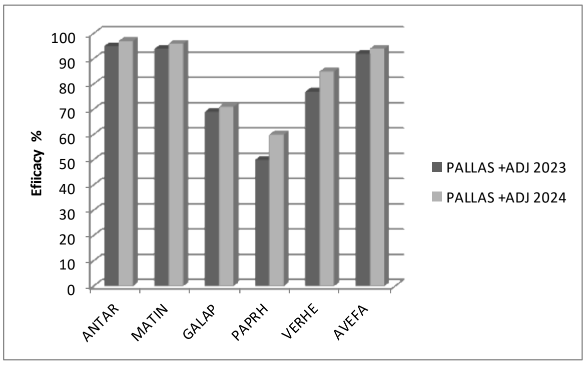

Figure 3 **The efficacy (%) of the herbicides Pallas 75WG + Ad on weeds control from the wheat crop (Fundulea, 2023-2024)**

Figure 4 shows the average efficacy results (%) recorded after post-emergence application (BBCH 31) of the herbicide combination Omnera (1.0 l/ha) + Foxtrot 69 EW (1.0 l/ha).

Omnera herbicide is composed of 3 active substances (fluroxypyr 135 g/l + thifensulfuron methyl 30 g/l + metsulfuron methyl 5 g/l), very effective when applied to small weeds in the active growth phase (2 - 6 leaves). The degree and duration of control may depend on the weed spectrum and degree of infestation, the size of the weeds at the time of application, the technology applied and the environmental conditions during and after treatment.

Foxtrot 69 EW (fenoxaprop-P-ethyl 69 g/l + cloquintocet mexil 34.5 g/l (safener) is a systemic herbicide for controlling annual monocotyledonous weeds, a graminicide dedicated to protecting cereals, selective for the crop due to the safener incorporated in the formulation.

The results obtained show a good control effect (96-100%) for the annual dicotyledons: *Anthemis arvensis, Matricaria inodora, Galium aparine, Papaver sp*., and *Veronica hederifolia.*

The monocotyledonous species *Avena fatua*, after treatment, recorded a very good efficacy - 96%.

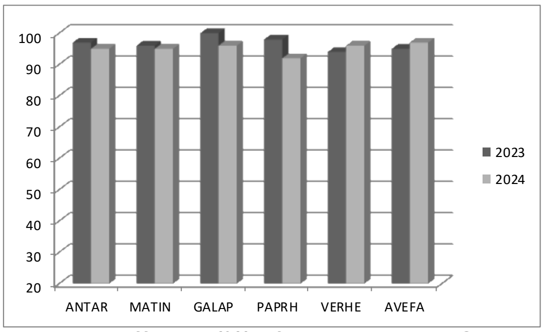

Figure 4 **The efficacy (%) of the herbicides Omnera + Foxtrot 69 EW on weeds control from the wheat crop (Fundulea, 2023-2024)**

In the wheat experiment, the average yield obtained in the control plot was 3.25 t/ha. Following the treatments with herbicides applied to wheat crops, the production was different from treatment to treatment.

The herbicide treatments: Floramix (70.8 g/kg piroxsulam + 14.2 g/kg florasulam + 70.8 g/kg cloquintocet-mexil - safener) + Dasoil 26-2 N (Adjuvant); Pallas (7.5% piroxsulam + 7.5% cloquintocet-mexil safener) + Adjuvant; Omnera + Foxtrot 69 EW (135 g/l fluroxypyr + 30 g/l thifensulfuron metil + 5 g/l metsulfuron metil 69 g/l fenoxaprop-P-etil + 34.5 g/l cloquintocet mexil - safener), postemergently (BBCH -31) applied to the crop, the average production obtained in 2023 recorded the target value: 4.3 - 5.3t/ha. In 2024, the average production obtained was between 5-5.6 t/ha in the treated variants.

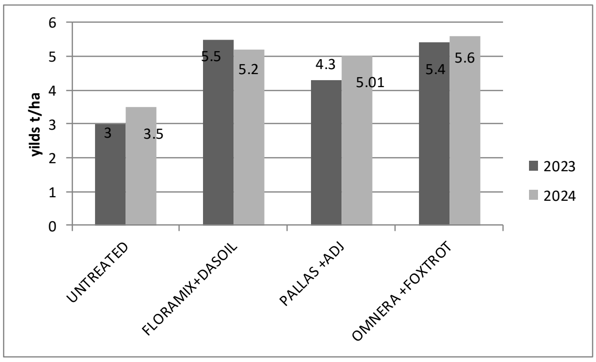

Figure 5 **The wheat yields (t/ha) under the 3 experimental treatments (Fundulea, 2023-2024)**

The chemical control of the weed species existing in the wheat crop, on the type of cambic chernozem soil from Fundulea, represents an especially important and necessary technological measure.

CONCLUSIONS

The wheat crop showed a high degree of weeding and diversified with characteristic weeds:
- annual dicotyledons: *Anthemis arvense, Matricaria inodora, Galium aparine, Papaver sp., Veronica hederifolia,* and monocotyledon: *Avena fatua.*

In the variants treated with herbicides, no phytotoxic symptoms were recorded for the cultivated variety - PITAR.

The degree of control of herbicide treatments depends on the level of infestation, dominance, weed spectrum, applied dose and climatic conditions.

The yields obtained was in close correlation with: the biological potential of the wheat variety, the efficiency of each treatment and the recorded climatic conditions.

ACKNOWLEGMENTS

This paper was supported by the project ADER 2.1.4 ,,Cercetări privind perfecțtionarea managementului integrat de combaterea buruienilor la principalele culturii de cămp în contextul schimbărilor climatice și a restricțiilor Green Deal privind explotarea durabilă a resurselor de mediu''.

REFERENCES

Anghel, GH., Chirilă, GH., Ciocârlan, V.,Ulinici, A., 1972 – *Buruienile din culturile agricole și combaterea lor.* Editura Ceres.

Duarte, N. F., Silva, J. B., Souza, I. F. 2002 – *Compatição de plantas daninhas com a cultura do milho no municipio de Ijaci.***,** Mg. Ciência e Agrotecnologia, 26, 983-992.

Ionescu, N., Ionescu, S.G., 2013 – *Cercetări privind biodiversitatea florilor de tip ligulat ale speciei maize in North-West India.* Maydica, 61, 1-7.

Matricaria inodora. An. INCDA Fundulea, 81: 95-102.

Lambrada, R., 1995 – *The role of improved weed management in the context of IPM and sustainable agriculture.* 9th EWRS Symposium, Budapest, Hungary: 685-693.

Mortensen, D.A, Bastiaans, L., Sattin, M., 2000 – *The role of ecology in the development of weed mangement systems; an outlook. Weed Research, 40:49-62.*

Oerke, E. C., 2006 – *Crop losses to pests.* Journal of Agricultural Science, 144, 31-43. https://doi.org/10.1017.

Popescu, A., 2007 – *Rezultate experimentale privind combaterea chimică a buruienilor din culturile de câmp* - ANALE. I.N.C.D.A. FUNDULEA, VOL. LXXV, 2007, Volum Jubiliar (In Romanian).

Roman A.N., Lazureanu A., 2012- *Research regarding the impact of weed control on grain maize yield in 2011***,** Volume 16(4), 117- 121, 2012, JOURNAL of Horticulture, Forestry and Biotechnology.

Schlichting, G.D., 1986 – *The evolution of phenotipic plasticity in plants.* Annual Review of Ecology and Systematic, 17: 667- 693.

Singh K., Tarundeep K., Bhullar,M. S. and Brar,A. S., 2016 -*The critical period for weed control in spring maize in north-west India.,* Journal article, Italy, 2279-8013 0025-6153, 61, (1).

Sokal, R. R., & Rohlf, F. J. 1981- *Biometry: The princeples and practice of statistics in biological research.* Freeman.

ORGANIC AGRICULTURE IN ROMANIA: STATUS AND PERSPECTIVES

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Abstract

Romania’s organic agriculture expanded steadily between 2021 and 2024. According to MADR (2023), the Romanian Rural Network (2024), and international reports, organic farmland reached 644,520 ha in 2022, approx. 693,000 ha in 2023, and continued to grow modestly in 2024, approaching 710,000 ha (approx. 4.6% of Utilized Agricultural Area - UAA). Certified operators increased to nearly 14,000 in 2023. The production mix remains dominated by cereals, oilseeds, and pastures, while horticulture and medicinal plants hold smaller but high-value shares. The operator structure shows over 95% producers and less than 2% processors, highlighting a structural bottleneck. Romania remains a net exporter of raw organic materials with a domestic market below €100 million. At EU level, organic farmland reached 17.7 million ha in 2023, with global organic retail sales estimated at €136.4 billion. These trends illustrate Romania’s opportunities and gaps compared to European and global benchmarks.

Keywords: organic farming; Romania; MADR; operators; EU; Biofach 2025

Introduction. Organic farming in Romania began in the 1990s and accelerated after EU accession in 2007. Official MADR statistics show 644,520 ha in 2022, growing to approx. 693,000 ha in 2023, and projected near 710,000 ha in 2024. Despite this progress, Romania’s share of organic farmland (approx. 4.6% of UAA) remains below the EU average (approx. 9%). The domestic market is underdeveloped, with consumption below €3 per capita compared to more than €50 in Western Europe. This study synthesizes national and European sources (MADR, RRN-PAC, FiBL/IFOAM, Eurostat, ECA 2024, Biofach 2025) to evaluate Romania’s organic sector in the context of global and EU trends.

MATERIAL AND METHOD

The study draws on official Romanian sources (MADR, 2023; RRN-PAC, 2024), EU statistics (Eurostat, 2024), and international reports (FiBL/IFOAM 2024–2025, USDA/FAS 2024). Biofach 2025 insights were integrated into the discussion to connect Romania’s trajectory to broader global market trends. Data for 2023–2024 remain provisional and may be revised.

RESULTS AND DISCUSSIONS

Organic farmland (2000–2024)

The organic area expanded from less than 100,000 ha in 2000 to 644,520 ha in 2022, approx. 693,000 ha in 2023, and approx.710,000 ha in 2024. This steady increase reflects growing support measures and farmer interest.

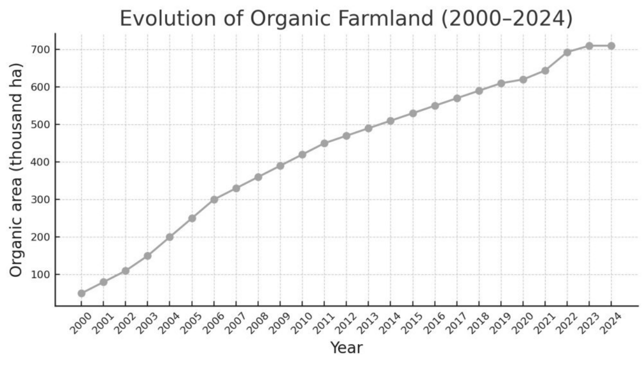

Figure 1 **Evolution of Organic Farmland (2000-2024)**

Certified operators (2000–2024)

The number of certified operators reached 14,000 in 2023 and 14,100 in 2024, showing a

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stabilisation trend after a decade of growth. more than 95% of these operators are primary producers.

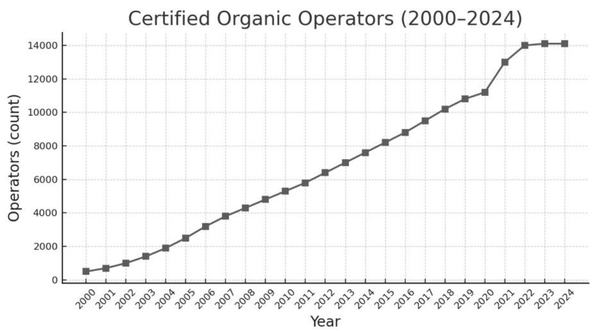

Figure 2 **Certified Organic Operators(2000-2024)**

Crop structure (2021)

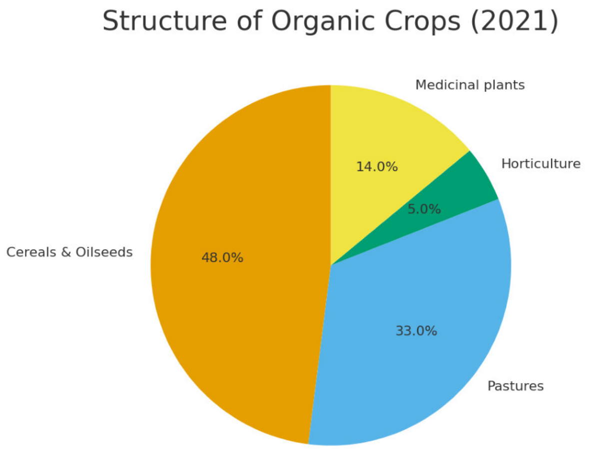

Figure 3 **Structure of Organic Crops**

Organic land use is dominated by cereals and pastures, which together represent over 80% of the certified area. horticulture and medicinal and aromatic plants (maps) are marginal but have high added value and export potential.

Operator typology (2021)

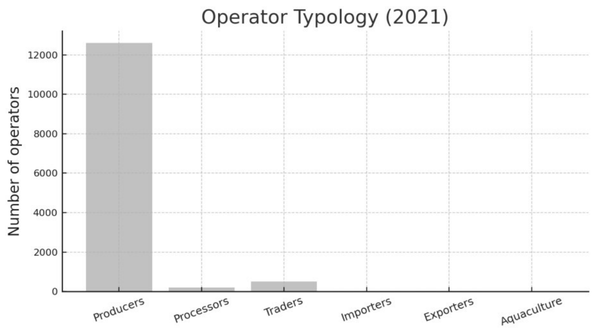

Figure 4 **Operator typology**

Processors account for less than 2% of operators, while traders, importers, and aquaculture producers are negligible. This imbalance demonstrates Romania's weak downstream capacity, limiting the development of a diversified domestic market.

Trade balance

Romania exports approximately four times more organic products than it imports, mostly bulk cereals and oilseeds. imports are limited but include higher value-added categories such as fruit and vegetables.

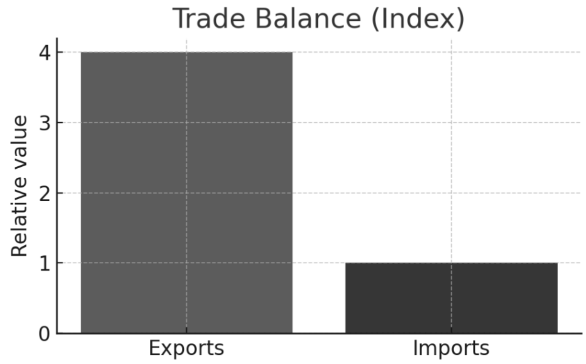

Figure 5 **Trade balance**

Domestic market

The Romanian organic retail market is valued at less than €100 million, well below the eu average (~€1.7 billion per country). this highlights the gap in consumer awareness and institutional demand.

European and Global context. In 2023, EU organic farmland reached 17.7 million ha. globally, FIBL and IFOAM (2025) reported ~99 million ha and €136.4 billion retail sales. Romania remains below the EU average but shows significant potential for expansion.

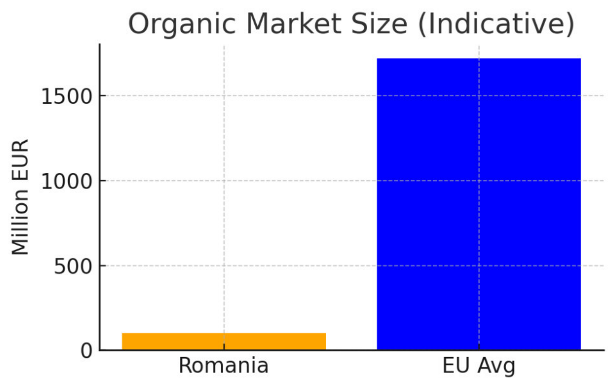

Figure 6 **Organic Market size Romania vs EU Avg**

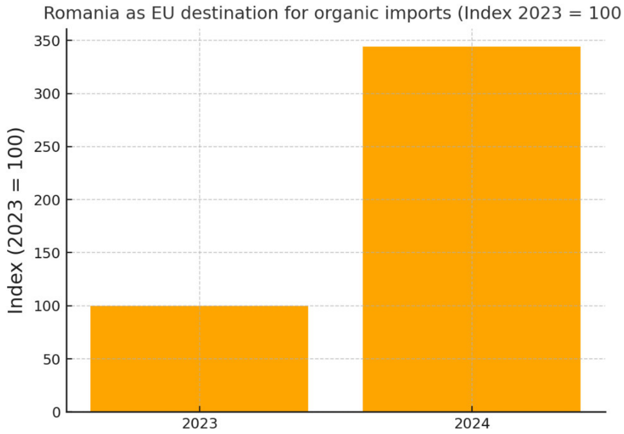

Figure 7 **Romania’s organic import destination index: 2023 = 100 vs. 2024 = 344 (traces-based; ec analytical brief no. 7, 2025).**

TRACES-based insights (2024)

According to DG AGRI’s analytical brief no. 7 (2025), based on traces data, romania’s role as a destination for eu organic imports increased sharply by +244% in 2024. the import index rose from 100 in 2023 to 344 in 2024, indicating strengthened trade dynamics and improved logistics.

Table 1

Key indicators of organic agriculture in Romania, 2022–2024.

Year	Organic Farmland (ha)	Operators (count)	Share of uaa (%)	Imports (index 2023=100)
2022	644,520	13,000	4.2	–
2023	693,000	14,000	4.5	100
2024*	710,000 (prov.)	14,100	4.6	344

CONCLUSIONS

Romania’s organic farmland reached ~710,000 ha in 2024, with ~14,100 operators. Despite this growth, the sector faces structural bottlenecks: weak processing capacity, low domestic demand, and reliance on raw commodity exports. To align with EU Green Deal objectives, Romania must:
(i) strengthen SME processing and logistics;
(ii) retain operators after conversion;
(iii) stimulate consumer demand through education and public procurement.

ACKNOWLEGMENTS

The author thanks the Doctoral School of IULS Iași and the Association 'Produs în Iași' for support.

REFERENCES

Biofach (2025). Closing Report 2025 – Taking Action. NürnbergMesse, Nuremberg.

Biofach (2025). Organic boom with obstacles – FiBL/IFOAM survey results. NürnbergMesse, Nuremberg.

European Commission (2025). TRACES NT – Organic operator certificates directory.

European Commission, DG AGRI (2025). Analytical Brief No. 7: EU organic imports 2024 (based on TRACES).

European Court of Auditors (2024). Special Report 19/2024: Organic Farming in the EU. Luxembourg.

Eurostat (2024). Developments in Organic Farming. Statistics Explained.

FiBL and IFOAM (2024/2025). The World of Organic Agriculture: Statistics and Emerging Trends. Frick: FiBL.

MADR (2023). Lista operatorilor certificați în agricultura ecologică. Ministry of Agriculture and Rural Development, Bucharest.

RRN-PAC (2024). Agricultura ecologică – sustenabilitate, inovare și protecția mediului. Romanian Rural Network, Bucharest.

USDA/FAS (2024). EU Organics Market Begins to Recover. GAIN Report GM2025-0003.

DEVELOPMENT OF A FUNCTIONAL BEVERAGE BASED ON FOOD BY-PRODUCTS, ENRICHED WITH BLACKCURRANT POWDER: TECHNOLOGICAL AND EXPERIMENTAL ASPECTS

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Abstract

Functional foods are also referred to as "foods of the future" since they are defined as foods that, while still being categorized as food, have additional advantageous components that can enhance bodily health in addition to their present fundamental nutritional value. Brewery spent malt, rye bread, and blackcurrant pomace powder are three food industry byproducts that were valorized to create the novel functional beverage known as ROOTS. The study's objectives were to use the HACCP system for food safety, optimize the technological manufacturing process, and qualitatively characterize the finished product. The technological process included the stages of infusion, controlled fermentation and pasteurization, identified as critical control points. The results demonstrated that the obtained beverage has an average pH of 3.9, alcohol content <0.5% vol., high antioxidant activity and a balanced sensory profile. The product is part of current trends in circular economy and sustainable consumption, offering a functional, natural and sustainable alternative to conventional beverages.

Keywords: functional beverage; food by-products; controlled processes; food safety.

The European circular economy places a high priority on reducing food loss and recovering resources. Every year, one-third of the food produced worldwide is lost or wasted, with significant negative effects on the environment and economy, according to FAO. In this regard, the beverage sector presents special chances to profit from fermentation processes, food byproducts, and the possibility of technological advancement (Sharma S. *et al.*, 2021). Functional foods are also referred to as ”foods of the future” in a study by Obayomi *et al*. (2024) because they are defined as foods that, in addition to their current essential nutritional value, contain additional beneficial components that can benefit the body's health while still being considered food. According to the same authors, foods in the functional category have the potential to improve health and fulfill an individual's physiological needs, but they cannot treat illnesses.

According to Gupta *et al.* (2023) ”any non-alcoholic beverage that offers additional health benefits through the incorporation of a bioactive component derived from plant, animal, marine, or microorganisms” is the definition of a functional beverage.

MATERIAL AND METHOD

Raw materials used: The primary raw materials used to make ROOTS, a functional beverage, were food industry by-products that were chosen for their nutritional value, availability locally, and potential for reintroduction into the food chain. In keeping with the circular economy's tenets and the demands of food safety management systems, the goal was to incorporate them into a sustainable process (ISO 22000:2018).

Technological process: The ROOTS functional beverage was created using a technological technique that was adapted to the utilization of food byproducts, modern safety and sustainability regulations, and the traditional principles of kvass manufacturing. An optimized flow served as the foundation for the technological stage sequence, which was confirmed by HACCP risk analysis and the identification of important control points.

Physico-chemical analyses: The physico-chemical determinations aimed to characterize the composition of the ROOTS beverage and verify

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compliance with internal product specifications. Some of the analyses were performed in the quality control laboratory of the Faculty of Agriculture at USV Iași, using standardized methods according to AOAC (2019) and ISO 2172/2018, some being performed in specialized accredited laboratories.

Parameters analyzed:

- pH was determined with a digital pH meter (Hanna Instruments, USA) calibrated daily with pH 4.00 and 7.00 buffer solutions.
- Total acidity was expressed in g lactic acid/L, by titration with 0.1 N NaOH solution until the phenolphthalein indicator turns.
- The soluble solids content (°Brix) was measured with the Atago digital refractometer, at 20°C, on a degassed sample.
- Density was determined by the pycnometric method at 20°C.
- The reducing sugar content was determined by the Lane-Eynon method, expressed in g glucose/100 mL.
- Dissolved carbon dioxide (CO_2) was determined by volumetric analysis according to the EBC 9.37 (European Brewery Convention) method.
- The ethanol content was evaluated by gas chromatography (GC Agilent 7890A, DB-WAX capillary column, FID detector), expressed in % vol.
- Total ash was determined by incineration at 550°C (AOAC 940.26 method).
- The dietary fiber and total polyphenol content was analyzed by the gravimetric method (AOAC 985.29) and the Folin–Ciocalteu method, respectively, expressed in mg GAE/100 mL.

Microbiological analyses: The microbiological control was carried out to assess the safety of the final product and the efficiency of the process steps identified as critical points (fermentation and pasteurization). The determinations were carried out according to the standards SR EN ISO 21528-1:2017 and SR EN ISO 21527-1:2018, on samples collected at three times: after primary fermentation, after pasteurization and after 7 days of storage.

Microbiological parameters analyzed:

- *Enterobacteriaceae* – by seeding on VRBG agar medium, incubation at 37°C for 24 h.
- Yeasts and molds – on YGC agar medium, incubation at 25°C for 5 days.
- Lactic acid bacteria – on MRS agar, anaerobic incubation at 30°C for 72 h.
- *Salmonella spp*. and *Listeria monocytogenes* – qualitative tests performed according to European legislation (Reg. EC 2073/2005).

Sensory analysis: The sensory evaluation of the ROOTS beverage was carried out to determine the level of consumer acceptability and the correlation of analytical data with subjective perception. The test was carried out in the accredited sensory analysis laboratory of USV Iași, under controlled conditions (temperature 20 ± 2°C, standard lighting). A number of 25 untrained evaluators, selected from the university population (age 20–40), participated in the product testing, completing a questionnaire with a rating on a 9-point scale (from 1 – ”*not at all pleasant*” to 9 – ”*very pleasant*”). The analyzed attributes were:

- appearance (clarity, color, foam);
- smell/aroma (malty, fruity, fermentative notes);
- taste (sweet-sour balance, aftertaste, astringency);
- texture (effervescence level, body, swallowing sensation);
- overall acceptability.

Implementation of HACCP requirements - Given the use of food by-products in the formulation of ROOTS beverage and the fermentative nature of the technological process, the implementation of a HACCP (Hazard Analysis and Critical Control Points) system was essential to guarantee food safety and compliance with the ISO 22000:2018 standard.

RESULTS AND DISCUSSIONS

Raw materials

1. Brewers' Spent Grain (BSG) - It represents the solid residue resulting from the brewing process, after the extraction of the malt wort. It was collected from the local producer, in a wet state (≈75% humidity). To prevent microbial growth, the spent grain was processed immediately or dried at 60°C to a humidity of 8–10%. BSG is a valuable source of dietary fiber (≈42%), protein (≈19%) and phenolic compounds (Ikram S *et al*, 2017). Through subsequent thermal processing (infusion at 80°C), part of these bioactive components is transferred to the liquid phase of the beverage, contributing to the malt aroma and oxidative stability.
2. Rye Bread Waste (RBW) - The surplus bread was provided by the local partner, under a zero waste agreement. The products were selected based on freshness and the absence of mold, then dried at 100°C for 15–20 minutes to avoid the development of unwanted microflora. Rye bread provides the beverage with fermentable carbohydrates, aromatic Maillard compounds and a characteristic reddish-brown color. The bread also contributes to the fiber load (≈6%) and the content of B vitamins, derived from the wholemeal flour (Kaszuba J *et al*., 2024).
3. Blackcurrant Pomace Powder (BPP) - This raw material was obtained in the microproduction workshops of the "Ion Ionescu de la Brad" University of Life Sciences in Iași, by drying at 40°C the pomace resulting from pressing blackcurrant juice (Ribes nigrum L.), to 5%

humidity. The powder was subsequently finely ground (size <0.5 mm) and stored at 4°C, in airtight packaging. BPP is a concentrated source of anthocyanins (3.1 mg C3G/g), polyphenols (≈9.8 mg GAE/g) and dietary fiber (≈15%), contributing both to the color intensity and to the antioxidant and functional profile of the beverage.

4. White sugar and brewer's yeast (*Saccharomyces cerevisiae*) - Sugar was added at a concentration of 15 g/L in the "priming" stage, acting as a fermentable substrate for obtaining natural carbonation. *Saccharomyces cerevisiae* yeast was used as the inoculum for the controlled fermentation, due to its ability to adapt to complex environments and moderate alcohol production (<0.5% vol.). It was rehydrated before use and inoculated at a temperature of 25°C.

5. Technological water - The water used was of drinking quality, according to Order 161/2006, subjected to filtration and microbiological verification (absence of coliforms and mesophilic bacteria). All raw materials were previously analyzed from a physico-chemical and microbiological point of view, ensuring full traceability through compliance documents and batch codes.

Technological process - The diagram of the technological operations for manufacturing the functional drink is shown in figure 1.

1. *Raw material reception* - All ingredients were received according to internal quality specifications. At this level, organoleptic controls, moisture determinations and verification of compliance documents were carried out. A traceability register was drawn up for each batch, which includes the origin, date of reception and internal identification code. Non-compliant raw materials (presence of mold, foreign bodies, atypical odors) were rejected.

2. *Raw material storage* - BSG was stored for a maximum of 24 h at 4°C or dried for later use. The RBW and BPP were stored at room temperature (18–20°C), in clean, ventilated spaces, away from moisture and light. Sensitive materials (yeast, sugar) were stored in sealed containers, under strict hygienic conditions.

3. *Infusion and maceration* - This is the essential stage for the extraction of soluble compounds and the inactivation of contaminating microflora. The solid ingredients (spent malt, dried bread and currant powder) were introduced into water at 80°C, maintained for 60–90 minutes, under gentle agitation. The following effects were achieved through this heat treatment: solubilization of sugars, diffusion of anthocyanin pigments, release of aromatic compounds and reduction of microbial load. The resulting must had an average density of 1,040 g/cm³ and an intense reddish-brown color.

4. *Cooling and inoculation* - After maceration, the liquid was rapidly cooled to 20–25°C using a double heat exchanger, thus preventing the development of unwanted microorganisms. Inoculation was performed with Saccharomyces cerevisiae yeast at a rate of 0.05% (m/m), rehydrated according to the manufacturer's instructions. In some experimental variants, mixed fermentation (yeast + lactic acid bacteria) was also tested to obtain a complex aromatic profile and a balanced acidity.

5. *Primary fermentation* - The fermentation process took place in stainless steel tanks, at 22–25°C, for a period of 18–24 hours. The monitored parameters were: temperature, pH (<4.2) and °Bx. The decrease in sugar content and natural acidification indicated the completion of fermentation. Once the preset limits were reached, the process was stopped by cooling the mixture to 4°C, preventing excessive alcohol accumulation. The result was a raw, non-carbonated drink, with an opalescent appearance and a characteristic aroma of fermented malt.

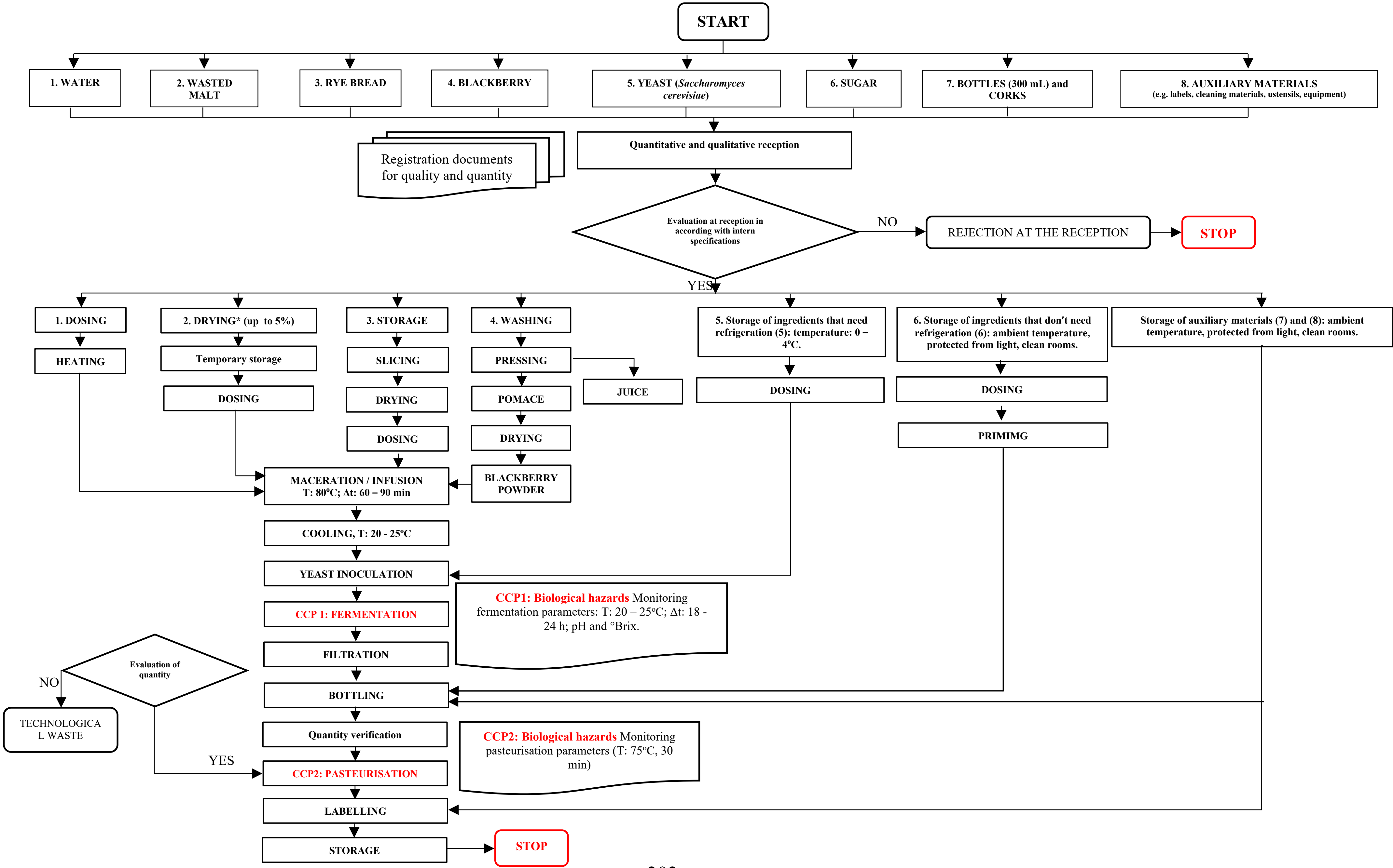
6. *Filtration and homogenization* - The fermented liquid was coarsely filtered through sterile textile sieves to remove large cereal particles and pulp residues. Fine filtration (5 µm plates) was applied only in samples intended for microbiological evaluation.

7. *Bottling and sugar addition* (*priming*) - The beverage was bottled in brown glass bottles (330 mL) fitted with metal caps. Before closing, sugar was added at a dose of 15 g/L to allow a slight secondary fermentation in the bottle, which generates natural carbonation. The bottles were kept at room temperature for 12 hours, then refrigerated at 4°C.

8. *Pasteurization* - For microbiological stabilization, the sealed bottles were pasteurized in a water bath at 75°C for 25 minutes, ensuring the destruction of residual yeasts and potentially pathogenic microorganisms. This step was automatically monitored by temperature sensors with continuous data recording.

9. *Labeling and final storage* - After cooling, the bottles were labeled with the ingredients, nutritional content, gluten warnings and shelf life (180 days). The finished products were stored at 18–20°C, protected from light, in recycled cardboard boxes.

Implementation of HACCP - Given the use of by-products in the formulation of beverage and the fermentative nature of the technological process, the implementation of a HACCP system was essential to guarantee food safety and compliance with the ISO 22000:2018 standard.


START
1. WATER
2. WASTED MALT
3. RYE BREAD
4. BLACKBERRY
5. YEAST (Saccharomyces cerevisiae)
6. SUGAR
7. BOTTLES (300 mL) and CORKS
8. AUXILIARY MATERIALS (e.g. labels, cleaning materials, ustensils, equipment)
Registration documents for quality and quantity
Quantitative and qualitative reception
Evaluation at reception in according with intern specifications
NO
REJECTION AT THE RECEPTION
STOP
YES
1. DOSING
HEATING
2. DRYING* (up to 5%)
Temporary storage
DOSING
3. STORAGE
SLICING
DRYING
DOSING
4. WASHING
PRESSING
JUICE
POMACE
DRYING
BLACKBERRY POWDER
5. Storage of ingredients that need refrigeration (5): temperature: 0 – 4ºC.
DOSING
6. Storage of ingredients that don't need refrigeration (6): ambient temperature, protected from light, clean rooms.
DOSING
PRIMIMG
Storage of auxiliary materials (7) and (8): ambient temperature, protected from light, clean rooms.
MACERATION / INFUSION T: 80ºC; Δt: 60 – 90 min
COOLING, T: 20 - 25ºC
YEAST INOCULATION
CCP 1: FERMENTATION
CCP1: Biological hazards Monitoring fermentation parameters: T: 20 – 25ºC; Δt: 18 - 24 h; pH and °Brix.
FILTRATION
Evaluation of quantity
NO
TECHNOLOGICAL WASTE
BOTTLING
Quantity verification
YES
CCP2: PASTEURISATION
CCP2: Biological hazards Monitoring pasteurisation parameters (T: 75ºC, 30 min)
LABELLING
STORAGE
STOP

The technological flow was graphically represented and validated on-site by the HACCP team, according to the principles of the Codex Alimentarius (Rev. 2020). The diagram included the stages of reception, storage, maceration, fermentation, filtration, bottling, pasteurization and labeling, each of which is correlated with hygiene and control procedures.

For each stage of the process, possible biological (bacteria, molds, contaminating yeasts), chemical (detergent residues, pesticides) and physical (metal fragments, solid impurities) hazards were analyzed, according to the ISO 22000:2018 methodology. The risks were assessed based on the probability of occurrence and the severity of the consequence, resulting in a risk classification matrix (low, medium, high).

Based on the decision tree, two critical control points were identified:

- CCP1 – Primary fermentation: monitoring of temperature (22–25°C), pH (<4.2) and duration (18–24 h) to prevent the development of unwanted microflora.
- CCP2 – Pasteurization: maintaining a temperature of 75°C for a minimum of 25 minutes to inactivate pathogenic microorganisms and stabilize the product.

The maceration, cooling, inoculation, maturation and labeling steps were classified as OPRPs (Operational Prerequisite Programs), controlled by continuous monitoring of temperature and equipment hygiene.

For each CCP, measurable critical limits, monitoring procedures (pH meter, digital thermometers, automatic recordings) and corrective actions, such as isolating non-compliant batches or resuming heat treatment, were defined. All data were recorded in specific monitoring sheets.

From a food safety perspective, the implemented HACCP system identified and controlled major biological risks by strictly monitoring fermentation and pasteurization temperatures. Thus, the process ensures microbiological stability without the use of chemical preservatives.

Physico-chemical characterization - The physico-chemical analyses performed on ROOTS beverage confirmed that the technological and qualitative parameters targeted during the product development phase were achieved. The average values obtained were: pH 3.9±0.1, total acidity 5.5 ±0.2 g/L, alcohol content 0.3% vol, reducing sugars 2.4 g/100 mL, CO_2 2.5 g/L and density 1.010 g/cm³.

These results indicate a weakly acidic, microbiologically stable drink with a moderate carbonation level specific to natural fermentation. The mild acidity and pH below 4.0 contribute to protection against pathogenic microorganisms and enhance the sensation of freshness. The low ethanol values (<0.5% vol) confirm the classification of the product in the category of fermented non-alcoholic beverages.

The high content of total polyphenols (33 ± 2 mg GAE/100 mL) and vitamin C (≈4 mg/100 mL) demonstrates the significant contribution of blackcurrant powder and antioxidant compounds from malt and bread. Compared to similar commercial beverages (kombucha, traditional kvass), ROOTS presents a superior antioxidant value, due to the synergy between the anthocyanins from blackcurrant marc and the phenolic compounds from cereals.

In addition, the presence of dietary fiber (≈0.8 g/100 mL) gives the product a functional character, contributing to digestion and the regulation of carbohydrate metabolism. These results confirm that the reuse of food by-products does not compromise nutritional quality, but on the contrary, it amplifies it by transferring residual bioactive compounds.

Microbiological evaluation and stability over time - The results of the microbiological analyses revealed full compliance with the limits allowed by the ISO 21528-1:2017 and ISO 21527-1:2018 standards. 24 h after primary fermentation, the predominance of the *Saccharomyces cerevisiae* population was observed, accompanied by a limited presence of beneficial lactic acid bacteria (*Lactobacillus spp.*), responsible for the rapid acidification of the medium (pH <4.2).

After pasteurization, all samples showed absence of *Enterobacteriaceae*, yeasts and molds <1 cfu/g and absence of *Salmonella spp.* and *Listeria monocytogenes*. Following stability tests carried out after 7 days of storage at 18–20°C, the microbiological parameters were maintained within safe limits, without the development of spoilage microflora.

These results confirm the effectiveness of the pasteurization process (75°C/25 min) as a critical control point (CCP2) and the importance of combining the heat treatment with the natural acidity of the beverage in ensuring microbiological stability.

Controlled fermentation (CCP1) allowed for a balanced fermentation, without excessive alcohol formation, avoiding defects such as the "mousy" taste or ethanol odors, sometimes encountered in spontaneous fermentations.

Sensory profile and consumer acceptability - The sensory analysis, conducted on a sample of 25 evaluators, demonstrated a high degree of overall acceptability. The average score of 8.1 ± 0.4 (on a 9-point scale) highlighted the positive perception of the product in terms of taste, color and aroma.

The main attributes appreciated were:

- aroma – specific of malt and black fruits, with balanced sweet-sour notes;
- color – intense reddish-brown, due to the anthocyanin pigments in the currants;
- taste – pleasant, slightly sour, with a fruity aftertaste and a sensation of freshness;
- natural effervescence – giving a fine and creamy texture;
- aftertaste – persistent, with slightly astringent notes typical of blackcurrants.

Statistical analysis (ANOVA, $p<0.05$) revealed significant correlations between color perception, aroma intensity and overall acceptability. Also, 87% of respondents stated that they would purchase the product if it were commercially available, indicating a high market potential for the LOHAS (Lifestyles of Health and Sustainability) segment.

CONCLUSIONS

The results obtained demonstrate the technological feasibility and economic viability of the ROOTS beverage as an innovative, safe and sustainable product. The synergy between controlled biological processes (lactic and alcoholic fermentation), the use of recycled ingredients and the strict control of critical parameters led to the production of a beverage with:

- excellent microbiological stability without preservatives;
- high antioxidant and nutritional properties;
- distinct and attractive sensory profile for modern consumers;
- low environmental impact and added value for the circular economy.

Thus, ROOTS demonstrates that food innovation based on the recovery of by-products can generate competitive products, with scientific, economic and social relevance, constituting a model of best practices for the sustainable development of the functional beverage industry. By turning by-products into useful resources, the functional beverage ROOTS serves as a practical illustration of how circular economy concepts are incorporated into the food business. The outcomes attest to the product's safety, stability, and sensory appeal, as well as its potential for industrial growth and commercial use. BPP enrichment greatly enhances the drink's nutritional and antioxidant profile, providing it distinctive qualities among handmade fermented goods. Overall, the experiment shows how clever component recovery can help create sustainable beverages with extra ecological and nutritional value.

REFERENCES

Gupta A., Sanwal N., Bareen M.A., Barua S., Sharma N., Olatunji O.J., Nirmal N.P., Sahu J.K., 2023 - *Trends in functional beverages: Functional ingredients, processing technologies, stability, health benefits, and consumer perspective.* Food Res. Int., vol. 170, 113046.

Ikram S., Huang L., Zhang H., Wang J., Yin, M., 2017 - *Composition and Nutrient Value Proposition of Brewers Spent Grain.* Journal of Food Science, vol. 82, no. 10, pp. 2232-2242. https://doi.org/10.1111/1750-3841.13794

Kaszuba J., Jańczak-Pieniążek M., Migut D., Kapusta I., Buczek J., 2024 - *Comparison of the Antioxidant and Sensorial Properties of Kvass Produced from Mountain Rye Bread with the Addition of Selected Plant Raw Materials.* Foods, vol. 13, pp. 357. https://doi.org/10.3390/foods13030357

Obayomi O.V., Olaniran A.F., Owa S.O., 2024 - *Unveiling the role of functional foods with emphasis on prebiotics and probiotics in human health: A review.* J. Funct. Foods, vol. 119, 106337

Sharma S., Singh A., Sharma S., Kant A., Sevda S., Taherzadeh M.J., Garlapati V.K., 2021 - *Functional foods as a formulation ingredients in beverages: Technological advancements and constraints*. Bioengineered, vol. 12, pp. 11055–11075.

***Food and Agriculture Organization of the United Nations (FAO), 2023. Global food losses and food waste – Extent, causes and prevention. Rome

***Codex Alimentarius – HACCP principles

*****ISO 22000:2018** - Food safety management systems - Requirements for any organization in the food chain

***AOAC (2019) - Official Methods of Analysis of the Association of Official Analytical Chemists: Official Methods of Analysis of AOAC International. 21st Edition, AOAC, Washington DC.

***ISO 2172:2018** - Fruit juice. Determination of soluble solids content — Pycnometric method

*****SR EN ISO 21528-1:2017** - Detection of Enterobacteriaceae

*****SR EN ISO 21527-1:2018** - Microbiology of food and animal feeding stuffs - Horizontal method for the enumeration of yeasts and moulds - Part 1: Colony count technique in products with water activity greater than 0,95.

NUTRITIONAL AND SENSORY EVALUATION OF WHEY CHEESE PRODUCED WITH DRIED BLACK CHOKEBERRY POMACE

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Abstract

The integration of fruit by-products into dairy products is a chance to improve nutritional value and sensory attractiveness while promoting sustainable food production. This study examines the nutritional and sensory assessment of cheese made with the incorporation of dried black chokeberry (*Aronia melanocarpa*) pomace. Nutritional analyses concentrated on proximate composition, dietary fiber, phenolic compounds, and antioxidant capacity, contrasting enriched cheeses with control samples. The results revealed a substantial enhancement in total polyphenols (4.45 ± 0.27-9.13 ± 0.31 mg GAE/g dw), dietary fiber, and antioxidant activity (26.43 ± 0.24-48.94 ± 0.34 µmol TE/g dw) in cheeses fortified with chokeberry pomace, underscoring its potential as a functional ingredient. Sensory evaluation demonstrated that moderate incorporation of pomace was positively perceived, particularly through improvements in colour and appearance, whereas higher inclusion levels were associated with a slight reduction in overall flavour acceptability. The results indicate that dried black chokeberry pomace can be effectively employed in cheese production to enhance nutritional attributes while preserving acceptable sensory qualities, hence facilitating the creation of value-added functional dairy products.

Keywords: Aronia Pomace, Anthocyanins, Antioxidant activity, Cheese Enhancement, Consumer Acceptance

The nutraceutical and dietary supplement industries are seeing swift growth. There is a growing focus on utilising commodities formerly seen as trash, like pomace, seeds, and leaves, in the quest for useful raw materials. This strategy aligns with the European Union's zero-waste objectives established for 2025 and aids in the progression of the United Nations Sustainable Development Goals. Recent studies have highlighted the significant importance of fruit by-products, which are especially abundant in bioactive chemicals linked to various health benefits (Saracila *et al.,* 2024). Presently, researchers and the food industry are concentrating on the development of functional food formulations and nutraceuticals, so aligning this study with global trends (Tamkutė *et al.,* 2021).

Black chokeberry, or aronia (*Aronia melanocarpa*), is a shrub belonging to the *Rosaceae* family, indigenous to North America and introduced to Europe approximately a century ago. The edible components of black chokeberry consist mostly of its fruits, which are small, dark, cherry-like berries. Black chokeberry is widely recognized as one of the richest natural sources of bioactive compounds, particularly anthocyanins, flavonoids, and other phenolic constituents (Sidor *et al.,* 2019). These phytochemicals are associated with strong antioxidant activity, anti-inflammatory effects, and potential health-promoting properties, including cardiovascular protection, improved glucose metabolism, and immune modulation (Martins *et al.,* 2024).

Raw, unrefined black chokeberry fruits are infrequently ingested due to their astringent flavour; yet, they are extensively utilised in the food sector for the production of juices, syrups, jams, fruit teas, and dietary supplements (Jurendic *et al.,* 2021). By-products generated during fruit processing, particularly pomace, are increasingly being valorized for food applications. Chokeberry pomace consists of approximately 28–35% skin, 60–70% seeds, and about 10% pulp. It represents a valuable source of polyphenols, vitamins, and dietary fiber, while being relatively low in calories (Sarv *et al.,* 2021).

Studies have shown that pomace contains higher levels of procyanidins compared to juices and fresh fruits, highlighting its potential as a rich source of natural antioxidants (Raczkowska *et al.,* 2022). Chokeberry pomace may serve as a component for the formulation of antioxidant-rich meals and nutraceuticals. Although considerable research has been conducted on the valorization of

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agro-industrial by-products, including fruit pomace, the utilization of juice-pressing residues from certain fruit species remains insufficiently explored (Repajić *et al.,* 2025). Dried and powdered pomace has been reported to function as a versatile ingredient in various products, such as bakery items, confectionery, functional foods, and teas (Raczkowska *et al.,* 2012).

The incorporation of fruit by-products into dairy products has gained considerable attention as part of sustainable food system strategies that aim to reduce waste, enhance nutritional value, and improve functional properties. In the dairy sector, several studies have successfully demonstrated the incorporation of fruit by-products into yogurts, cheeses, and fermented milk products, leading to improved antioxidant activity, extended shelf life, and enhanced consumer appeal (Tarchi *et al.,* 2024). Whey cheese, a traditional dairy product valued for its high protein content and unique texture, provides an excellent matrix for fortification with plant-derived bioactive ingredients. Such approaches not only enhance the nutritional profile of cheese but also contribute to the development of innovative functional foods that align with consumer demand for healthier diets (Dodan *et al.,* 2025).

The present study focuses on the nutritional and sensory evaluation of whey cheese enriched with dried black chokeberry pomace(BCP). By examining its phytochemical composition, phytochemical, antioxidant capacity, color, texture….and sensory performance, this research seeks to demonstrate the potential of chokeberry pomace as a natural, value-adding ingredient for the dairy industry, while simultaneously promoting sustainable utilization of fruit by-products.

MATERIAL AND METHOD

Fresh black chokeberry fruits (*Aronia melanocarpa* L.) were purchased in August 2024 from a local supermarket in Iași County, Romania, and processed immediately after sorting. Pomace, obtained as a by-product during laboratory juice extraction, was frozen at –30 °C and subsequently freeze-dried for 48 h at 42 °C under a pressure of 0.10 mBar using a CHRIST Alpha 1–4 LD plus freeze-dryer (Germany) until a dry weight of approximately 98% was achieved. The resulting freeze-dried pomace was ground into a fine powder and stored in glass jars at room temperature, in the dark, until further analysis.

Two hundred liters of cow's milk were supplied by the Rediu Iași Research Station of the University of Life Sciences.

Folin–Ciocalteu reagent, 1% citric acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), ethanol, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS), potassium chloride solution, sodium hydroxide, sodium nitrite, gallic acid, sodium acetate solution, aluminum chloride, and sodium carbonate were purchased from Sigma-Aldrich (Steinheim, Darmstadt, Germany). All other reagents used in the experiments were of analytical grade.

Bioactive compounds were extracted from BCP powder using the ultrasound-assisted method described by Saracila *et al.* (2023), with slight modifications. Briefly, 1 g of BCP powder was mixed with 10 mL of 70% ethanol acidified with 1% citric acid solution at an acid-to-solvent ratio of 1:9. The mixture was sonicated in an ultrasonic bath (Elmasonic S 180 H, Elma, Singen, Germany) for 42 min at 40 kHz and 40 °C, followed by centrifugation at 6000 rpm for 10 min at 4 °C. The obtained supernatant was collected and subjected to phytochemical characterization.

The determination of bioactive compounds and antioxidant activity of BCP extract.

The total anthocyanin content of the extract was quantified spectrophotometrically using an Analytik Jena UV-Vis spectrophotometer (Specord 210 Plus, Jena, Germany) following the modified method of Cacak-Pietrzak *et al.* (2023). 200 µL of each sample was mixed with 800 µL of buffer solutions at pH 1.0 and pH 4.5 in spectrophotometer cuvettes. After a 15 min incubation in the dark to allow reaction, absorbance readings were recorded at 520 nm and 700 nm. The results were expressed in milligrams cyanidin 3-glucoside equivalents (C3G) per 100 grams of dry weight (d.w.).

Total flavonoid content was determined according to the method of Cacak-Pietrzak *et al.* (2023), with slight modifications. 0.25 mL of extract solution was mixed with 0.075 mL of 5% sodium nitrite and 2 mL of distilled water. After 5 min, 0.15 mL of 10% aluminum chloride solution was added, and the mixture was left to react for 6 min. Subsequently, 0.5 mL of 1 M sodium hydroxide was added, and the absorbance of the final solution was immediately recorded at 510 nm. Results were expressed as mg catechin equivalents (CE) per g dry weight (d.w.) based on a standard calibration curve prepared with catechin.

Total polyphenol content was determined using the Folin–Ciocâlteu colorimetric method as described by Cacak-Pietrzak *et al.,* (2023). 0.20 mL of extract was mixed with 15.8 mL of distilled water and 1 mL of Folin–Ciocâlteu reagent. After 10 min, 3 mL of 20% (w/v) sodium carbonate solution was added, and the mixture was incubated for 60 min at room temperature. Absorbance was subsequently measured at 765 nm. Results were expressed as mg gallic acid equivalents (GAE) per g dry weight (d.w.) based on a calibration curve constructed with gallic acid standards.

Antioxidant activity (DPPH and ABTS methods). The antioxidant activity of the dried BCP sample was evaluated using the DPPH radical scavenging assay. Briefly, 0.1 mL of BCP extract was mixed with 3.9 mL of 0.1 M methanolic DPPH solution and incubated in the dark at room temperature for 30 min. The absorbance of the reaction mixture was then measured at 515 nm using a UV–Vis spectrophotometer (Biochrom Libra S22, Cambridge, UK).

The antioxidant activity of the dried BCP sample was also assessed using the ABTS radical cation ($ABTS^{\bullet +}$) decolorization assay. The $ABTS^{\bullet +}$ solution was generated by reacting 7 mM ABTS with 2.45 mM potassium persulfate and incubating the mixture for 16–24 h at room temperature in the dark. The resulting stock solution was diluted with ethanol to obtain an absorbance of 0.700 at 734 nm. For the assay, 50 µL of extract was mixed with 1.95 mL of the adjusted $ABTS^{\bullet +}$ solution and incubated for 2 h at room temperature in the dark. Absorbance was then measured at 734 nm. Results were expressed as µmol Trolox equivalents (TE) per gram of dry weight (d.w.). (Cacak-Pietrzak *et al.,* 2023).

Cheese manufacturing. The functionality of whey cheese was evaluated by supplementing it with black chokeberry pomace (BCP) powder at two concentrations, 10% and 20%. The control group (WC) consisted of whey cheese without powder addition.

Whey-type cheese was produced from whey obtained during cheese manufacture, following the technological process. The whey was first normalized with citric acid to an acidity of 11° Thörner (ºT) and heated to 60–65 °C, after which whole milk (3.9% fat) was added. The mixture was then heated to 72 °C and maintained for 5 min to promote albumin denaturation. Heating was resumed until the temperature reached 84–85 °C, at which point 250 mL of DAIRSAL+ was added. The process was continued until 88–90 °C, after which heating was stopped and the curd was collected in baskets to drain and cool. The cooled whey cheese was divided into three batches: WC (control), WCBCP1 (10% BCP), and WCBCP2 (20% BCP). The powder was incorporated by mixing, followed by dosing into thermo-welded plastic cups, which were stored at 4–6 °C until analysis.

The physicochemical properties of the supplemented cheese samples—including moisture, dry matter, pH, protein, fat, carbohydrates, fiber, ash, salt, and energy content—were determined according to the Association of Official Analytical Chemists (AOAC, 2000) and Gavril *et al.,* (2024).

The texture of the samples was evaluated using a Mark-10 ESM 300 texturometer (New York, NY, USA) fitted with a 7i-50 series digital dynamometer with a range of 0 to 1000 N, and a resolution of 0.2 N. Compression tests were performed with a cylindrical probe (model TA4) measuring 38.1 mm in diameter and 20 mm in height. The samples, prepared in a cylindrical form (30 mm diameter × 40 mm height), were subjected to a double compression cycle with a penetration speed of 1 mm/s, producing characteristic force–time curves. The maximum penetration force of the samples was recorded and the mechanical work or energy required to section the sample was calculated.

Mineral analysis. For mineral determination, 1 g of each sample was digested with nitric acid (HNO_3) and hydrochloric acid (HCl) in an 8:2 ratio at 180 °C for 40 minutes. The digested material was diluted to 25 mL with deionized water in a volumetric flask. The concentrations of P, K, Mg, Zn, Cu, Fe, and Na were quantified using Atomic Absorption Spectrophotometry, following the method described by Stoica *et al*. (2024).

Color analysis. Color measurements of black chokeberry pomace and BCP-enriched cheese samples were performed using the CIELAB system (L, a, b*) with a MINOLTA Chroma Meter CR-410 (Konica Minolta, Osaka, Japan), following the procedure described by Dag *et al.* (2017). From these primary values, Chroma ($\sqrt{(a^*)^2 + (b^*)^2}$), Hue angle (180 + arctan(b*/a*) for quadrant IV (+a*, -b*),), and total color difference (ΔE=$\sqrt{(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)^2}$), were calculated to further characterize color attributes.

Sensorial analysis. Sensory evaluation of the enriched cheese samples was conducted by a panel of twenty untrained assessors. Prior to participation, panelists were informed about the objectives of the study and the procedures for handling personal data. Each panelist evaluated 10 sensory descriptors: visual appearance, odor, aroma, color, taste, aftertaste, hardness, adhesiveness, chewability, and overall acceptability. Attributes were scored on a seven-point hedonic scale, where 1 represented “extremely low” and 7 indicated “extremely high.” The evaluation was performed in accordance with the specifications outlined in ISO 13299.

Statistical Analysis. All analyses were performed in duplicate, and results are presented as mean values ± standard deviations. Data were subjected to one-way analysis of variance (ANOVA) after verifying normality and homoscedasticity assumptions. Post-hoc comparisons were carried out using Tukey’s test at a 95% confidence interval, with differences considered statistically significant at $p < 0.05$. Statistical analyses were performed using Minitab software, version 18 (Minitab Inc., State College, PA, USA).

RESULTS AND DISCUSSIONS

BCP powder is produced from the solid by-products that remain after juice processing of *Aronia melanocarpa* berries. BCP powder is recognized as a valuable source of bioactive compounds, particularly anthocyanins and other flavonoids, which contribute to its strong antioxidant capacity.

Table 1

Phytochemical content of the BCP extract

Parameters	***Sample* BCP**
Total anthocyanins (mg/100g d.w.)	84.26±1.08
Total flavonoids (mg CE/g d.w.)	5.46±0.09
Total polyphenols (mg GAE/g d.w.)	10.68±0.15
DPPH (μmol TE/g d.w.)	14.68±0.13
ABTS (μmol TE/g d.w.)	1055.83 ±4.82
L*	23.57±0.04
a*	13.08±0.09
b*	4.01±0.05

The phytochemical analysis of the BCP extract in *Table 1* revealed that it is particularly rich in bioactive compounds, with anthocyanins representing the dominant fraction. The total anthocyanin content was 84.26 mg/100 g d.w., confirming the extract as a concentrated source of natural pigments, consistent with the characteristic deep purple coloration of chokeberry products. In addition, appreciable levels of total flavonoids (5.46 mg CE/g d.w.) and total polyphenols (10.68 mg GAE/g d.w.) were recorded, indicating that the extract contains a diverse spectrum of phenolic compounds that may contribute synergistically to its bioactivity. According to Saracila *et al.* (2024), black chokeberry pomace is characterized by a relatively high total polyphenol content (22.94 mg GAE/g), while exhibiting a comparatively low total flavonoid content (1.89 mg CE/g).

The antioxidant potential of the extract was notably high, as demonstrated by the radical scavenging assays. The DPPH value reached 14.68 µmol TE/g d.w., while ABTS activity exceeded 1055 µmol TE/g d.w., reflecting a strong capacity to neutralize free radicals. This antioxidant strength aligns with the high phenolic content, particularly anthocyanins, which are well recognized for their redox properties.

Colorimetric measurements (L*, a*, b*) further characterized the extract's visual properties. A relatively low lightness value (L* = 23.57) confirmed its dark appearance, while the positive a* value (13.08) and low b* value (4.01) positioned the extract within the red–purple region of the CIELab color space, consistent with its anthocyanin-rich profile.

Taken together, these results demonstrate that the BCP extract is a highly pigmented, anthocyanin-dense matrix with strong antioxidant activity, making it a promising functional ingredient for food fortification and value-added product development.

Table 2

Phytochemical profile of the control and BCP-supplemented Cheeses

Parameters	***Type of* Cheese**		
	WC	**WCBCP1**	**WCBCP2**
Total anthocyanins (mg/100g d.w.)	-	27.48±1.23[b]	46.59±1.68[a]
Total flavonoids (mg CE/g d.w.)	1.16±0.11[c]	2.98±0.10[b]	7.41±0.13[a]
Total polyphenols (mg GAE/g d.w.)	1.43±0.13[c]	4.45±0.27[b]	9.13±0.31[a]
DPPH (μmol TE/g d.w.)	12.67±0.22[c]	26.43±0.24[b]	48.94±0.34[a]
ABTS (μmol TE/g d.w.)	482.92±2.13[c]	687.86±4.18[b]	929.93±8.29[a]

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

The phytochemical composition of the cheeses showed a clear enrichment effect following supplementation with black chokeberry pomace. As expected, no anthocyanins were detected in the control (WC), whereas both supplemented samples contained significant amounts, reaching 27.48 mg/100 g d.w. in WCBP1 and 46.59 mg/100 g d.w. in WCBP2. This confirms the effective incorporation of chokeberry-derived pigments into the cheese matrix, with concentrations increasing proportionally to the supplementation level. Total flavonoids and total polyphenols also increased markedly with pomace addition: flavonoids rose from 1.16 mg CE/g d.w. in the control to 2.98 and 7.41 mg CE/g d.w. in WCBP1 and WCBP2, respectively, while polyphenols increased more than six-fold, from 1.43 mg GAE/g d.w. in the control to 4.45 in WCBP1 and 9.13 in WCBP2.

The antioxidant activity, measured by DPPH and ABTS assays, followed the same trend. DPPH values more than doubled in WCBP1 (26.43 µmol TE/g d.w.) and nearly quadrupled in WCBP2 (48.94 µmol TE/g d.w.) compared to the control (12.67 µmol TE/g d.w.). Similarly, ABTS values increased significantly from 482.92 µmol TE/g d.w. in the control to 687.86 µmol TE/g d.w. in WCBP1 and 929.93 µmol TE/g d.w. in WCBP2. These results demonstrate that chokeberry pomace supplementation markedly enhances the functional potential of cheese, particularly by enriching it with anthocyanins, flavonoids, and polyphenols that directly contribute to higher antioxidant activity.

Overall, the data indicate that the phytochemical and antioxidant properties of cheese are strongly dependent on the level of pomace incorporation, with WCBP2 exhibiting the most pronounced improvements. This confirms the suitability of chokeberry pomace as a functional ingredient for the development of value-added dairy products. These findings are consistent with those of Lucera *et al.* (2018), who reported that the incorporation of grape pomace powder into cheese resulted in a significant enhancement of total phenolic content, flavonoids, and antioxidant activity relative to the control cheese.

Table 3

Chemical composition of the control and BCP-supplemented Cheeses

Parameters	***Type of Cheese***		
	WC	**WCBCP1**	**WCBCP2**
Total dry matter (%)	22.53±0.15^{c}	28.78±0.16^{b}	35.19±0.18^{a}
Fat (%)	5.05±0.04^{a}	4.79±0.03^{ab}	4.48±0.02^{b}
Protein (%)	11.13±0.014^{a}	10.68±0.13^{b}	10.21±0.12^{b}
Crude fiber (%)	0.00±0.00^{c}	4.76±0.03^{b}	9.57±0.06^{a}
Carbohydrate (%)	5.23±0.10^{c}	7.21±0.14^{b}	9.59±0.15^{a}
Moisture (%)	77.23±0.26^{a}	71.02±0.24^{b}	64.42±0.23^{c}
Ash (%)	1.11±0.02^{a}	1.22±0.03^{a}	1.31±0.03^{a}
Salt (%)	0.92±0.04^{a}	0.85±0.03^{a}	0.78±0.02^{a}
pH	5.86 ± 0.10^{a}	5.76 ± 0.09^{a}	5.61 ± 0.10^{a}
Energy value (Kcal/100 g)	110.89 ±0.06^{c}	124.19±0.07^{b}	138.66±0.08^{a}

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

Table 4

Mineral composition of the control and BCP-supplemented Cheese samples

Parameters	***Type of Cheese***		
	WC	**WCBCP1**	**WCBCP2**
Sodium (Na, mg/100 g)	20.32 ± 0.28^{c}	39.67 ± 0.43^{b}	54.75 ± 0.52^{a}
Phosphorus (P, mg/100 g)	5.70 ± 0.21^{c}	9.84 ± 0.29^{b}	14.29 ± 0.33^{a}
Potassium (K, mg/100 g)	99.82± 0.81^{c}	125.38± 0.89^{b}	140.20 ± 0.92^{a}
Magnesium (Mg, mg/100 g)	61.18 ± 0.52^{c}	73.49 ± 0.63^{b}	81.30 ± 0.79^{a}
Zinc (Zn, mg/100 g)	0.45 ± 0.04^{c}	1.53 ± 0.11^{b}	2.41 ± 0.12^{a}
Copper (Cu, mg/100 g)	0.05± 0.01^{c}	0.11± 0.02^{b}	0.15± 0.03^{a}
Iron (Fe, mg/100 g)	0.61± 0.01^{c}	1.84± 0.09^{b}	2.44± 0.14^{a}

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

Incorporation of BCP into the cheese samples markedly improved their chemical composition compared with the control as was seen in *Table 3*. BCP addition significantly increased dry matter, fiber, carbohydrate, and energy values, while reducing protein, fat (slightly), and moisture.

Ash, salt, and pH remained unaffected, showing BCP incorporation does not alter mineral content or acidity.

Statistically, all parameters with different superscript letters differ at $p < 0.05$. The clearest dose-dependent trends were observed in dry matter, fiber, carbohydrate, moisture, and energy value.

Gaglio *et al.* (2021) developed a novel fresh ewe's milk pressed cheese ("primosale") by incorporating 1% (w/w) grape pomace powder and employing selected Lactococcus lactis strains resistant to the main grape phenolic compounds. The fortified cheese demonstrated a reduced fat content, increased protein levels, enhanced antioxidant activity, and a higher degree of secondary lipid oxidation compared to the control.

The textural properties of whey cheese (WC) were significantly influenced by supplementation with black chokeberry pomace

(BCP) powder at two concentrations (10% WCBCP1 and 20% WCBCP2). The control sample (WC) exhibited the highest maximum penetration force (17.76 N) and mechanical work (90.01 mJ), indicating a firmer and more resistant structure. In contrast, the addition of BCP powder led to a progressive reduction in both parameters, with WCBCP1 showing 13.01 N and 30.83 mJ, while WCBCP2 displayed the lowest values, 8.36 N and 22.61 mJ, respectively. These results suggest that BCP incorporation softens the cheese matrix, reducing cutting resistance and structural compactness in a concentration-dependent manner. The observed effect may be attributed to the high fiber content of the pomace, which interferes with protein-protein interactions and alters the microstructure of the cheese, resulting in a more tender texture.

Abd Elhamid (2016) investigated the effect of supplementing Egyptian “Kariesh” cheese with varying levels of wheat bran (0.1–0.5% *w/w*) as a prebiotic source on its physicochemical, rheological, and sensory properties. The fortified cheeses showed an increased yield and moisture content, accompanied by reductions in pH, protein concentration, and textural firmness compared with the control. *Table 4* summarizes the mineral composition of the analyzed samples. The incorporation of BCP powder into whey cheese significantly enhanced its mineral content in a dose-dependent manner. Compared to the control, WCBCP1 and WCBCP2 showed progressive increases in sodium (from 20.32 to 39.67 and 54.75 mg/100 g), phosphorus (from 5.70 to 9.84 and 14.29 mg/100 g), potassium (from 99.82 to 125.38 and 140.20 mg/100 g), and magnesium (from 61.18 to 73.49 and 81.30 mg/100 g). Similarly, trace elements such as zinc, copper, and iron were substantially higher in fortified samples, with iron increasing from 0.61 mg/100 g in the control to 2.44 mg/100 g in WCBCP2. These results confirm that BCP supplementation is an effective strategy to improve the mineral profile of whey cheese, potentially enhancing its nutritional value and functional properties. Color evaluation of the control and BCP-supplemented Cheese samples were shown in *table 5*.

The colorimetric analysis revealed substantial differences between the control (WC) and the cheeses supplemented with black chokeberry pomace (WCBP1 and WCBP2). The lightness value (L*) decreased sharply from 82.61 in the control to 44.62 and 29.95 in WCBP1 and WCBP2, respectively, indicating that pomace supplementation produced significantly darker cheeses, with the effect being more pronounced at higher levels.

Table 5

Color evaluation of the control and BCP-supplemented Cheese samples

Parameters	***Type of Cheese***		
	WC	**WCBCP1**	**WCBCP 2**
L*	82.61±0.13ᵃ	44.62±0.25ᵇ	29.95±0.18ᶜ
a*	1.09±0.04ᵃ	12.27±0.11ᵇ	13.66±0.13ᶜ
b*	13.56±0.09ᶜ	-0.96±0.03ᵇ	-0.62±0.08ᵃ
Chroma	13.60±0.10ᶜ	12.30±0.07ᵇ	13.67±0.06ᵃ
Hue angle	1.49±0.02ᵃ	359.90±0.01ᵇ	359.95±0.01ᵇ
ΔE	-	42.18±0.03ᵇ	55.97±0.09ᶜ

Values within a row that do not share a common letter differ significantly at $p < 0.05$.

The redness index (a*) showed the opposite trend, increasing markedly with pomace addition, particularly in WCBP2 (13.66), which demonstrates a strong red hue compared with the nearly neutral value in the control (1.09). The chokeberry pomace natural pigments, predominantly anthocyanins, impart attractive red–purple hues that can improve product appearance and consumer appeal.

The b* coordinate shifted from a positive value in the control (13.56), indicative of yellow tones, to negative values in both supplemented samples, confirming the loss of yellow coloration and dominance of purple–red tones derived from chokeberry pigments. The redness parameter (a*) rose sharply from 1.09 in the control to 12.27 and 13.66 in WCBP1 and WCBP2, respectively, while the yellowness parameter (b*) changed from a strongly positive value (13.56) in the control to negative values (–0.96 and –0.62). This shift places the pomace-supplemented cheeses within Quadrant IV of the CIELab color space (+a, –b), which corresponds to red–bluish hues, in contrast to the yellowish tones of the control.

Chroma values decreased slightly in WCBP1 but were restored in WCBP2, suggesting more intense and saturated colors at higher supplementation. Similarly, the hue angle shifted from 1.49 in the control to approximately 360° in the supplemented cheeses, reflecting the transition from yellowish tones to a red-dominated hue. The total color difference (ΔE) between the control and supplemented cheeses was very high, reaching 42.18 for WCBP1 and 55.97 for WCBP2, confirming that pomace incorporation induced visually perceptible and substantial color modifications. Overall, these results indicate that chokeberry pomace supplementation strongly enhances the red coloration of cheese, with higher addition levels producing more intense pigmentation but also leading to darker and less luminous products.

Sensory evaluation scores of control and BCP-supplemented Cheeses. Figure 1 illustrates the mean values of the sensory scores. The sensory evaluation demonstrated that the incorporation of dried black chokeberry pomace improved most quality attributes of the cheese compared to the control. In terms of appearance, odour, aroma, and taste, the sample with moderate supplementation (WCBP1) consistently achieved the highest scores, suggesting that a balanced level of pomace addition enhanced overall sensory perception without overpowering the product.

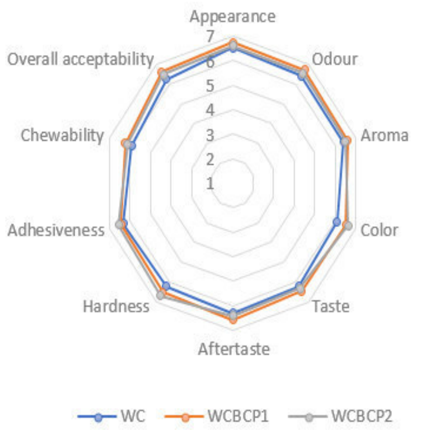

Figure 1. **Comparative diagram of the sensory attributes specific to analyzed cheeses**

Color was markedly improved in both supplemented cheeses (Figure 2), with the highest value observed for WCBP2, reflecting the strong pigmentation potential of chokeberry pomace. Textural attributes also benefited from pomace incorporation, as hardness and adhesiveness were most pronounced in WCBP2, while chewability reached its optimum in WCBP1. Regarding aftertaste, both enriched samples outperformed the control, with WCBP1 again recording the best score. Overall acceptability followed the same trend, with WCBP1 being the most preferred cheese, indicating that moderate supplementation offered the most favorable balance across sensory attributes. By contrast, the higher pomace concentration (WCBP2) enhanced visual and structural properties but slightly diminished flavour-related acceptance, reflecting the trade-off between nutritional enrichment and sensory preference. The incorporation of dried black chokeberry pomace improved most sensory attributes compared to the control. WCBP1 (moderate addition) achieved the highest scores across odour, aroma, taste, aftertaste, chewability, and overall acceptability, suggesting it represents the optimal supplementation level. WCBP2 (higher addition) particularly enhanced color, hardness, and adhesiveness, though with a slight reduction in taste- and aroma-related attributes. Mileriené *et al.* (2021) employed liquid whey protein, a common by-product of the dairy industry, to develop an edible coating enriched with 0.3% Chinese cinnamon extract aimed at extending the shelf life of Eastern European curd cheese. Application of the coating effectively enhanced the color and appearance of the cheese, while leaving its sensory attributes unaffected. Overall, chokeberry pomace enhances both visual and functional sensory properties of cheese, with moderate levels being most consumer-preferred.

Figure 2. **Cheese samples with different percentages of BCP: WC (control), 10% (WCBCP1), and 20% (WCBCP 2)**

CONCLUSIONS

The present study demonstrated that the incorporation of dried black chokeberry pomace into whey cheese significantly enhanced its nutritional, functional, and sensory properties. The pomace-supplemented cheeses exhibited markedly higher levels of anthocyanins, flavonoids, and total polyphenols compared to the control, which translated into improved antioxidant capacity as confirmed by DPPH and ABTS assays. Instrumental color analysis revealed a clear shift from the light-yellow tones of the control to the red-purple hues of supplemented cheeses.

Incorporation of dried black chokeberry pomace into whey cheese led to a marked increase in dry matter, fiber, minerals, and carbohydrate contents, while simultaneously enhancing the cheese's color, texture, and overall phytochemical profile. Sensory evaluation further confirmed the potential of chokeberry pomace as a value-adding ingredient. Moderate supplementation (WCBP1) yielded the highest scores for odor, aroma, taste, aftertaste, chewability, and overall acceptability, suggesting that this concentration provided the most balanced improvement without negatively impacting flavor.

Overall, these findings highlight dried black chokeberry pomace as a promising functional ingredient for the dairy industry, offering both nutritional enrichment and sensory enhancement while contributing to sustainable by-product utilization. Future research should further explore consumer acceptance, shelf-life stability, and the bioavailability of chokeberry-derived bioactive compounds in dairy matrices.

REFERENCES

Abd Elhamid, A.M. 2016 - *Physicochemical, Rheological and Sensory Properties of Egyptian Kariesh Cheese Containing Wheat Bran*. International Journal of Dairy Technology, 69 (3), 425–432. https://doi.org/10.1111/1471-0307.12278

AOAC International. Official Methods of Analysis, 17th ed.; AOAC International: Rockville, Maryland, 2000.

Cacak-Pietrzak G.; Dziki D.; Gawlik-Dziki U.; Parol-Nadłonek N.; Kalisz S.; Krajewska A.; Stępniewska S. 2023 - *Wheat Bread Enriched with Black Chokeberry (Aronia melanocarpa L.) Pomace: Physicochemical Properties and Sensory Evaluation*. Applied Sciences, 13 (12), 6936. https://doi.org/10.3390/app13126936

Dag D.; Kilercioglu M.; Oztop M.H. 2017 - *Physical and Chemical Characteristics of Encapsulated Goldenberry (Physalis peruviana L.) Juice Powder*. Lebensm. Wiss. Technol., 83, 86 − 94.

Dodan A.; Marc R.A.; Mureşan C.C.; Pop C.R.; Michiu D.; Filip M.R.; Muntean M.V. 2025 - *Nutritional and Microbiological Properties of Cheese with Dried Elderberry and Red Grape Pomace*. Turkish Journal of Agriculture and Forestry, 49 (1), 125 − 140.

Gaglio, R.; Barbaccia, P.; Barbera, M.; Restivo, I.; Attanzio, A.; Maniaci, G.; et al. 2021 - *The Use of Winery By-Products to Enhance the Functional Aspects of the Fresh Ovine "Primosale"* Cheese. Foods, 10 (2), 461. https://doi.org/10.3390/foods10020461

Gavril (Rațu) R. N., P. M., Carlescu, I. D., Veleșcu, V. N., Arsenoaia, F., Stoica, N. Stanciuc, I. Aprodu, O. E., Constantin, G. Rapeanu 2024- *The development of value-added yogurt based on pumpkin peel powder as a bioactive powder,* Journal of Agriculture and Food Research, 16, 101098.

ISO 13299. 2016 - *Sensory Analysis, Methodology—General Guidance for Establishing a Sensory Profile*. International Organization for Standardization (ISO), Geneva, Switzerland.

Jurendic T.; Ščetar M. 2021 - *Aronia melanocarpa Products and By-Products for Health and Nutrition: A Review*. Antioxidants, 10, 1052.

Lucera, A.; Costa, C.; Marinelli, V.; Saccotelli, M.; Del Nobile, M.; Conte, A. 2018 - *Fruit and Vegetable By-Products to Fortify Spreadable Cheese*. Antioxidants, 7 (5), 61. https://doi.org/10.3390/antiox7050061

Martins M.S.; Gonçalves A.C.; Alves G.; Silva L.R. 2023 - *Blackberries and Mulberries: Berries with Significant Health-Promoting Properties*. International Journal of Molecular Sciences, 24, 12024.

Mileriene, J.; Serniene, L.; Kondrotiene, K.; Lauciene, L.; Kasetiene, N.; Sekmokiene, D.; et al. 2021 - *Quality and Nutritional Characteristics of Traditional Curd Cheese Enriched with Thermo-Coagulated Acid Whey Protein and Indigenous Lactococcus lactis Strain*. International Journal of Food Science and Technology, 56 (6), 2853–2863. https://doi.org/10.1111/IJFS.14922

Raczkowska E.; Nowicka P.; Wojdyło A.; Styczyńska M.; Lazar Z. 2022 - *Chokeberry Pomace as a Component Shaping the Content of Bioactive Compounds and Nutritional, Health-Promoting (Anti-Diabetic and Antioxidant) and Sensory Properties of Shortcrust Pastries Sweetened with Sucrose and Erythritol*. Antioxidants, 11, 190.

Repajić M.; Zorić M.; Magnabosca I.; Pedisić S.; Dragović-Uzelac V.; Elez Garofulić I. 2025 - *Bioactive Power of Black Chokeberry Pomace as Affected by Advanced Extraction Techniques and Cryogrinding.* Molecules, 30 (16), 3383. https://doi.org/10.3390/molecules30163383

Saracila M.; Untea A.E.; Oancea A.G.; Varzaru I.; Vlaicu P.A. 2024 - *Comparative Analysis of Black Chokeberry (Aronia melanocarpa L.) Fruit, Leaves, and Pomace for Their Phytochemical Composition, Antioxidant Potential, and Polyphenol Bioaccessibility***.** Foods, 13 (12), 1856**.** https://doi.org/10.3390/foods13121856

Sarv V.; Venskutonis P.R.; Rätsep R.; Aluvee A.; Kazernavičiūtė R.; Bhat R. 2021 - Antioxidants Characterization of the Fruit, Juice, and Pomace of Sweet Rowanberry (*Sorbus aucuparia* L.) Cultivated in Estonia. *Antioxidants*, **10**, 1779.

Sidor A.; Gramza-Michałowska A. 2019 - *Black Chokeberry Aronia melanocarpa L.—A Qualitative Composition, Phenolic Profile and Antioxidant Potential*. Molecules, 24, 3710.

Stoica, F., Rațu, R. N., Lipșa, F. D., Motrescu, I., Cara, I. G., Rapeanu, G., Jităreanu, G. 2024 -. *Exploitation of red beet peel powder as a natural food ingredient in whey-fruit based beverage*. International Journal of Food Properties, 27(1), 44-67.

Tamkutė L.; Vaicekauskaitė R.; Gil B.M.; Rovira Carballido J.; Venskutonis P.R. 2021 - *Black Chokeberry (Aronia melanocarpa L.) Pomace Extracts Inhibit Food Pathogenic and Spoilage Bacteria and Increase the Microbiological Safety of Pork Products.* Journal of Food Processing and Preservation, 45 (3), e15220.

Tarchi I.; Boudalia S.; Ozogul F.; Câmara J.S.; Bhat Z.F.; Hassoun A.; Aït-Kaddour A. 2024 - *Valorization of Agri-Food Waste and By-Products in Cheese and Other Dairy Foods: An Updated Review*. Food Bioscience, 58, 103751.

EVALUATION OF FOOD SAFETY IN A WHEY-BASED FERMENTED PRODUCT

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Abstract
Although long considered a by-product of cheesemaking, whey has been proven by this study to be a resource with high nutritional and functional value. Its utilization in the form of a fermented beverage, plain or enriched with elderberry extract, has been confirmed as an efficient strategy both technologically and sensory-wise. The study confirmed the potential of acid whey as a substrate for functional fermented beverages, with physicochemical values showing a low pH (4.45 ± 0.00), high titratable acidity and a nutritional composition characterized by 1.02% protein, 3.74% lactose and 0.72% ash. Microbiological analyses showed a low microbial load (NTG ~2×10^4 UFC/mL), below the limit set by EC Regulation no. 1441/2007, and the absence of E. coli and coliform bacteria colonies confirmed the safety of the sample. From a sensory point of view, the variants with the addition of elderberry extract were the best appreciated, due to their balanced taste, natural aroma and pleasant appearance. The results obtained indicate that fermented whey beverages can be classified as safe, nutritious and attractive products, with potential for use in the functional food industry and within the circular economy.

Keywords: whey, fermented product, food safety

Functional foods and beverages constitute a highly inventive and dynamic sector within the food industry, attracting increasing consumer attention due to their health benefits that extend beyond basic nutrition (Corbo *et al.,* 2014).

As consumers become increasingly aware of the special characteristics and, above all, the health benefits of fermented milks, the dairy industry is challenged to manage the large-scale production of these products in a sustainable way, without compromising the technological and functional qualities that define the traditional products from which they are derived. Whey and its constituents are increasingly used as functional ingredients in foods and nutritional goods, while bioactive proteins are facing increased demand in the pharmaceutical and food sectors (Jelicic, 2008). To date, research has focused on the formulation of sweet-sour whey beverages, whether native or powdered, delactosized or deproteinized (Skryplonek *et al.,* 2019).

As the dairy industry continues to develop and produce large volumes of whey, its intelligent valorization becomes increasingly important. Beyond the challenges related to its management, whey offers considerable potential in the development of functional food products, including fermented whey-based beverages. These have gained increased interest due to their nutritional properties, their ability to support the development of a probiotic microbiota and their technological versatility.

Whey is the liquid component, known as cheese whey, which is derived from the separation of the curd during milk coagulation by enzymes or proteolytic acids. (Buchanan *et al.,* 2023). Approximately 80–90% of milk processed in cheese factories is converted into whey, resulting in an estimated global production of 180–190 million tonnes of waste, of which 100 million tonnes is whey annually (Chandrapala *et al.* 2015; Flinois *et al.,* 2019). Currently, the reuse rate of whey in Europe exceeds 75%, but in other regions of the world it is only 50%, highlighting the waste of a product with high nutritional value.

Whey can be used both as a functional ingredient in food and as animal feed (Macwan *et al.,* 2016). Fermented foods, obtained by the controlled growth of microorganisms and enzymatic conversion of food components, represent one of the main sources of food globally, contributing to approximately one third of the human diet (Terpou *et al.,* 2025).

The fermentation of whey with lactic acid bacteria modifies its structural and biochemical profile, leading to the generation of bioactive peptides with functional roles in immunity, oxidative balance, gut microbiota composition, and

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the regulation of hypertension and inflammation (Marco *et al.,* 2017). Fermented whey beverages represent complex microbial ecosystems shaped by the lactic substrate, processing conditions, and the inoculated microorganisms. Unprocessed whey retains a diverse microbiota originating from both the raw milk and the processing environment, including lactic acid bacteria, wild yeasts, micrococci, and occasionally coliforms or bacterial spores (Pescuma *et al.,* 2010). Modern fermentation technologies address this by combining pasteurisation with selective inoculation, resulting in a controlled microbial community dominated by beneficial bacteria.

The research aims to validate the functional potential of the beverage, in line with current trends in the food industry, focusing specifically on microbiological stability and the ability to provide a safe, viable food adapted to the needs of responsible and modern consumption.

MATERIAL AND METHOD

In this study, both the raw material whey and the fermented beverage obtained as follows were analyzed: a control sample of whey without the addition of elderberry syrup and two samples of fermented whey, obtained by adding elderberry syrup in quantities of 5 mL and, respectively, 10 mL. The investigations included both physicochemical and microbiological analyses.

Microbiological and physicochemical determinations were performed on the whey used as raw material. The physicochemical determinations focused on parameters such as density, pH, titratable acidity, volatile acidity, alcoholic strength, sugar content and dry matter content.

The microbiological analyses aimed to quantify the total number of bacteria, as well as to identify and enumerate coliform bacteria and the species *Escherichia coli.*

The total bacterial count in the control whey and in the fermented beverages was determined by the serial dilution method, based on the identification of viable mesophilic aerobic bacteria capable of developing on specific culture media at temperatures of 30–37 °C. Additionally, simple Gram staining was performed to confirm cellular morphology.

The determination of coliform bacteria and E. coli was carried out using the chromogenic medium RAPID'E. coli 2 Agar (Bio-Rad). The medium was prepared by suspending 37 g of powder/L in 1000 mL of distilled water, followed by sterilisation at 121 °C for 15 minutes in an autoclave. After cooling, the medium was poured into sterile Petri dishes and used for the enumeration of total coliforms and *E. coli* in the analysed samples.

Figure 1. **Sampling and performing successive dilutions**

Figure 2. **Appearance during inoculation by the Spread Plate Technique**

The physico-chemical analyses were performed using standard analytical procedures, in compliance with the relevant regulations and methodological guidelines established by the Association of Official Analytical Chemists (AOAC, 2010) and (Gavril *et al.* 2024).

The technological process carried out within the dairy microproduction workshop began with the collection of fresh whey, followed by its defatting through the separation of fat using a centrifugal separator. The raw material was subsequently subjected to pasteurisation and an additional centrifugation step to ensure the complete removal of lipids, in accordance with the objective of obtaining a fat-free final product.

Figure 3
pH determination

Figure 4
Creamed whey

Next, the whey was heated to approximately 30 °c to provide optimal conditions for the inoculation of selected yeasts. Following this thermal treatment, the whey was gradually cooled to room temperature and left to rest overnight, an essential step for the complete sedimentation of protein fractions, which were subsequently removed by filtration through sterile cheesecloth.

To adjust the flavour profile and improve fermentability, an invert sugar syrup (50%) was added. The composition of this syrup included 20% water, while sugar and citric acid accounted for 2% of the total whey–sugar mass, with the proportions measured precisely.

Primary fermentation was initiated by inoculating the mixture with 6.3 g of active culture of *Saccharomyces cerevisiae bayanus* per 9 l of whey. The yeast was activated in 100 ml of syrup at 26 °c to prevent thermal inactivation, thereby obtaining an active starter culture distributed uniformly throughout the whey. The inoculum was prepared by adding 1% sugar to a volume of filtered whey, followed by incubation at 25 °c for 48 hours.

The inoculated mixture was fermented at 22 °c for 14 days, during which the yeast partially metabolised the available sugars, generating carbon dioxide and aromatic compounds. At the end of primary fermentation, the beverage was bottled, leaving a headspace of approximately 5% for gas accumulation, and sealed with crown cork caps.

Figure 5 **The primary fermentation process**

Secondary fermentation, champagne-type (in bottle), was performed by adding two different concentrations of elderberry syrup, adjusted according to the previously determined sugar content, so that the final product did not exceed 17 g/l of sugars. Specifically, 5 ml (z5) and 10 ml (z6) of diluted elderberry syrup were added, while the control sample (z4) contained no syrup. The yeast was reactivated (0.66 g for the remaining whey volume) under the same rehydration conditions.

In total, nine bottles of fermented beverage were obtained: three with 5 ml elderberry syrup, three with 10 ml, and three control bottles (yeast only). These samples were subsequently subjected to physico-chemical, microbiological, and sensory analyses in order to achieve a comprehensive characterisation of the final product.Carbonation of the beverage was achieved naturally, through the fermentation of residual sugars by yeast. The samples were coded as follows: *Z1* – raw whey, *Z2* – inoculated whey, *Z3* – post-primary fermentation whey, *Z4* – control sample (without elderberry syrup), *Z5* – whey with 5 mL elderberry syrup, *Z6* – whey with 10 mL elderberry syrup

Figure 6 **The fermented beverage samples**

The physico-chemical examinations of the fermented beverage were carried out in the Oenology Laboratory to establish key quality indicators. Analyses were conducted in accordance with OIV standards and national regulations.

Determination of alcohol content- Alcohol strength, expressed as % v/v at 20 °C, quantifies the ethanol concentration. The method involves neutralisation with calcium hydroxide, distillation using the Dujardin-Salleron apparatus, and measurement of the distillate with an alcoholmeter.

Determination of density-Density was assessed with a hydrostatic balance based on Archimedes' principle, representing the ratio of mass to volume of the beverage at 20 °C, expressed in g/cm³.

Determination of titratable acidity- Acidity was determined by titration with standardised NaOH, using bromothymol blue as indicator after CO_2 removal. The endpoint corresponds to a stable blue-green hue, in line with STAS 6128/1-79.

Determination of volatile acidity- Volatile acidity, mainly from acetic acid and its salts, was quantified by distillation of the sample acidified with tartaric acid, followed by titration of the distillate with 0.1 N NaOH using phenolphthalein as indicator (STAS 6182/2-86).

Determination of reducing sugars- Reducing sugars (glucose, fructose, lactose, maltose, invert sugar) were evaluated refractometrically, by measuring the refractive index of the solution.

The colour analysis of the fermented beverage samples was carried out using a Konica Minolta Chroma Meter CR-410, applying a D50 illuminant, a 2° standard observer, and the CIE L*, a*, b* colour space parameters were analysed following the procedure described by Dag *et al.* (2017).

Determination of sensory quality- Sensory evaluation was conducted after 24 h of cold stabilisation by a trained panel of 15 assessors, in accordance with ISO 22935-1 and ISO 8586-1 standards.

RESULTS AND DISCUSSIONS

In order to evaluate the quality of whey, a series of physico-chemical parameters were analysed. The pH was 4.45 ± 0.00, indicating the pronounced acidity of acid whey, while density was 1.025 ± 0.02 g/cm³, consistent with fresh whey and suggesting a moderate level of lactose and salts with good digestibility.

Table 1

Physico-chemical parameters of whey

Parameters	Value
pH	4.45±0.00
Density g/cm^3	1.025±0.02
Water, %	93.51±0.00
Non-fat dry matter, %	6.47±0.06
Dry matter %	6.48±0.05
Fat, %	0.01±0.01
Protein, %	1.02±0.02
Ash, %	0.72±0.00
Lactose	3.74±0.00
Titrable acidity (g/L acid lactic)	10.60±0.05

Water content reached 93.51 ± 0.00%, underlining the aqueous nature of whey and the need for preservation methods such as pasteurisation or fermentation. Total dry matter was 6.48 ± 0.05%, very close to the fat-free dry matter of 6.47 ± 0.06%, showing negligible fat content. Indeed, fat accounted for only 0.01 ±

0.01%, confirming its classification as skimmed whey, suitable for dietary applications.

Proteins were present at 1.02 ± 0.02%, mainly α-lactalbumin and β-lactoglobulin, known for their high biological value and digestibility. Ash content was 0.72 ± 0.00%, reflecting an adequate supply of essential minerals, while lactose, at 3.74 ± 0.00%, dominated the dry matter, contributing both to energy value and fermentation potential.

Titratable acidity averaged 10.6 ± 0.05 g lactic acid/L, reinforcing the acidic character and offering insight into freshness and fermentation status. Together, these findings define the specific profile of acid whey and highlight its potential as a valuable raw material for functional and fermented food production.

As shown in *table 2,* NTG values for the control whey (Z1) and yeast-inoculated sample (Z2) ranged between 16.63 × 10^3 and 21.68 × 10^3 CFU/mL, remaining well below the maximum permitted limit of 100,000 CFU/mL set by Regulation (EC) No. 1441/2007. After the onset of fermentation (Z3), NTG values stabilised at ~19 × 10^3 CFU/mL. With further fermentation (Z4–Z6), a sharp reduction was recorded, reaching minimum values of 3.5 × 10^2 CFU/mL. These results indicate effective process control and confirm the improved microbiological stability of the final fermented whey products.

Table 2

Results regarding the total number of germs in the analyzed samples

Sample	Sample	Dilution	NTG		Conclusion Reg. 1441/2007 of the Commission in 05/12/2007
			PCA	GPCA	
Z1	Whey control	10^{-1}	-	21.68x10^3	Satisfactorily
		10^{-2}	-	19.99x10^3	
Z2	Whey inoculated with yeast	10^{-1}	-	20.59x10^3	Satisfactorily
		10^{-2}	-	16.63x10^3	
Z3	Whey after first fermentation	10^{-1}	19.05x10^3	-	Satisfactorily
		10^{-2}	18.95x10^3	-	
Z4	Fermented whey	10^{-1}	8.55x10^3	-	Satisfactorily
		10^{-2}	8.15x10^2	-	
Z5	Fermented whey+5 ml syrup	10^{-1}	8.25x10^2	-	Satisfactorily
		10^{-2}	8.10x10^2	-	
Z6	Fermented whey+10 ml syrup	10^{-1}	4.15x10^2	-	Satisfactorily
		10^{-2}	3.50x10^2	-	

From a microbiological perspective, the use of a chromogenic medium ensured both sensitivity and specificity in detecting potential contaminants, while its application alongside standard decimal dilutions allowed for precise quantification. The results (Figure 5) showed a complete absence of *Escherichia coli* and coliforms across all samples (Z1–Z6), regardless of the technological stage. The control whey (Z1) exhibited no faecal contamination, confirming the quality of the raw material, and inoculation with yeast cultures (Z2) did not alter this profile. Similarly, the fermentation stages (Z3–Z6), including syrup addition, revealed no microbial risk.

These findings highlight the effectiveness of hygienic control throughout processing and confirm compliance with Regulation (EC) No. 2073/2005. The constant absence of coliforms and *E. coli* indicates that the fermented whey beverages meet safety standards and can be considered suitable functional products with minimal microbiological risk, supporting their integration into the category of health-promoting foods.

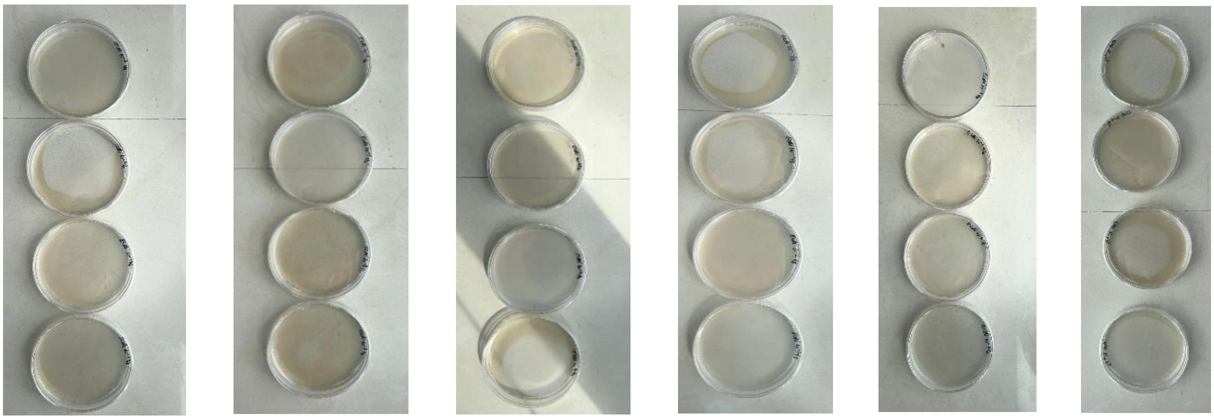

Figure 5 **Rapid *E-coli* medium inoculated with control whey (Z1), whey inoculated with yeast (Z2) and whey after the two fermentations (Z3,Z4,Z5,Z6) to highlight the possible presence of the *E. Coli* species. The results were negative (original photo)**

Table 3 presents the results obtained for the physico-chemical parameters of the fermented beverage with the addition of elderflower syrup. The density shows only minor variations, increasing gradually from 0.983 g/cm³ in Z4 to 0.991 g/cm³ in Z6, a change attributable to the incorporation of syrup, which contributes to higher dissolved solids and residual fermentation metabolites.

Table 3

Physico-chemical results of fermented whey beverage with added elderberry

Sample	pH	Density at 20 °C	Titratable acidity (g/L tartaric acid)	Volatile acidity (g/L acetic acid)	Alcohol concentration, %	Non-reducing sugars
Z4	4.00±0.01	0.98±0.03	8.50±0.01	0.62±0.01	2.30±0.04	5.50±0.5
Z5	3.79±0.1	0.98±0.2	8.80±0.12	0.57±0.02	3.30±0.06	4.19±0.01
Z6	3.8±0.12	0.99±0.1	9.10±0.3	0.50±0.04	3.80±0.01	3.50±0.07

Titratable acidity, expressed as g tartaric acid/L, increased slightly from 8.50 g/L in Z4 to 9.10 g/L in Z6, indicating intensified fermentative activity and the presence of organic acids derived from both fermentation and the acidic compounds of the syrup. Conversely, volatile acidity decreased with the increasing syrup concentration (0.62 g/L in Z4 to 0.50 g/L in Z6), suggesting a moderating effect of bioactive compounds from elderflower syrup on volatile acid production, particularly acetic acid. Alcohol concentration displayed a distinct upward trend, rising from 2.3% vol. in Z4 to 3.8% vol. in Z6, fully consistent with the additional fermentable carbohydrates supplied by the syrup. Non-reducing sugars decreased significantly from 5.5 g/L in Z4 to 3.5 g/L in Z6, confirming their consumption during alcoholic fermentation by Saccharomyces cerevisiae.

The pH decreased marginally from 4.0 (Z4) to 3.8 (Z6), indicating gradual acidification due to organic acid generation, while remaining within the acceptable range for fermented beverages and enhancing microbiological stability.

Overall, the incorporation of elderflower syrup positively influenced the fermentation process by increasing alcohol content and reducing residual sugars, while maintaining acid–base balance and ensuring the stability of the final product.

Table 4 presents the colour parameters (CIE L*, a*, b*) of fermented whey samples supplemented with elderflower syrup.

Table 4

Color parameter results

Sample	L*	a*(D65)	b*(D65)
Z4	66.21	-5.54	12.19
Z5	65.27	-5.33	11.20
Z6	66.38	-5.49	11.74

The lightness values (L*) remained relatively constant, ranging between 65.27 (Z5) and 66.38 (Z6), indicating minimal variation in brightness across samples. The a* values were consistently negative (from –5.54 to –5.33), reflecting the greenish hue characteristic of whey, with only slight shifts following syrup addition. Similarly, the b* coordinate showed positive values (11.20–12.19), confirming the presence of yellow tones, with minor reductions observed in the syrup-enriched variants compared to the control. Overall, the incorporation of elderflower syrup produced subtle changes in chromatic attributes, without significantly altering the visual profile of the fermented whey.

The quality of fermented whey beverages is closely linked to their sensory profile. In the interpretation of the results obtained from the sensory evaluation of the control sample (Z4) and those supplemented with elderflower syrup (Z5 and Z6), significant differences can be observed.

Figure 6 **Comparative sensory profile of fermented whey beverages**

Figure 6 shows that the control sample recorded lower and more uniform scores, with a simpler profile in terms of colour, aroma, and taste. In contrast, highlights that the beverage enriched with 10% elderflower syrup (Z6) obtained the highest ratings for colour, clarity, aroma, and overall acceptability, reflecting the positive contribution of the syrup.

The intermediate sample (Z5) achieved scores between the two extremes, indicating a proportional improvement in visual and flavour attributes. The control sample was appreciated for its stability, but it lacked aromatic richness and balance. Overall, Z6 scored highest, reflecting enhanced sensory qualities and confirming the innovation brought by the addition of elderflower syrup.

CONCLUSIONS

In conclusion, the present research highlights and validates the high potential of whey, from both a technological and nutritional perspective, as a valuable substrate for the development of functional fermented beverages. This approach supports the sustainability of the food industry, contributes to the advancement of the circular economy, and promotes the intelligent conversion of a by-product into a value-added food, aligned with contemporary trends in nutrition and public health.

REFERENCES

AOAC (2010) Official Methods of Analysis of Association of Official Analytical Chemists. 18th Edition, Washington, DC.

Buchanan, D., Martindale, W., Romeih, E., & Hebishy, E. (2023). Recent advances in whey processing and valorisation: Technological and environmental perspectives. *International Journal of Dairy Technology*, 76(1), 5–20. https://doi.org/10.1111/1471-0307.12935

Chandrapala, J., & Leong, T. (2015). Ultrasonic processing for dairy applications: Recent advances. Food Engineering Reviews, 7(2), 143–158.SCIRP

Corbo, M. R., Bevilacqua, A., Petruzzi, L., Casanova, F. P., & Sinigaglia, M. (2014). Functional beverages: The emerging side of functional foods: Commercial trends, research, and health implications. *Comprehensive Reviews in Food Science and Food Safety*, *13*(6), 1192–1206. doi:10.1111/1541-4337.12109

Dag D.; Kilercioglu M.; Oztop M.H. 2017 - *Physical and Chemical Characteristics of Encapsulated Goldenberry (Physalis peruviana L.) Juice Powder*. Lebensm. Wiss. Technol., 83, 86 − 94.

Flinois, J. C., Dando, R., & Padilla-Zakour, O. I. (2019). Effects of replacing buttermilk with yogurt acid whey in ranch dressing. Journal of Dairy Science, 102(5), 3896–3905.ScienceDirect

Gavril (Rațu) R. N., P. M., Carlescu, I. D., Veleșcu, V. N., Arsenoaia, F., Stoica, N. Stanciuc, I. Aprodu, O. E., Constantin, G. Rapeanu 2024- *The development of value-added yogurt based on pumpkin peel powder as a bioactive powder,* Journal of Agriculture and Food Research, 16, 101098.

Jeličić, I., Božanić, R., & Tratnik, L. (2008). Whey-based beverages: A new generation of dairy products. Mljekarstvo, 58(3), 257–274.journals.acspublisher.com+2PMC+2Academia+2

Lipșa F.D., Ulea E., 2018. *Practicum de Microbiologie Alimentară*. Editura *„Ion Ionescu de la Brad”*, pp. 38-61. Iași

Macwan, S. R., et al. (2016). Whey and its utilization: A review. International Journal of Current Microbiology and Applied Sciences, 5(8), 134–155.ijcmas.com

Marco, M. L., et al. (2017). Health benefits of fermented milk and whey: A review. Journal of Dairy Science, 100(12), 991–1003.

Pescuma, M., et al. (2010). Fermentation of whey with lactic acid bacteria: A review. International Journal of Dairy Technology, 63(3), 1–10.

Terpou, A., Dahiya, D., & Nigam, P. S. (2025). Evolving Dynamics of Fermented Food Microbiota and the Gut Microenvironment: Strategic Pathways to Enhance Human Health. *Foods*, *14*(13), 2361. https://doi.org/10.3390/foods14132361

Skryplonek, K., Dmytrów, I., & Mituniewicz-Małek, A. (2019). Probiotic fermented beverages based on acid whey. *Journal of Dairy Science*, *102*(9), 7773–7780. doi:10.3168/jds.2019-16385.

Consilier editorial: Vasile VÎNTU

Tehnoredactori: Cătălin CIOBOTARU, Tiberiu Emilian SARBU, Bianca BALINT

Corector: Iulian GABUR

Bun de tipar: 30.11.2025

Apărut: decembrie 2025. Format 210x297

Editura: ,,Ion Ionescu de la Brad'' Iaşi
Aleea M. Sadoveanu nr. 3, 700490
Tel. 0232-218300; fax 0232-260650
E-mail: editura@uiasi.ro

ISSN: 1454-7414

PRINTED IN ROMANIA

Tipar Digital realizat la **Tipografia PIM**
Şoseaua Ştefan cel Mare nr. 11
Iaşi – 700498
Tel./fax: **0232-212740**
e-mail: editurapim@pimcopy.ro
www.pimcopy.ro

Editorial Consultant: Vasile VÎNTU

Technical Editors: Cătălin CIOBOTARU, Tiberiu Emilian SARBU, Bianca BALINT

Reader: Iulian GABUR

Imprimatur: 30.11.2025

Published: December 2025. Format 210x297

Publishing House: “Ion Ionescu de la Brad’’ Iaşi

Aleea M. Sadoveanu nr. 3, 700490
Tel. 0232-218300; fax 0232-260650
E-mail: editura@uiasi.ro

ISSN: 1454-7414

PRINTED IN ROMANIA

PIM Digital Printing Press
Şoseaua Ştefan cel Mare nr. 11
Iaşi – 700498
Tel./fax: **0232-212740**
e-mail: editurapim@pimcopy.ro
www.pimcopy.ro