CHANGES IN METABOLIC EFFICIENCY DURING CORN SEED GERMINATION

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Abstract

Plant growth can be defined as an irreversible process of increasing size and biomass, often associated with the formation of new structures: root and shoot growth is a complex multistage biochemical and physiological process. The purpose of this study was to evaluate changes in the metabolic efficiency of corn seeds during ten days of their germination. The objects of the study were seeds of corn hybrids P280, P398 and P402, which have different ripening periods and differ in endosperm structure. The metabolic efficiency of seeds was determined after 5, 7 and 10 days of germination under optimal conditions. The maximum content of reserve substances utilized for germination and root/shoot growth was observed during 5-7 days of seed germination. Moreover, for two hybrids (P398 and P402) it was necessary to germinate for 7 days to achieve the highest metabolic efficiency, but hybrids P280 had the maximum metabolic efficiency on the 5th day. After this period the metabolic efficiency of seeds decreased. The obtained results can be used to change the methodological approaches to the comparative determination of metabolic efficiency of corn seeds of various hybrids.

Key words: corn seed, germination, metabolic efficiency

Germination of corn seeds, like that of all plants, is a complex multifunctional process. Seeds that have a high degree of germination are usually more resistant to various adverse environmental conditions, infection by pathogenic microorganisms, and are characterized by high growth and development speed. The higher the ability of a plant to produce metabolic products necessary for life, the wider the reaction norm of a given plant and the better its ability to adapt. These properties are especially important for food grade corn hybrids, as they are more demanding in terms of cultivation conditions (Jiang F. *et al*, 2023).

Plant growth can be defined as an irreversible process of increasing size and biomass, often associated with the formation of new structures. The growth of roots and seedlings is a complex multi-stage biochemical and physiological process from the point of view of physiology. In order to provide the plant embryo, cells with a sufficiently high amount of energy, complex oxidative reduction reactions and an increase in the efficiency of using reserve substances for seed germination or metabolic efficiency must occur in the plant. Resumption of metabolic activity and mobilization of reserves are key steps to maintain seedling and root growth before photosynthetic mechanisms are activated (Rosental L. *et al,* 2014).

The initial stages in seed development, which affect its subsequent sowing qualities, are the foundation for building the life of a plant; these are, in a way, critical points, the indicators of which will indicate the survival of the species and the plant's resistance to various abiotic factors (Grzesik M., Romanowska-Duda Z., 2014; Meng A. *et al,* 2022). Therefore, it is necessary to learn much more about the key processes associated with seed germination.

The standard method of International Seed Testing Association (ISTA) prescribed the germination of corn seeds during seven days (ISTA, 2017). Earlier, the metabolic efficiency of various hybrids of corn was investigated after 7th day of seeds germination according to international rules (Ivanova R. *et al,* 2022; Borovskaia A. *et al,* 2023). It is known well that under ideal conditions of temperature and soil moisture corn germinates in 7-10 days. However, Grzesik M., Romanowska-Duda Z. (2014) and Omar S. *et al,* (2022) showed that the dynamics of corn seed germination under optimal laboratory conditions reaches its maximum on the 5th day. Sikder S. *et al*, (2009) also determined the metabolic efficiency of corn at 5th

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day after seeds placement for germination. No observations of changes in metabolic efficiency by days of corn seed germination were found.

This study examined changes in root/shoot vigour and metabolic efficiency of food-grade corn seeds at different time during germination using hybrid seeds containing various amount of starch and protein in the grain.

MATERIAL AND METHOD

The experiments were carried out in 2024 in laboratory conditions in the Institute of Genetics, Physiology and Plant Protection, Moldova State University, Republic of Moldova.

Seed materials. The seeds of food-grade corn hybrids were generously contributed by the National Center for Seed Research and Production, Institute of Crop Science „Porumbeni". The hybrids have different ripening periods and differ in the structure of the endosperm, namely:

a) Porumbeni 280su (P280) is medium-season hybrid of sweet corn, FAO 300. In the phase of technical maturity, the grain contains 14.0% total sugar and 31.4% starch. It is distinguished by a large wrinkled angular grain consisting of a floury endosperm.
b) Porumbeni 398 (P398) is medium-early hybrid corn that belongs to the popcorn group, FAO 400. The grain has a siliceous consistency and is characterized by a high specific gravity of vitreous endosperm. The floury part of the endosperm is present only near the embryo. The grain has a high protein content (16%).
c) Porumbeni 402 (P402) is medium-late dent-flint hybrid of corn, FAO 400. The endosperm on the sides of the grain is horn-shaped, in the center and top it is mealy and loose. Corn is the most widespread among other groups. The grain contains 70-75% starch, up to 15% protein and 3-6% fat.

The weight of 1000 seeds of the P280 hybrid were 142.1±4.3 g; of P398 – 157.8±8.3 g; and of P402 – 279.3±7.6 g.

Laboratory testing. Each experiment consisted of 100 seeds (25 seeds on 4 replicates). Vigour and metabolic efficiency determination procedure included following steps:

a) germination of seeds in optimal conditions. Index of total germination was determined on the fifth, seventh and tenth days;
b) measure of roots and shoots length of germinated seeds;
c) vigour I of roots and vigour II of shoots were determined as the common value of the germination percentage and the length of roots and shoots, respectively (Kerecki S. *et al*, 2021);
d) separation of roots and shoots from seeds;
e) drying of biomass (separated roots, shoots, seeds);
f) determination of dry biomass weight;
g) calculation of reserve substances (SMR, g/unit) mobilized from seeds for energetic support of physiological processes of germination as follows:

SMR = SMU- (RMU + EMU + SMG)

where: SMU - dry weight of seeds before germination, g/unit; RMU - dry mass of roots, g/unit; EMU - dry weight of shoots, g/unit; SMG - dry weight of seeds after germination, g/unit.

h) seed metabolic efficiency (SME) was determined as the ratio of the sum of roots and shoots dry weight (g) to the reserve substances spent on energetic support, according to equation, described by (Sikder S. *et al*, 2009, Borovskaia A. *et al,* 2023):

SME = (RMU + EMU) / SMR

Statistical analysis. Analysis of variance (ANOVA) was performed using the software package Statgraphics Plus 5.0.

RESULTS AND DISCUSSIONS

Germination rate and dynamics of root/shoot growth is genotype dependent and can be evaluated in initial stage of development. The length of root/shoot measured at fifth day of corn seed germination was very different in tested hybrids. The significant differences in the root/shoot length between the groups was determined (*table 1, 2*) with a high confidence level (99.9%).

Tabel 1

Analysis of variance for root length of different corn hybrids at 5th day of germination

Source	Sum of squares		Df	Mean square	F-ratio
Between groups	138.37		2	69.188	17.15
Within groups	1169.62		290	4.033	
Total	1307.99		292		

*Significance level is $p < 0.0001$

Our results are in good agreement with the data reported by other researchers (Omar S. *et al,* 2022). The significant differences between the root/shoot lengths of selected corn varieties was also showed (Omar S. *et al,* 2022). However, in our experiments statistical difference was observed only in the first 5-7 days of seed germination.

Tabel 2

Analysis of variance for shoot length of different corn hybrids at 5th day of germination

Source	Sum of squares	Df	Mean square	F-ratio	P-value*
Between groups	456.94	2	228.47	127.86	0.0000
Within groups	511.04	286	1.786		
Total	967.98	288			

*Significance level is $p < 0.0001$

Increasing the duration of corn seed germination from five to ten days showed that root growth occurs more slowly that shoots elongation (*table 3*). During the additional 5 days of seed germination, the length of the roots increased by 0.63 cm (P280) and 2.22 cm (P398), while the length of the shoots increased by 1.98-2.63 times.

During ten days of germination the roots length of the tested hybrids did not differ significantly, but the shoots length varied significantly. A similar pattern was found for the vigour of shoots and roots. As the period of seed germination increased, the vigour index also increased, and more significantly for shoots than for roots (*table 3*). The metabolic processes intensified with increasing the duration of corn seed germination that reflected in more mobilization of reserve substances for root/shoot growth. Thus, in five days of corn seed germination approximately a quarter was used, in seven days - third and in ten days - half of the reserve substances (*table 3*).

The activation of metabolism at the stage of seed germination is caused by the intensity of respiration, which is associated with a number of oxidation-reduction reactions occurring in the plant organism. The starch is the first reserve substances that supports the respiratory process during seed germination and then fats. In this case, a significant release of energy and large losses of dry matter (up to 45-47%). There is a close connection between the growth of plant tissues (root/shoot) and their respiration.

According to our data, 52.8–81.5% of the total amount of reserve substances mobilized from seeds were spent on respiration and energy support for the physiological processes of germination and growth of roots and shoots. As the germination time of seeds increased, the amount of reserve substances spent on respiration and energy support of physiological processes increased in the P 280 hybrid, fluctuated in P398 and was practically stable in the P402 hybrid. Because of increasing in the proportion of reserve substances spent on respiration and energy support of physiological processes in the P280 hybrid, the metabolic efficiency decreased. This may be due to the small size of the grain, the weight of which was 2 times less than that of the P402 hybrid. Metabolic efficiency of the P402 hybrid slowly and no significant increased from five to ten days of germination.

It necessary to mention that, during 5 days of germination the seeds with the lower weight (P280, P398) had the metabolic efficiency higher that the seeds of P402 hybrid. Similar findings were made for mature maize seeds, which showed significantly higher seed weights but exhibited slower seed germination rates (Meena R.K. *et al.*, 2018).

Table 3

Morphological and physiological features of corn seeds in stage of germination

Traits	Hybrids								
	P280			P398			P402		
	Germination days								
	5	7	10	5	7	10	5	7	10
Root length, cm	6.19	6.33	6.82	4.56	5.62	6.80	5.02	5.22	6.16
Shoot length, cm	1.93	3.18	3.82	2.91	2.94	5.77	1.88	3.37	4.95
Root vigour	594.5	626.5	653.1	446.0	541.5	680.5	497.1	517.1	599.9
Shoot vigour	184.8	313.9	367.1	284.8	283.9	577.2	186.1	333.9	480.2
Total reserve substances mobilized from corn seed for germination, %	26.32	37.02	49.82	23.26	27.12	44.23	19.69	31.97	41.89
Reserve substance spent for respiration and energy support, % of total mobilized	67.65	71.10	81.50	63.76	52.80	61.33	73.45	71.56	71.20
Metabolic efficiency	0.4783	0.4064	0.2270	0.5684	0.8938	0.6306	0.3614	0.3975	0.4046

Activation of seed metabolism during swelling and germination, apparently, is a "cascade" process that can be represented as follows: an unswollen seed contains only a limited number of key enzymes; these enzymes are activated when the seed absorbs water, then the products of the reactions they catalyze induce the development of the activity of other enzymes, and this continues until the activity of all metabolic processes in the seed reaches an optimal level.

Metabolic activity is not the same as metabolic efficiency. Metabolic activity can be appreciated by root/shoot elongation and increase in its weight and vigour. Metabolic efficiency is inversely proportional with high the Pearson coefficient of correlation (0.9499 – 0.9991) to the amount of reserve substances mobilized for respiration and energy support of physiological processes of seed germination. In our experiments, the use of reserve substances was more effective in the seeds of P280 hybrid for 5 days, in P398 - for 7 days, and in P402 hybrid for 10 days.

In this regard, comparing the metabolic efficiency of germination of seeds of different hybrids in the 7 days established by ISTA (2017) may lead to erroneous conclusions. Considering that seeds have different sizes and, accordingly, different contents of reserve substances, their metabolic efficiency should be assessed in the first 5 days of germination.

CONCLUSIONS

Corn seeds of hybrids P280, P398 and P402 differing in size, weight, content of reserve substances and endosperm structure demonstrated various dynamics of root/shoot growth and metabolic efficiency on 5, 7 and 10 days of germination. The obtained results show that comparative determination of metabolic activity and metabolic efficiency of different corn hybrids can be carried out during the first five days of seed germination.

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