IDENTIFICATION OF LOCAL TOMATO VARIETIES (*SOLANUM LYCOPERSICUM*) WITH GENETIC RESISTANCE TO RADIAL CRACKING

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Abstract

The study was conducted in 2023, with the main objective of evaluating the resistance to radial cracking of fruits of 44 tomato landraces from 5 countries. 15 of these landracess come from different geographical regions of Romania, particularly Transylvania. This phenomenon is caused by alternating climatic conditions between drought and heavy rains, and it is quite a common problem for this crop. The landraces were studied in the experimental field of UASVM Cluj-Napoca, and the applied technology was ecological. The evaluation of tomato cracking resistance was performed by determining the frequency of cracked fruits, the intensity of cracking, and the degree of cracking coverage (following the model used in phytopathology). The Kruskal-Wallis test and the Dunn post-hoc test were used for statistical analysis. The Bonferroni correction was applied for the adjustment of multiple comparisons. The results highlighted significant differences between landraces in terms of cracking resistance. Among the 44 landraces, five cherry landraces (520 CDN, 525 CDN, 503 USA, 533 PL, and 509 CDN) did not show any radial cracking on the fruits. Nine normal-sized tomato landraces - 532 DJ, 515 CDN, 516 CDN, 519 CDN, 542 MS, 541 DJ, 526 CDN, 524 CDN, and 527 CDN - exhibited very high resistance to cracking. Conversely, 29 landraces were found to be highly sensitive to this phenomenon, with p-values below 0.0011628, indicating very low genetic resistance. The crack-resistant cultivars can be used directly in organic farming or can serve as the genetic basis for the creation of new tomato varieties, in the context of climate change and the need to optimize the use of fresh water resources.

Key words: tomatoes, radial cracking, genetic resistance, landraces, climate change

Tomatoes (*Solanum lycopersicum*) are among the most important vegetables cultivated on a large scale and are believed to have been domesticated in Central America. They arrived in Europe in the 16th century thanks to Spanish explorers. In 2022, 4.9 million hectares were cultivated globally, with a total production of 186 million tons, making it the most widely cultivated vegetable species in the world (FAO, 2022). The largest global producers of tomatoes are China, India, Turkey, the USA, and Egypt, while within the European Union (EU), the main producers are Italy, Spain, Poland, Greece, France, and the Netherlands. Romania ranks 7th in the EU in terms of tomato production (Agridata, 2023).

Efforts to increase agricultural production have resulted in the industrialized farming systems used today. Among these efforts is the practice of cultivating high-yield hybrids. With the emergence of intensive agriculture, there has been a decline in the number of landraces cultivated, due to the development of modern cultivars, hybrids, and intensive farms (Corradoa, 2014). Although these agricultural practices are more financially feasible in the short and medium term, they lead to the intensification of "genetic erosion" (Rogers, 2004) through the loss of local varieties, which are an important source of genes that confer resistance to biotic and abiotic stress factors. The FAO estimated that from 1900 to 2000, approximately 75% of the genetic diversity of cultivated plants disappeared (FAO, 2004) and estimates that by 2055, an additional 22% of the wild varieties of major crop plants will also disappear (Jarvis, 2008). The reintroduction of local tomato varieties, as well as other vegetables, into agriculture necessitates the identification of the most suitable varieties for a specific climate or microclimate. Marone (2021) claims that preserving local varieties and agricultural biodiversity, in general, constitutes an important source of genes for better nutrient absorption and utilization from the soil, as well as resistance to diseases, pests, drought, and other stress factors. Thus, the specific characteristics of these varieties can be exploited without the additional costs created by climate change.

An important step in the development of organic tomato cultivation is studying the ability of fruits from various local varieties to withstand stress caused by the alternation between periods of drought and heavy rainfall. This alternation is typical for the summer period and manifests itself through the occurrence of cracks on the surface of tomato fruits, resulting from increased rigidity and resistance of the cuticle. This phenomenon appears

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42-49 days after flowering (Ehret *et al*, 1993). Numerous researchers have pointed out that high temperatures reduce the breakage resistance of the fruit's pericarp (De Oliveira *et al*, 2015). Additionally, irregular and excessive irrigation increases the incidence of fruit cracking (Kasai *et al*, 2008; Hossain and Nonami, 2010; Khadivi-Khub, 2015).

The development of berry-type fruits occurs in two phases: the cell division phase followed by the cell expansion phase. When the expansion of the cells in the mesocarp, due to turgor pressure, exceeds the resistance capacity of the exocarp cells, the exocarp cracks. Subsequently, the fissures rapidly spread toward the mesocarp of the fruit. Therefore, resistance to cracking is directly proportional to the thickness of the exocarp (Khadivi-Khub, 2015; Ginzberg, 2015). Yang et al. (2016) suggest that the thickness of the exocarp should be the main criterion for assessing tomato resistance to cracking.

From a biochemical perspective, Domínguez *et al*, (2011) attribute the extensibility of the cuticle to cutin—a fatty lipid substance on the surface of the fruit—while polysaccharides and flavonoids are responsible for the rigidity of the cuticle.

Cracks can be radial or concentric, and their development is partially influenced by the genetic system. Research in this field has demonstrated the existence of specific genes for both radial cracks (Young, 1958) and concentric cracks (Avdeyeev, 1979). These genes determine, in turn, the chemical composition of the cuticle and exocarp, and consequently their biomechanics (Domínguez *et al*, 2009). Ultimately, for practitioners, the type of cracks is not very important, as both are equally damaging to tomato crops and storage. Moreover, the preventive measures for this phenomenon are the same for both types of cracks.

Another important characteristic is the length of the cracks, which is known to be controlled by a set of genes separate from those responsible for their orientation (Cortes, 1983). Clearly, the intensity of periods of alternating drought and heavy rainfall also plays a significant role in this equation. Cuartero *et al*, (1981) conclude that the heritability of this trait is low and that environmental influence is high.

The weakening of the plant due to the appearance of cracks on the fruit occurs through both the process of water loss and the creation of an entry point for phytopathogenic agents (Liu, 2022). Fruits with cracks can thus develop associated complications that lead to economic losses.

Global warming is known to have an intensifying effect on weather events, making them noticeably more intense in recent years, with some tending towards being labeled as "extreme events." Such extreme events include sudden shifts from prolonged droughts to short periods of heavy rainfall, which in turn affect agricultural production, including tomato yields. Managing water resources is becoming increasingly important in the context of global warming and the reduction of freshwater resources. The dynamics of precipitation patterns, one of the sources of freshwater, are deeply influenced by climate change. These climatic changes cause significant variations in average precipitation values (Konapala, 2020). The rise in global temperatures contributes to the accelerated evaporation of water from soil and bodies of water, thereby reducing water availability for agriculture, industry, and human consumption. These changes necessitate the development and implementation of advanced technologies and strategic adaptations to optimize the use of freshwater resources. Among these measures is the implementation of sustainable agricultural practices aimed at reducing water consumption, such as identifying and utilizing varieties and cultivars resistant to the alternation of drought and heavy rainfall.

This study examined 44 landraces/traditional tomato cultivars. The aim of the research was to identify solutions for adapting agriculture to climate change. The main objective was to determine the most resistant landraces/traditional cultivars to radial cracking. Identifying these can contribute to the development of sustainable agricultural practices through the more responsible use of available water resources.

MATERIAL AND METHOD

Plant Material and Growing Conditions

The experiment took place in 2023 at the Agrobotanical Garden of UASVM Cluj-Napoca. In this study, 44 landraces and traditional tomato cultivars (513 CDN, 520 CDN, 525 CDN, 533 PL, 503 USA, 509 CDN, 542 MS, 514 CDN, 511 CDN, 541 DJ, 537 DJ, 515 CDN, 516 CDN, 535 DJ, 510 CDN, 536 DJ, 544 MS, 517 CDN, 539 DJ, 527 CDN, 519 CDN, 530 CDN, 518 CDN, 521 CDN, 538 MS, 524 CDN, CHANDONA, 508 CDN, 540 DJ, 526 CDN, 504 USA, 522 CDN, 512 CDN, 523 CDN, 543 MS, 532 DJ, CASSIANA, 531 CDN, DANAMARI, 528 CDN, 529 CDN, 534 DJ, 505 BE, 506 BE) were cultivated. These were obtained from various sources such as seed fairs organized in Romania and European NGOs specializing in the preservation and cultivation of landraces and old varieties. The CHANDONA, CASSIANA, and

DANAMARI varieties were obtained at UASVM Cluj-Napoca through negative selection from landraces from Alba and Sălaj counties, which is why they are considered traditional cultivars. These varieties were homologated and patented by ISTIS (State Institute for Variety Testing and Registration) in Bucharest.

After selecting the landraces/traditional cultivars used in the study, the germination capacity of each was determined using glass germinators. One hundred seeds from each variety were soaked and placed on a hemp fiber substrate. Based on the results obtained from this process, the seeds were sown in cups with fine peat in a greenhouse at the end of March. The classic technology for producing seedlings was then applied until the beginning of May, when they were transplanted into the field.

The experimental field was divided into 44 variants (each representing a variety), with 10 plants per variant. The crop was maintained organically, using recycled wooden stakes for plant support and jute twine for tying the plants. Mulch made of hay and leaves was applied to maintain soil moisture, prevent erosion, and inhibit weed growth. This mulch also facilitated access to the field in conditions of high humidity. For disease and pest control, seven phytosanitary treatments were carried out, including three with Bordeaux mixture (*Bouillie Bordelaise WDG*, 1%), two with horsetail macerate (*Equisetum arvense*, 20%), and two with nettle macerate (*Urtica dioica*, 20%). When using Bordeaux mixture (Bouillie Bordelaise WDG), the limits imposed in organic farming for this product (4 kg/ha/year) were observed. The first spraying was performed when the foliage reached a density that favors infections, and after fruit set, to avoid flower abortion.

The summer of 2023 was characterized by prolonged periods of drought followed by short periods of heavy rainfall, creating ideal conditions for radial cracking in tomato fruits. In July and August, four such periods were recorded, with 15-18 days without precipitation and high temperatures, followed by rains measuring 21-32 mm.

Observations and measurements were made during July and August when cracks appeared. The evaluation of tomato resistance to cracking was performed by determining the frequency of cracked fruits ($F\% = \frac{n*100}{100}$) and the intensity of cracks ($I\% = \frac{\sum(i*f)}{n}$), and subsequently calculating the degree of crack coverage for each cultivar ($DCC\% = \frac{FxI}{100}$), following the model used in phytopathology. In our experiments, radial cracks were predominant (about 90%), which is why we did not differentiate between the two categories of cracks—radial and concentric—in our observations.

Statistical Analysis

To compare the resistance to radial cracking among the 44 tomato landraces, we used the Kruskal-Wallis method, a non-parametric test suitable for comparisons between multiple groups without assuming normal distribution. This test is appropriate for the high variability in the data.

The statistical analysis was conducted using Microsoft Excel and the Real Statistics Resource Pack, applying the Kruskal-Wallis test, followed by the Dunn post-hoc test to identify significant differences between varieties. Due to the large number of multiple comparisons, we applied the Bonferroni correction, adjusting the significance level *p* to ~0.0011628 to prevent Type I errors. The 513 CDN variety was chosen as the control due to the absence of radial cracks, serving as an ideal reference point for comparing the cracking resistance of the other varieties**.**

RESULTS AND DISCUSSIONS

The synthesized data presented in Table 1 show the average frequency of fruit cracking (F%), the average intensity of cracking (I%), the average degree of crack coverage (DCC%), and the *p*-value calculated based on DCC% for each of the 44 cultivars.

Our research shows that the cherry landraces (figure 1) 520 CDN, 525 CDN, 503 USA, and 509 CDN demonstrated remarkable resistance equal to the control variety, with no cracks recorded from the alternating drought and heavy rainfall. Nine normal-sized tomato landraces (figure 2) — 532 DJ, 515 CDN, 516 CDN, 519 CDN, 542 MS, 541 DJ, 526 CDN, 524 CDN, and 527 CDN — also exhibited high resistance, although they sporadically developed small radial cracks during the ripening period. These performances make them ideal candidates for use in organic agriculture and for selection in breeding programs. Our results align with the literature, which highlights the correlation between fruit size and the intensity of tomato fruit cracking. Thus, varieties with larger fruits tend to have a higher incidence of cracks (Emmons and Scott, 1998; Demers *et al*, 2001). What is noteworthy in our studies is that we identified large-fruited landraces that exhibit resistance to cracking. Similar research was conducted by Espana *et al*, (2014), but they only studied tomato varieties with different patterns of cuticle growth. Their experiments focused on the correlations between the mechanical properties of the cuticle and tomato fruit growth.

Table 1

Analysis of Tomato Landraces: Fruit Type, Crack Frequency and Intensity, Degree of Coverage, and Statistical Significance

No.	Landraces	Fruit type	Mean frequency of cracked fruits (F%)	Mean intensity of cracks (I%)	Mean degree of crack coverage (DCC%)	*p*-value DCC%
1	513 CDN	Ch	0	0	0	Control
2	520 CDN	Ch	0	0	0	1.000000000000
3	525 CDN	Ch	0	0	0	1.000000000000
4	503 USA	Ch	0	0	0	1.000000000000
5	509 CDN	Ch	0	0	0	1.000000000000
6	533 PL	Ch	0	0	0	1.000000000000
7	532 DJ	N	5	1	0.05	0.379149547644
8	515 CDN	N	5	2	0.1	0.253534216513
9	516 CDN	N	5	2	0.1	0.225085853246
10	519 CDN	N	10	2.5	0.25	0.042438478416
11	542 MS	N	15	2	0.3	0.027373930212
12	541 DJ	N	10	3	0.3	0.026165219938
13	526 CDN	N	10	3	0.3	0.017878384987
14	524 CDN	N	15	3	0.45	0.004779892411
15	527 CDN	N	10	5	0.5	0.004523932031
16	540 DJ	N	20	3	0.6	0.001057060005
17	539 DJ	N	15	5	0.75	0.000835048389
18	538 MS	N	15	4	0.6	0.000798734388
19	512 CDN	N	20	3	0.6	0.000615839113
20	536 DJ	N	20	3	0.6	0.000578995904
21	508 CDN	N	15	4	0.6	0.000506374409
22	544 MS	N	20	3	0.6	0.000503058979
23	521 CDN	N	15	5	0.75	0.000461760128
24	CHANDONA	N	15	4	0.6	0.000357256894
25	514 CDN	N	20	3	0.6	0.000320712056
26	518 CDN	N	25	3	0.75	0.000190130602
27	535 DJ	N	25	3	0.75	0.000125675942
28	504 USA	N	20	4	0.8	0.000051695781
29	523 CDN	N	30	3	0.9	0.000031267837
30	CASSIANA	N	25	4	1	0.000019193367
31	531 CDN	N	25	4	1	0.000008407160
32	537 DJ	N	30	4	1.2	0.000006116238
33	517 CDN	N	25	4	1	0.000002702334
34	530 CDN	N	25	5	1.25	0.000001213991
35	534 DJ	N	40	5	2	0.000000559318
36	543 MS	N	30	4	1.2	0.000000383546
37	522 CDN	N	50	4	2	0.000000299747
38	510 CDN	N	30	5	1.5	0.000000147496
39	DANAMARI	N	25	7	1.75	0.000000144700
40	511 CDN	N	35	5	1.75	0.000000042077
41	506 BE	N	40	5	2	0.000000028046
42	528 CDN	N	40	6	2.4	0.000000000455
43	505 BE	N	40	8	3.2	0.000000000126
44	529 CDN	N	70	8	5.6	0.000000000002

Meaning of symbols: Ch – Cherry, N - Normal

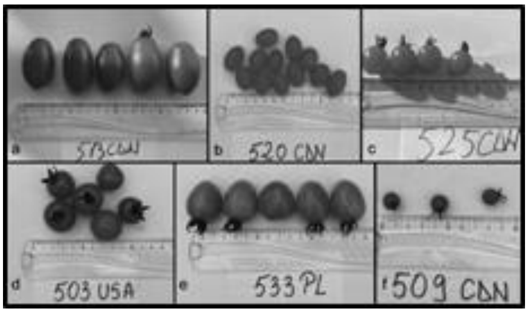

Figure 1. **Cherry tomato landraces with high resistance to cracking (a. 513 CDN, b. 520 CDN, c. 525 CDN, d. 503 USA, e. 533 PL, f. 509 CDN)**

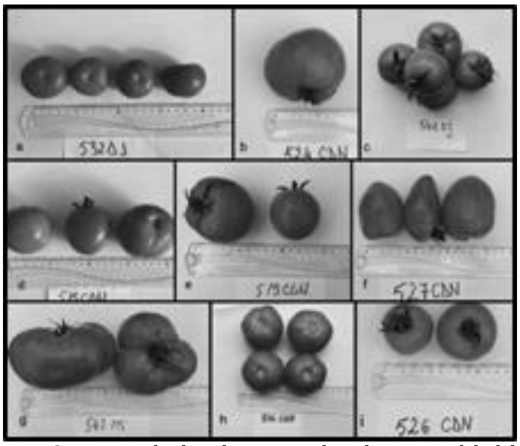

Figure 2. **Normal-sized tomato landraces with high resistance to cracking (a. 532 DJ, b. 524 CDN, c. 541 DJ, d. 515 CDN, e. 519 CDN, f. 527 CDN, g. 542 MS, h. 516 CDN, i. 526 CDN)**

29 normal-sized landraces/traditional tomato cultivars (540 DJ, 539 DJ, 538 MS, 512 CDN, 536 DJ, 508 CDN, 544 MS, 521 CDN, CHANDONA, 514 CDN, 518 CDN, 535 DJ, 504 USA, 523 CDN, CASSIANA, 531 CDN, 537 DJ, 517 CDN, 530 CDN, 534 DJ, 543 MS, 522 CDN, 510 CDN, DANAMARI, 511 CDN, 506 BE, 528 CDN, 505 BE, 529 CDN) showed statistically significant differences compared to the control. These varieties performed poorly during the two months of observations, as they recorded a significantly higher frequency and intensity of radial cracks compared to the control variety. Although some of these landraces/cultivars exhibit exceptional taste and technological qualities (such as high productivity and resistance to pathogens), they can only be cultivated under irrigation conditions.

Similar studies on the resistance of tomato varieties to cracking have been conducted by numerous researchers: Peet and Willits (1995), Cotner *et al*, (1969), Cortés *et al*, (1983), Wacquant (1995); Emmons and Scott (1998). The conclusions of these studies highlight the limited number of tomato varieties with resistance to cracking and the fact that this resistance is mainly determined by the thickness of the epicarp.

The Kruskal-Wallis test result indicated an H value of 308.645, with a p-value < $5.13E^{-42}$, confirming significant differences between the varieties. Subsequently, the Dunn post-hoc test, adjusted using the Bonferroni correction (~0.001), allowed for the identification of varieties that show significant differences compared to 513 CDN variety. The study results emphasize the importance of conserving local tomato landraces, especially given climate change and the need to improve freshwater management in agriculture. The cherry and normal-sized landraces that demonstrated high resistance to radial cracking clearly illustrate the potential of these valuable genetic resources. The literature repeatedly recognizes the importance of preserving landraces and traditional cultivars, which are essential sources of genes conferring resistance to various biotic and abiotic stresses (Rogers, 2004; Marone *et al*, 2021). Our study validates these perspectives, demonstrating that tomato landraces can be successfully used in breeding programs to create new varieties capable of coping with climate challenges. In a global context where freshwater resources are becoming increasingly limited, using cultivars resistant to water stress and cracking can significantly reduce the need for intensive irrigation, thus diminishing the impact on these vital resources (Konapala *et al*, 2020).

This study not only highlights the resistant local varieties but also underscores the need for continued research, given the limited number of studies on the possibilities of identifying genes responsible for resistance to radial cracking.

CONCLUSIONS

Global climate change and the depletion of natural resources necessitate finding solutions for sustainable agriculture.

Periods of drought alternating with rainy periods are becoming increasingly frequent in the current climate context. This alternation promotes cracking in tomato fruits, which then become entry points for pathogens and negatively affect the commercial appearance of the fruits.

Organic agriculture, characterized by reduced energy inputs and minimal pollution, is a rapidly expanding field. In the European Union, it is projected that by 2030, organically cultivated areas will reach 25%, while currently, in Romania, only 4.4% of the cultivated area is organic.

Our research aimed to identify tomato landraces and traditional tomato cultivars resistant to the alternation of drought and heavy rainfall. Of the 44 cultivars studied in the experimental field under conditions favorable to this phenomenon, six cherry-type landraces — 513 CDN, 520 CDN, 525 CDN, 503 USA, 533 PL, 509 CDN — and nine normal-sized landraces — 532 DJ, 515 CDN, 516 CDN, 519 CDN, 542 MS, 541 DJ, 526 CDN, 524 CDN, and 527 CDN — proved to be the most resistant to cracking. These cultivars are suitable for direct use in organic farming and can also serve as valuable genetic sources for breeding work.

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