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PRELIMINARY STUDY ON THE FRUIT MORPHOLOGY, AGRONOMIC, AND PHYSIO-CHEMICAL CHARACTERISTICS OF TOMATO VARIETIES IN GREENHOUSE CONDITIONS

Andreea ANTAL-TREMURICI, Silvica AMBĂRUŞ, Alexandru BUTE, Petre Marian BREZEANU, Gabriel-Alin IOSOB, Creola BREZEANU

Vegetable Research and Development Station Bacău, 220 Calea Bârladului Street, Bacău, Romania

Corresponding author email: antal_andreea97@yahoo.com

Abstract

Greenhouses are now one of the most effective industries in agricultural structure, used to preserve a monitored environment suitable for crop management throughout the year. The demand for tomato products is increasing year after year, providing ample opportunities for the tomato market to grow. The variety of tomato genotypes provides a gene pool for future breeding, because they may contain traits useful for the development of new varieties and hybrids with improved quantitative and qualitative characteristics. The study aimed to evaluate the performance of five indeterminate genotypes of tomato to determine their performance under greenhouse conditions. The research was conducted utilizing biological material from the Vegetable Research and Development Station in Bacau. The data collected were: number of days till appearance of the first flowers, number of days till first fruit development, date of first harvest, as well as the outer color of the immature and ripe fruit. The results of investigations on phenotype characteristics such as fruit weight, height, diameter, dry matter content, TSS, water, minerals, and titratable acidity are discussed in the paper.

***Key words**: greenhouse tomato quality, growing conditions, genotypes, local cultivar, solanaceous.*

INTRODUCTION

The agriculture industry is expected to go through a number of changes in the upcoming years. As a result of climate change, temperatures are expected to rise, but so is the price of energy. Growing crops in greenhouses requires a lot of natural resources. Any modification to the ecosystem caused by a shift in the climate system would alter the distribution of water and the patterns of precipitation.

According to official statistics from FAO in 2021, on an area of 18.130 ha, Romania produced 500.200 tons of tomatoes, and had an average production of 27.58 tons/ha (FAOSTAT, 2021). The interest in consuming high quality fresh or processed tomatoes continues to increase. In Romania, the annual net average of tomato consumption per capita was recorded in 2021 as 45.1 kg/inhabitant (INS, 2022),which is a relevant indicator for the vegetable market.

Due to its geographic location, Romania provides favorable conditions for growing extra-early vegetable crops in greenhouses since, from December to February, it experiences higher levels of light radiation than Western European nations. Following Bucharest (Popești greenhouses 142 ha), the largest greenhouse fields, distribution patterns, and production specializations were discovered in Arad, Timiș, Bihor, and Dolj. Additionally, zone I (Bihor, Arad, and Timiș counties) and the entire southern region of Romania were home to the most advantageous regions for the protected cultures (areas coated in various forms of plastic) (Drăghici et al., 2021; Popa et al., 2021).

Greenhouse farming is a technology that is widely used in Europe to promote efforts to achieve food security, is the technique of regulating the environmental factors for the benefit of the plant under protective cultivation. Greenhouses offer a dependable option to growing high-quality tomatoes both in and out of season by providing the ideal climatic conditions necessary for their best development and output.

To cultivate tomatoes in the greenhouse, it is necessary to take into account three important factors: the microclimate within the greenhouse (light and temperature), the cultivar being used, and the unique cultivation technology. The benefits of the technology used to grow tomatoes in greenhouses include the improved quality of the tomatoes, the staggered harvesting of the yield, the extension of the plants' autumn vegetative season, and the avoidance of hail and torrential rain-related risks (Inculet & Stoleru, 2021).

The tomato is one of the most significant members of the *Solanaceae* family and is grown extensively in many areas throughout the world. It was first cultivated in Mexico and the Andean region of South America. Nowadays, tomato (*Solanum esculentum*) is the second most important fruit or vegetable crop next to potato (*Solanum tuberosum*), with approximately 189.13 million tons of tomato fruits produced on 5.16 million ha each year (FAOSTAT, 2021).

The tomato fruit has a high nutritional value and may contain approximately 93% to 94% water. It is also an excellent source of minerals, acids, vitamins (A, B, and C), as well as tocopherols, which are beneficial to human health. The tomato fruit contains 3.4% of total sugars, 4.7% of total solids, 15 to 30 mg of ascorbic acid per 100 grams, 7.5 mg of titrable acidity per 100 milliliters, and 20 to 50 mg of lycopene per 100 grams (Chadha, 2012; Naranjo et al., 2016).

It is a self-pollinated annual crop with chromosome number $2n = 2x = 24$ (Peralta et al., 2008). It requires relatively cool, dry climate for high fruits yields and qualities. For growth and development, 20–27 °C is the ideal range. Flooding and waterlogging are not tolerated (Grubben & Denton, 2004). It is also a well-known model species for research on the growth of fruit and the accumulation of phytochemicals. Identifying genotypes with high antioxidant capacities and nutritionally rich phytochemicals is imperative for improving human health. (Raza et al., 2022).

To produce tomato crops with the proper agronomical characteristics, it is essential to understand and manage the diversity of tomato genetic resources.

Some intensive production system in greenhouses in Europe uses cultivars with undetermined growth practices and low densities that range from two to three plants per square meter; the stems of the plants are frequently trimmed, resulting in a single stem that reaches a length of more than seven meters; and it is left to harvest fifteen or more bunches per plant in a single crop cycle per year (Chapagain & Wiesman, 2004). Numerous investigations have demonstrated that tomato genotypes with indeterminate growth are the most popular (Meena & Bahadur, 2015; Maciel et al., 2016). According to Sacco et al. (2015), 77.2% of the genotypes taken for cultivation had undetermined growth.

In the intensification of greenhouse tomato production, one of the most important factors is the introduction of new high-yielding varieties and hybrids, which have excellent resistance against diseases and pests and are adaptable to new technologies and unfavorable climatic conditions (Gavrish, 2015). In Romania, tomatoes are grown in greenhouses under conditions of continuous monoculture, which reduces yield efficiency, both quantitatively and qualitatively (Soare et al., 2018). After four years of continuous culture, Bogoescu et al. (2011) showed that the output efficiency dropped to 48%, requiring the application of soil disinfection techniques.

Plant breeding applied on tomato has produced high-yielding varieties, though little attention has been paid to the fruit quality. Kumar et al. (2015) investigated tomato lines for quantitative features such as plant height, fruit yield, fruit weight, total soluble solids, fruit weight loss, and fruit shelf-life in greenhouses as well as plants that were grown in field conditions. They discovered that the plant height ranged from 93.3 to 165 cm in greenhouse circumstances. Fruit weight ranged from 34.4 to 82.0 g, while the total amount of fruit produced per plant ranged from 615 to 1730 g per fruit, and seed lodges were from two to five

Several studies about the genetic structure of tomatoes have devided it into four major groups: processing, fresh market, cherry, and traditional tomatoes or landraces (Williams & Clair, 1993; Robbins et al., 2011; Casals et al., 2018). The first three groups were representative of contemporary tomato cultivars developed by breeders in the 20th century. These tomato varieties were distinguished by their various culinary applications and the introduction of genes from wild species, primarily to increase disease resistance and also to create new cultivars (Blanca et al., 2022). For example, fruits of cherry varieties are tiny and weigh between 2 and 23 g per fruit. The weight of the fruit of normal size varies very much, comprising between 33 and 550 g (Maxim et al., 2023).

In contrast, the term "Landrace" is used to refer to a group of populations or clones of a plant species that are naturally adapted to the local environmental circumstances, as stated in Article 2 of Directive 2008/62/EC. Landraces are also called with many terms like “conservation varieties”, “farmer varieties”, “local varieties”, “primitive varieties”, “local populations”, “peasant varieties” or “traditional varieties” (Conversa et al., 2020; Maxim et al., 2020; Maxim et al., 2023). There are numerous landraces of tomato that might vary in terms of phenotypic and genotypic traits. The number of fruits, first fruiting internode length, fruit weight, fruit yield per plant, number of leaves, and other phenotypic traits are examples of phenotypic characteristics. When different varieties are given the same inputs, such as irrigation and fertilizer, their performances will also differ, and this can be seen clearly from the phenotype of the variety (Marasini & Paudel, 2017).

Traditional cultivars or local landraces selected for a specific area may also be a very suitable genetic pool to increase tomato crop performance. Traditional varieties can be exploited to create new varieties due to their great genetic diversity. Also, they might play a significant part in long-term food security and could help local economies grow (Fullana-Pericàs et al., 2019; Maxim et al., 2020; Scarano et al., 2020). Additional benefits of regional cultivars and landraces include their greater flavor and adaptability for organic farming.

In Romania, the Suceava Bank for Plant Genetic Resources holds 218 landraces and cultivars of tomato. In 2020, there were 77 tomato varieties listed in the official Romanian variety catalogue, of which 64 were appropriate for fresh consumption and 13 for the processing industry (M.A.D.R., 2020).

The study aimed to evaluate the performance of five indeterminate genotypes of tomato to determine their performance under greenhouse conditions at the Vegetable Research and Development Station in Bacau. During the experiment season, some investigations were conducted, such as the number of days until the first flowers appeared, the number of days until the first fruit development, the date of the first harvest, and the outer color of the immature and ripe fruit. In this article, we discuss some phenotypic characteristics such as fruit weight, height, diameter, dry matter content, TSS, water, minerals, and titratable acidity.

To fulfill the rising demand of consumers, breeders need to identify valuable materials featured by tomato plants of the indeterminate variety that produce more, are of superior quality, and are of ideal shape, size, and color. Therefore, there is a need for genetic development and to find potential indeterminate tomato varieties that are suitable for protected production under certain agroclimatic conditions.

MATERIALS AND METHODS

The trial was executed at the Vegetable Research and Development Station in Bacau, during 2022 year, in greenhouse conditions. The greenhouse where the experiment was located is covered with glass, has a height of 3.4 m, and an area of 3000 sq m.

The biological material, represented by five indeterminate local populations of tomato (PL1, PL2, PL3, PL4, and PL5), was collected and conserved from VRDS Bacau. The experiment was established using seedlings obtained into alveolar pallets with 70 alveoli and sowing was realised on February 25, using a textured substrate with a medium fertilization containing microelements. During the growth of the seedlings, four treatments with Previcur and Laser were carried out, a fungicide to prevent the plant falling of tomato, and five foliar fertilization with Green Plant 20: 20: 20.

Manual planting was made when the seedling was well-developed in the second decade of May, when the healthy seedling had the age of 57 days. During the vegetation period, periodic observations on the resistance of pests and diseases and the progress of plant development in protected areas were accomplished. When necessary, manual weeding was done around the plants and at intervals, and for the fight against pests and diseases, treatments with Mospilan were performed. Green Plant were used for fertilizing the plants.

The experiment was divided into four furrows with two rows on each furrow. The distances between the rows are 70 cm, the distance of the passageway between lines of 100 cm. The placement in the plot consisted of five variants; each variant corresponds to two furrows with two rows each. The number of tomato plants for each variant is 48, with 12 plants per row. and a distance of 35 cm between them. The total number of seedlings planted was: 5 variants x 48 plants = 240 plants.

Biological and phenological observations were collected: number of days till appearance of the first flowers, number of days till first fruits development, date of first harvest, the type of inflorescence, as well as the outer colour of the immature and ripe fruit.

The qualitative and quantitative determinations traced the descriptors elaborated by IPGRI (The International Institute for Plants Genetic Resources) with some changes. Some morphological characteristics, such as the diameter and height of the fruits as well as the number of lodges, were noted. The quality of the investigated material cultivated in greenhouse conditions was assessed by determining the total soluble solids (TSS), dry matter (DM), water, minerals, carotene, lycopene, and titratable acidity. The fruits were harvested when physiological stage of maturity was achieved.

Using an electronic caliper that shows accurate and clear data (in inches and mm), the diameter and height of the fruits were measured biometrically, and the weight was estimated using the balance Kern.

The total soluble solids content (TSS) was quantified using a handheld high-precision portable refractometer, and the results were expressed in Brix, according to 932:12 methods (AOAC, 2005). To calculate the dry matter content, freshly collected samples were dried for 24 hours at 103 ± 2°C in a forced air-drying oven (Biobase) to generate a constant mass. Deviations from 100% were indicated by water content. After calcination at 1000°C, the mineral quantity was determined by measurements and reported to be 100% of the fresh weight of the material. Carotene and lycopene pigments were assessed spectrophotometrically.

The titratable acidity of tomato juice was measured following the next method: 50 g of vegetable material was chopped into small pieces and boiled in 250-300 ml of distilled water. Until the material was completely destroyed, it was filled with distilled water, and finally it was allowed to drop below 200 ml. All the extract was filtrated. The titratable acidity of tomato juice was estimated by titrating 10 mL of the tomato juice against a 0.1 N NaOH solution using phenolphthalein as an indicator until the end point was reached. The acid content of the fruit sample was calculated based on the volume of 0.1 N NaOH used for neutralizing the acid content in the sample and multiplying by a correction factor of 0.0067 to estimate titratable acidity as a percentage of malic acid. The titratable acidity was calculated using the following equation: % malic acid = mL NaOH x F x 25 x 2 x 0.0067.

The collected morphological data was analyzed using statistical methods. For statistical analysis, the IBM SPSS Statistics program, version 26.0, was used. Tukey's test was performed in order to estimate the significant difference between the variants means. Differences between groups were considered significant when $p \leq 0.05$. The findings were presented as means with standard deviations.

RESULTS AND DISCUSSIONS

Morphological traits

The results for the investigated local populations with indeterminate genotypes are presented to highlight their performance under greenhouse conditions and to observe the differences and similarities between them. To study earliness, for each variant studied, the following data were observed: date of flowering, date of appearance of the first fruit, date of the first harvest, type of inflorescence, and the exterior color of the immature fruit of the tomato. Referring to the type of inflorescence, each variant had a number of 1-2 ramifications, and the predominant color of the fruit at the immature stage was light green on the entire surface for the numbers PL1, PL2, and PL3, and dark green toward the envelope and light green towards the pistillate tip or PL4 and PL5.

Days to flowering, fruiting and maturity of crop are the important phenological events which determine the productivity of a crop. The days from sowing to fruit ripening ranged from 124 days (PL4) to 131days (PL2). According to the The International Plant Genetic Resources Institute developed descriptors for tomatoes, reaching maturity is defined as when 50% of the plants have at least one ripe fruit. In Table 1, it can be seen that the time required for flowering to begin varied between 69 and 72 days, the time it took for fruit to develop varied between 81 and 86 days, and the beginning of maturation was achieved faster in the PL4 variant, at 124 days.

Table 1. Phenological investigations of tomatoes

Variant	Days till starting flowering	Days till fruit development	Days till harvest
PL1	69.30±0.15c	83.30±0.15c	129.30±0.15c
PL2	72.30±0.15a	86.30±0.15b	131.30±0.15a
PL3	72.30±0.15a	87.30±0.15a	130.30±0.15b
PL4	71.50±0.17b	81.30±0.15d	124.30±0.15e
PL5	67.30±0.15d	80.30±0.15e	126.30±0.15d

Values represent the average ± standard error. Within each column, different letters mean significant differences between variants, according to Tukey's test at $p \leq 0.05$.

The predominant color of the fruit at maturity was brick red, which has been observed in four out of five local populations contributing to our collection. The red combination was red-orange, red, bright red, and sometimes red with green streaks. The other color present on the outer surface of the ripe fruits was dark pink, which is associated with the PL4 variant. An excellent fruit shape variability was also observed. In four out of five local populations, the shape the shape of the fruit was round, mostly slightly flattened, while for the PL4 the cordiform shape was representative.

Table 2. Mean values of biometrical measurement of the fruits of tomato

Variant	Height (cm)	Width (cm)	Weight (g/ fruit)	Seed lodges
PL1	6.96±0.32b	9.35±0.51b	365.35±51.83 b	6.00±0.26 b
PL2	6.45±0.22b	8.04±0.23b	253.65±20.19 b	5.40±0.16 b
PL3	6.74±0.18b	8.05±0.23b	249.14±17.93 b	6.00±0.00 b
PL4	10.55±0.16 a	11.82±0.80 a	621.70±59.84a	8.00±0.21a
PL5	6.38±0.12b	8.06±0.18b	236.06±15.85 b	5.40±0.16 b

Values represent the average ± standard error. Within each column, different letters mean significant differences between variants, according to Tukey's test at $p \leq 0.05$.

The fruit morphological traits were assessed during the main harvest, by measurements of ten fruits per genotype. The fruit width had average values between 8.04±0.23 cm (PL2) and 11.82±0.8 cm (PL4).

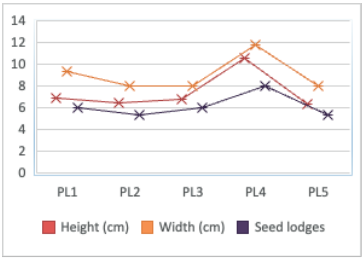

Figure 1. Width, height and seed lodges of tomatoes

According to our investigations, PL1, PL2, PL3, and PL5 can be analyzed together due to its similarly of biometrical measurements (Figure 1). PL1 had the highest values of 6.96 cm height, 9.35 cm width, and 365.35 g fruit weight, while PL5 had the lowest values of height (6.38 cm), PL2 had the minimum width (8.04 cm), and the smallest weight was obtained by PL5 (236.38 g) (Table 2). The variant with the heart shape (PL4) was superior to all other values, and the seed lodges varied between 5 and 8 for all variants.

Biochemical parameters

According to Grierson and Kader (1986), ripe tomatoes present changes in some synthetic chemical elements, such as pigments (beta-carotene and lycopene), aromatic compounds, and some acids (citric and malic), which are primarily in charge of producing the color, flavor, and taste. The primary source of carotenoid intake for humans is the consumption of fruits and vegetables. In this regard, tomatoes are recognized as a primary source of lycopene, followed by β-carotene in tomato fruits, containing 2.62-60.40 mg/100 g fresh weight. The range of lycopene content can vary greatly, depending on numerous factors such as variety, ripening stage, cultivation technology, and geographic location.

The antioxidant activity of lycopene as well as β-carotene along with the abundance of this in tomatoes make this food a rich source of antioxidant activity. Murariu et al. (2021), demonstrate that the lycopene content of eight tomato genotypes cultivated in the plastic tunnel was higher than those cultivated in the field with an average value of 8.44 mg·100 g^{-1}F.W. Literature presents values of lycopene for different varieties of tomato from different regions of the world with mean values between 1.86 to 14.62 mg·100 g^{-1}F.W.

In this research the results for lycopene, β-carotene (expressed as mg 100 g^{-1} of fresh weight - F.W.), and titratable acidity (expressed as % of malic acid) of analyzed tomato varieties are presented in Table 3. The main factors with influence on carotene and lycopene biosynthesis are the genotype and temperature. The pigment content is associated with maturity and also with fruit quality (Brezeanu et al., 2021).

Table 3. Assessment of fruit quality characteristics for tomato landraces tested

Variant	β-carotene mg 100 g^{-1}F.W.	Lycopene mg 100 g^{-1}F.W.	Titratable acidity (% malic acid)
PL1	4.93±0.02e	3.81±0.02e	0.24±0.003d
PL2	7.08±0.005c	5.28±0.04c	0.34±0.009b
PL3	5.15±0,000d	3.96±0.01d	0.38±0.011a
PL4	10.22±0.011a	7.34±0.02a	0.28±0.006c
PL5	7.80±0.000b	5.81±0.04b	0.35±0.006ab

Values represent the average ± standard error. Within each column, different letters mean significant differences between variants, according to Tukey's test at $p \leq 0.05$.

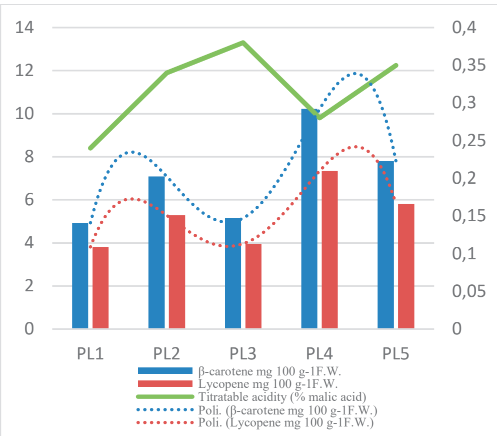

Figure 2. Physiological investigation of tomatoes

The beta-carotene values ranged between 4.93 for PL1 and 10.22 mg 100 g^{-1}F.W. for PL4, which has the highest value (Figure 2). The genotypes studied influenced the lycopene content which values varied within relatively low limits, with values between 3.96±0.01 mg·100 g^{-1}F.W. for PL3 and 7.34±0.02 mg·100 g^{-1}F.W. in the case of PL4, the differences being significant in terms of statistical analysis. Frusciante et al. (2007), analyzed the nutritional value of eighteen tomato genotypes and obtained significant variation among all analyzed genotypes for lycopene and β-carotene content.

Titratable acidity (TA) is an important quality attribute for processing tomatoes, because the higher this value, the easier it is to control microbial deteriorations in processed tomato products such as canned products (Thakur et al., 1996). TA in tomato fruits can be affected by several factors (Lovelli et al., 2017) however the average acidity value of processing tomatoes is 0.35 g 100 g^{-1} FW. In a study conducted in Southern Italy, the mean value of nine tomato genotypes for malic acid was 1255.0 mg kg^{-1}F.W., and varied from 687.0 to 1808 mg kg^{-1}F.W. (Parisi et al., 2022). In our research, the proportion of acid malic was between 0.24 % for PL1 and it raised to 0.35 for PL5.

Table 4. Mean values of physiological characteristics of the tomato landraces

Variant	TSS °Brix	Dry matter %	Water %	MINERALS %
PL1	4.90±0.12ab	4.92±0.007d	95.08±0.003b	0.16±0.003e
PL2	5.27±0.09a	5.52±0.010b	94.48±0.003d	0.35±0.003a
PL3	5.07±0.09ab	5.64±0.003a	94.36±0.003e	0.30±0.003c
PL4	5.33±0.15a	5.22±0.003c	94.78±0.003c	0.33±0.003b
PL5	4.60±0.12b	4.66±0.003e	95.34±0.003a	0.28±0.006d

Values represent the average ± standard error. Within each column, different letters mean significant differences between variants, according to Tukey's test at $p \leq 0.05$.

The results obtained highlight that the highest sugar content, of 5.33 °Brix, was recorded for PL4, with not significant statstical differences. Regarding genotype factor, the dry matter content varied within low limits, being between 4,66 % and 5.64 %, the values obtained showing, however significant statistical differences. The highest value, of 5.64%, was obtained by PL3, while the lowest value, of 4.66%, was registered by PL5.

In general, the water content of tomato fruits ranged from 92.87% to 96.57% with an average of 94.53% (Athinodorou et al., 2021). Our results confirmed in Table 4 that the water content of tomato fruits is between 94.36% (PL3) and 95.34% (PL5), and the content of minerals is between 0.16% (PL1) and 0.35 % (PL2).

CONCLUSIONS

The present study provides essential information on the morphological and biochemical traits of these tomato local populations. For agriculture, it is crucial to gather and characterize germplasm on a morphological, agronomic, and biochemical level. In this manner, we are able to select the best varieties for different growing environments. It aids breeders in identifying the best parents for novel varieties.

Tomatoes provide a wide range of nutrients, which, along with other components, play a fundamental role in human health. The local populations studied are rich in lycopene and beta-carotene, water, and minerals. The most abundant components in our tomatoes are carotenoids. Also, the rich content of dry matter demonstrates that the fruits of tomatoes present fermity, which facilitates long-term storage.

The local populations with indeterminate growth analyzed in this research showed small differences in the varieties and demonstrated that they could be used as parental genotypes or as pre-breeding material in future variety development for fruit shape, size, color, and flavor desirable for the local market.

Because of the high antioxidant value of tomato genotypes found in current research, it is possible to identify qualitative genotypes that are currently unused and technical practices to produce tomatoes in a system under greenhouse climate conditions.

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