

## Research on the Influence of Genotype on Key Fruit Morphological Traits in Paprika Pepper Grown in High Tunnels

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**Abstract.** In Romania, paprika pepper has been grown since the nineteenth century, introduced by Bulgarian gardeners who had a tradition of maintaining fruit shape and uniformity. In western Romania, the first paprika crops were established around 1923 in the Timișoara region (Cenadul Mare, Tomnatic, Lovrin). The biological material used in the three research years (2022, 2023, and 2024) consisted of six paprika genotypes ('Bolero F1', 'Fono F1', 'Palotas F1', 'Szegedi 80', and 'Szikra F1'). Morphological traits were assessed through biometric measurements: fruit length with and without peduncle, fruit diameter, and fruit weight. The paprika genotypes tested and analyzed show strong phenotypic diversity in their morphological traits. For fruit weight, highly significant differences are evident in the hybrids 'Fono' and 'Palotas', compared with the genotypes 'Szegedi 80' and 'Szikra F1'. Highly significant positive correlations were identified between fruit length and shape index in the genotypes 'Bolero F1' and 'Szegedi 80', and between fruit diameter and fruit weight in the hybrids 'Palotas' and 'Szikra'.

**Keywords:** Spice paprika pepper powder, *Capsicum annuum* L., morphological characters, high tunnel

### INTRODUCTION

According to the current taxonomy, the genus *Capsicum* belongs to the order Solanales, family Solanaceae, subfamily Solanoideae, tribe Capsiceae, subtribe Capsicinae, and includes 38 wild species and five recognized cultivated species (*Capsicum annuum* L., *Capsicum chinense* Jacq., *Capsicum frutescens* L., *Capsicum pubescens* Ruiz & Pavon, and *Capsicum baccatum* L.) (USDA-ARS, 2011; Bosland, Votava, 2012). Within *Capsicum annuum* L., numerous varietal types exist, differing in fruit size and shape, pungency, and color. All paprika types have been selected for high ASTA values (Official Analytical Methods of the American Spice Trade Association), which ensure a bright red powder (ASTA, 1999; Sasvari, 2005; Crosby, 2008).

Paprika pepper cultivated in Central Europe was pungent until 1920, when in Szeged (Hungary) a plant with sweet fruits was found and later grafted onto plants with pungent fruits (Sasvari, 2005). In Romania, paprika pepper has been grown since the nineteenth century, introduced by Bulgarian gardeners who had a tradition of maintaining fruit shape and uniformity (Ursu et al. 2013, Madose et al., 2020). In western Romania, the first paprika crops were established around 1923 in the Timișoara region (Cenadul Mare, Tomnatic, Lovrin) (Ursu et al., 2012; Posta et al., 2016).

More than 25 pigments have been identified in paprika fruits: green chlorophylls, the yellow-orange pigments lutein, zeaxanthin, violaxanthin, antheraxanthin,  $\beta$ -cryptoxanthin,  $\beta$ -carotene, etc. The color of paprika powder is determined by the ratio of red pigments (capsanthin and capsorubin) to yellow pigments (carotene and violaxanthin). The red pigments capsanthin, capsorubin and cryptoxanthin are unique to the *Capsicum* species. (Koncsek et al., 2016; Klátyik et al., 2017; Norazian et al., 2019; Hornero-Méndez et al., 2000; Egyed, 2024).

Paprika varieties and hybrids present plants with different growth types: indeterminate plants with dichotomous branching at 15–25 cm above the soil, where most flowers form on secondary branches; semi-indeterminate plants with shorter secondary branches; determinate plants whose main stem branches bear solitary or paired flowers; and bush-type plants with flowers arranged in clusters (Markus F., Kapitany J., 2000; 2001).

Until the beginning of the twenty-first century, paprika pepper was grown in open fields with yields of about 5 kg per square meter, a relatively low efficiency. This led to the expansion of paprika cultivation in high tunnels and to improved cultivation technologies, enabling yields of 8–10 kg/m<sup>2</sup> of fresh fruits (Somogy et al., 2000; Koncsek et al., 2016, Poșta et al., 2016; Parvin et al., 2024).

Paprika fruits are medium-sized, red in various shades, with either a certain degree of pungency or fully sweet. The best-known types are those from Hungary, bearing smooth fruits with thin flesh (1–3 mm) and a length of 8–12 cm. Spanish genotypes show greater variability in fruit size and shape, most having conical, flattened fruits with low or no pungency (Ursu et al., 2013).

## MATERIAL AND METHODS

The comparative trials with five paprika genotypes were carried out in 2022–2024 in high-tunnel protected structures at the Agricultural Research and Development Station Lovrin, Timiș County, Romania (45°58'15"N, 20°47'02"E). The experiments were arranged in a randomized block design with three replications.

The eco-pedological conditions of the experimental site can be summarized as follows:

- soil classified as weakly gleyed chernozem, medium loam-clay, rich in humus at the surface, representative for the low Banat Plain;
- pH values slightly lower (6.60) in the worked layer, with a mildly acidic reaction, indicating a slight leaching of bases from the soil colloidal complex;
- the mean annual temperature for January 2022 to September 2024 was 12.5 °C, 1.7 °C higher than the 70-year multiannual mean, with significant deviations recorded in spring and autumn.

The biological material used in the three research years (2022, 2023, and 2024) consisted of six paprika genotypes. Below is a description of the genotypes according to data from seed companies.

'Boloro F1' (ZKI Ltd.) is a sweet paprika hybrid with indeterminate growth and plant height reaching 2–2.5 m in protected cultivation. Fruits are pointed, dark red, and contain 16–17% dry matter at harvest.

'Fono F1' (ZKI Ltd.) is a sweet, indeterminate hybrid with abundant foliage. The plants form downward-pointing fruits with concentrated ripening and ASTA color values of 130–270.

'Palotas F1' (ZKI Ltd.) is an early-medium, indeterminate hybrid suitable for high-tunnel and open-field cultivation.

'Szegedi 80' (ZKI Ltd.) is an early variety with indeterminate growth, pendulous fruits, and an ASTA pigment content of 260–380.

'Szikra F1' (ZKI Ltd.) is a new hot paprika hybrid with indeterminate growth, high pigment content (ASTA 350–400), and capsaicin levels of 700–1000 units.

Seedling production took place in the propagation greenhouse by sowing one seed per 5×5×5 cm cell. Seedlings were 40–45 days old at planting, 20–25 cm tall, with 4–5 leaves. The substrate consisted of white peat, moderately decomposed (0–5 mm), pH 6.0, fertilizer level 1.0 g/l, with added nutrients (nitrogen 140 mg N/l, phosphorus 100 mg P<sub>2</sub>O<sub>5</sub>/l, potassium 180 mg K<sub>2</sub>O/l, magnesium 100 mg Mg/l, plus trace elements, iron as EDTA chelate), mixed with horticultural perlite, an inorganic, lightweight material containing 74–77% amorphous silica dioxide. Its porous structure improves aeration and water retention.

Field preparation included applying manure (approx. 40 t/ha) and incorporating it during 30 cm soil tillage. Planting was done manually when temperatures exceeded 15 °C in the tunnel and soil temperature at 8–10 cm depth reached the same threshold, typically between 1 and 5 April. The planting scheme was 80+40×30 cm, resulting in 5.5 plants/m<sup>2</sup> (Ursu et al., 2012; Poșta et al., 2016).

Crop management included staking plants with twine up to 2 m height, fertilization during the growing period (foliar and drip-applied), maintaining optimal soil moisture, and plant protection. Fertilization used ecologically certified products from the polynutrient category (Cropmax 0.2%, Lithovit Standard 0.5%), containing macroelements (N, P, K), mesoelements (Ca, Mg, S), and microelements (Fe, Zn, Cu, Mn, Mo, B). Calcium deficiency causes growth stagnation and blossom-end rot, prevented using YaraLiva Calcinit at 20 kg/ha. Magnesium influences fruit quality, while boron and manganese affect carbohydrate synthesis and fruiting. Additional fertigation products included Ferticare 3 (10:5:26) at 20 kg/ha and Agriplant 4 (8:14:25 + 3 MgO) at 0.3%. During the season, 10–12 irrigations were applied through drip irrigation, maintaining soil moisture between 65–70% of AWC. Disease and pest control was performed using the following foliar fungicides: Ortiva Top (azoxystrobin and difenoconazole) 1 L/ha; Amistar (azoxystrobin 250 g/l) 0.75–1.0 L/ha; Switch 62.5 WG (fludioxonil 250 g/kg and cyprodinil 375 g/kg) 0.8 kg/ha; Signum (boscalid 26.7% and pyraclostrobin 6.7%) 0.15%. Insecticides applied were: Affirm (emamectin benzoate 9.5 g/kg) 1.5 kg/ha; Vertimec 1.8 EC (abamectin 18 g/l) 1 L/ha; Minecto Alpha (cyantraniliprole 100 g/l and acibenzolar-S-methyl 12.5 g/l) 1.0 L/ha; Closer 120 SC (sulfoxaflor 120 g/l) 0.08 L/ha; Alverde (metaflumizone 240 g/l) 0.1%.

Morphological traits were assessed through biometric measurements: fruit length with and without peduncle, fruit diameter, and fruit weight. For statistical analysis of the similarity between the concentrations of the analytes obtained between the samples, the ANOVA test and Tukey's test were carried out in the JASP Team software year 2025 (version 0.95.1). Statistical analysis to determine the difference in analyte concentrations between processing was tested using Student's *t*-test for equal or different variances, which was verified using the F-test. A significant level of 5% was assumed for each analysis.

## RESULTS AND DISCUSSIONS

The trait of yield stability defines a genotype's ability to produce harvests that, under different environmental conditions, remain closer to its genetic potential and maintain consistency (Madosa et al., 2020). A direct assessment of production capacity is possible only when not only individual values are considered, but also

values derived from the analysis of series of individuals large enough to ensure reliability and repeatability of experimental results (Berar, 2011).

The determination of production potential in paprika genotypes grown in high tunnels was carried out using the following morphological traits: fruit length with peduncle and without peduncle, fruit diameter, and fruit weight with peduncle and without peduncle. The analysis of genotype influence on each morphological fruit trait was performed using descriptive statistics and multiple comparison procedures.

**Table 1.** Descriptive statistics for fruit length with peduncle in paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                          | Length of the fruit including the peduncle (cm) |               |                  |                  |                 |
|--------------------------|-------------------------------------------------|---------------|------------------|------------------|-----------------|
|                          | cv. 'Bolero F1'                                 | cv. 'Fono F1' | cv. 'Palotas F1' | cv. 'Szegedi 80' | cv. 'Szikra F1' |
| Mean                     | 16.63                                           | 18.25         | 17.73            | 15.24            | 14.59           |
| Std. Error of Mean       | 0.298                                           | 0.469         | 0.806            | 0.217            | 0.106           |
| Std. Deviation           | 0.597                                           | 0.938         | 1.612            | 0.435            | 0.211           |
| Coefficient of variation | 0.036                                           | 0.051         | 0.091            | 0.029            | 0.014           |
| Variance                 | 0.356                                           | 0.880         | 2.598            | 0.189            | 0.045           |
| Minimum                  | 15.79                                           | 16.95         | 15.59            | 14.89            | 14.36           |
| Maximum                  | 17.12                                           | 19.13         | 19.48            | 15.85            | 14.87           |

The fruit length with peduncle in the paprika genotypes ranged from 14.36 cm in the hybrid 'Szikra' to 19.48 cm in 'Palotas F1'. In comparison, the hybrid 'Fono' recorded the highest mean fruit length, exceeding 18 cm. Based on the multiple comparison of the paprika genotypes, the hybrid 'Fono' shows a highly significant positive difference compared with 'Szikra' (table 2).

**Table 2.** Post Hoc Comparisons for fruit length with peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|              |              | 95% CI for Mean Difference |        |       | t      | P <sub>Tukey</sub> |
|--------------|--------------|----------------------------|--------|-------|--------|--------------------|
|              |              | Mean Difference            | Lower  | Upper |        |                    |
| 'Bolero F1'  | 'Fono F1'    | -1.620                     | -3.590 | 0.350 | -2.540 | 0.133              |
|              | 'Palotas F1' | -1.100                     | -3.070 | 0.870 | -1.725 | 0.449              |
|              | 'Szegedi 80' | 1.392                      | -0.577 | 3.362 | 2.183  | 0.238              |
|              | 'Szikra F1'  | 2.040                      | 0.070  | 4.010 | 3.198  | 0.041 *            |
| 'Fono F1'    | 'Palotas F1' | 0.520                      | -1.450 | 2.490 | 0.815  | 0.922              |
|              | 'Szegedi 80' | 3.012                      | 1.043  | 4.982 | 4.723  | 0.002 **           |
|              | 'Szikra F1'  | 3.660                      | 1.690  | 5.630 | 5.738  | < 0.001 ***        |
| 'Palotas F1' | 'Szegedi 80' | 2.493                      | 0.523  | 4.462 | 3.908  | 0.010 *            |
|              | 'Szikra F1'  | 3.140                      | 1.170  | 5.110 | 4.923  | 0.001 **           |
| 'Szegedi 80' | 'Szikra F1'  | 0.648                      | -1.322 | 2.617 | 1.015  | 0.845              |

\*  $p < 0.5$ , \*\*  $p < 0.1$ , \*\*\*  $p < 0.01$

The determination of fruit length without peduncle is a morphological trait also included among the descriptors of the genus *Capsicum*, representing the economically useful biomass that contributes directly to the final product (paprika powder).

**Table 3.** Descriptive statistics for fruit length without peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                    | Fruit length excluding the peduncle (cm) |               |                  |                  |                 |
|--------------------|------------------------------------------|---------------|------------------|------------------|-----------------|
|                    | cv. 'Bolero F1'                          | cv. 'Fono F1' | cv. 'Palotas F1' | cv. 'Szegedi 80' | cv. 'Szikra F1' |
| Mean               | 11.73                                    | 12.88         | 12.87            | 11.31            | 11.12           |
| Std. Error of Mean | 0.237                                    | 0.338         | 0.410            | 0.161            | 0.193           |
| Std. Deviation     | 0.474                                    | 0.677         | 0.821            | 0.323            | 0.387           |

**Table 3.** Descriptive statistics for fruit length without peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                          | Fruit length excluding the peduncle (cm) |               |                  |                  |                 |
|--------------------------|------------------------------------------|---------------|------------------|------------------|-----------------|
|                          | cv. 'Bolero F1'                          | cv. 'Fono F1' | cv. 'Palotas F1' | cv. 'Szegedi 80' | cv. 'Szikra F1' |
| Coefficient of variation | 0.040                                    | 0.053         | 0.064            | 0.029            | 0.035           |
| Variance                 | 0.225                                    | 0.458         | 0.673            | 0.104            | 0.149           |
| Minimum                  | 11.31                                    | 11.93         | 11.72            | 10.98            | 10.62           |
| Maximum                  | 12.39                                    | 13.47         | 13.58            | 11.75            | 11.56           |

Based on the multiple comparison of the paprika genotypes for fruit length without peduncle, Table 4 shows a distinctly significant positive difference for the hybrids 'Fono' and 'Palotas' compared with 'Szikra F1'.

**Table 4.** Post Hoc Comparisons for fruit length without peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|              |              | Mean Difference | 95% CI for Mean Difference |       | t      | P <sub>Tukey</sub> |
|--------------|--------------|-----------------|----------------------------|-------|--------|--------------------|
|              |              |                 | Lower                      | Upper |        |                    |
| 'Bolero F1'  | 'Fono F1'    | -1.150          | -2.389                     | 0.089 | -2.866 | 0.075              |
|              | 'Palotas F1' | -1.145          | -2.384                     | 0.094 | -2.854 | 0.077              |
|              | 'Szegedi 80' | 0.412           | -0.826                     | 1.651 | 1.028  | 0.839              |
|              | 'Szikra F1'  | 0.602           | -0.636                     | 1.841 | 1.502  | 0.577              |
| 'Fono F1'    | 'Palotas F1' | 0.005           | -1.234                     | 1.244 | 0.012  | 0.000              |
|              | 'Szegedi 80' | 1.562           | 0.324                      | 2.801 | 3.895  | 0.011 *            |
|              | 'Szikra F1'  | 1.753           | 0.514                      | 2.991 | 4.368  | 0.004 **           |
| 'Palotas F1' | 'Szegedi 80' | 1.557           | 0.319                      | 2.796 | 3.882  | 0.011 *            |
|              | 'Szikra F1'  | 1.748           | 0.509                      | 2.986 | 4.356  | 0.004 **           |
| 'Szegedi 80' | 'Szikra F1'  | 0.190           | -1.049                     | 1.429 | 0.474  | 0.989              |

\*  $p < 0.5$ , \*\*  $p < 0.1$

Fruit diameter in paprika is another morphological trait that influences the quantity of dried fruits, in direct relation to pericarp thickness. From the comparative analysis of the experimental results presented in Tables 5 and 6, it can be seen that no statistically validated differences exist among the evaluated genotypes. However, the genotypes 'Szegedi 80' and 'Szikra F1' show a mean fruit diameter of approximately 2.5 cm.

**Table 5.** Descriptive statistics for fruit diameter in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                          | Largest fruit diameter (cm) |               |                  |                  |                 |
|--------------------------|-----------------------------|---------------|------------------|------------------|-----------------|
|                          | cv. 'Bolero F1'             | cv. 'Fono F1' | cv. 'Palotas F1' | cv. 'Szegedi 80' | cv. 'Szikra F1' |
| Mean                     | 2.120                       | 2.170         | 1.870            | 2.555            | 2.463           |
| Std. Error of Mean       | 0.024                       | 0.059         | 0.159            | 0.091            | 0.017           |
| Std. Deviation           | 0.049                       | 0.118         | 0.319            | 0.181            | 0.034           |
| Coefficient of variation | 0.023                       | 0.054         | 0.170            | 0.071            | 0.014           |
| Variance                 | 0.002                       | 0.014         | 0.102            | 0.033            | 0.001           |
| Minimum                  | 2.060                       | 2.050         | 1.470            | 2.310            | 2.430           |
| Maximum                  | 2.180                       | 2.330         | 2.250            | 2.740            | 2.510           |

**Table 6.** Post Hoc Comparisons for fruit diameter in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                 |              |        | 95% CI for Mean Difference |        |        |         |
|-----------------|--------------|--------|----------------------------|--------|--------|---------|
| Mean Difference |              |        | Lower                      | Upper  | t      | Ptukey  |
| 'Bolero F1'     | 'Fono F1'    | -0.050 | -0.431                     | 0.331  | -0.406 | 0.994   |
|                 | 'Palotas F1' | 0.250  | -0.131                     | 0.631  | 2.029  | 0.300   |
|                 | 'Szegedi 80' | -0.435 | -0.816                     | -0.054 | -3.530 | 0.022   |
|                 | 'Szikra F1'  | -0.343 | -0.723                     | 0.038  | -2.779 | 0.088   |
| 'Fono F1'       | 'Palotas F1' | 0.300  | -0.081                     | 0.681  | 2.434  | 0.159   |
|                 | 'Szegedi 80' | -0.385 | -0.766                     | -0.004 | -3.124 | 0.047   |
|                 | 'Szikra F1'  | -0.293 | -0.673                     | 0.088  | -2.374 | 0.176   |
| 'Palotas F1'    | 'Szegedi 80' | -0.685 | -1.066                     | -0.304 | -5.559 | < 0.001 |
|                 | 'Szikra F1'  | -0.593 | -0.973                     | -0.212 | -4.808 | 0.002   |
| 'Szegedi 80'    | 'Szikra F1'  | 0.092  | -0.288                     | 0.473  | 0.751  | 0.941   |

Fruit diameter shows considerable phenotypic diversity within the genus *Capsicum*, and this morphological trait can also be influenced by technological factors such as the cultivation system (high-tunnel protected culture) and the type and quantity of polynutrients used in the fertilization program (Bere Semeredi, 2015; Amro et al., 2023).

**Table 7.** Descriptive statistics for fruit weight with peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                          | Fruit weight with peduncle (g) |               |                  |                  |                 |
|--------------------------|--------------------------------|---------------|------------------|------------------|-----------------|
|                          | cv. 'Bolero F1'                | cv. 'Fono F1' | cv. 'Palotas F1' | cv. 'Szegedi 80' | cv. 'Szikra F1' |
| Mean                     | 27.38                          | 31.49         | 31.59            | 19.21            | 19.07           |
| Std. Error of Mean       | 1.210                          | 1.836         | 2.206            | 0.327            | 0.338           |
| Std. Deviation           | 2.419                          | 3.671         | 4.412            | 0.653            | 0.675           |
| Coefficient of variation | 0.088                          | 0.117         | 0.140            | 0.034            | 0.035           |
| Variance                 | 5.852                          | 13.48         | 19.47            | 0.427            | 0.456           |
| Minimum                  | 24.07                          | 26.35         | 26.31            | 18.41            | 18.34           |
| Maximum                  | 29.79                          | 34.71         | 37.11            | 20.01            | 19.97           |

The total fruit weight of paprika ranged from 19.07 g in 'Szikra F1' to 31.59 g in the hybrid 'Palotas'. The comparative analysis of the genotypes from this perspective highlights highly significant positive differences for the hybrids 'Fono' and 'Palotas' compared with the genotypes 'Szegedi 80' and 'Szikra F1'.

**Table 8.** Post Hoc Comparisons for fruit weight with peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                 |              |        | 95% CI for Mean Difference |        |        |                    |
|-----------------|--------------|--------|----------------------------|--------|--------|--------------------|
| Mean Difference |              |        | Lower                      | Upper  | t      | P <sub>tukey</sub> |
| 'Bolero F1'     | 'Fono F1'    | -4.110 | -10.261                    | 2.041  | -2.063 | 0.285              |
|                 | 'Palotas F1' | -4.215 | -10.366                    | 1.936  | -2.116 | 0.264              |
|                 | 'Szegedi 80' | 8.165  | 2.014                      | 14.316 | 4.099  | 0.007 **           |
|                 | 'Szikra F1'  | 8.303  | 2.151                      | 14.454 | 4.168  | 0.006 **           |
| 'Fono F1'       | 'Palotas F1' | -0.105 | -6.256                     | 6.046  | -0.053 | 0.000              |
|                 | 'Szegedi 80' | 12.275 | 6.124                      | 18.426 | 6.162  | < 0.001***         |
|                 | 'Szikra F1'  | 12.413 | 6.261                      | 18.564 | 6.231  | < 0.001***         |
| 'Palotas F1'    | 'Szegedi 80' | 12.380 | 6.229                      | 18.531 | 6.215  | < 0.001***         |
|                 | 'Szikra F1'  | 12.518 | 6.366                      | 18.669 | 6.284  | < 0.001***         |
| 'Szegedi 80'    | 'Szikra F1'  | 0.138  | -6.014                     | 6.289  | 0.069  | 0.000              |

\*\* p < 0.1, \*\*\* p < 0.01

Production capacity is a highly complex trait due to the intricate genetic determinism in the genus *Capsicum*, involving not only polymeric genes but also numerous effects with multiple actions on major genes. In addition, the influence of environmental factors contributes substantially to the extent to which genetic value is expressed in the plant phenotype.

**Table 9.** Descriptive statistics for fruit weight without peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|                          | Fruit weight without peduncle (g) |               |                  |                  |                 |
|--------------------------|-----------------------------------|---------------|------------------|------------------|-----------------|
|                          | cv. 'Bolero F1'                   | cv. 'Fono F1' | cv. 'Palotas F1' | cv. 'Szegedi 80' | cv. 'Szikra F1' |
| Mean                     | 26.36                             | 29.10         | 29.33            | 18.01            | 17.58           |
| Std. Error of Mean       | 1.144                             | 1.606         | 2.137            | 0.216            | 0.342           |
| Std. Deviation           | 2.289                             | 3.211         | 4.275            | 0.432            | 0.684           |
| Coefficient of variation | 0.087                             | 0.110         | 0.146            | 0.024            | 0.039           |
| Variance                 | 5.238                             | 10.31         | 18.27            | 0.187            | 0.468           |
| Minimum                  | 23.31                             | 24.63         | 23.88            | 17.41            | 16.89           |
| Maximum                  | 28.82                             | 32.03         | 34.32            | 18.41            | 18.51           |

The comparative analysis of the paprika genotypes with respect to fruit weight without peduncle shows that the same highly significant positive differences are maintained for the genotypes 'Fono F1' and 'Palotas F1', compared with 'Szegedi 80' and 'Szikra F1'.

**Table 10.** Post Hoc Comparisons for fruit weight without peduncle in the paprika genotypes (ARDS Lovrin, Timis, Romania 2022-2024)

|              |              | Mean Difference | 95% CI for Mean Difference |        | t      | Ptukey      |
|--------------|--------------|-----------------|----------------------------|--------|--------|-------------|
|              |              |                 | Lower                      | Upper  |        |             |
| 'Bolero F1'  | 'Fono F1'    | -2.738          | -8.471                     | 2.996  | -1.474 | 0.593       |
|              | 'Palotas F1' | -2.968          | -8.701                     | 2.766  | -1.598 | 0.520       |
|              | 'Szegedi 80' | 8.352           | 2.619                      | 14.086 | 4.498  | 0.003 **    |
|              | 'Szikra F1'  | 8.787           | 3.054                      | 14.521 | 4.733  | 0.002 **    |
| 'Fono F1'    | 'Palotas F1' | -0.230          | -5.964                     | 5.504  | -0.124 | 0.000       |
|              | 'Szegedi 80' | 11.090          | 5.356                      | 16.824 | 5.973  | < 0.001 *** |
|              | 'Szikra F1'  | 11.525          | 5.791                      | 17.259 | 6.207  | < 0.001 *** |
| 'Palotas F1' | 'Szegedi 80' | 11.320          | 5.586                      | 17.054 | 6.097  | < 0.001 *** |
|              | 'Szikra F1'  | 11.755          | 6.021                      | 17.489 | 6.331  | < 0.001 *** |
| 'Szegedi 80' | 'Szikra F1'  | 0.435           | -5.299                     | 6.169  | 0.234  | 0.999       |

\*\* p < 0.1, \*\*\* p < 0.01

For fruit weight in *Capsicum annuum*, particularly in small-fruited varieties (paprika and hot peppers), similar results have been obtained in both cultivation systems, open-field and high-tunnel (Ciulca, 2010; Daood Hussein, 2014; Agapie et al., 2020). Fruit weight may also be influenced by the number of fruits per plant and by plant height (Egyed, 2022; Dinu, 2024).

To determine the interdependence of the morphological traits, four variables were considered: "x" – fruit length without peduncle; "y" – fruit diameter; "z" – shape index; "w" – fruit weight without peduncle. These variables enabled the calculation of simple, partial, and multiple correlation coefficients (Table 11).

**Table 11.** Pearson correlation coefficients for the morphological traits analyzed in paprika fruits (ARDS Lovrin, Timis, Romania 2022-2024)

|                    | Pepper genotypes for paprika powder |               |                  |                  |                 |
|--------------------|-------------------------------------|---------------|------------------|------------------|-----------------|
|                    | cv. 'Bolero F1'                     | cv. 'Fono F1' | cv. 'Palotas F1' | cv. 'Szegedi 80' | cv. 'Szikra F1' |
| Simple correlation |                                     |               |                  |                  |                 |
| $r_{xy} =$         | 0.030                               | 0.307         | 0.526 **         | -0.586 °         | -0.372          |
| $r_{xz} =$         | 0.765 ***                           | 0.301         | -0.160           | 0.800 ***        | 0.711 **        |
| $r_{xw} =$         | 0.435                               | 0.814 ***     | 0.570 **         | 0.167            | -0.285          |

|                                  |            |            |            |            |            |
|----------------------------------|------------|------------|------------|------------|------------|
| $ryz =$                          | -0.611 °   | -0.807 °°° | -0.889 °°° | -0.951 °°° | -0.903 °°° |
| $ryw =$                          | -0.179     | 0.228      | 0.847 ***  | 0.321      | 0.838 ***  |
| $rzw =$                          | 0.438      | 0.240      | -0.703 °°  | -0.172     | -0.781 °°° |
| First grade partial correlation  |            |            |            |            |            |
| $rx^*y^*z =$                     | 0.978 ***  | 0.981 ***  | 0.852 ***  | 0.946 ***  | 0.902 ***  |
| $rx^*y^*w =$                     | 0.122      | 0.216      | 0.099      | -0.685 °°  | -0.254     |
| $rx^*z^*y =$                     | 0.991 ***  | 0.981 ***  | 0.793 ***  | 0.970 ***  | 0.945 ***  |
| $rx^*z^*w =$                     | 0.710 **   | 0.187      | 0.413      | 0.853 ***  | 0.816 ***  |
| $rx^*w^*y =$                     | 0.447      | 0.803 ***  | 0.274      | 0.463      | 0.053      |
| $rx^*w^*z =$                     | 0.171      | 0.801 ***  | 0.652 **   | 0.516 *    | 0.617 *    |
| $ry^*z^*x =$                     | -0.986 °°° | -0.992 °°° | -0.959 °°° | -0.992 °°° | -0.980 °°° |
| $ry^*z^*w =$                     | -0.602 °   | -0.912 °°° | -0.777 °°° | -0.960 °°° | -0.731 °°  |
| $ry^*w^*x =$                     | -0.214     | -0.041     | 0.783 ***  | 0.525 *    | 0.823 ***  |
| $ry^*w^*z =$                     | 0.124      | 0.738 **   | 0.683      | 0.517 *    | 0.495      |
| $ry^*z^*x =$                     | 0.182      | -0.009     | -0.755 °°  | -0.518 °   | -0.858 °°° |
| $ry^*z^*w =$                     | 0.422      | 0.740 **   | 0.207      | 0.456      | -0.100     |
| Second grade partial correlation |            |            |            |            |            |
| $rx^*y^*zw =$                    | 0.978 ***  | 0.966 ***  | 0.734 **   | 0.926 ***  | 0.872 ***  |
| $rx^*z^*yw =$                    | 0.989 ***  | 0.966 ***  | 0.783 ***  | 0.963 ***  | 0.956 ***  |
| $rx^*w^*yz =$                    | 0.242      | 0.597 *    | 0.184      | 0.096      | 0.454      |
| Multiple correlation             |            |            |            |            |            |
| $Rx^*yz =$                       | 0.991 ***  | 0.983 ***  | 0.856 ***  | 0.981 ***  | 0.952 ***  |
| $Rx^*yw =$                       | 0.448      | 0.824 ***  | 0.576 *    | 0.696 **   | 0.375      |
| $Rx^*zw =$                       | 0.773 ***  | 0.821 ***  | 0.663 *    | 0.858 ***  | 0.833 ***  |
| $Ry^*xz =$                       | 0.986 ***  | 0.993 ***  | 0.970 ***  | 0.995 ***  | 0.982 ***  |
| $Ry^*xw =$                       | 0.216      | 0.310      | 0.849 ***  | 0.724 **   | 0.849 ***  |
| $Ry^*zw =$                       | 0.618 *    | 0.917 ***  | 0.942 ***  | 0.964 ***  | 0.928 ***  |
| $Rz^*xy =$                       | 0.994 ***  | 0.993 ***  | 0.960 ***  | 0.997 ***  | 0.990 ***  |
| $Rz^*xw =$                       | 0.774 ***  | 0.302      | 0.762 ***  | 0.858 ***  | 0.932 ***  |
| $Rz^*yw =$                       | 0.696 **   | 0.918 ***  | 0.894 ***  | 0.961 ***  | 0.904 ***  |

Morphological fruit traits (variables): "x" – length without peduncle; "y" – diameter; "z" – shape index;

"w" – weight without peduncle.

\* / ° p 5%, \*\* / °° p 1%, \*\*\* / °°° p 0.1%.

From the analysis of the correlation coefficients presented in the adjacent table, the following aspects can be observed:

- a highly significant positive correlation between fruit length and shape index in the genotypes 'Bolero F1' and 'Szegedi 80', between fruit diameter and fruit weight in the hybrids 'Palotas' and 'Szikra', and between fruit length and fruit weight in the hybrid 'Fono';
- the shape index is highly significantly and positively correlated with the interaction between fruit length and fruit diameter in all paprika genotypes grown in high tunnels;
- fruit diameter is also highly significantly and positively correlated with the interdependence of fruit length and shape index.

The influence and interdependence of morphological traits on production capacity is supported by similar results obtained in long-term, complex research studies (Somogyi et al., 2000; Somogyi, 2010; Ursu et al., 2012; Pošta and Balint, 2015; Pošta et al., 2016; Parvin et al., 2024).

## CONCLUSIONS

Based on the experimental results obtained from determining the morphological traits that define production capacity in paprika grown in high tunnels, the following conclusions can be drawn:

- the paprika genotypes tested and analyzed show strong phenotypic diversity in their morphological traits;
- the hybrids 'Fono' and 'Palotas' record higher fruit length values compared with the other paprika genotypes;
- for fruit weight, highly significant differences are evident in the hybrids 'Fono' and 'Palotas', compared with the genotypes 'Szegedi 80' and 'Szikra F1';
- highly significant positive correlations were identified between fruit length and shape index in the genotypes 'Bolero F1' and 'Szegedi 80', and between fruit diameter and fruit weight in the hybrids 'Palotas' and 'Szikra'.

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**REFERENCES**

1. Agapie Ovidia Loredana, Florin Stănică, Costel Vinătoru, Bianca Tănase, Elena Barcanu, Geanina Negoșanu and Ion Gherase. Description of Valuable Genotypes from Germplasm Collection of Hot Peppers Set by Directions of Use. *Bulletin UASVM CJ Horticulture*, 2020, 77(2):117-121, <https://doi.org/10.15835/buasvmcn-hort:2020.0043>
2. Amro H.A. Mohamed, Mohamed H.Z. El-Dekeshey, Sahar M.A. Gazal, Dena S. Mselhi. Effect of Foliar Application of Salicylic Acid and Potassium Silicate on Productivity and Physical Quality Characteristics of Hot Pepper (*Capsicum annuum* L.) Fruits. *Assiut Journal of Agricultural Sciences*, 2023, 54(1):251-269 [10.21608/ajas.2022.166454.1183](https://doi.org/10.21608/ajas.2022.166454.1183)
3. ASTA. Official analytical methods of the American spice trade association (2nd ed.) "ASTA cleanliness specifications for spices, seeds, and herbs", 1999, In: ASTA Inc. (Eds.), Engelwoods Cliff., New Jersey, NJ, USA.
4. Berar V., Nedelea G., Poșta Gh. Cercetări privind îmbunătățirea tehnologiei de cultură a ardeiului de boia în condiții de solar pentru obținerea produsului finit de calitate. 2011. Romania, Ed. Eurobit, Timisoara.
5. Bere Semeredi A. A., Berar V. Researches concerning the yield traits variability of some paprika cultivars. *JOURNAL of Horticulture, Forestry and Biotechnology*, 2015, Volume 19(2), pp. 152- 156.
6. Bere Semeredi A. A., Berar V. Assessment of the phenotypic diversity between some paprika cultivars for yield traits. *JOURNAL of Horticulture, Forestry and Biotechnology*, 2015, Volume 19(2), pp. 157- 161.
7. Bosland P.W., Votava E.J. Peppers: vegetable and spice capsicums. 2<sup>nd</sup> ed., 2012, Wallingford CABI United Kingdom, 230 pp.
8. Ciulca Sorin, Emilian Madosa, Adriana Ciulca, Sabin Chis. Stability Analysis of Fruit Weight in Paprika Pepper. *Bulletin UASVM Agriculture*, 2010, 67(1):235-239
9. Crosby K.M. Pepper, p. 221-248. In Prohens, J. and F. Nuez (eds.). *Vegetables, II: Fabaceae, Liliaceae, Umbelliferae, and Solanaceae*, 2008, Springer, New York, NY.
10. Daood Hussein G., Gábor Palotás, Gabriella Palotás, György Somogyi, Zoltán Pék, Lajos Helyes. Carotenoid and antioxidant content of ground paprika from indoor-cultivated traditional varieties and new hybrids of spice red peppers. *Food Research International*, 2014, Volume 65, Part B, pages 231-237, <https://doi.org/10.1016/j.foodres.2014.04.048>
11. Dinu Maria, Soare Rodica, Ivan Claudia-Georgiana. Analysis of the diversity of some hot pepper (*Capsicum annuum* L.) populations from southwest Romania on the base of morphological and production characters. *Annals of the University of Craiova*, 2024, vol. XXIX (LXV), pp. 165-172.
12. Egyed Emese, Rózsa Melinda, Rózsa S., Gocan Tincuța-Marta, Măniuțiu D.N. Behavior of two hot pepper hybrids (*Capsicum annuum* L.) under Transylvania growing conditions. *JOURNAL of Horticulture, Forestry and Biotechnology*, 2022, Volume 26(3), pp. 56-60.
13. Egyed Emese, Roxana L. Stoian-Dod, Alexandru-Ioan Apahidean, Emese Gál, Sándor Rózsa, Tincuța M. Gocan, Dănuț-Nicolae Măniuțiu. Accumulation of capsaicin in two chili pepper varieties (*Capsicum annuum* L.) at different stages of fruit maturity. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 2024, Volume 52, Issue 4, Article number 13953, [doi:10.15835/nbha52413953](https://doi.org/10.15835/nbha52413953)
14. Hornero-Méndez D., Gómez-Ladrón de Guevara R., and Mínguez-Mosquera M.I. Carotenoid biosynthesis changes in five red pepper (*Capsicum annuum* L.) cultivars during ripening. *Cultivar selection for breeding. Journal of Food and Agricultural Chemistry*, 2000, 48(9):3857–3864, [10.1021/jf991020r](https://doi.org/10.1021/jf991020r)
15. Klátyik Szandra, Helga Molnár, Miklós Pék, Ildikó Bata-Vidács, Nóra Adányi and András Székács. Quality Management Systems – a Selective Presentation of Case-studies Showcasing Its Evolution. Chapter 6: Quality Management in Spice Paprika Production: From Cultivation to End Product. 2017, pp. 115-133, DOI: 10.5772/intechopen.71227
16. Koncsek A., Zs. H. Horváth, A. Véha, H. G. Daood, L. Helyes. Colour evolution of conventionally and organically cultivated Hungarian red spice paprika varieties. *Analecta Technica Szegedinsia*, 2016, vol. 10, no. 1, pp. 6-15, [10.14232/analecta.2016.1.6-15](https://doi.org/10.14232/analecta.2016.1.6-15)
17. Madoșă Emilian, Lavinia Sasu, Sorin Ciulca, Giancarla Velicevici, Constantin Avădanei, Adriana Ciulca, Sorina Popescu, Ioan Sărac. Studies on the variability of the productivity components in a collection of paprika pepper landraces. *Current Trends in Natural Sciences*, 2020, Vol. 9, Issue 17, pp. 15-22, <https://doi.org/10.47068/ctns.2020.v9i17.002>
18. Madoșă Emilian, Lavinia Sasu, Sorin Ciulca, Constantin Avădanei, Adriana Ciulca, Giancarla Velicevici. Studies on the variability of the productivity components in a collection of hot pepper landraces (*Capsicum*

- annuum* var. *microcarpum*). Current Trends in Natural Sciences, 2021, Vol. 10, Issue 19, pp. 201-208, <https://doi.org/10.47068/ctns.2021.v10i19.027>
19. Márkus F., Kapitány J. The importance of Szeged results for establishing the World wide reputation of the Hungaryan red peppers. Hungaryan agricultural research, 2000, vol. 9, nr. 2.
  20. Márkus F., Kapitány J. A fűszerpaprika termesztése és feldolgozása. 2001. Mezőgazdasági Szaktudós Kiadó, Budapest, p. 112.
  21. Norazian Mohd Hassan, Nurul Asyiqin Yusof, Amirah Fareeza Yahaya, Nurul Nasyitah Mohd Rozali and Rashidi Othman. Carotenoids of Capsicum Fruits: Pigment Profile and Health-Promoting Functional Attributes. Antioxidants, 2019, 8, 469, 10.3390/antiox8100469
  22. Parvin Nighat, Mst Salma Masuda, Mst Tanjina Shahanaaj Turin, Sohana Jui, Mst. Anamika Amzad, Mst. Ananya Khatun, Md Arifuzzaman, Rahma Ibrahim Alshamrani and Eakhlas Uddin Ahmed. Characterization of pepper (*Capsicum spp.*) germplasms based on morphological and phytochemical characters in Bangladesh. CABI Agriculture and Bioscience, 2024, 5:62, <https://doi.org/10.1186/s43170-024-00268-5>
  23. Poșta Gh., Balint M. Research regarding the interaction genotype x technological factors in morphological features of chilli pepper cultivated in solaria at the Experimental Station of Timisoara, Romania. JOURNAL of Horticulture, Forestry and Biotechnology, 2015, Volume 19(2), pp. 28-34.
  24. Poșta Gheorghe, Marius Balint, Alin Dobrei, Alina Georgeta Dobrei, Daniela Sabina Poșta, Marcel Danci. Research Regarding the Interaction Genotype x Technological Factors in Morphological Features of Chilli Pepper Cultivated in Solaria at the Experimental Station of Timisoara, Romania. Elsevier Agriculture and Agricultural Science Procedia, 2016, 10:178-184
  25. Sasvari Joanne. 2005. *Paprika: A Spicy Memoir from Hungary*. Toronto, ON: CanWest Books. p. 202. ISBN 9781897229057.
  26. Smith C.E. Plant remains. The Prehistory of the Tehuacan Valley, 1967, ed Byers DS (Univ of Texas Press, Austin, TX), pp 220–255.
  27. Smith C.E. Jr. Current archaeological evidence for the beginning of American agriculture. Studies in the Neolithic and Urban Revolutions, The V. Gordon Childe Colloquium, 1987, ed Manzanilla L (British Archaeological Reports, Oxford, UK), pp 81–101.
  28. Somogyi N., Pék M., Mihály A., Applied spice paprika (*Capsicum annum* L., var. *Longum*) growing technologies and processing in Hungary. Acta Horticulturae, 2000, 536, 389-396 10.17660/ActaHortic.2000.536.47
  29. Somogyi N. 2010. Hibrid fűszerpaprika nemesítés és hajtatasos termesztéstechnológia. Doktori értekezés, Keszthely, Pannon Egyetem Georgikon Kar, Növénytermesztési és Kertészeti Tudományok Doktori Iskola.
  30. Ursu P., Berar V., Poșta Gh. Researches Concerning the Influence of Some Morphological Characters on Paprika Pepper Yield used in Solarium Type. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture, 2012, 69(1):344-353 10.15835/buasvmcn-hort:8539
  31. Ursu P., Berar V., Poșta Gh. Studies concerning the influence of genotype and planting density on some morphological characters in an assortment of paprika pepper cultivars grown in solarium type. JOURNAL of Horticulture, Forestry and Biotechnology, 2013, Volume 17(2), pp. 342-347.
  32. Ursu P., Berar V., Poșta Gh. Studies regarding the evaluation of the interaction between genotype x technological factors in the case of some morphological and production characters at paprika pepper cultivated in solarium type. JOURNAL of Horticulture, Forestry and Biotechnology, 2013, Volume 17(2):348-352.
  33. Ursu P., Berar V., Poșta Gh. Studies concerning the influence of genotype and planting density on fruit number and yield per plant at some paprika pepper cultivars grown in solarium type. Paripex – Indian Journal of Research, 2013, 2(8):134-137.
  34. USDA-ARS. Grin Species Records of Capsicum; National Germplasm Resources Laboratory, 2011, Beltsville, MD, USA.
  35. Zhani Kaouther, Wissem Hamdi, Sami Sedraoui, Rami Fendri, Oula Lajimi, Chérif Hannachi. Agronomic evaluation of Tunisian accessions of chili pepper (*Capsicum frutescens* L.). International Research Journal of Engineering and Technology, 2015, Volume: 02 Issue: 04, pp. 28-34.