UDC 575. 630
https://doi.org/10.2298/GENSR2601001P
Original scientific article

GENOTYPIC VARIATION IN FRUIT AND SEED YIELD COMPONENTS OF EGGPLANT (*Solanum melongena* L.) UNDER TEMPERATE AGROECOLOGICAL CONDITIONS

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Popović V., S. Vlajić, A. Takač (2026): *Genotypic variation in fruit and seed yield components of eggplant (Solanum melongena L.) under temperate agroecological conditions.*- Genetika, Vol 58, No. 1, 1-10.

This three-year field study evaluated fruit and seed yield components in three morphologically distinct eggplant (*Solanum melongena* L.) cultivars Domaci Srednje Dugi (DSD), Chinese Snake-shaped (CS), and Violeta Lunga di Romagna (VLR) under agroecological conditions of northern Serbia. Statistically highly significant differences were recorded among cultivars for all investigated traits, including plant height, fruit morphology, number of fruits per plant, fruit and seed yield per plant and per hectare, and the fruit-to-seed ratio. The VLR cultivar exhibited the highest fruit yield (33.5 t ha^{-1}), primarily due to its large fruit weight, while the DSD cultivar had the highest seed yield (420.0 kg ha^{-1}) and the most favorable fruit-to-seed ratio (67.9 g g^{-1}). Correlation analysis revealed strong interdependencies among yield traits. Fruit yield was positively associated with fruit weight and biomass per seed unit, while seed yield showed negative correlations with both plant height and fruit length. These findings suggest that genotypic variation is a key determinant of yield performance and biomass partitioning in eggplant, with implications for cultivar selection targeting either fruit production or seed efficiency.

Key words: cultivar variability, fruit morphology, fruit yield, seed yield, *Solanum melongena* L.

INTRODUCTION

Eggplant (*Solanum melongena* L.) is cultivated globally on approximately 1.92 million hectares, with an average yield of 31.62 t ha^{-1} and an annual production exceeding 60 million

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tons (FAOSTAT, 2023). It is of considerable economic significance, particularly in Asia, which accounts for over 90% of global production, as well as in parts of Europe and Africa. The countries with the largest cultivated areas include China (831,869 ha), India (681,000 ha), Egypt (63,468 ha), Bangladesh (54,903 ha), Indonesia (49,458 ha), the Philippines (22,006 ha), Iran (19,193 ha), Turkey (16,662 ha), and Côte d'Ivoire (16,000 ha). The Mediterranean region, including Egypt, Turkey, and Italy contributes an estimated 2.5 to 2.8 million tons to annual global production (PASSAM *et al*., 2010). In the Republic of Serbia, eggplant is grown on approximately 100 hectares, with an average yield of 20.46 t ha^{-1} (FAOSTAT, 2023). Introduced from Turkey, eggplant has been cultivated in Serbian home gardens for over a century. In recent years, open-field production has been expanding, primarily to meet the demand for traditional culinary uses (TAKAČ and GVOZDENOVIĆ, 2005).

The eggplant produces a fruit that is botanically classified as a berry. In the Solanaceae family, fruit morphology demonstrates extensive phenotypic variation, particularly in size, shape, and color, both within and between species, reflecting underlying genetic diversity (SINGH *et al*., 2009; WANG *et al*., 2015). Eggplant cultivars are classified according to fruit number per plant as low-yielding (up to 5 fruits), medium-yielding (5–12 fruits), and high-yielding (more than 12 fruits). Based on individual fruit weight, they are further categorized as small-fruited (100–200 g), medium (200–400 g), large (400–800 g), and very large (over 800 g). In Serbia, the majority of commonly cultivated cultivars produce fruits weighing between 400 and 1,000 grams. Fruit morphology is highly variable, with shapes ranging from round and pyriform to serpentine, and lengths between 10 and 40 cm. The skin color of unripe fruits varies widely and may include dark purple, light purple, green, red, white, or yellow, with or without surface gloss (TAKAČ and GVOZDENOVIĆ, 2005). Upon full ripening, fruit coloration typically shifts to dark brown, yellow-brown, or dark yellow hues (POPOVIĆ *et al*., 2022). Fruit yield in eggplant is a highly complicated trait that is influenced by a number of genetic and environmental factors that are intertwined during distinct stages of plant development (THOMAS *et al*., 2022).

Eggplant seeds are small, flat, and reniform in shape. Approximately 250 seeds are contained in one gram. In Serbia, the average seed yield is about 250 kg ha^{-1} (TAKAČ and GVOZDENOVIĆ, 2005), although yields can reach up to 600 kg ha^{-1} in some other countries (CHEN and LI, 1995). It is well established that fruits designated for seed extraction are harvested at a more advanced maturity stage than those intended for fresh consumption (GEORGE, 1985). Seeds are typically obtained from fully mature fruits, which are chopped or crushed and then subjected to fermentation. The upper portion of the fruit, near the calyx, is generally devoid of seeds and is commonly discarded to ease processing. The majority of seeds are concentrated in the lower half of the fruit (GVOZDENOVIĆ *et al*., 2011).

One of the primary objectives in eggplant breeding is to enhance yield potential and fruit quality, while also improving adaptability to diverse environmental conditions (BORGATO *et al*., 2007). The development of new cultivars is often driven by the need to respond to specific ecological and climatic factors. Notable phenotypic variability can be observed even within a single variety, with traits such as plant height, fruit size, and yield being influenced by climate, light exposure, geographical location, and cultivation practices (PRODANOVIĆ *et al*., 2015).

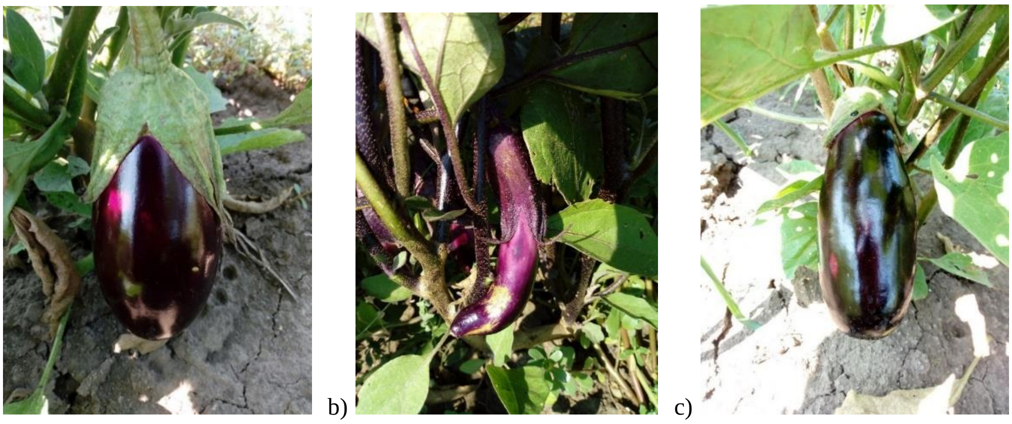
The objectives of this study were to investigate the genotypic variability among three morphologically distinct eggplant cultivars with respect to fruit and seed yield components under temperate agroecological conditions of northern Serbia. Particular attention was given to assessing how genotypic differences influence traits such as plant height, fruit morphology, number of fruits per plant, fruit and seed yield, as well as the fruit-to-seed ratio. Understanding genotypic variation aims to contribute to cultivar selection focused on improving yield performance, whether targeting fruit production or efficient seed yield, which is crucial for future breeding programs and the adaptation of cultivars to specific growing conditions.

MATERIALS AND METHODS

Plant Material

The study involved three morphologically distinct cultivars of eggplant (*Solanum melongena* L.) from the collection of the Institute of Field and Vegetable Crops, Novi Sad. These cultivars originated from diverse agroecological regions:

1. ***Domaci srednje dugi (DSD)*** – A Serbian early-maturing cultivar widely grown across the Republic of Serbia (ZDRAVKOVIĆ *et al*., 2011). Belonging to *S. melongena* subsp. **occidentale**, it exhibits a multi-branched growth habit (3–4 branches) with broad, light green leaves (Figure 1a).
2. ***Chinese snake-shaped (CS)*** – A late-maturing cultivar of Chinese origin, characterized by elongated fruit, branched and vigorous growth, the presence of fine trichomes and pedicel spines, and strong anthocyanin pigmentation in the stem, leaves, and calyx (Figure 1b).
3. ***Violeta Lunga di Romagna (VLR) –*** An Italian mid- to late-maturing cultivar with large, tobacco-like light green leaves and elongated fruits ranging from purple to dark purple, accompanied by green calyx lobes (Figure 1c).



a) b) c)

Figure 1.a) Domaći srednje dugi cultivar, b) Chinese snake-shaped cultivar, c)Violeta lunga di romagna cultivar

Field Experiment

The field trials were conducted over three consecutive growing seasons (2017–2019) at the experimental station of the Institute in Novi Sad (Rimski Šančevi; 45°19'52.2"N, 19°50'10.4"E). Seeds were sown in early April under greenhouse conditions. Seedlings were pricked out 12–14 days after sowing and transplanted into seedling trays at 10 × 10 cm spacing to enhance vegetative growth and uniformity.

Transplanting to the field occurred in the second half of May using a randomized complete block design with five replications. Each plot comprised 50 plants, with row spacing of 70 cm and 50 cm between plants within rows. The experiment was established on a different field plot each year. Preceding crops included pea (*Pisum sativum*) in 2017, and wheat (*Triticum* spp.) in 2018 and 2019.

Soil preparation involved loosening to a depth of 35 cm, followed by two disk harrowings, 25 days apart. In October, before plowing (30 cm), mineral fertilizer (NPK 8:16:24) was applied at 400 kg ha^{-1}. In spring, additional fertilization was carried out with NPK 15:15:15 (200 kg ha^{-1}) in mid-April, and ammonium nitrate (200 kg ha^{-1}) was applied four weeks after transplanting. Standard crop management practices, including irrigation and plant protection measures, were applied in accordance with expert guidelines.

Meteorological Conditions

Climatic data (air temperature and precipitation) for all three years were obtained from the Republic Hydrometeorological Service of Serbia (2025). Monthly averages are shown in Figure 2 (a-c). Air temperatures were relatively consistent across seasons, with August being the warmest month (average 24.4 °C). Precipitation varied more considerably, with 2017 being notably dry, while June 2018 and May 2019 were the wettest months in their respective seasons.

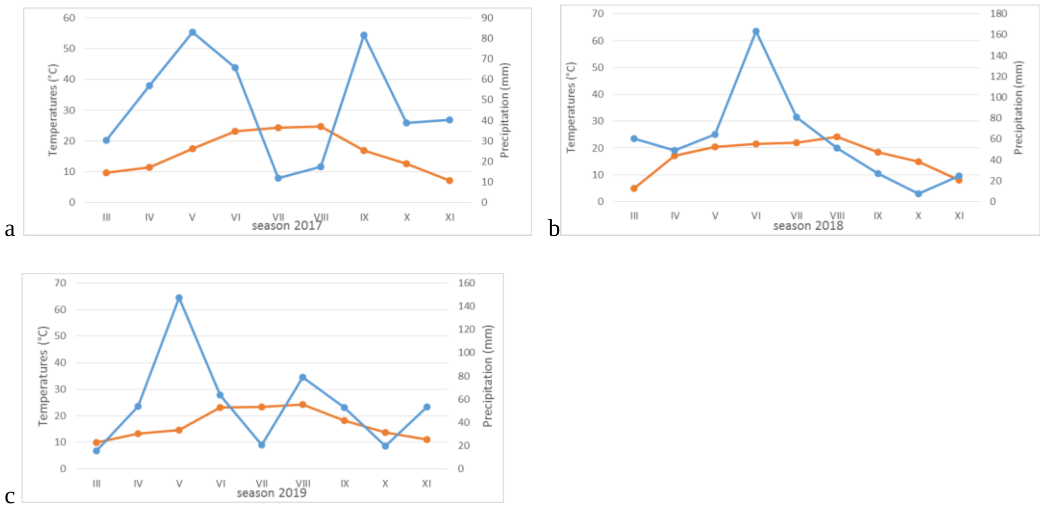


Figure 2. Monthly air temperature and precipitation patterns during the 2017 (a), 2018 (b), 2019 (c) growing season at the experimental site of the evaluated eggplant cultivars

Measured Parameters

Comparative evaluation of fruit and seed yield components was conducted among the three cultivars. The following traits were analyzed:

- Plant height (PH, cm)
- Fruit length (FL, cm)
- Fruit width (FW, cm)
- Fruit weight (FWt, g)
- Number of fruits per plant (FN)
- Fruit yield per plant (FP, g)
- Total fruit yield per hectare (TFY, t ha^{-1})
- Total seed yield per hectare (TSY, kg ha^{-1})
- Fruit-to-seed ratio (FSR, g)

For fruit traits (FL, FW, FWt, FN, FP and TFY), unripe fruits (dark purple) were analyzed. Fully ripe fruits (dark brown) were used for TSY and FSR determination. Fruits were chopped and fermented for up to three days, after which seeds were extracted, washed, and dried. The seed yield per hectare and the fruit mass required for 1 g of seed were subsequently calculated.

Statistical Analysis

Data were analyzed using Statistica 13 (StatSoft Inc., Tulsa, OK, USA). A combined two-way ANOVA was applied with year and cultivar as factors, including their interaction. Differences among means were tested using the LSD test at $p<0.05$ and $p<0.01$. Normality and homogeneity of variances were verified using the Shapiro–Wilk and Levene's tests. ANOVA results (df, MS, F, p) are presented in Tables 1a and 2a. Pearson's correlation coefficients were calculated to assess relationships among traits.

RESULTS AND DISCUSSION

Morphological traits

Plant height (PH). Significant genotypic differences were found for PH (Table 1), with CS being the tallest (78.8 cm) and DSD the shortest (62.6 cm). The combined ANOVA (Table 1a) confirmed that year, cultivar, and their interaction significantly influenced PH ($p<0.001$), indicating both genetic and environmental effects on vegetative growth. Similar genetic variability in PH has been reported in broader genotype studies, suggesting PH is a reliable selection criterion in breeding programs (UDDIN *et al*., 2021).

Fruit morphology (FL and FW). Fruit length (FL) and fruit width (FW) varied significantly among cultivars (Table 1). The longer fruits in CS and wider fruits in DSD reflect morphological divergence, which is consistent with findings from large germplasm studies where morphological descriptors showed extensive variation across diverse eggplant accessions (UDDIN *et al*., 2021; RO *et al*., 2022). These morphological differences are important for both market classes and genetic resource characterization.

Fruit weight (FWt) and fruit number (FN). VLR exhibited the highest average FWt (315.0 g), whereas CS had the greatest FN (4.7) (Table 1). The combined analysis (Table 1a) confirmed significant effects of year and genotype on these traits (p<0.001), highlighting genotype-specific performance across environments. This pattern aligns with observations in multi-genotype research where fruit weight and number per plant often contribute directly to yield potential (UDDIN *et al*., 2021).

Table 1. Morphological traits of three eggplant (Solanum melongena L.) cultivars grown under agroecological conditions of Serbia (2017–2019).

Cultivar (c)	PH (cm)	FL (cm)	FW (cm)	FWt (g)	FN (pcs.)
DSD	62.6±0.39	18.6±0.16	8.5±0.08	243.0±1,36	4.2±0.05
CS	78.8±0.58	29.3±0.20	6.5±0.05	228.1±1,40	4.7±0.04
VLR	66.8±0.28	21.3±0.21	7.4±0.07	315.0±1,85	3.8±0.04
Average	69.4±1.06	23.1±0.69	7.5±0.13	262.1±5,78	4.2±0.06
CV%	10.28	20.16	11.56	14.81	9.56
LSD_c(0,01)	1.65	0.72	0.25	5.92	0.16
LSD_c(0,05)	1.24	0.54	0.18	4.43	0.12

A three-year average (2017-2019) ± standard error of mean (SE), the analysis of variance, (LSD test, p < 0.01).

Table 1a. Combined analysis of variance (ANOVA) for the effects of year, cultivar, and their interaction on measured morphological traits

Source	df	PH (cm)			FL (cm)			FW (cm)			FWt (g)			FN (pcs.)		
		MS	F	p	MS	F	p	MS	F	p	MS	F	p	MS	F	p
Year	2	39.68	88.89	<0.001	4.28	71.54	<0.001	0.22	16.75	<0.001	382.23	35.74	<0.001	0.34	38.81	<0.001
Cultivar	2	1061.82	2378.39	<0.001	462.06	7715.22	<0.001	14.68	1119.88	<0.001	32595.72	3047.69	<0.001	3.05	347.47	<0.001
Year × Cultivar	4	4.58	10.25	<0.001	1.26	2.32	0.0760	0.06	4.59	0.0042	86.95	8.13	<0.001	0.10	11.70	<0.001
Error	36	0.45	-	-	0.06	-	-	0.01	-	-	10.70	-	-	0.01	-	-

*****Values represent mean squares (MS) and F-values from two-way ANOVA. All effects were highly significant (p < 0.001). Assumptions of normality and homogeneity of variance were verified.

Yield components

Fruit yield (FP and TFY). Total fruit yield per plant (FP) and total fruit yield per hectare (TFY) differed significantly among cultivars (Table 2), with VLR achieving the highest yields. Although CS exhibited the greatest plant height and the highest number of fruits per plant, it nonetheless produced the lowest overall fruit yield. This outcome can be attributed to its comparatively low individual fruit weight, which was the smallest among all tested varieties. Comparable genotypic variation for fruit yield was observed in studies with larger genotype sets, where yield components exhibited wide phenotypic ranges and correlations with morphological traits (UDDIN *et al*., 2021).

Seed yield (TSY) and fruit-to-seed ratio (FSR). DSD exhibited the highest TSY and most favorable FSR (Table 2). Seed production efficiency is a critical breeding consideration, especially in cultivars used for seed propagation. The combined ANOVA (Table 2a) indicated consistent and significant year × cultivar interactions (p<0.001), underscoring the influence of yearly conditions on yield responses. While the present study did not measure qualitative seed parameters (e.g., germination energy, total germination, dormancy), these important seed quality traits were analyzed in detail in our previous work (POPOVIĆ *et al*., 2022), which documented how seed maturity influences seed vigor and germination capacity in eggplant. This information complements the present findings by providing a broader perspective on seed performance without redundancy of analyses.

Table 2. Fruit and seed yield components of tested eggplant cultivars under field conditions in Serbia (2017–2019).

Cultivar (c)	FP (g)	TFY (t ha^{-1})	TSY (kg ha^{-1})	FSR (g)
DSD	1020.6±6.50	28.6±0.23	420.0±2.35	67.9±0.41
CS	1071.6±3.91	30.0±0.31	377.6±2.44	79.4±0.46
VLR	1197.0±6.69	33.5±0.26	382.6±2.83	87.6±0.41
Average	1096.4±11.56	30.7±0.35	393.4±3.19	78.3±1.24
CV%	7.13	7.56	5.45	10.64
LSD $_c$(0,01)	22.27	1.03	9.72	1.63
LSD $_c$(0,05)	16.66	0.77	7.27	1.22

A three-year average (2017-2019) ± standard error of mean (SE), The analysis of variance, (LSD test, $p < 0.01$).

Table 2a. Combined analysis of variance (ANOVA) for the effects of year, cultivar, and their interaction on measured yield-related traits

Source	df	FP (g)			TFY (t ha^{-1})			TSY (kg ha^{-1})			FSR (g)		
		MS	F	p	MS	F	p	MS	F	p	MS	F	p
Year	2	3610.35	30.09	<0.001	3.43	20.26	<0.001	1001.81	27.01	<0.001	37.97	52.30	<0.001
Cultivar	2	123605.19	1030.23	<0.001	111.10	656.56	<0.001	8086.62	218.01	<0.001	1493.19	2056.42	<0.001
Year × Cultivar	4	731.67	6.10	0.007	1.21	7.17	0.002	110.65	2.98	0.0317	7.19	9.90	<0.001
Error	36	119.98	-	-	0.17	-	-	37.09	-	-	0.73	-	-

*Values represent mean squares (MS) and F-values from two-way ANOVA. All effects were highly significant ($p < 0.001$). Assumptions of normality and homogeneity of variance were verified.

Trait relationships

Correlation analysis revealed significant interrelations among traits (Table 3). For instance, PH was strongly correlated with FL and FN, whereas FW was negatively associated with both. Positive associations between fruit weight and yield components reinforce the role of fruit size in productivity, consistent with multi-genotype evaluations highlighting similar trait linkages (UDDIN *et al*., 2021). Negative correlations observed between some vegetative and reproductive traits may reflect genetic trade-offs that breeders must navigate when selecting for specific ideotypes.

Table 3. Pearson correlation matrix among fruit and seed yield traits in tested eggplant cultivars. Lower diagonal shows correlation coefficients (r), and upper diagonal shows corresponding p-values.

	PH	FL	FW	FWt	FN	FP	TFY	TSY	FSR
PH*	1	<0.0001	<0.0001	0.0094	<0.0001	0.7494	0.5860	<0.0001	0.0157
FL	0.98**	1	<0.0001	0.0065	<0.0001	0.8315	0.7333	<0.0001	0.0207
FW	-0.85**	-0.88**	1	0.4377	0.0054	0.0790	0.1644	<0.0001	0.0001
FWt	-0.38	-0.40	0.12	1	<0.0001	<0.0001	<0.0001	0.2642	<0.0001
FN	0.71**	0.72**	-0.41	-0.80**	1	0.0002	0.0012	0.6014	0.0494
FP	0.05	0.03	-0.26	0.89**	-0.53	1	<0.0001	0.0021	<0.0001
TFY	0.08	0.05	-0.21	0.85**	-0.47	0.95**	1	0.0178	<0.0001
TSY	-0.61**	-0.63**	0.88**	-0.17	-0.08	-0.45	-0.35	1	<0.0001
FSR	0.35	0.34	-0.55	0.71**	-0.29	0.93**	0.90**	-0.68**	1

*****PH – Plant height; FL – Fruit length; FW – Fruit width; FWt – Fruit weight; FN – Fruit number per plant; FP – Fruit yield per plant; TFY – Total fruit yield; TSY – Total seed yield; FSR – Fruit-to-seed ratio

Statistically significant correlations at $p < 0.05$ (*) and $p < 0.01$ (**) are indicated.

Broad context and breeding implications

The significant genotypic variation observed across morphological and yield traits reflects the broad phenotypic diversity present in eggplant germplasm. Large studies involving dozens to hundreds of genotypes have documented wide ranges of variation for PH, FL, FW, yield, and trait associations, offering valuable benchmarks for trait selection and breeding (UDDIN *et al*., 2021; DAMNJANOVIĆ *et al*., 2022). The present study contributes to this broader body of knowledge by identifying cultivar-specific performance under temperate conditions, thereby informing breeding strategies tailored to distinct production goals (e.g., high fruit yield vs. efficient seed production). Continued integration of diverse germplasm resources and trait association studies will be essential to optimize eggplant performance across environments.

CONCLUSION

In this study, significant differences were observed among eggplant cultivars for all evaluated morphological and yield traits under temperate agroecological conditions of Serbia. The results indicate that cultivar background strongly influences the expression of productivity related traits and their balance between fruit and seed production. VLR showed the highest FP and TFY, CS had the tallest plants and the highest number of fruits per plant, while DSD achieved the highest TSY and the most efficient fruit-to-seed conversion. These results confirm that genotypic variation strongly influences the balance between fruit and seed productivity in eggplant. The findings suggest that VLR is suitable for fruit production, whereas DSD may be more appropriate for seed production under similar environmental conditions. However, further evaluation across a broader range of genotypes is needed to generalize these conclusions for wider breeding programs.

Received, October 10th, 2025
Accepted March 12th, 2026

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GENOTIPSKE RAZLIKE U KOMPONENTAMA PRINOSA PLODA I SEMENA KOD PLAVOG PATLIDŽANA (*Solanum melongena* L.) U UMERENIM AGROEKOLOŠKIM USLOVIMA

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Izvod

U trogodišnjem ogledu na polju ispitivane su komponente prinosa ploda i semena kod tri morfološki različite sorte plavog patlidžana (*Solanum melongena* L.): Domaći Srednje Dugi (DSD), Kineski zmijoliki (CS) i Violeta Lunga di Romagna (VLR), u agroekološkim uslovima severne Srbije. Kod svih ispitivanih osobina, uključujući visinu biljke, morfologiju ploda, broj plodova po biljci, prinos ploda i semena po biljci i po hektaru, kao i odnos mase ploda i mase semena, zabeležene su statistički visoko značajne razlike između sorti. Sorta VLR ostvarila je najviši prinos ploda (33,5 t ha^{-1}), zahvaljujući krupnim plodovima, dok je sorta DSD imala najveći prinos semena (420,0 kg ha^{-1}) i najpovoljniji odnos mase ploda i semena (67,9 g g^{-1}). Korelaciona analiza ukazala je na jake međusobne zavisnosti između komponenti prinosa. Prinos ploda pozitivno je korelirao sa masom ploda i količinom biljne mase po gramu semena, dok je prinos semena pokazao negativne korelacije sa visinom biljke i dužinom ploda. Dobijeni rezultati potvrđuju da varijabilnost genotipa značajno utiče na raspodelu biomase i proizvodni potencijal, što ima važne implikacije za izbor sorte u cilju ostvarivanja većeg prinosa ploda ili semena.

Primljeno 10. IX. 2025.
Odobreno 12. III. 2026.

How to cite this article: Popović V., S. Vlajić, A. Takač (2026): *Genotypic variation in fruit and seed yield components of eggplant (Solanum melongena L.) under temperate agroecological conditions*- Genetika, Vol 58, No. 1, 1-10.