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Variability of fruit traits in Macedonian embroidered pepper genotypes

Варијабилност на плодови карактеристики кај генотипови од македонска везена пиперка

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Abstract

Embroidered pepper is a unique type of Macedonian pepper with specific quantitative fruit characteristics. Until a few years ago, this type of pepper was not studied at all, developed, and described in detail, so still, there is a lack of information on this type of pepper. The aim of this study was to assess the performance of ten embroidered pepper genotypes in three environments. In the evaluation process, seven morphological traits of the fruits were characterized (fruit length, fruit width, fruit weight, fruit pedicel length, fruit wall thickness, number of locules, and number of fruits. Evaluation results assess the effects of the genotype, environment, and their interaction on the expression of embroidered peppers fruit characteristics. Considering the data from all analyzed traits lowest values were observed in environment 2 (v. Stajkovtci). All the genotypes performed the best results for all traits in environment 3 (Radovish), followed by environment 1 (v. Gluvo). There is still a need for multiple year testing for the best performing genotypes in a specific environment to be recommended to the farmers.

Keywords: Embroidered pepper, fruit traits, variability

Апстракт

Везената пиперка е уникатен вид на македонска пиперка со специфични квантитативни карактеристики на плодот. До пред неколку години овој вид воопшто не беше проучуван и карактеризиран, така што сè уште постои недостаток на информации за овој вид пиперка. Целта на оваа студија беше да се оценат перформансите на десет генотипови везена пиперка на три локации. Во процесот на евалуација беше извршена фенотипска карактеризација на седум морфолошки својства на плодовите (должина на плод, ширина на плод, маса на плод, должина на дршка, дебелина на sид, број на локули и број на плодови). Резултатите од евалуацијата го проценуваат влијанието на генотипот, животната средина и нивната интеракција врз експресијата на својства кај везената пиперка. За сите анализирани својства најниски вредности беа забележани на локацијата 2 (с. Стајковци). Сите генотипови дадоа најдобри резултати во однос на анализираните својства на локацијата 3 (Радовиш), проследено со локацијата 1 (с. Глуво). Постои потреба од повеќегодишно тестирање на генотиповите со најдобри перформанси во одредена средина за да истите бидат препорачани на фармерите.

Клучни зборови: везена пиперка, карактеристики на плодот, варијабилност

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Introduction

The *Capsicum* genus belongs to the Solanaceae family. It comprises more than 30 species that originated in America, but only five of them, *Capsicum annuum, C. chinense, C. frutescens, C. baccatum*, and *C. pubescens* have been domesticated (Pozzobon et al. 2006; Moscone et al. 2007; Misra et al. 2011).

There is evidence that pepper existed in human nutrition between 7200 and 5200 B.C. in the regions of South America (Macneish, 1964; Danojević & Medić-Pap 2018). Pepper is one of the essential vegetables globally, used in all traditional and contemporary cuisines. The incredible diversity of different pepper types provide an opportunity for various uses of pepper fruits as fresh, dried and processed. Due to increased commercial interest for pepper, breeding programs are directed toward improving qualitative and quantitative fruit traits and yield.

Genetic uniformity is the main characteristic of commercial varieties, and therefore they are more affected by different biotic and abiotic stresses (Votava et al. 2005). Autochthonous varieties and local populations of peppers, selected and grown by farmers over a long period, are well adapted to the specific agro-climatic conditions. They are a valuable source of genes that need to be fully utilized (Pacheco–Olvera et al. 2012; Mondal et al. 2016). According to Moreno et al. (2010), diverse environmental conditions affect the adaptability of local varieties. Phenotype expression is a result of the combined effects of the genotype (G) and environment (E) as well as their interaction (GxE). GxE interaction significantly influences the selection process of genotypes with more valuable characteristics (Delacy et al. 1996). Many experiments with different germplasm were carried out in order to determine the influence of genotype, environment, and their interaction on the expression of traits, obtaining different results (Rêgo et al. 2003; Sudré et al. 2005; Nascimento et al. 2014; Nascimento et al. 2015; Rêgo et al. 2015a, 2015b; Cabral et al. 2017; Todorova & Djinovic 2017; Pessoa et al. 2018; Nankar et al. 2020).

North Macedonia abounds in extremely rich diversity of different pepper types. Among them is a unique Macedonian type of embroidered pepper with specific fruit characteristics, distinctive aroma, and striking off-white striations on the skin. This pepper type is commonly used ingredient in traditional Macedonian cuisine as fresh, dried, processed, or for the preparation of the well-known spice (Bukov pepper, Bukovec). Whole dried embroidered peppers are often added to enhance the flavor of various dishes, combined with beans, meat, potatoes, and other vegetables. Embroidered peppers are an ornament of traditional Macedonian houses due to the unique drying process (the fruits are usually threaded on strings and dried outside). This pepper type is a national heritage that is still preserved and maintained by people in rural areas (Jankulovska et al. 2019). Different varieties of this species are grown on Macedonia's whole territory, perfectly adapted and acclimatized to environmental conditions. Although the country is small, it abounds in the multitude of micro-climates that shape biodiversity in that environment. Therefore, when a seed from one region is planted in another, significant differences in morphological characteristics and yield can be detected. Considering that there is a lack of scientific information on embroidered peppers' performance in different environments, it is crucial to determine the influence of genotype, environment, and their interaction on the expression of morphological traits. Based on the obtained results, the best performing genotypes in a specific environment can be recommended to the farmers for growing.

Material and methods

Ten local landraces of embroidered pepper (G106, G154, G159, G225, G302, G336, G391, G488, G501, G650) were analyzed in this research in order to determine the influence of genotype (G), environment (E), and genotype-by-environment interaction (GxE) on the expression of fruit quantitative traits. The experiment was conducted in a randomized block design with two replications, each comprising three plants, planted in plots with 50 cm between and 30 cm within row distance. Standard agronomic practices have been applied during the vegetative growth season. Thirty randomly selected fully matured fruits per genotype (five per plant) were characterized for seven morphological traits (fruit length (FL, cm), fruit width (FWI, cm), fruit weight (FWE, g), fruit pedicel length (FPL, cm), fruit wall thickness (FWT, cm), number of locules (NL) and number of fruits per plant (NF)), in three environments (v. Gluvo in 2018 - E1, v. Stajkovtci in 2019 - E2 and Radovish in 2019 - E3) according to Descriptors for Capsicum developed by the IPGRI et al. 1995.

The obtained data were subjected to analysis of variance (ANOVA) and the average values for all traits were compared by LSD-test.

Results

Analysis of variance showed that environment had a significant effect on all analyzed traits (Table 1). Genotype had a significant effect on the expression of all traits, except on the number of locules per fruit. Similarly, GxE interaction significantly influenced the expression of all traits except the fruit width.

Table 1. Analysis of Variance (ANOVA) for fruit traits of evaluated embroidered pepper genotypes

Source of variability	Df	FL	FWI	FPL	FWE	FWT	NL	NF
R (Replication)	1	1.46	0.043	0.794	0	0.00028	0.0667	0
G (Genotype)	9	90.68**	1.121**	2.578**	1319**	0.03798**	0.2222	441.2**
E (Environment)	2	93.26**	14.483**	9.594**	3949**	0.12287**	0.65*	383.2**
GxE	18	15.93**	1.892	1.25*	343*	0.02136**	0.5944**	60.1**
Error	29	4.67	0.243	0.564	142	0.0072	0.1701	1.2

ns F - test not significant; * F-test significant on level P<0.05; ** F- test significant on level P<0.01

NOTE: Abbreviations are representation of following fruit traits: FL-fruit length, FWI-fruit width, FPL-fruit pedicel length, FWE-fruit weight, FWT-fruit wall thickness, NL-number of locules and NF-number of fruits.

Fruit length

The highest average value for fruit length was determined in E3, and it was significantly higher than the same parameter in the other two environments (Table 2). The lowest FL values were detected in genotypes G391 (5.15 cm) and G302 (6.25 cm) in E1, which differed statistically from the r values of all other genotypes. The highest value was observed for G159 (19.9 cm), significantly higher compared to the other genotypes. G391 had the lowest fruit length in E1 and E2, as well as the lowest average value for this trait (9.13 cm), followed by G302 (9.27 cm). All the landraces had the longest fruits in E3, except G154, which had the lowest FL in this environment.

Table 2. Variability of fruit length (cm) for analysed embroidered pepper genotypes

Genotype	E1	E2	E3	Average
	Fruit length (cm)			
G106	15.80	16.50	16.50	16.27c
G154	13.75	14.55	10.85	13.05b
G159	19.90	18.15	20.50	19.52e
G225	17.10	13.65	18.50	16.42c
G302	6.25	8.80	12.75	9.27a
G336	17.95	19.80	18.60	18.78d
G391	5.15	8.18	14.05	9.13a
G488	14.40	15.30	26.50	18.73d
G501	17.90	14.50	23.65	18.68d
G650	16.70	14.20	19.75	16.88c
Average	14.49a	14.363a	18.165b	

GxE $LSD_{0.05}$=0.68

Fruit width

Large variations in fruit width between the genotypes were found in different environments, indicating significant divergence of the material selected for the study (Table 3). The lowest average fruit width was observed in G302 (2.08 cm), and it significantly deviates from all other values. The highest average FWI was detected in G106 (3.53 cm)). The genotype G302 had the thinnest fruits in E1 and E2. G225 in E1 and E3 had more than two times higher value for this trait compared to its performance in E2. Compared to all other genotypes, the lowest average value was observed in G302 (2.08 cm), and the highest in G106 (3.85 cm). Fruit width showed significant differences between all three environments, with the lowest values in E2.

Table 3. Variability of fruit width (cm) for analysed embroidered pepper genotypes

Genotype	E1	E2	E3	Average
	Fruit width (cm)			
G106	3.25	3.85	3.50	3.53f
G154	2.85	2.05	3.00	2.63c
G159	3.10	2.00	2.65	2.58c
G225	3.60	1.70	3.45	2.92d
G302	1.85	1.60	2.80	2.08a
G336	2.70	3.30	3.00	3.00d
G391	2.30	2.25	2.35	2.30b
G488	2.80	1.85	3.45	2.70c
G501	3.35	2.15	3.50	3.00d
G650	3.35	2.60	3.80	3.25e
Average	2.915b	2.335a	3.15b	

Fruit pedicel length

The average values for fruit pedicel length ranged from 2.1 cm in G225 under the conditions in E2 to 7 cm for G336 in E3 (Table 4). The highest values for this trait were detected in E3, significantly higher compared to the other two environments.

Table 4. Variability of fruit pedicel length (cm) for analysed embroidered pepper genotypes

Genotype	E1	E2	E3	Average
G106	4.10	3.30	3.50	3.63b
G154	3.25	3.90	4.20	3.78bc
G159	4.00	3.15	5.00	4.05de
G225	4.45	2.10	5.25	3.93cd
G302	3.25	3.20	3.25	3.23a
G336	3.95	5.75	7.00	5.57g
G391	3.10	3.80	4.90	3.93cd
G488	4.00	4.30	6.00	4.77f
G501	5.00	3.15	4.70	4.28e
G650	3.25	3.05	5.00	3.77bc
Average	3.835a	3.57a	4.88b	

GxE $LSD_{0.05}$=0.238

Fruit weight

High variability was observed in the fruit weight of the analyzed genotypes (Table 5), ranging from 8.35 g (G391 in E1) to 74.75 g (G488 in E3). The FW average in E3 was more than two times higher than in E2. All genotypes had the lowest fruit weight in E2 except for G336 and G391. On contrary, G336 had the highest fruit weight in this environment. G501 had the highest value for this trait in E3, three times higher than the weight of the same genotype in E2. In E3, the genotype G488 expressed the highest fruit weight, which was the highest value for this characteristic in all three environments. The highest average fruit weight was observed in G336 (61.47 cm). Significantly different values were detected in all three environments.

Table 5. Variability of fruit weight (g) for analysed embroidered pepper genotypes

Genotype	E1	E2	E3	Average
G106	47.65	43.75	56.30	49.23e
G154	45.65	22.50	29.40	32.52b
G159	59.35	19.15	45.55	41.35c
G225	52.25	11.65	48.85	37.58c
G302	10.65	10.45	34.60	18.57a
G336	49.50	62.55	72.35	61.47f
G391	8.35	12.95	22.60	14.63a
G488	42.70	18.60	74.75	45.35d
G501	66.30	19.30	68.75	51.45e
G650	54.40	27.05	69.45	50.30e
Average	43.68b	24.795a	52.26c	

GxE $LSD_{0.05}$=3.77

Fruit wall thickness

Data regarding wall thickness showed significantly different results among the genotypes (Table 6). The wall thickness had the highest values in G650 (0.75 mm) and G488 (0.68 mm) at E3. The genotypes were characterized by significantly thicker fruit wall in this environment than in the other two. The lowest average value was detected in G154 (0.27 mm).

Table 6. Variability of fruit wall thickness (mm) for analysed embroidered pepper genotypes

Genotype	E1	E2	E3	Average
G106	0.30	0.55	0.40	0.42d
G154	0.26	0.25	0.30	0.27a
G159	0.40	0.20	0.30	0.30b
G225	0.30	0.30	0.40	0.33c
G302	0.20	0.20	0.35	0.25a
G336	0.38	0.40	0.55	0.44def
G391	0.28	0.35	0.40	0.34c
G488	0.40	0.25	0.65	0.43def
G501	0.40	0.45	0.50	0.45ef
G650	0.33	0.30	0.75	0.46f
Average	0.3235a	0.325a	0.46b	

GxE $LSD_{0.05}$=0.027

Number of locules

The number of locules ranged from 1.5 to 3.5 (Table 7). The highest and lowest values for this trait were observed in E3, the highest in G159 (3.5), and the lowest in G154 (1.5). The average number of locules was the highest in E1, significantly higher than in E2 and E3.

Table 7. Variability of number of locules for analysed embroidered pepper genotypes

Genotype	E1	E2	E3	Average
G106	3.00	2.00	3.00	2.67
G154	3.00	2.50	1.50	2.33
G159	2.00	2.00	3.50	2.50
G225	3.00	2.50	2.50	2.67
G302	2.00	2.50	2.50	2.33
G336	2.50	3.00	3.00	2.83
G391	3.00	2.00	2.00	2.33
G488	3.00	2.00	2.00	2.33
G501	3.00	2.00	2.00	2.33
G650	2.50	3.00	2.50	2.67
Average	2.7b	2.35a	2.45a	

GxE $LSD_{0.05}$=0.131

Number of fruits per plant

Under the environment's influence, the genotypes significantly varied considering the number of fruits per plant (Table 8). The results from this study indicated that G106 in E2 (1.45) had the lowest number of fruits, opposite to G391 which produced the most fruits per plant (45.10) in E1. The genotype G391 had the highest number of fruits per plant in all environments. The values for this trait were significantly different between the environments.

Table 8. Variability of number of fruits per plant for analysed embroidered pepper genotypes

Genotype	E1	E2	E3	Average
G106	8.40	1.45	5.90	5.25d
G154	6.40	1.80	5.55	4.58bc
G159	5.80	2.50	5.70	4.67c
G225	6.20	1.80	7.95	5.32d
G302	14.05	2.50	15.00	10.52g
G336	3.35	2.70	5.30	3.78a
G391	45.10	11.25	40.20	32.18h
G488	5.75	5.30	15.70	8.92f
G501	5.85	3.15	9.10	6.03e
G650	5.50	2.80	4.60	4.30b
Average	10.64b	3.525a	11.5c	

GxE $LSD_{0.05}$=0.347

Discussion

This study provides valuable knowledge for fruit morphological traits in ten embroidered pepper genotypes. The obtained results showed significantly high variation of the studied traits among the genotypes in all three environments. Based on the results from this study, the environment significantly affected all analyzed characteristics. The genotype and GxE interaction had a significant effect on the expression of all traits, except for the number of locules per fruit and fruit width, respectively. Many researchers performed experiments on different pepper germplasm to determine the influence of genotype, environment and their interaction on the expression of traits of interest and obtained different results (Noman et al. 2015; Cabral et al. 2017). Nkansah et al. (2017) found that the environment had a significant effect on the expression of different traits, but not for the number of locules per fruit.

Moreover, genotypes' performance in different environments varied significantly and a wide range of values for fruit traits, yield and quality, were observed (Noman et al. 2015; Cabral et al. 2017; Todorova & Djinovic, 2017).

The pepper yield is directly influenced by the fruit's size, which is calculated by the length, width, and weight of the fruit (Bozokalfa & Kilic, 2010). It is known that solid fruits are easy to handle during harvest, transport, processing (Panthee et al. 2013), and are more attractive for consumers.

The demand and interest for peppers in terms of size, shape, and other specific traits vary depending on pepper type, the traditional use in the country, and different country regions. Danojević et al. (2016) analyzed different pepper types and found that in southern Serbia, peppers with longer fruits are more preferred by consumers, opposite to the northern part of the country, where shorter fruits are more favored. Considering embroidered peppers in Macedonia, longer, straight, fully embroidered peppers are more attractive to consumers than short and medium fruits with a curved shape. There is an exception when it comes to the short and tiny embroidered pepper locally named Badzanaci. They are very hot and usually required by people enjoying extreme pungency. According to the results of this study, the genotype G159 with a fruit length of 19.9 cm would be more attractive for consumers than genotypes G391 and G302. All genotypes were characterized with the highest FL values in E3, except G154, which had the lowest value in this environment. Other researchers analyzed different pepper collections in other locations and found fruit length ranging from 4.7-15.6 cm (Akinci & Akinci, 2004), 5.8-11.94 cm (Sermenli & Mavi, 2010) and 8.3-11.1 cm (Idowu-Agida et al. 2010). This variation was due to the different germplasm included in their studies and different environments in which they were grown.

Large variations in fruit width between the genotypes were found in different environments, indicating a significant diversity of the material selected for the study. FWI ranged from 1.6 cm (G302 in E2) to 3.85 cm (G106 in E2). Nankar et al. (2020) recorded significant differences for this trait, with the highest average width of 8.65 cm and the lowest of 0.94 cm. In the other authors' studies, fruit width ranged from 0.9-4.1 cm (Akinci & Akinci, 2004), 1.5-3.8 cm (Qaryouti et al. 2003), 1.73-2.88 cm (Sermenli & Mavi, 2010), and 3.9-6.3 cm (Idowu-Agida et al. 2010).

Fruit pedicel length showed the highest value (7 cm) for this trait in E3, which was significantly higher than in the other two environments. According to Setiamihardja & Knavei (1990) pedicel length is positively correlated with fruit length.

The values observed for fruit weight ranged from 8.38 g (G391 in E1) to 74.75 g (G488 in E3). The FWE average in E3 (52.26 g) was more than two times higher than in E2 (24.795 g). Significant differences for average fruit weight were detected by other researchers as well: 8.0-34 g (Qaryouti et al. 2003), 5.0-15.1 g (Akinci & Akinci, 2004).

Regarding the attack of insect pests, wall thickness can be an important trait (Quresh et al. 2015). It can also be an important feature during storage, but very thick walls reduce its digestibility (Weryszko-Chmielewska & Michałojć, 2012). Data regarding FWT showed significantly different results among the genotypes. The wall thickness had the highest values in G650 (0.75 mm) and G488 (0.68 mm) at E3. The average wall thickness was significantly higher in this environment than in the other two.

One of the most crucial decision for the farmers is to choose the most suitable variety for cultivation in specific agro-climatic conditions (Todorova & Djinovic, 2017). The number of fruits significantly varied between the genotypes and across different environments in this study which is in accordance with the results obtained by other researchers (Kanwar et al. 2014; Cabral et al. 2017).

Considering the data from all analyzed traits, which denote the lowest values for fruit weight and number of fruits per plant in v. Stajkovtci, it can be concluded that it is not suitable environment for growing embroidered peppers. Although the best performing embroidered pepper genotypes considering different morphological traits of the fruits were detected for each environment, there is still need to assess more genotypes during multiple years in order to select and recommend the most suitable genotype/s for growing in a specific environment.

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