RESEARCH ARTICLE

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Evaluation of sweet pepper cultivars and breeding lines for chemical and sensory quality

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ABSTRACT
Pepper is well known for the high content of bioactive compounds and strong antioxidant capacity formed by vitamins, carotenoids, flavonoids and polyphenols. Twenty nine pepper genotypes of different colours and shapes were studied during 2018-2020 period at the Maritsa VCRI. They were analyzed by basic chemical components (dry matter, total sugars, ascorbic acid, total pigments) and sensory traits. A genotype assessment toward above mentioned characters was established. The genotype factor had the greatest influence on the dry matter of the *conical* and *kapia* types; on the ascorbic acid and ASTA units of the cultivars and breeding lines with red-colored fruits (*kapia* and *ratund*); on the total sugars of all studied types. A strong negative correlation was found between the total sensory evaluation and the dry matter content of green pepper fruits from the *conical* type (r = -0.908**). The correlation between the total sensory assessment and the total sugar content of the green pepper fruits of the *conical* type was significant (r = 0.857*) and strongly positive for the *blocky* and *bell* ones (r = 0.958**). Based on the experiment, appropriate genotypes were selected as perspective lines or parental components in the breeding of high-quality pepper varieties.

Key words: *Capsicum annuum* L., ascorbic acid, total sugars, ASTA, taste

Introduction

Sweet pepper (*Capsicum annuum* L.) is one of the most important vegetable crops of the Balkan region. The geographical specificity of the region, the natural selection and purposeful breeding of the pepper define genetic differences in the shape, color, taste, biological value and the way of its use (Todorov & Todorova, 2002; Krasteva et al., 2012).

Pepper is well known for the high content of bioactive compounds and strong antioxidant capacity formed by vitamins, carotenoids, flavonoids and polyphenols. It is among the most popular vegetables worldwide due to the good combination of color, flavor and nutritional value (Gomez-Ladron & Pardo-Gonzalez, 1996; Dereje, 2003; Zsom et al., 2010).

Pepper fruit quality is affected by many factors. Ascorbic acid synthesis, dry matter content and total sugars were found to be genetically determined (Roura et al., 2001; Pevicharova et al., 2007). Their amounts in sweet pepper fruits can vary depending on climatic conditions, soil nutrient availability, the use of conventional or organic production technologies, etc. (Szafirowska & Elkner, 2008; Caruso et al., 2018).

Soare et al. (2017) found that the dry matter content ranged from 5.66% to 9.33% with the highest values recorded for long and red-fruited genotypes. The oblong and red fruits were also distinguished by higher values of reducing sugars up to 5.76%. In an experiment on the nutritional value of sweet pepper cultivars, Cebula et al., (2015) reported fruit dry matter content between 7.0 and 9.0 g/100g and soluble sugar content between 3.20 and 4.92 g/100 g of fresh material. A study of the different stages of ripening showed that the content of sugars and vitamin C generally increased until the optimum stage of ripeness is reached (Almela et al., 1996).

Increasing of ascorbic acid levels in pepper fruits is an important goal in the creation of genetic material from different pepper species. In the study by Soare et al., (2017) the value of this component was the highest in the red sweet pepper (204 mg/100 g) and the lowest in the green one (125 mg/100 g). The content of ascorbic acid was in close range according to the study of Cebula et al., (2015) where the ascorbic acid varied from 116.3 to 190.5 mg/100 g in sweet pepper fruits. The influence of pepper maturity on the level of ascorbic acid is also confirmed by the results obtained by Fanika et al. (2024). More ascorbic acid was analyzed in red fruit juice (1.19 mg/ml) than in green one (0.33 mg/ml). According to Valšíková et al., (2006) red pepper has a higher content of vitamin C compared to green and yellow fruits. In the ripening process its amount increases which correlates positively with changes in dry matter (Niklis et al., 2002).

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Apart from its biological value sweet pepper has a very good taste. It is used as fresh and processed. The quality of sweet pepper can be characterized by considering physical, chemical and sensory characteristics such as appearance, taste, texture and nutritional value. (Rocha et al., 2013). Although chemical characterization is important, taste (i.e. the overall sensation provided by the interplay of taste, aroma, mouthfeel, sight and sound) plays a key role in consumer preference and thus has become a major critical quality parameter (Eggink et al., 2012). The taste characteristics are highly dependent on the genotype but also on the growing conditions (Hallmann et al., 2019) and from the fruit ripening stage (Cisternas-Jamet et al., 2020).

The breeding process meets some specific requirements for production of pepper. The fruits should be of intensive and homogeneous red colour, thick enough, sweet and not bitter (Pevicharova & Todorova, 2014). According to Zarić et al., (2010), proper knowledge of the perception of consumers is one of the prerequisites for successful marketing agricultural-food products.

The modern breeding program at Maritsa Vegetable Crops Research Institute is mainly aimed at the creation of breeding lines, cultivars and hybrids suitable for early and mid-early field production with a various direction of use. It focuses on creating genotypes with high biological value and good sensory profile (Pevicharova & Todorova, 2014; Todorova & Pevicharova, 2018, 2021). In this sense, the availability of information about the genetic diversity among the genotypes, their characterization according to a set of quality traits is an important prerequisite for the effectiveness of breeding programs, both on a national scale and worldwide.

The goal of this research was to evaluate pepper genotypes from various colors and shapes with respect to their chemical and sensory properties, and to identify the most suitable for successful breeding of high-quality pepper cultivars.

Materials and Methods

Plant material

Twenty nine pepper genotypes from four variety groups were studied in the experiment. They were with different shape of the fruits and ways of usage. While the fruits of *conical*, *blocky* and *bell* types are preferred by consumers in intermediate stage of maturity – green, pale yellow the fruits of *kapia* and *ratund* (pumpkin) types are consumed mainly at maturity stage – red, orange etc. The included cultivars and breeding lines were studied according these preferences and were as follows: Stryama, Sivria 600, 379/16, 441/16, 685/15, 695/15 and K 1016 with *conical* shape type; Kalinkov 800/7, Byal Kalinkov, 275/16, 287/16, 310/16 and 315/16 with *blocky* and *bell* shape type; Kurtovska kapia 1, Kurtovska kapia 1619, Ivaylovska kapia, 597/17, 640/16, 668/16, 680/16, 717/16 and 724/16 by *kapia* type; Bulgarski ratund, 215/16, 231/16, 243/16, 244/16, 246/16 and 251/16 by *ratund* (pumpkin) type (Figure 1).

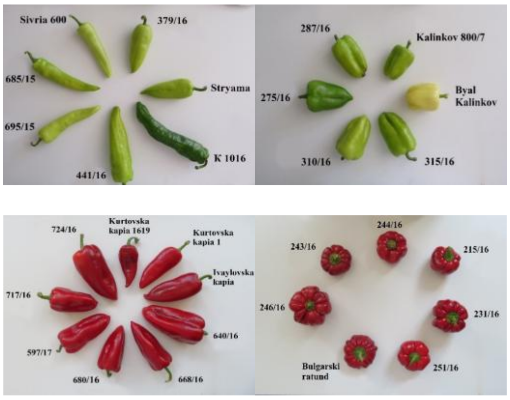

Figure 1. *Studied pepper cultivars and breeding lines.*

Field design

The investigation was carried out at the Maritsa Vegetable Crops Research Institute, Plovdiv, Bulgaria, in three consecutive years (2018-2020). The sowing was done at the end of March in a non heated glasshouse. In the middle of May the seedlings were transplanted in an open field. The experiment was realized on an alluvial meadow soil type, using the randomized complete block method with 3 replicates and 20 plants per replicate for each genotype according to the scheme 120 + 40/15 cm. During the growing period, standard agronomic practices such as irrigation, fertilization and plant protection were utilized. Fruits of *conical*, *blocky* and *bell* genotypes were harvested at technical (intermediate) maturity (in green) and those of *kapia* and *ratund* genotypes at botanical maturity (in red).

Chemical analyses

Analysis of the chemical compounds of the fruits was performed at the Laboratory for Vegetable Quality Control of Maritsa Institute. Samples of 15 fruits per replication for each genotype were assessed on the followed fruit quality parameters: dry matter by drying the samples at 50°C to constant weight (%); ascorbic acid (mg/100 g^{-1} fresh weight) by Tilman’s reaction with 2,6-dichlorophenolindophenol (Genadiev et al., 1969); total sugars (%) by Schoorl-Regenbogen (Genadiev et al., 1969); and total pigments in ASTA units (Manuelyan, 1979).

Sensory analyses

Right after harvesting pepper fruits from each genotype were selected on the base of minimum variation in shape, colour and size. The both investigated types of green pepper (*conical*, *blocky* and *bell*) and *ratund* type was evaluated on fresh fruits. The *kapia* type genotypes were rated as roasted. The sensory analysis was performed on the traits: appearance, fruit shape, colour (external and internal), aroma, visible fibre, sourness, sweetness, bitterness, hotness, texture and overall taste. A five-point panel test with 0.25-step was used. The total sensory evaluation was formed on the basis of complete perception, but not as an arithmetic average from evaluation for individual sensory traits. Four trained panelists participated in the test.

Data analyses

Significant differences in the studied traits were determined by Duncan's multiple range test at P<0.05 (DMRT). It was done separately for each pepper group formed on the base on fruit shape and color. A two-way analysis of variance was applied to assess the effect of genotype, year of cultivation and their influence (%) on the content of the studied chemical compounds and the total sensory evaluation. Pearson's correlation coefficients were estimated to examine the relationships between the sensory evaluation and the analyzed chemical components. All the data obtained were statistically processed using SPSS-16 software for Windows.

Climatic conditions

Weather data were compiled from March to September during the period 2018-2020 (Figure 2). The average minimum and maximum air temperature (°C) as well as rainfalls (mm) were taken from the Bulgarian weather site Stringmeteo.

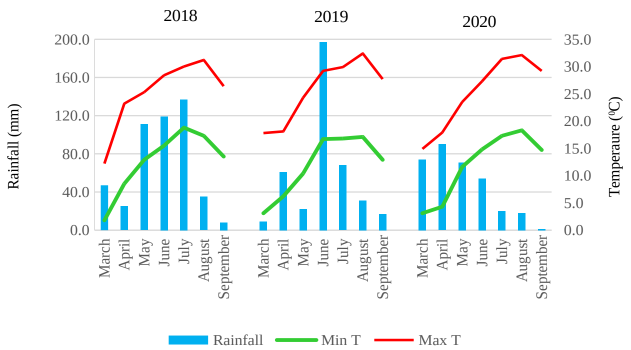

Figure 2. *Average minimum temperature, average maximum temperatures and total rainfall during the pepper growth period.*

Results

Fresh pepper is an excellent source of ascorbic acid. The chemical components of the studied lines and varieties showed significant differences. The ascorbic acid content in green peppers of the *conical* type varied from 100.71 to 118.48 mg/100 g^{-1} (Table 1). The results obtained were consistent with those analyzed by Savova et al., (2013), who reported an ascorbic acid content of 102 mg/100 g^{-1} in green pepper, and Durucasu and Tokusoglu (2007), who reported 133 mg/100 g^{-1}. Breeding line 685/15 was the richest in ascorbic acid among green peppers of the *conical* type. Lines 441/16 and K 1016 also showed relatively good biological value with an ascorbic acid content above 110 mg/100 g^{-1}.

Table 1. *Basic chemical components in green fruits of conical type pepper genotypes.*

Genotype	Dry matter (%)	Ascorbic acid (mg per 100 g)	Total sugars (%)
Stryama	7.38^{b}	100.71^{ns}	2.89^{ab}
379/16	7.82^{b}	106.47^{ns}	3.24^{a}
Sivria 600	8.00^{ab}	109.61^{ns}	2.55^{ab}
685/15	9.14^{a}	118.48^{ns}	2.46^{b}
695/15	8.47^{ab}	104.81^{ns}	2.76^{ab}
441/16	8.16^{ab}	110.50^{ns}	2.91^{ab}
K 1016	8.40^{ab}	116.06^{ns}	2.91^{ab}

a,b… - Duncan's multiple range test (P<0.05)

The dry matter content of the *conical* type green peppers ranged from 7.38% to 9.14%, depending on the genotype (Table 1). The lowest average value was recorded in the fruits of Stryama while line 685/15 showed the highest one.

Line 379/16 had the highest values of total sugars among all studied genotypes (Table 1). Compared to the original Stryama variety, this dihaploid line had increased dry matter and total sugar levels. Accessions 441/16 and K 1016 also showed good results, with a total sugar level of 2.91%. The lowest sugar content of 2.46% was found in line 685/15.

Peppers of the *blocky* and *bell* types that are harvested at technical maturity (green) are preferred by Bulgarian consumers. Among the six variants examined, no significant differences were observed in the dry matter content (Table 2).

Table 2. *Basic chemical components in green fruits of blocky and bell pepper genotypes.*

Genotype	Dry matter (%)	Ascorbic acid (mg per 100 g)	Total sugars (%)
Kalinkov 800/7	8.17^{ns}	144.18^{a}	2.75^{bc}
287/16	7.71^{ns}	135.24^{a}	3.03^{a}
275/16	7.88^{ns}	119.32^{ab}	2.86^{ab}
310/16	7.76^{ns}	133.56^{a}	2.89^{ab}
315/16	7.90^{ns}	124.51^{ab}	2.93^{a}
Byal Kalinkov	7.41^{ns}	104.24^{b}	2.57^{c}

a,b… - Duncan's multiple range test (P<0.05), ns – not significant.

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Kalinkov 800/7, distinguished by its high ascorbic acid and dry matter content, was the leader in this group. The sweetest fruits were observed in line 287/16, with a total sugar content of 3.03%, followed by 315/16 with 2.93%.

In general, both shape types of cultivars and breeding lines showed almost similar levels of dry matter and total sugar contents in the green fruits (Figure 3). All of them were rich in ascorbic acid with values over 100 mg per 100 g. *Blocky* and *bell* type fruits had higher levels compared to the *conical* ones.

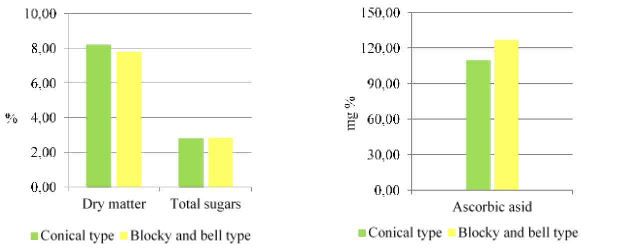

Figure 3. *Average values of the analyzed chemical components in conical, blocky and bell genotypes (green fruits) minimum temperature, average maximum temperatures and total rainfall during the pepper.*

The analyzed genotypes possessed good sensory characteristics (Figure 4). From an organoleptic point of view, Stryama variety, lines K 1016 and 685/15, and dihaploid line 379/16 of the conical type, as well as lines 287/16 and 315/16 of the blocky and bell type, were defined as the most promising for the future breeding studies as suitable parental components or developing of new cultivars. Their high sensory evaluations, based on taste, sweetness and texture, justify their inclusion in breeding programs.

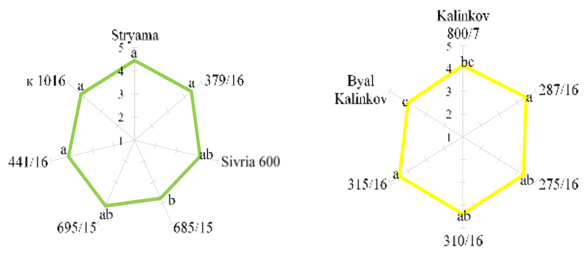

Figure 4. *Sensory profile of conical, blocky and bell pepper genotypes (green fruits).*

The high fruit quality was one trait shared by the genotypes of the pepper under investigation of the *kapia* type. (Table 3). The total sugar levels were at or over 5%, with the exception of line 717/16, which had the lowest sugar content of 4.90%. The leader in ascorbic acid content was Kurtovska kapia 1 (179.45 mg/100 g^{-1}), followed by Ivaylovska kapia (172.26 mg/100 g^{-1}), which is a proof that in recent years high-guality cultivars have been created in Maritsa Institute.

Table 3. *Basic chemical components of kapia type genotypes (sweet red fruits).*

Genotype	Dry matter (%)	Ascorbic acid (mg per 100 g)	Total sugars (%)	Total pigments (ASTA)
Kurtovska kapia 1	9.43^{b}	179.45 ^{a}	5.06^{ab}	8.3^{c}
Ivaylovska kapia	10.75^{a}	172.26^{ab}	5.35^{ab}	13.6^{ab}
640/16	10.27^{a}	154.80^{ab}	5.34^{ab}	11.4^{abc}
668/16	10.46^{a}	156.24^{ab}	5.24^{ab}	11.8^{abc}
680/16	10.18^{a}	149.73 ^{b}	5.18^{ab}	9.9^{bc}
597/17	10.33^{a}	161.30^{ab}	5.48^{a}	13.3^{abc}
717/16	10.04^{ab}	164.45^{ab}	4.90^{b}	16.0^{a}
724/16	10.17^{a}	149.97^{b}	5.37^{ab}	10.3^{bc}
Kurtovska kapia 1619	10.76^{a}	170.29^{ab}	5.38^{ab}	12.6^{abc}

a,b… - Duncan's multiple range test ($P<0.05$)

They could be used as an initial material in the breeding process for quality improvement of sweet red pepper. The results support the findings of Pevicharova and Todorova (2021).

Żurawik et al. (2020) found that the dry matter content of red pepper fruits was higher than that of green pepper fruits. All studied accessions of this type, with only one exception, had a dry matter content of more than 10%. Kurtovska kapia 1619 had the highest value of 10.76%. This component aligns with the findings of Buczkowska and Michałojć (2012), which state that the dry matter content of pepper fruits should be 10.5%.

Line 717/16 showed the highest level of total pigments reaching 16 ASTA units. Line 597/17 is also noteworthy, as the fruits had relatively high values of the studied components, making it particularly suitable for inclusion in future hybridization programs.

The *ratund* type cultivars and breeding lines were statistically distinguishable in terms of dry matter, ascorbic acid content and total pigments (Table 4). Line 244/16 had the highest ascorbic acid content (207.70 mg/100 g^{-1}) along with the highest dry matter content. With the second-highest ascorbic acid content, Bulgarski ratund was determined as the best variety in terms of a complex of the studied chemical components. The fruits of all genotypes were well pigmented with a saturated and homogeneous color. Line 243/16 possessed higher content of total pigments.

The *kapia* type group had higher values of dry matter and total sugar contents when the average values of chemical parameters were compared to the *ratund* type. In contrast, the *ratund* type performed significantly better in terms of total pigments (ASTA) and ascorbic acid content (Figure 5).

Table 4. *Basic chemical components of ratund type genotypes (sweet red fruits).*

Genotype	Dry matter (%)	Ascorbic acid (mg per 100 g)	Total sugars (%)	Total pigments (ASTA)
Bulgarski ratund	9.75^{ab}	206.63^{a}	4.80^{ns}	13.1^{ab}
246/16	9.18^{b}	180.7^{b}	4.88^{ns}	11.4^{b}
243/16	9.75^{ab}	189.50^{ab}	4.44^{ns}	16.4^{a}
244/16	10.29^{a}	207.70^{a}	4.73^{ns}	15.3^{ab}
215/16	9.42^{b}	188.99^{ab}	4.51^{ns}	11.4^{b}
231/16	9.91^{ab}	190.01^{ab}	4.68^{ns}	15.2^{ab}
251/16	9.59^{ab}	190. 25^{ab}	4.49^{ns}	10.7^{b}

a,b… - Duncan's multiple range test ($P<0.05$), ns - not significant

The data obtained showed that the genotypes from both *kapia* and *ratund* types had good sensory profiles nevertheless different ways of testing – roasted and fresh, respectively (Figure 6). The breeding line 680/16 of the *kapia* type was the leader in the total sensory evaluation due to the intense color, well-expressed sweetness, and excellent overall taste of its fruits. Ivaylovska kapia also had good sensory characteristics due to easily peeled fruits and a thick pericarp after roasting (unpublished data).

The sensory profiles of the genotypes in the *ratund* type did not differ significantly. They all received a high rating of more than 4.

The genotype had the greatest influence on the dry matter of the *conical* and *kapia* types (Table 5). However, the genotype effect was insignificant for ascorbic acid in all green pepper genotypes. Ascorbic acid was influenced by it in the *kapia* and *ratund* types. The genotype also affected the total sugars and the overall sensory evaluation across all groups, except for those of the *ratund* type. Genotype greatly affects the content of pigments in both types assessed at maturity stage with red sweet fruits.

It was established that the year significantly influenced all analyzed chemical components of the *conical* type fruits. Its value was relatively high for dry matter and total sugars in *blocky* and *bell* pepper types. Ascorbic acid and total pigments were also affected by the year factor in red pepper fruits.

A very strong negative correlation was found between the total sensory evaluation and the dry matter content of green pepper fruits of the *conical* type (Figure 7). Since fruits from this group are primarily consumed fresh, the panelists provided lower ratings for rougher and drier textures, which are linked to higher dry matter content and higher ratings for juicy and delicate pericarps, where dry matter content is rather low.

With high correlation coefficient values over 0.850, there was a positive relationship between the overall sensory rating and the total sugar content of both green pepper types. Our findings support the assertion made by Bernardo et al. (2008) that higher carbohydrate values in peppers determine better taste qualities.

No notable correlations were identified between the total sensory assessment and the analyzed compounds in red sweet pepper that affect specific taste characteristics, particularly the dry matter content and total sugars (Figure 7).

Discussion

Pepper is a good source of nutrients and antioxidant compounds, especially vitamin C. Howard et al. (2006) determined the total ascorbic acid content of fresh pepper by high-performance liquid chromatography at the green and red

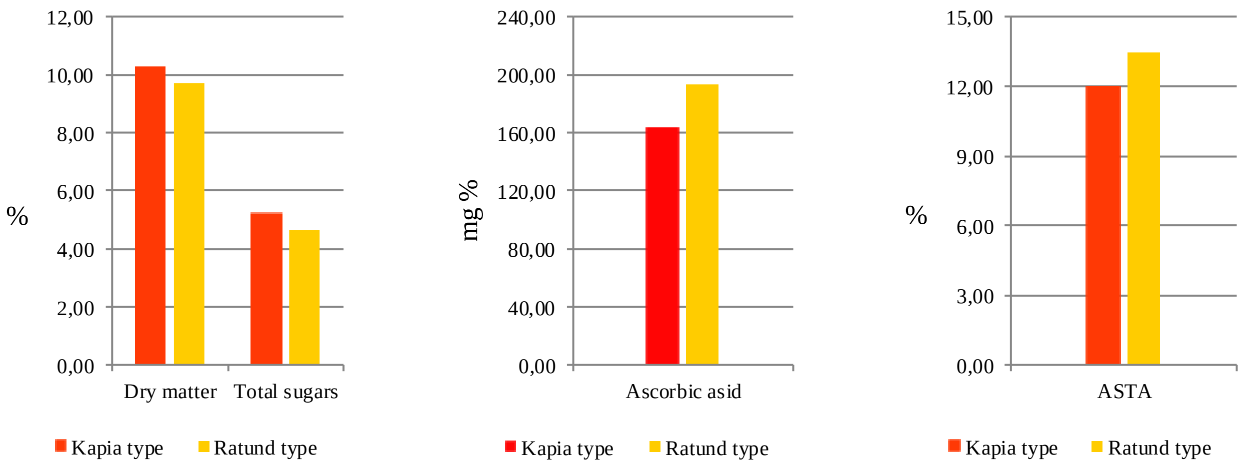

Figure 5. *Average values of chemical components in kapia and ratund type cultivars and breeding lines (red fruits).*

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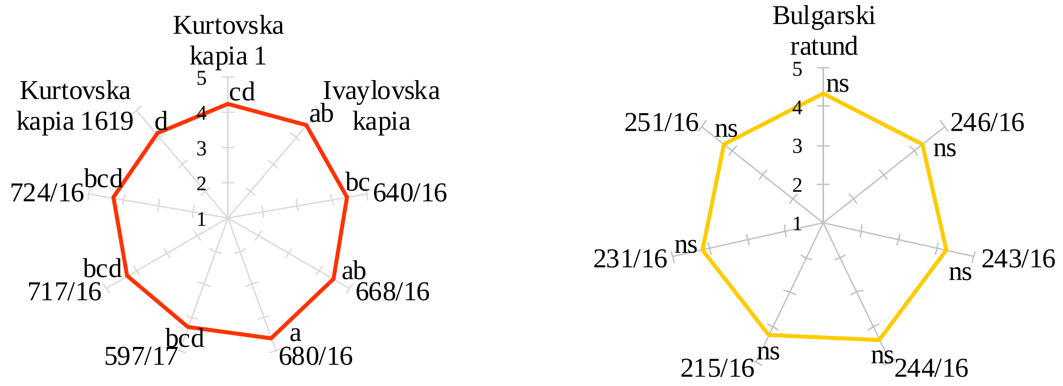

Figure 6. *Sensory profile of the kapia and ratund type genotypes (red fruits).*

maturity stages, ranging between 76.1 and 243.1 mg/100 g^{-1}. The recommended daily dose of vitamin C is 100 mg for adults (Naidu, 2003). All of the pepper genotypes examined had significant levels of ascorbic acid; two varieties, Bulgarski ratund and line 244/16 of the *ratund* type, had levels above 200 mg/100 g^{-1}. The daily required intake of this vital vitamin would be satisfied by consuming 100 g of each type of pepper.

This study demonstrated the genetic variation in ascorbic acid among various local pepper genotypes included in the investigation. The results were in accordance with the results of many researchers who have monitored the amount of vitamin C in pepper genotypes with different fruit shapes and colors (Brezeanu et al., 2022; Afnani et al., 2023; Mladenović et al., 2024). In our experiment, the influence of genotype on ascorbic acid synthesis was better expressed in both types of

Table 5. *Influence of the variation factors on the studied characters in pepper.*

Characters	Factor A (genotype)	Factor B (year)	A x B	Residue
		Conical type		
Dry matter	46.01***	32.33***	8.82	12.84
Ascorbic acid	9.71	15.64**	47.51*	27.13
Total sugars	33.84***	36.34***	19.39**	10.43
Total sensory evaluation	37.46***	8.52*	15.01	39.02
		Blocky and *bell* type		
Dry matter	8.53	42.12***	25.13	24.23
Ascorbic acid	16.66	13.73	22.73	46.88
Total sugars	15.60*	60.23***	9.38	14.79
Total sensory evaluation	32.87*	6.10	7.39	53.66
		Kapia type		
Dry matter	41.41**	2.90	25.85	29.85
Ascorbic acid	28.40**	25.73***	16.96	28.90
Total sugars	23.71*	4.67	38.72	32.90
Total pigments	43.10***	17.52***	23.55*	15.83
Total sensory evaluation	37.73***	3.06	16.43	42.79
		Ratund type		
Dry matter	24.36	13.80	15.17	46.68
Ascorbic acid	30.23***	22.95***	32.93**	13.89
Total sugars	16.29	23.81**	27.63	32.25
Total pigments	46.59***	13.18*	15.76	24.47
Total sensory evaluation	3.69	1.57	33.63	61.12

* - $p<0.05$; ** - $p<0.01$; *** - $p<0.001$

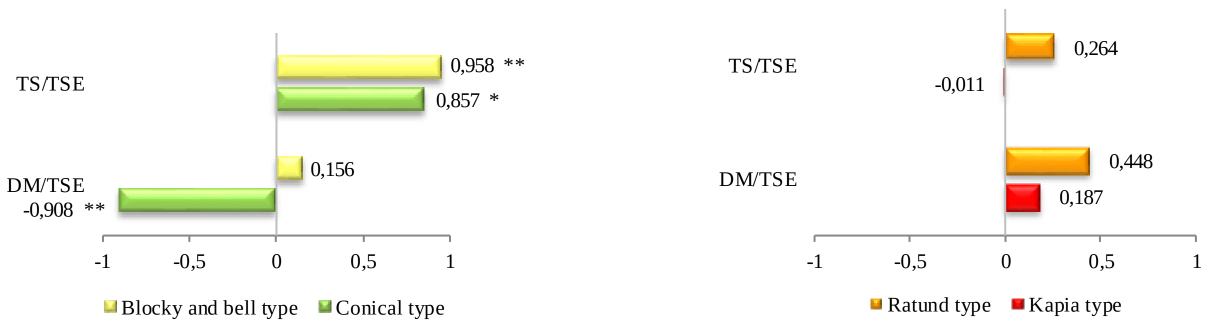

Figure 7. *Correlation coefficients of the sensory evaluation with the content of dry matter and total sugars in sweet green and red pepper genotypes.*

red pepper.

The complicated process of vitamin C biosynthesis is controlled by a number of environmental variables, such as rainfall, temperature, and light. The three experimental years were similar in terms of minimum and maximum temperatures during the ripening period of pepper fruits (Figure 2). More significant differences were observed in the amount of precipitation. During the third year of our experiment, precipitation was noticeably lower. According to Mostafa et al. (2024), ascorbic acid content in sweet pepper was enhanced under conditions of water deficit. The changes in ascorbic acid levels depending on meteorological conditions were determined by the values of the factor *year* from the two-way analysis of variance (Table 5). In the majority of genotypes examined, it significantly affected ascorbic acid content.

One of the pepper characteristics that are most often researched is dry matter. Various studies have found dry matter values ranging from 8.14% (Hallmann & Rembiałkowska, 2008) to 13.3–15.05% (Topuz & Ozdemir, 2007). The values obtained in the current study varied between 7.38% and 10.76%. The dry matter content in green peppers was approximately 1 to 2% less than that found in red peppers.

The total sugar content in sweet peppers has not been extensively researched, however, it plays a significant role in the organoleptic properties of the fruit, enhancing its flavor profile (Pevicharova et al., 2007). Different pepper genotypes differ in sugar content and composition. Under Denev et al. (2019), the total sugar content varied between 1.09% and 7.38%, consistent with the data obtained in this study. The two examined factors, *genotype* and *year*, significantly affected the total sugar content in green pepper.

In addition to its high biological value, pepper's intense aroma, crunchy texture, and rich flavor make it a year-round food in Bulgaria. Performing sensory analysis in parallel with analysis of important chemical components provides more comprehensive information about the nutritional quality of pepper fruits. Among the pepper genotypes under study, accessions with green fruits and the *kapia* type with red fruits exhibited a clear expression of the genetic determination of the sensory profile. Throughout the experimental period, the genotype factor had a greater impact (more than 32%) on the overall sensory evaluation than the factor *year* (Table 5). In general, there isn't much scientific research on pepper's flavor characteristics. However, sensory quality is the primary factor influencing consumer purchasing decisions. Breeders must therefore focus on the pepper sensory qualities in addition to boosting productivity and resistance to economically significant diseases.

Conclusion

In this study, basic chemical components and total sensory evaluation of twenty-nine sweet *Capsicum annuum* L. cultivars and breeding lines from different colours and shapes were analyzed. The results reveal significant diversity between genotypes for all investigated traits. Such diversity provides a solid foundation for the successful breeding of new lines and cultivars that combine superior sensory qualities with high biological value. Pepper vegetable crop holds considerable promise for research, necessitating additional analysis to gain a deeper understanding of its traits and qualities. Such insights could lead to innovative approaches for enhancing and broadening its consumer market.

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