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Evaluation of the quality traits of red cherry tomato varieties grown in alkaline soil

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Abstract

The diversity and quantity of organic acids and the sugar content affect the taste, storage, and processing quality in ripe tomato fruits. Therefore, understanding the genetic potential of different tomato (*Lycopersicon* Mill.) varieties for this and other traits is an important first step in the early-stage research to select varieties for various uses. In this study, four red cherry tomato (*Lycopersicon esculentum* Mill.) varieties belonging to subsp. *cultum*, subsp. *spontaneum*, and subsp. *subspontaneum* were evaluated for their genetic potential to produce titratable acids (TA), especially ascorbic acid (AA), total carbohydrates (TCH), and seed protein content (SPC) in ripe fruit when grown under temperate climate zone conditions and in alkaline soil. This information is of great importance for the breeding programmes as well as for the process of development of new improved cherry tomato varieties. The correlation between biochemical properties of fruit and some physico-chemical parameters such as ash (AS), dry matter (DM), moisture (M), and acidity (pH) as well as the differences between studied varieties for each trait were investigated using statistical analysis. The results showed that all the studied varieties are susceptible to grow in the alkaline soil with pH up to 7.9 with the acceptable fruit quality. Significant differences were observed in ascorbic acid, ash, DM, and moisture content among all studied varieties. No differences were observed for pH, titratable acids, total carbohydrates, and seed protein content. *L. esculentum* var. *cerasiforme* showed the best potential to be included in the breeding programmes for the alkaline soil management under agroecological conditions of the temperate climate zone.

Keywords: tomato fruit, ascorbic acid, titratable acidity, total carbohydrate analysis, seed protein content, pH, ash, dry matter.

Introduction

The favourable taste and high nutritional value of tomatoes beneficial for human health are recognised worldwide; therefore, tomatoes are consumed by each generation and in every part of the world (Zhu et al., 2018). According to its botanical characteristics, tomato is considered as a fruit, but it is mostly prepared and consumed as a vegetable (Razifard et al., 2020).

Tomato (*Lycopersicon* Mill.) constitutes a great source of nutrients like minerals, fibres, phenolic acids, flavonoids, and other bioactive compounds. It is also an excellent source of antioxidants, particularly vitamins such as tocopherols, ascorbic acid, retinol, and carotenoids, especially lycopene and beta carotene (Ali et al., 2020). Since the last decade, cherry tomatoes have become more popular due to their attractive appearance, good taste, and nutritional properties.

A great diversity of nutrients valuable for human health, a pleasant taste, and an appropriate shape and size increase the demand of cherry tomatoes on the domestic and global market. According to the Central Intelligence Agency's World Factbook (US Department of Agriculture, 2019), the international trade of tomatoes was valued at $9 billion. The export from the Republic of North Macedonia was estimated to more than $11,576,000, and the country was ranged at 37th place from 118 countries. According to the state statistical data, around 151 187 t of tomatoes were produced in North Macedonia in 2022 with a yield of 26 935 kg ha^{-1}.

Cherry tomatoes have become more popular among farmers and consumers worldwide. They are intended for fresh consumption and processing. The nutritional composition of tomatoes can vary depending

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on several factors such as genetic, cultivation practices, environmental factors, harvesting period, storage period, etc. (Hernández Suárez et al., 2008). The taste of tomatoes is the first and most important step by which consumers decide for a given product. From the economic point of view, the shelf life of fruits is also important for the market, as a longer shelf life will contribute to lower economic losses and less waste contributing to a cleaner environment. The diversity and quantity of acids in ripe tomato fruits affect the taste, storage, and processing quality of tomatoes.

In this study, four domestic red cherry tomato varieties were evaluated for their genetic potential to produce acids, special attention giving to ascorbic acid as one of the most abundant in tomatoes and very important for human health. This information is of great importance for the development process of new improved cherry tomato varieties with a high potential to produce acids in the ecological conditions of the temperate climate zone. Anyway, the achievement of phytonutrient content begins with the variety selection.

The quality of tomato fruit can differ considerably between varieties (Ceballos, Vallejo, 2012). Therefore, of particular importance is to know the genetic potential of existing varieties for the most important quality traits when grown in different climatic regions and under different cultivation techniques to be included in specific breeding programmes or to be used as genetic resources for the selection and development of new improved varieties.

In this early-stage study, some biochemical and physico-chemical parameters were investigated as indicators of fruit quality in four red cherry tomato varieties grown in alkaline soil and the temperate climate zone. Furthermore, the relationship between the total seed protein content (SPC), the coefficient of fruit, and the studied biochemical and physico-chemical parameters was investigated by correlation analysis. Significant differences were identified between the studied tomato varieties in relation to the investigated traits with the aim to suggest the most suitable variety/ies to be included in the breeding programmes in alkaline soil, intended for fresh markets, and the most suitable ones to serve as a source of specific genes for the improvement of taste and nutritional value in the development of new varieties.

Material and methods

Plant material. Four red cherry tomato (*Lycopersicon esculentum* Mill.) varieties: (1) var. *pyriforme* from subsp. *subspontaneum*, (2) var. *cerasiforme*, (3) var. *grandifolium* from subsp. *cultum*, and (4) var. *racemigerum* from subsp. *spontaneum*, were investigated in the study. Seed material was obtained from the National Germplasm Bank of the Republic of North Macedonia. All varieties are round shaped, except the *L. esculentum* var. *pyriforme*, whose fruits are pear shaped. Tomato fruits of the studied varieties were collected and evaluated for their quality traits at the fully ripe stage (BBCH 89).

Method of cultivation. The open-field experiment was conducted in 2020 in the Skopje Region, an extensive vegetable production area in North Macedonia, which belongs to the temperate climate zone. It has 280 sunny days per year with an average minimum and maximum temperature of 8.6°C and 20.3°C, respectively, and an average rainfall of 3.4 mm (Figure).

Plants were grown in the same agroecological conditions under a randomised complete block design (RCBD) system in three replications. To avoid the influence of pre-harvest factors on the genotype-related variability of field-grown tomatoes, each replication consisted of 20 plants. At the sowing stage, the cultivation method involved the use of a commercial substrate rich in N, P, and K and less in B, Mn, Zn, Fe, Mo, and Cu, after which the seedlings were transferred in the field. The cultivation was performed without the use of pesticides.

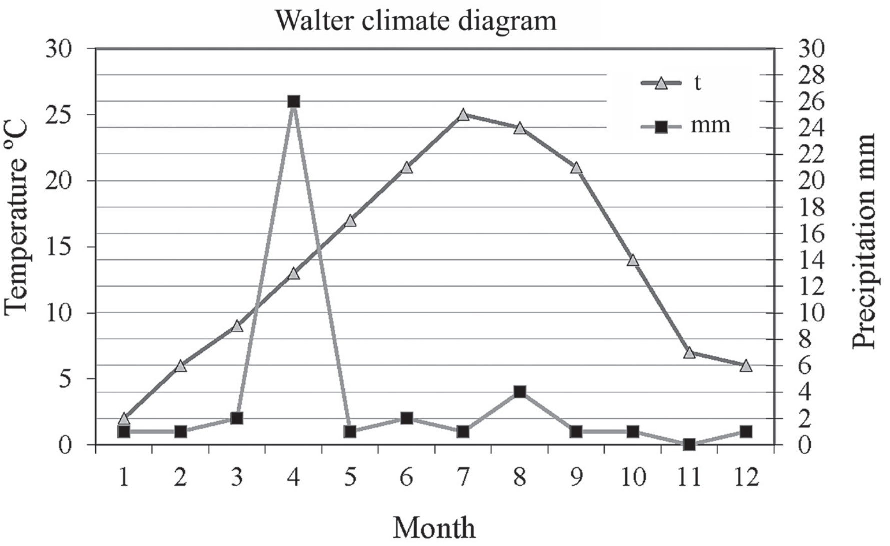

Figure. Walter climate diagram of the Skopje Region, North Macedonia in 2020

Soil quality. Soil samples for quality control were taken from the 30 cm depth using the standard procedure and analysed for pH, phosphorous (P_2O_5), nitrogen (N total), potassium (K_2O), humus, and calcium carbonate ($CaCO_3$) before planting. According to the obtained results, the soil was classified as alluvial, moderately fertile, and alkaline (Table 1).

Table 1. Soil quality of the experimental area

Parameter	Result	Method
pH	7.89	ISO 10390:2015
P_2O_5	34.70 mg 100 g^{-1}	ISO 15959:2016
N total	0.115%	ISO 11261:1995
K_2O	28.50 mg 100 g^{-1}	ISO 17319:2015
$CaCO_3$	5.10%	ISO 10693:1995
Humus	2.10%	FAO 2021

Biochemical analysis. The content of ascorbic acid (AA) was determined by titration. For that purpose, tomato fruits obtained from each variety were homogenised using a laboratory blender, then 100 g of the obtained juice were blended with 50 ml of distilled water and filtrated through the cheesecloth. The residue was washed with 30 ml of distilled water adding three portions of 10 ml each. The extract was filled up to 100 ml with distilled water in a volumetric flask. From this solution, 20 ml were taken and transferred to a 250 ml Erlenmeyer flask. Then 150 ml of distilled water and 1 ml of a starch indicator were added. The titration was done using 0.005 mol L^{-1} iodine solution. The endpoint is reached when a dark blue-black colour occurs due to the formation of a starch-iodine complex (Helmenstine, 2020). The content of total carbohydrates (TCH) was determined colorimetrically using a spectrophotometer Jenway 6715 UV Vis (Cole-Parmer, US) according to the phenol-sulfuric acid method (Nielsen, 2017). Titratable acidity (TA) was determined by titration according to the AOAC Official Method 942.15 (AOAC, 2000). Seed proteins were extracted according to Doonan (1996). For this purpose, the seeds were homogenised with a buffer containing 0.0625 M Tris-HCl, 2% (w/v) sodium dodecyl sulphate, 5% (v/v) β-mercaptoethanol, and 10% (w/v) glycerol using an indicator bromophenol blue. Quantification was made colorimetricaly at $\lambda = 546$ using a spectrophotometer Jenway 6715 UV Vis.

Physicochemical analysis. Acidity (pH) was determined potentiometrically using a pH meter Hanna HI 2211-01 (Merck, Germany) according to the procedure described in the European Pharmacopoeia (2005). To determine the content of ash (AS), 2.0 g of tomato fruits were burned to ashes in a muffle furnace at 600°C according to the method of Owusu et al. (2012). To determine the moisture (M) and dry matter (DM) content, 10 g of tiny pieces of tomato fruits were placed in an oven at 105°C until the constant mass was reached according to the method of Gharezi et al. (2012).

Morphological analysis. The coefficient of fruit (Cf) was determined for randomly selected fruits as the ratio of fruit height to width using the Fagbohoun and Kiki (1999) formula:

$$\mathrm{Cf} = \frac{\text{average fruit heigh}}{\text{average fruit diameter}}.$$

According to the shape coefficient, the varieties were classified into three categories of a form: Cf < 0.8 – a flattened shape, Cf > 1 – an elongated form, and 0.8 < Cf < 1 – a round shape.

Statistical analysis. To characterise the studied varieties, a descriptive statistical analysis including the mean, median, maximum, minimum, and standard deviation (SD) was used. The normality of the population was analysed by the Shapiro-Wilk test (W). The test rejects the hypothesis of normality when the *p*-value is less than or equal to 0.05. Identification of significant differences between the studied varieties for the investigated quality parameters showing a normal distribution was evaluated using the one-way one-factor analysis of variation (ANOVA) followed by the least significant difference (LSD) and post hoc test. For parameters that violate the assumption of normality, a non-parametric alternative to the one-way ANOVA and Kruskal-Wallis test was used followed by the Dunn's Q post hoc test, which is an alternative to the Tukey test used when only differences in a small subset of all possible pairs are tested. To determine the relationship between the investigated traits, the correlation analysis of independent samples was performed. All statistical calculations were performed with the software SPSS Statistics (IBM Corp., USA).

Results and discussion

Total carbohydrate (TCH) analysis. TCH content in fruits is considered as an indicator for determining the food quality and is an important energy source for humans and animals (Comerford et al., 2021). The TCH analysis provides information on nutrition, the standard of identity, water retention, flavours, the desirable texture, and the stability of food products (BeMiller, 2018). Tomatoes are considered as relatively low in TCH and, therefore, are suitable for people following a low-carb diet. The TCH content is a vital characteristic of the taste of tomatoes and, as mentioned before, depends on the varieties, climate characteristics, and agronomic practices (BeMiller, 2018). The research of Venkadeswaran et al. (2018) highlights the importance of the duration and intensity of the sunlight during the growing season of cherry tomatoes for the amount of TCH. When tomatoes are grown under the shade net conditions, the amount of TCH content in fruits is much lower: in the study of Venkadeswaran et al. (2018), it was found ranged from 1.56% to 2.05%. Since the studied varieties were grown in an open field under temperate climate zone conditions with unlimited sun conditions with 280 sunny days and an average minimum and maximum temperature during the growth season of 14.7°C and 28.3°C, the TCH content was much higher, in a range from 4.74% to 7.74% (Table 2).

No significant differences in the TCH content were observed between the studied varieties (Table 3), which suggested that there was no specific expression of genes associated with this trait in any of the studied varieties.

Table 2. Descriptive statistical analysis of the studied *Lycopersicon esculentum* varieties for the investigated traits

	M %	DM %	AS %	pH	TA %	AA mg 100 g^{-1} FW	TCH %	SPC %	Cf
					var. *pyriforme*				
Min.	93.17	6.70	0.49	4.34	0.63	18.70	4.92	30.60	1.35
Max.	93.30	6.83	0.55	4.35	0.66	18.89	4.98	31.00	1.57
Mean	93.23	6.77	0.52	4.34	0.65	18.81	4.95	30.80	1.47
Median	93.22	6.78	0.52	4.34	0.65	18.84	4.96	30.80	1.48
SD	0.05	0.05	0.02	3.09	0.01	0.08	0.02	0.16	0.16
					var. *cerasiforme*				
Min.	92.10	7.57	0.77	4.56	0.51	22.22	5.12	35.80	0.86
Max.	92.43	7.90	0.83	4.57	0.52	22.30	5.18	36.10	0.92
Mean	92.30	7.70	0.80	4.57	0.52	22.27	5.14	35.90	0.90
Median	92.38	7.62	0.80	4.57	0.52	22.28	5.12	35.80	0.91
SD	0.15	0.15	0.02	0.01	0.00	0.03	0.03	0.14	0.05
					var. *grandifolium*				
Min.	93.25	6.64	0.58	4.62	0.51	20.08	7.74	33.90	0.79
Max.	93.36	6.75	0.63	4.62	0.52	20.14	4.78	34.20	0.84
Mean	93.30	6.70	0.61	4.62	0.52	20.11	5.75	34.10	0.82
Median	93.28	6.72	0.62	4.62	0.52	20.12	4.78	34.20	0.82
SD	0.05	0.05	0.02	0.02	0.00	0.02	1.40	0.17	0.17
					var. *racemigerum*				
Min.	92.56	7.36	0.66	4.55	0,54	21.00	5.06	32.50	0.77
Max.	92.64	7.44	0.71	4.56	0,59	21.08	5.10	33.00	0.82
Mean	92.59	7.41	0.69	4.55	0.56	21.04	5.07	32.80	0.79
Median	92.58	7.42	0.69	4.55	0.55	21.03	5.06	32.80	0.79
SD	0.03	0.03	0.02	0.00	0.02	0.03	0.02	0.21	0.18
W	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p < 0.05$	$p < 0.05$	$p > 0.05$	$p < 0.05$	$p < 0.05$	

Min. – minimum, Max. – maximum, SD – standard deviation, W – Shapiro-Wilk test; M – moisture, DM – dry matter, AS – ash, pH – acidity, TA – titratable acidity, AA – ascorbic acid, FW – fresh weight, TCH – total carbohydrates, SPC – seed protein content, Cf – coefficient of fruit

Table 3. Results of the Kruskal-Wallis test comparing non-normally distributed variables among the studied *Lycopersicon esculentum* varieties

	N	DF	Mean rank	H	*P*-value	χ_0^2
			Acidity (pH)			
var. *pyriforme*	3	3	6	10.38	0.001	16.266
var. *cerasiforme*	3	3	24			
var. *grandifolium*	3	3	33			
var. *racemigerum*	3	3	15			
			Titratable acidity (TA) %			
var. *pyriforme*	3	3	33	9.759	0.005	12.838
var. *cerasiforme*	3	3	10.5			
var. *grandifolium*	3	3	10.5			
var. *racemigerum*	3	3	24			
			Total carbohydrates (TCH) %			
var. *pyriforme*	3	3	12	4.83	0.1	6.251
var. *cerasiforme*	3	3	30			
var. *grandifolium*	3	3	15			
var. *racemigerum*	3	3	21			
			Seed protein content (SPC) %			
var. *pyriforme*	3	3	2	**10.42**	0.01	11.345
var. *cerasiforme*	3	3	11			
var. *grandifolium*	3	3	8			
var. *racemigerum*	3	3	5			

N – number of samples, DF – degree of freedom, H – test statistic value, *P* – probability, χ_0^2 – critical values for Kruskal-Wallis test

Titratable acidity (TA). TA and TCH content in tomato fruit is one of the most important properties not only for quality, but also for taste. According to Bastías et al. (2011), citric and malic acids, which account for more than 90% of TA, are responsible for the acid taste of harvestable fruits of tomato. A high TA and TCH content is required for a favourable taste. A high TA and a low TCH content will produce a tart taste, while a high TCH and a low TA content will result in too sweet and no tasty tomato (Davies, Hobson, 1981). The most desirable and favourable taste is due to a high TA and a high TCH content. The investigated varieties in this study showed a high TA content of 0.51–0.66% (Table 2). Much lower TA content of 0.1–0.34% was found in cherry tomatoes grown under limited sunlight (Venkadeswaran et al., 2018). In the study of Mukherjee et al. (2020), the TA content was 0.1–0.83%, while in the study of Akanksha et al. (2022), it was 0.49–0.71%. There were no significant differences in this trait between the studied varieties (Table 3). In this study, the highest TA content was found in the var. *pyriforme* followed by the var. *racemigerum*, and the lowest TA content was observed in the var. *grandifolium* and *cerasiforme*. Varieties of *grandifolium*, *cerasiforme*, and *racemigerum* had a high sugar to acid ratio of 11.14, 9.95, and 9.06, respectively, while the var. *pyriforme* had a relatively low sugar to acid ratio of 7.66.

Some countries, such as France, have established quantifiable indicators to evaluate the taste of tomato fruits. The French prefer sweet taste tomatoes, and the most desirable sugar to acid ratio in this country is 10. Most of the population, especially children, prefer a sweet taste of tomatoes, so the var. *grandifolium* and var. *cerasiforme* are recommended for the breeding programmes intended for the fresh consumption as the most tasteful ones. The var. *pyriforme* had the largest fruit size and the highest TA content. In this study, the correlation analysis revealed a strong positive correlation between TA and Cf (Table 4).

Table 4. Correlation analysis of the investigated traits of *Lycopersicon esculentum* varieties

	M	DM	AS	pH	TA	AA	TCH	SPC	Cf
M	1								
DM	−1	1							
AS	−0.92	0.92	1						
pH	−0.32	0.32	0.64	1					
TA	0.42	−0.42	−0.74	−0.97	1				
AA	−0.90	0.90	0.99	0.68	−0.77	1			
TCH	0.41	−0.42	−0.03	0.70	−0.64	0.02	1		
SPC	−0.60	0.60	0.86	0.81	−0.92	0.87	0.42	1	
Cf	0.44	−0.44	−0.67	−0.96	0.91	−0.72	−0.53	−0.71	1

M – moisture, DM – dry matter, AS – ash, pH – acidity, TA – titratable acidity, AA – ascorbic acid, TCH – total carbohydrates, SPC – seed protein content, Cf – coefficient of fruit

Ascorbic acid (AA) content, also known as vitamin C, is a non-enzymatic antioxidant that possesses beneficial effects for the human body. According to Malacrida et al. (2006), a higher AA content in tomatoes improves the postharvest fruit quality. Alenazi et al. (2020) found that AA is responsible for a better plant tolerance of biotic and abiotic stress. Thus, varieties with a high AA content are of particular importance for the breeding programmes and the fresh produce market. Data presented in the literature show that the AA content in cherry tomatoes can differ significantly, because there is a large intraspecific diversity in the tomato germplasm, and it is also influenced by various agroecological conditions, especially the light intensity during the vegetative period (Mellidou et al., 2021). In the present study, the AA content differs significantly among the studied varieties (Tables 5 and 6).

The highest AA content was found in the var. *cerasiforme* followed by the var. *racemigerum* and var. *grandifolium*. The var. *pyriforme* with the greatest TA content showed the lowest AA content (Table 2). Surprisingly, the correlation analysis showed that the AA content was negatively correlated with the TA content (Table 4). One possible theoretical explanation of this result is that the AA content in tomato fruit increases till beginning of ripening and then begins to decrease due to an increase in the ascorbate oxidase activity (Yahia et al., 2001). As a strong antioxidant, AA receives electrons from free radicals and is enzymatically processed from oxidised forms such as dehydroascorbate (DHA) and monodehydroascorbate (MDHA). If it is unable to be regenerated, DHA is irreversibly degraded producing a wide range of products including oxalic and threonic acids (Truffault et al., 2017). In this process, the AA content decreases generating other acids at the same time. Thus, the results of the correlation analysis between the AA and TA content in the literature are various. It is suggested to be influenced, among others, by the period of measurement and the environmental conditions, in which the plants grow. Future investigations should be performed to support this theoretical explanation, and it is strongly suggested to refer to data of the period when the measurement was performed as well as the environmental conditions of the scientific studies which analyse the AA content.

Seed protein content (SPC). The quality of seeds is of great importance in plant propagation and is determined by its potential to germinate and produce viable seedlings. From the agronomic point of view, the increase of SPC is an important characteristic of tomato because it contributes to a faster germination and a better stress tolerance (Rosental et al., 2016). Seed proteins such

Table 5. One-way ANOVA one-factor analysis ($\alpha = 0.05$) of the studied *Lycopersicon esculentum* varieties for the parameters with the normal distribution of data

Source of variation	SS	DF	MS	*F*	*P*-value	*F*-critical
			Ascorbic acid (AA) %			
Between groups	19.21	3	6.40	1829.11	1.10 e^{-11}	4.07
Within groups	0.028	8	0.0035			
Total	19.23	11				
			Ash (AS) %			
Between groups	0.13	3	0.04	53.97	1.19 e^{-05}	4.07
Within groups	0.01	8	0.0008			
Total	0.13	11				
			Dry matter (DM) %			
Between groups	2.13	3	0.71	69.29	4.6 e^{-06}	4.07
Within groups	0.08	8	0.01			
Total	2.21	11				
			Moisture (M) %			
Between groups	2.12	3	0.71	69.29	4.6 e^{-6}	4.07
Within groups	0.08	8	0.01			
Total	2.21	11				

SS – sum of squares, DF – degree of freedom, MS – mean square, *F* – statistical magnitude, *p*-value – level of significance

Table 6. Least significant difference (LSD) test between the studied *Lycopersicon esculentum* varieties for the normally distributed data

Varieties	LSD post hoc test			
	dry matter (DM)	ash (AS)	ascorbic acid (AA)	moisture (M)
pyriforme vs cerasiforme	<0.001	<0.001	<0.001	<0.001
pyriforme vs grandifolium	**0.443**	0.004	<0.001	**0.443**
pyriforme vs racemigerum	<0.001	<0.001	<0.001	0.001
cerasiforme vs grandifolium	<0.001	<0.001	<0.001	<0.001
cerasiforme vs racemigerum	0.008	0.001	<0.001	0.005
grandifolium vs racemigerum	<0.001	0.01	<0.001	<0.001

Significant at $p < 0.05$

as globulin, albumin, prolamin, and glutelin significantly affect the nutritional properties of tomato fruits, as they are high soluble and, therefore, better utilised by the human and animal metabolism (Kumar et al., 2022). In this study, the greatest SPC was found in the var. *cerassiforme* followed by the var. *grandifolium*, var. *racemigerum*, and var. *pyriforme*, although no significant differences in SPC were observed (Table 3).

Acidity (pH) is an important characteristic for the process of preservation, which can depend on the tomato variety, the soil characteristics, the picking time, and the storage method. Tomatoes belong to the category of acid food with a pH less than 4.6 or slightly higher, and there are not many differences between tomato varieties for this trait. The pH of the studied varieties varied between 4.34 and 4.62 (Table 2). The highest pH was found in the var. *grandifolium* followed by the var. *cerasiforme*, var. *racemigerum*, and var. *pyriforme*. According to Kelebek et al. (2017), pH of maximum 4.4 is the safety limit when tomatoes are intended for processing. Najeema et al. (2018) studied 30 cherry tomato genotypes and found pH values between 3.74 and 4.34. Compared to the available literature data, the studied varieties which were grown in alkaline soil had relatively high pH values but were still acceptable for the requirements of canning industry. The relatively low pH of tomatoes is an advantage in terms of product stability. This low pH can significantly reduce the development of microorganisms in fruits (Agassounon et al., 2012), as the pH lower than 4.5 is favourable to decrease the proliferation of microorganisms. No significant differences between the varieties were found for this trait (Table 3). The correlation analysis showed a significant negative correlation between the pH and TA content and between the pH and Cf (Table 4). These results are expected because the pH is a negative logarithm of the hydrogen ions present. pH was positively correlated with SPC indicating that more SPC will be present in the varieties with less acidity.

Dry matter (DM) content. It is assumed that controlling the DM content in tomatoes is the first step to control its quality (Guichard et al., 2001). Davies and Hobson (1981) showed that the ripe tomato fruit mainly contains from 5% to 8% DM, of which about 50% is fructose and glucose, and the other half consists of insoluble solids, organic acids, lipids, and minerals. A preferable tomato fruit quality characteristic is the higher percentage of DM content. The studied varieties showed significant differences in the DM content (Tables 5 and 6), which ranged between 6.64% and 7.90% (Table 2). The var. *cerasiforme* showed the highest content (median 7.70) of DM. This variety was also characterised by the highest AA content. The DM content was positively correlated with the AA, AS, and SPC content (Table 4).

Ash (AS) content is an important indicator of tomato fruit quality for nutritional evaluation. It refers to the inorganic residues that remain after the combustion or oxidation of organic matter in the fruit. The highest AS content indicates the higher mineral content in the fruit (Nielsen, 2017). According to the Food Data Centre Research (FDCR, 2019), the AS content in tomato fruit ranged from 0.37% to 0.6% per 100 g. Similar results have been obtained by other researchers worldwide. Agbemafle et al. (2015) reported 0.47–0.98% AS content in the study of tomato fruit quality control. In this study, the AS content varied significantly between the varieties (Tables 5 and 6) and ranged from 0.49% to 0.83% (Table 2). The highest AS content was observed in the var. *grandifolium* followed by the var. *cerasiforme*, var. *racemigerum*, and var. *pyriforme*. The AS content was positively correlated with the AA content and SPC and negatively correlated with the Cf and TA content (Table 4).

Statistical analysis. To obtain accurate and reliable conclusions from the statistical analysis, it is important to determine whether the data show a significant deviation from the normality, especially when small sample sizes (<30 or 40) are processed (Ghasemi, Zahediasl, 2012). In this study, the normality of data was tested using the Shapiro-Wilk test (Table 2). The moisture, DM, AS, and AA content showed the normal distribution of the data, while the pH, TA, TCH and SPC were not normally distributed. To determine the significant differences between the studied tomato varieties in terms of the investigated quality traits, the normally distributed data of M, DM, AS, and AA were processed using the one-factor analysis of one-way ANOVA. All *F* values obtained in this analysis were higher than the *F*-critical value (Table 5) indicating that there are differences between the studied varieties for each trait at the significance level less than 0.001. To identify which pairs of varieties tend to be different, the LSD post hoc test was used after the one-way ANOVA. The result showed significant differences between all varieties for the DM, AS, AA, and M content, except between the var. *pyriforme* and var. *grandifolium* for the DM and M content (Table 6). The result of the LSD test showed that the var. *pyriforme*, var. *cerasiforme*, and var. *racemigerum* differed significantly in the DM, M, AS, and AA content. The var. *pyriforme* significantly differed from the var. *grandifolium* in the AS and AA content (Table 6). The pH, TA, TCH, and SPC data that violate the assumption of normality were processed using the Kruskal-Wallis nonparametric test, which is considered suitable for the analysis of small samples. The analysis revealed no significant differences between the varieties in pH, TA, TCH, and SPC with significance levels of 0.001, 0.005, 0.1, and 0.01, respectively (Table 3).

Conclusions

Four red cherry tomato (*Lycopersicon esculentum* Mill.) varieties: var. *pyriforme*, var. *cerasiforme*, var. *grandifolium*, and var. *racemigerum*, obtained from the National Germplasm Bank of the Republic of North Macedonia, were evaluated for their quality traits.

According to the obtained results, the following conclusions were given:

1. All studied varieties are susceptible to grow in the alkaline soil with the pH up to 7.9 with the acceptable fruit quality.
2. Among the studied varieties, var. *cerasiforme* and var. *grandifolium* are suggested for the breeding programmes in alkaline soil and growing in the agroecological conditions of the temperate climate zone.
3. Var. *pyriforme* with a median value of pH 4.34 show a potential to be used in the processing industry.
4. The studied varieties differed significantly in terms of ascorbic acid (AA), ash (AS), dry matter (DM), and moisture (M) content.
5. Var. *cerasiforme* showed the greatest potential to be used in the breeding programmes for fresh consumption, as its appropriate parameters of taste, AA, and DM content were obtained.
6. No differences were found between the varieties in acidity (pH), total carbohydrates (TCH), seed protein content (SPC), and titratable acidity (TA).
7. SPC was found in the optimal range in all varieties suggesting that the seed produced from these varieties grown in the alkaline soil with pH up to 7.9 will possess a good potential for germination.
8. The lowest moisture and the highest DM content as well as the highest AA content in the var. *cerasiforme* suggest that this variety will have a longer shelf life than other studied varieties.
9. The occurrence of a negative correlation between TA and AA in tomato fruit should be investigated in further studies.

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