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RESEARCH ARTICLE

Determination and comparison of morpho-physiological characteristics of Turkish sweet cherry (*Prunus avium* L.) grown in Afyonkarahisar: local cultivars and genotypes

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Abstract The research focused on analyzing qualitative and quantitative morpho-physiological characteristics of local sweet cherry cultivars and genotypes. Quantitative and qualitative characteristics (fruit weight, fruit length, fruit width, fruit shape, fruit pistil end, fruit suture, fruit skin colour, fruit flesh colour, length of fruit stalk, thickness of fruit stalk, weight of fruit stalk, colour of fruit juice, fruit juiciness, eating quality, fruit sweetness, stone weight, stone shape, TA, pH, L*, a*, b*, H, croma, cracking index, sensitivity class) with UPOV descriptors were used in the evaluation. The findings revealed a significant variation among local cultivars and genotypes. It was determined that there was a low-level negative correlation between cracking index and fruit weight, fruit length, stone weight, TA, pH and L*; and a low-level positive correlation between fruit width, fruit stem length, thickness and weight, SCC, a*, b*, H and croma. The heat map and clustering analysis classified local cultivars and genotypes into two main clusters, each containing several secondary sub-clusters. This classification indicates a significant potential within the characterized sweet cherry collection for targeted breeding purposes. In particular, local sweet cherry cultivars and genotypes classified into several clusters show promise as potential parental candidates for hybridization in breeding. As a result of the research, local cultivars and genotypes with high fruit weight and cracking resistance were identified. The dendrogram showing the examined characteristics visually expresses the differentiation between local cultivars and genotypes, thus indicating clear distinctions. We believe these genotypes can be employed in breeding and breeding research.

Keywords Cracking indexes · Pomology · Correlation · Hierarchical cluster

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Introduction

Sweet cherry (*Prunus avium* L.) is one of the most popular stone fruits in Turkey and the world. This species is used as a table fruit; some of them are also used in the food industry as frozen fruit and fruit juice. The suitability of cultivars as tables or industrial cultivars varies according to the fruit's colour

and physical and biochemical properties (Bandi et al. 2010). In the classical sense, cherry breeding begins by selecting the best ones among local cultivars. The very popular 'Bing' cultivar emerged this way (Jayasankar and Kappel 2011). In the breeding programmes carried out, countries have set priorities to solve their problems. In general, the main objectives of cultivar breeding in cherry are incompatibility, fruit size, taste–aroma, fruit flesh firmness, fruit colour, resistance to fruit cracking, fruit stem length, productivity, early or late ripening, a long harvest period, extending shelf life, tolerance and resistance to diseases and pests, dwarfism, product with colourless juice and small seeds for industry, frost resistance and improvement in climatic adaptation such as chilling requirements (Brown et al. 1996; Saunier 1996).

Morphological characterization and evaluation are the first steps in assessing germplasm and can provide useful data for future breeding programmes (Mehmood et al. 2014; Ganopoulos et al. 2015). Characterization and evaluation allow researchers to make rational choices and contribute to conserving genetic resources. It also helps to record and collate information for traits that distinguish genotypes within a species or between species, allowing easy and rapid identification. It also allows comprehensive verification of misidentifications or duplicates of homogeneous samples and highlights possible processing errors that occur (Dangi et al. 2021). Morphological characterization remains the first stage in identifying and classifying germplasm, and techniques such as multivariate analysis serve as valuable tools for assessing accessions within a collection (Badenes et al. 2000; Rakonjac et al. 2010). The use of multivariate analysis is particularly favoured in cherry as the data obtained through morphological characterizations are derived from a large data set covering both qualitative and quantitative traits (Ganopoulos et al. 2018; Mehmood et al. 2014). Cluster analysis provides the means to analyze quantitative and qualitative characteristics simultaneously, treating each input as an equally weighted individual entity (Khadivi-Khub 2014). As is known, sweet cherry encompasses phenotypes with a wide range of flowering times, sizes, shapes, sugar content and other characteristics (Castede et al. 2015; Zambounis et al. 2016; Ganopoulos et al. 2018; El Baji et al. 2021; Schuller et al. 2021) and therefore such variants can be used to screen germplasm valuable for future breeding programmes.

Cracked fruits allow infections to enter and quickly deteriorate while transported and stored. There is substantial variation among cherry cultivars in terms of susceptibility to cracking. Most early cultivars, in particular, are prone to cracking. Breeding cultivars that are resistant to cracking take on added significance in this regard. It is crucial to demonstrate this trait in breeding research.

This study focused on the analysis of (1) Qualitative and quantitative morpho-physiological characteristics of local sweet cherry cultivars and genotypes, (2) The interrelation of the examined characteristics and (3) The calculation of cracking performance, which is an important quality criterion in cherry.

Material and methods

Plant material

The study was conducted in Afyonkarahisar province, which stands out with its cherry production and culture in the Aegean region, where Turkey's cherry production is the highest. Local cherry cultivars "Karaballı", "Gılli", and "Akçıllı", have been used in cherry production in this province for many years, and 4 different genotypes that stand out with their fruit quality by the local people were used. All local cultivars and genotypes used in the study were grafted on *P. mahaleb* rootstock. The trees forming the study material were 21–25 years old and planted 7.0×4.0 m. In addition, these gardens did not apply cultural practices such as pruning, irrigation and fertilization. Three plants of each local cultivar and genotype were selected for recording data on various morphological and physico-chemical characteristics.

Trial area and features

This study was carried out on local cherry cultivars and genotypes in Sultandağı/Kırca town in 2023. The monthly average precipitation, temperature, and relative humidity values of the study area are presented in Figs. 1 and 2 (TSMS 2023).

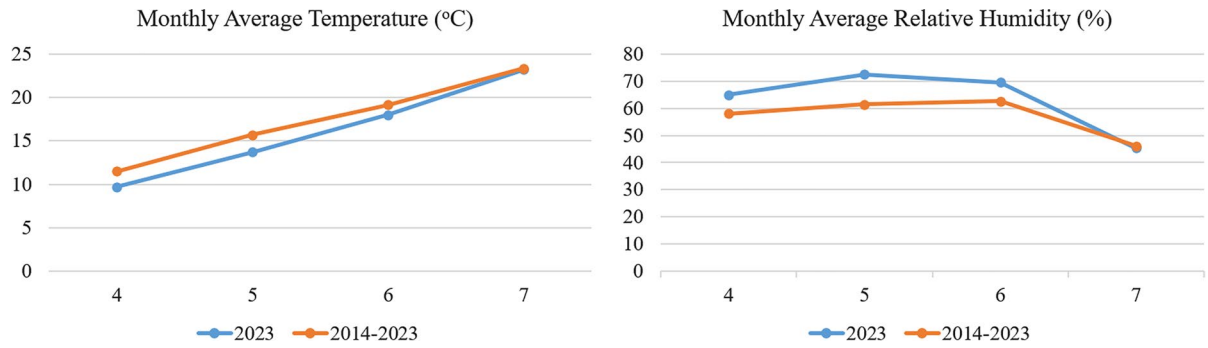

Fig. 1 Monthly average temperature (°C) and monthly average relative humidity (%) between April and July

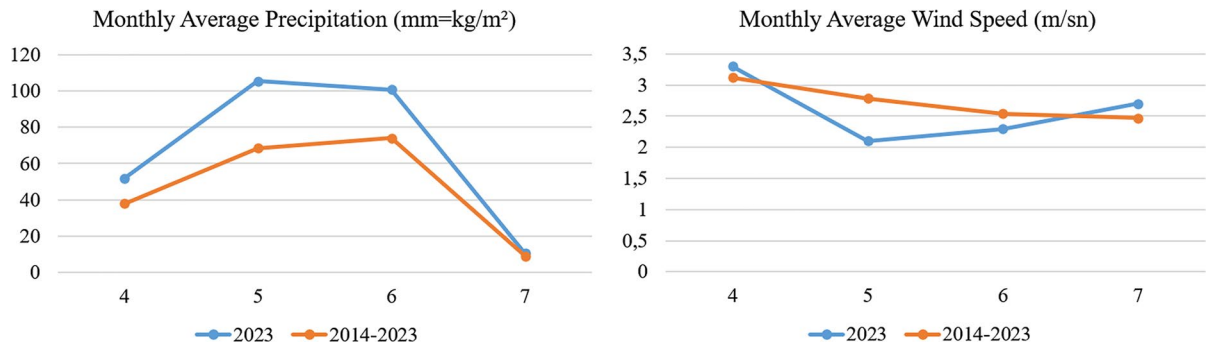

Fig. 2 Monthly total precipitation (mm = kg/m^2) and monthly average wind speed (m/sec) between April and July

Measurements and analyses

UPOV (2006) descriptors (fruit weight, fruit length, fruit width, fruit shape, fruit pistil end, fruit suture, fruit skin colour, fruit flesh colour, length of fruit stalk, colour of fruit juice, fruit juiciness, eating quality, fruit sweetness, stone shape) were used for pomological evaluation of local sweet cherry cultivars and genotypes. Scoring systems and grades were assigned in accordance with the UPOV descriptor (Supplementary Table 1).

Fruit (g), stone (g) and stem weight (g) were determined by weighing 50 fruits, stones and stems. Fruit width and length (mm) and fruit stem length and thickness were obtained using a digital calliper with a precision of 0.01 mm. The digital handheld refractometer (Greinorm 0–80 Brix, Germany) recorded water-soluble dry matter content (%) in homogenous juice. The pH was determined by a digital pH-meter (Hanna HI9124, Romania), and the titratable acid content (%, malic acid) was determined by the titration method. Fruit colour measurements (L*, a*, b*, chroma and H (hue^o) were obtained with a colourimeter (PCE Instruments Colorimeter, model PCE-CSM 1, Manchester, UK) at 2 different points on the peel surface of the fruit.

In the cracking test, the fruit stems were first cut at the level of the stem pit without damaging the fruit. The fruits with cut stems were placed in beakers and filled with pure water to cover them completely. The fruits were removed from the water after 2, 4 and 6 h, and the cracked fruits were counted. Immediately afterwards, those that did not crack were immersed in water again. This process was repeated 3 times. The cracking index was calculated according to the formula.

$$\text{Cracking index} = [(5a + 3b + c) \times 100]/250$$

a: Fruit cracking after 2 h; b: Fruit cracking after 4 h; c: The number of fruits that crack after 6 h. 5:

Multiplication factor for the number of fruits cracking after 2 h; 3: Multiplication factor for the number of fruits cracking after 4 h; 1: Number of fruits cracking after 6 h (Yıldırım and Koyuncu 2010).

According to the cracking index, genotypes and local cultivars were classified as resistant, medium resistant, sensitive and very sensitive. The cracking index class values were determined as resistant (≤10), moderately sensitive (≥10–≤20), sensitive (≥20–≤40) and very sensitive (≥40) (Greco et al. 2008).

Data analyses

Correlation analyses were performed to determine the relationships between genotypes and local cultivars regarding fruit characteristics. JMP® Pro 16.0.0 (Copyright © 2021 SAS Institute Inc.) software was used in the analyses. R Studio 2022.07.1 (© 2009–2022 RStudio, PBC) statistical software was used for heatmap hierarchical cluster analysis and correlation analysis. The open-source data visualization package "ggplot2" (Wickham 2016) was used for analysis with R.

Results

Analysis of qualitative characteristics

The qualitative characteristics of local cherry cultivars and genotypes are given in Table 1. All of the local sweet cherry cultivars and genotypes have 'medium' fruit weight, 'medium' fruit length and 'broad' fruit width. All of the genotypes and local cultivars "Gılli 1" and "Gılli 2" have 'oblate'; "Akçıllı", "Karaballı 2" and "Karaballı 3" have 'reniform' fruit shape, while only local cultivar "Karaballı 1" has 'circular' fruit shape. In the present study, a 'strongly conspicuous' suture was observed only in the "Akçıllı" local cultivar. In contrast, all other local cultivars and genotypes observed an 'absent or very weakly conspicuous' suture. All of the "Genotypes" had 'red' skin colour; local cultivars "Gılli 1", "Gılli 2", "Karaballı 1", "Karaballı 2" and "Karaballı 3" had 'dark red' skin colour, while only local cultivar "Akçıllı" had 'light red' skin colour. Similarly, "Genotype 2", "Gılli 1", "Gılli 2", "Karaballı 1", "Karaballı 2" and "Karaballı 3" have 'red' flesh colour, "Genotype 3" and "Genotype 4" have 'light red', "Akçıllı" and "Genotype 1" have 'yellow' flesh colour. 'Short' fruit stem was detected in all of the local cultivars and genotypes in the study. In terms of fruit juice colour, "Genotype 2", "Genotype 3", "Genotype 4", "Gılli 1" and "Gılli 2" were 'red'; "Karaballı 1", "Karaballı 2" and "Karaballı 3" were 'purple'; "Akçıllı" and "Genotype 1" were 'light yellow'. Surprisingly, 8 of the examined sweet cherry fruits had 'medium' juice, while only 2 of them had 'strong' juice. In our study, it was determined that "Akçıllı", "Genotype 1", "Genotype 2", "Gılli 1" and "Gılli 2" had 'excellent' eating quality and the others had 'good' eating quality. In addition, sweetness (^{o}Brix) was recorded as 'medium' and stone weight as 'large' in all local cultivars and genotypes. In terms of the stone shape, "Genotype 1", "Genotype 2", "Genotype 3" and "Genotype 4" have 'broad elliptic' and other local cultivars have 'circular' stone shapes.

Cluster analysis of qualitative variables

Cluster analysis was used in the study, which categorized local sweet cherry cultivars and genotypes into two main groups. The resulting dendrogram (Fig. 3) shows all the differences between sweet cherry cultivars and identifies several clusters of differences. Two main clusters, A and B, are defined in the dendrogram. The first cluster (A) is divided into one group, while the second cluster (B) is divided into two subgroups (B1 and B2). "Akçıllı" was collected in the first cluster, and other local cultivars and genotypes were collected in the second cluster. "Genotype 1", "Genotype 2", "Genotype 2" and "Genotype 4" were included in subgroup B1. In subgroup B2, "Gılli 1", "Gılli 2", "Karaballı 2", "Karaballı 3" and "Karaballı 1" were included. Based on the dendrogram, it is seen that the populations of local sweet cherry cultivars and genotypes used in the study exhibit significant phenotypic variability. According to the pomological characteristics, the dendrogram is divided into two clusters (X and Y). It is seen that X cluster is divided into X1 and X2 sub-clusters, of which fruit weight, fruit length, fruit sweetness, colour of fruit juice, fruit juiciness, and fruit shape are collected in sub-cluster X1; fruit flesh colour, length of fruit stalk characteristics are collected in sub-cluster X2. Cluster Y is similarly divided into Y1 and Y2 sub-clusters. It was determined that fruit width, stone shape, and fruit

Table 1 Comparative analysis of qualitative traits of sweet cherry genotype and local cultivars

Characters	Cultivar									
	Akçıllı	Genotype-1	Genotype-2	Genotype-3	Genotype-4	Gılli-1	Gılli-2	Karaballı-1	Karaballı-2	Karaballı-3
Fruit weight	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Fruit length	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Fruit width	Broad	Broad	Broad	Broad	Broad	Broad	Broad	Broad	Broad	Broad
Fruit shape	Reniform	Oblate	Oblate	Oblate	Oblate	Oblate	Oblate	Circular	Reniform	Reniform
Fruit pistil end	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Depressed	Depressed	Depressed
Fruit suture	Strongly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous	Absent or very weakly conspicuous
Fruit skin colour	Light red	Red	Red	Red	Red	Dark red	Dark red	Dark red	Dark red	Dark red
Fruit flesh colour	Yellow	Yellow	Red	Light red	Light red	Red	Red	Red	Red	Red
Length of fruit stalk	Short	Short	Short	Short	Short	Short	Short	Short	Short	Short
Colour of fruit juice	Light yellow	Light yellow	Red	Red	Red	Red	Red	Purple	Purple	Purple
Fruit juiciness	Medium	Medium	Medium	Strong	Strong	Medium	Medium	Medium	Medium	Medium
Eating quality	Excellent	Excellent	Excellent	Good	Good	Excellent	Excellent	Good	Good	Good
Fruit sweetness (^{o}Brix)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Stone weight	Large	Large	Large	Large	Large	Large	Large	Large	Medium	Large
Stone shape	Circular	Broad elliptic	Broad elliptic	Broad elliptic	Broad elliptic	Circular	Circular	Circular	Circular	Circular

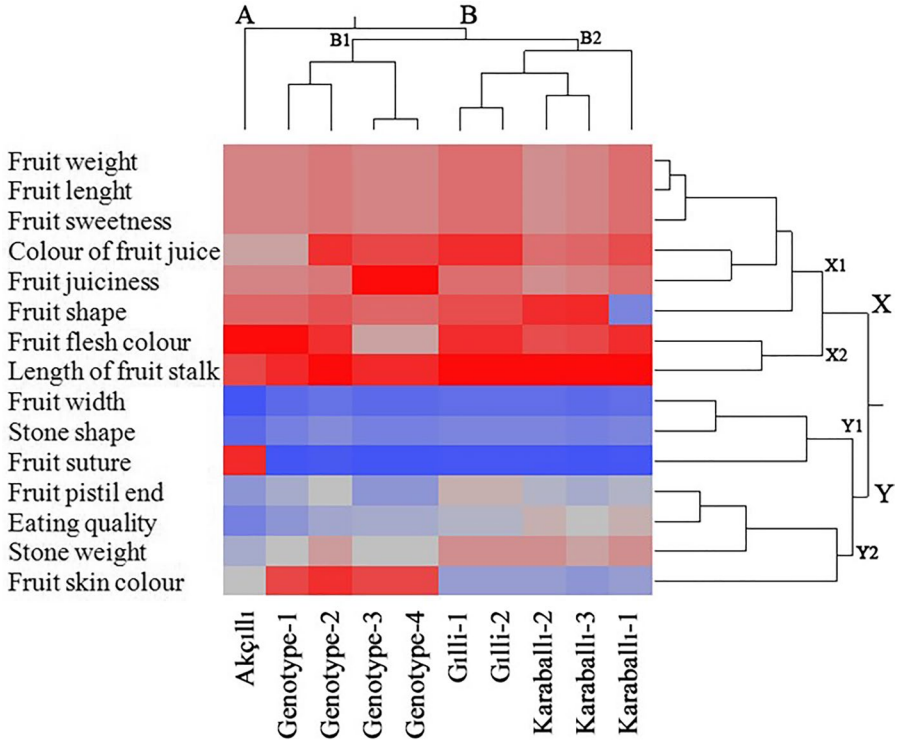

Fig. 3 Hierarchical clustering and heatmap analysis between local sweet cherry cultivars and genotypes and the qualitative characteristics examined (red shifting colours on the heatmap scale indicate an increase, and blue shifting colours indicate a decrease)

suture are in subset Y1; fruit pistil end, eating quality, stone weight, and fruit skin colour are in subset Y2.

Analysis of quantitative properties

Significant variations were obtained in local cultivars and genotypes in terms of fruit weight (Table 2). The highest fruit weight was determined in the local cultivar "Akçıllı" (5.14 g), followed by the local cultivar

Table 2 Fruit weight, width, length, seed weight, fruit stem length, fruit stem thickness and fruit stem weight of local cherry cultivars and genotypes

Local cherry cultivars and genotypes	Fruit weight	Fruit width	Fruit length	Seed weight	Fruit stem length	Fruit stem thickness	Fruit stem weight
Akçıllı	5.14 ± 0.38a	21.63 ± 0.21abc	18.49 ± 0.31	0.68 ± 0.02a	34.46 ± 2.12	1.15 ± 0.06	0.11 ± 0.01a
Genotip-1	4.60 ± 0.37ab	22.25 ± 0.63ab	18.72 ± 0.29	0.65 ± 0.04ab	32.95 ± 1.92	1.11 ± 0.05	0.09 ± 0.01bc
Genotip-2	4.53 ± 0.55ab	22.25 ± 0.37ab	18.69 ± 0.38	0.66 ± 0.02ab	31.79 ± 1.92	1.17 ± 0.11	0.08 ± 0.01c
Genotip-3	4.78 ± 0.22ab	22.40 ± 0.71a	18.88 ± 0.31	0.66 ± 0.04ab	36.10 ± 1.50	1.14 ± 0.03	0.08 ± 0.01c
Genotip-4	4.81 ± 0.45ab	22.80 ± 0.21a	18.86 ± 0.35	0.63 ± 0.00ab	34.40 ± 4.08	1.14 ± 0.06	0.09 ± 0.01bc
Gılli-1	4.64 ± 0.10ab	22.58 ± 0.19a	18.83 ± 0.10	0.66 ± 0.02ab	34.14 ± 2.94	1.09 ± 0.02	0.09 ± 0.01bc
Gılli-2	4.64 ± 0.07ab	22.17 ± 0.62ab	19.06 ± 0.66	0.65 ± 0.02ab	33.84 ± 1.75	1.14 ± 0.08	0.08 ± 0.01c
Karaballı-1	4.82 ± 0.19ab	20.92 ± 0.75bc	19.04 ± 0.58	0.66 ± 0.03ab	33.10 ± 1.08	1.13 ± 0.07	0.08 ± 0.01c
Karaballı-2	4.05 ± 0.14b	20.47 ± 0.18c	18.93 ± 0.27	0.58 ± 0.06b	33.74 ± 1.25	1.15 ± 0.07	0.10 ± 0.01ab
Karaballı-3	4.20 ± 0.17b	21.96 ± 0.55ab	18.62 ± 0.36	0.68 ± 0.01a	36.44 ± 1.06	1.11 ± 0.06	0.09 ± 0.01bc
$LSD_{0.05}$	0.31*	0.50***	0.39 ns	0.03*	2.17 ns	0.07 ns	0.01***

*$p < 0.05$; ***$p < 0.001$, ns: not significant

"Karaballı 1" (4.82 g), which was statistically in the same group. The lowest fruit weight was found in the local cultivar "Karaballı 2" (4.05 g). The highest fruit width was determined in the local cultivar "Gilli 1", which was in the same group with "Genotype 3" and "Genotype 4" genotypes (22.40, 22.80, 22.58 mm, respectively). The lowest fruit width was determined in the "Karaballı 2" local cultivar (20.47 mm). When the fruit lengths of local cultivars and genotypes were compared, it was determined that there was no difference between cultivars and genotypes; the highest fruit length was found in the local cultivar "Gılli 2" (19.06 mm), and the lowest was found in the local cultivar "Akçıllı" (18.49 mm).

The highest seed weight was found in the local cultivars "Akçıllı" and "Karaballı 3" in the same statistical group (0.68 g), and the lowest was found in the local cultivar "Karaballı 2" (0.58 g) (Table 2).

Similarly, there was no difference between local cultivars and genotypes in fruit stem length and thickness (Table 2). The highest fruit stem length was found in the local cultivar "Karaballı 3" (36.44 mm), and the lowest was found in the genotype "Genotype 2" (31.79 mm); the highest fruit stem thickness was found in the genotype "Genotype 2" (1.17 mm), and the lowest was found in the local cultivar "Gılli 1" (1.09 mm). The local cultivar "Akçıllı" (0.11 g) was found to have a significant fruit stem weight compared to other local cultivars and genotypes (Table 2). The lowest fruit stem weight was found in the "Genotype 2", "Genotype 3, "Gılli 2" and "Karaballı 1" local cultivars and genotypes (0.08 g), which had the same fruit stem weight and were in the same statistical group.

The TA content analysed in the fruit samples differed among local cherry cultivars and genotypes (Table 3). Among the local cherry cultivars and genotypes, the highest TA content was found in the "Gılli 2" local cultivar (9.37%), followed by the "Genotype 1" (9.32%), "Genotype 4" (9.25%) and "Akçıllı" (9.13%) local cultivars and genotypes in the same statistical group. The lowest TA was found in "Genotype 3" (7.62%) and "Gılli 2" (7.66%).

When the SCC contents of local cultivars and genotypes were compared, it was found that there was no difference between them, and the SCC content varied between 13.53 and 15.05%. The genotype "Genotype 3" had the highest SCC content of 15.05%. The local cultivar "Karaballı 3" had the lowest SCC content of

Table 3 TA, pH, SCC, L*, a*, b*, hue°, croma, cracking index and sensitivity class depending on local cherry cultivars and genotypes

Sweet Cherry	TA	pH	SSC	L*	a*	b*	hue°	croma	Cracking index	Sensitivity class
Akçıllı	9,13 ± 0,64a	4,37 ± 0,05a	15,04 ± 0,52	30,59 ± 1,45ab	17,73 ± 1,89ab	5,87 ± 0,75abc	17,80 ± 0,65ab	18,69 ± 2,02abc	7,73 ± 3,59bcd	Resistant
Genotip-1	9,32 ± 0,33a	4,35 ± 0,06ab	14,19 ± 0,42	33,05 ± 2,49a	21,17 ± 4,36a	6,97 ± 2,07ab	17,54 ± 1,58ab	22,32 ± 4,78a	6,00 ± 0,69d	Resistant
Genotip-2	9,03 ± 0,27ab	4,32 ± 0,06ab	14,54 ± 0,91	31,85 ± 1,10ab	20,74 ± 4,56a	7,44 ± 2,85ab	19,25 ± 2,94ab	22,04 ± 5,20a	9,73 ± 1,29abcd	Resistant
Genotip-3	7,62 ± 0,41b	4,33 ± 0,06ab	15,05 ± 0,80	32,96 ± 2,40a	22,92 ± 4,51a	8,23 ± 1,92a	20,15 ± 1,62a	24,26 ± 5,08a	12,40 ± 1,44a	Medium Sensitivity
Genotip-4	9,25 ± 0,74a	4,26 ± 0,05bc	14,03 ± 0,51	30,02 ± 1,17ab	20,71 ± 2,28a	6,79 ± 1,23ab	17,69 ± 1,05ab	21,82 ± 2,55ab	10,93 ± 1,29ab	Medium Sensitivity
Gilli-1	7,66 ± 0,22b	4,25 ± 0,01bc	13,87 ± 0,67	31,29 ± 0,49ab	16,93 ± 1,80ab	5,01 ± 0,81abc	16,09 ± 1,01abc	17,83 ± 1,67abc	6,00 ± 3,17d	Resistant
Gilli-2	9,37 ± 0,26a	4,32 ± 0,077ab	14,13 ± 0,46	30,98 ± 0,19ab	17,46 ± 1,24ab	5,22 ± 0,47abc	16,22 ± 0,88abc	18,40 ± 0,97abc	6,13 ± 2,20cd	Resistant
Karaballı-1	8,88 ± 0,20ab	4,20 ± 0,05c	14,87 ± 0,90	28,70 ± 0,67b	9,68 ± 2,61b	2,52 ± 1,02c	11,98 ± 2,60c	10,06 ± 2,75c	6,00 ± 1,06d	Resistant
Karaballı-2	8,59 ± 1,02ab	4,28 ± 0,07abc	14,40 ± 1,11	28,55 ± 0,45b	11,94 ± 2,16b	3,31 ± 0,83bc	14,73 ± 1,39bc	12,40 ± 2,29bc	9,87 ± 3,35abc	Resistant
Karaballı-3	8,64 ± 0,20ab	4,20 ± 0,12c	13,53 ± 0,12	28,97 ± 0,54b	9,44 ± 2,17b	2,18 ± 0,79c	12,06 ± 1,69c	9,71 ± 2,30c	11,60 ± 2,12a	Medium Sensitivity
$LSD_{0,05}$	0,50***	0,06*	0,70 n.s	1,34**	3,00***	1,46***	1,69***	3,29***	2,24**	

*: $P<0.05$, **$P<0.01$, ***$P<0.001$, n.s.: not significant

13.53%. On the other hand, there was a significant difference in the fruit juice pH of cherry genotypes and cultivars, which varied between 4.20 and 4.37.

Genotypes "Genotype 1" (33.05) and "Genotype 3" (32.96) ranked first in terms of the L* value from the fruit colour value. The lowest L* values were found in the "Karaballı 2", "Karaballı 1" and "Karaballı 3" local cultivars, with 28.55, 28.70 and 28.97 values, respectively. Similarly, a*, b*, hue^{o} and croma values varied between genotypes and local cultivars. In the measurements made on the fruit samples, it was determined that the genotypes named "Genotype 3", "Genotype 1", "Genotype 2" and "Genotype 4" had the highest a* values of 22.92, 21.17, 20.74 and 20.71, respectively, while the lowest a* values were 9.44, 9.68 and 11.94 in the local cultivars "Karaballı 3", "Karaballı 1" and "Karaballı 2", respectively. When the b* values of the samples were analysed, it was determined that the highest value was found in the genotype named "Genotype 3" (8.239), and the lowest values were 2.18 and 2.52 in the local cultivars "Karaballı 3" and "Karaballı 1", respectively. The hue^{o} values of local cultivars and genotypes varied between 11.98 and 20.15. The highest hue^{o} value was determined in "Genotype 3" (20.15), while the lowest hue^{o} values were determined in "Karaballı 1" (11.98) and "Karaballı 3" (12.06) local cultivars. The highest croma value was determined in the "Genotype 3" (24.26), "Genotype 1" (22.32) and "Genotype 2" (22.04) genotypes in the same statistical group, while the lowest was determined in the "Karaballı 3" (9.71) and "Karaballı 1" (10.06) local cultivars.

Significant variations were obtained in local cultivars and genotypes in terms of the cracking index (Table 3). The lowest cracking index was determined in genotype "Genotype 1" and local cultivars "Gılli 1" and "Karaballı 1" (6.00), which were in the same group statistically. The highest cracking index was determined in the "Genotype 3" genotype (12.40), followed by the "Karaballı 3" local cultivar (11.60) in the same statistical group.

When the local cultivars and genotypes examined in the study were grouped according to their susceptibility classes, it was determined that "Genotype 1", "Genotype 2", "Gılli 1", "Gılli 2", "Karaballı 1" and "Karaballı 2" local cultivars and genotypes were resistant; "Genotype 3", "Genotype 4" and "Karaballı 3" local cultivar genotypes were in the medium cracking sensitivity class.

The dark blue dots in Fig. 4 indicate strong positive correlations, and the dark red dots indicate strong negative correlations. Other circles show the strength and direction of the correlation according to their colour and size.

There was a low negative correlation between fruit weight and fruit stem thickness and cracking index and a low positive correlation between fruit width, fruit length, seed weight, fruit stem length, fruit stem weight, TA, pH, L* and hue^{o}. A moderate positive correlation existed between SCC, a*, b*, and croma. Similarly, a low-level negative correlation was found between the cracking index and fruit weight, fruit length, seed weight, TA, pH and L*; a low-level positive correlation was found between fruit width, fruit stem length, thickness and weight, SSC, a*, b*, hue^{o} and croma (Fig. 4).

Cluster analysis of quantitative variables

When the dendrogram (Fig. 5) is analysed, it is seen that local cherry cultivars and genotypes are clustered in two main groups as A and B. Group A is divided into A1 and A2 sub-groups, and sub-group A1 includes "Karaballı 1" and "Karaballı 2", and sub-group A2 includes "Karaballı 3" local cultivars. Similarly, group B is divided into subgroups B1 and B2, and subgroup B1 includes local cultivars "Gılli 1", "Gılli 2", "Genotype 1", "Genotype 2", "Genotype 3" and "Genotype 4", and subgroup B2 includes the local cultivar "Akçıllı 1". The 16 variables analysed were divided into two main groups (X and Y). There were 6 traits in the X1 subgroup, 3 in the X2 subgroup, 1 in the Y1 subgroup and 6 in the Y2 subgroup. When the map is analysed, it is seen that SSC, fruit stem length, cracking index, L*, a*, b*, croma and hue^{o} of "Genotype 3" and fruit weight, seed weight, fruit stem thickness, SSC, fruit stem weight, TA and pH of "Akçıllı 1" increased compared to other local cultivars and genotypes.

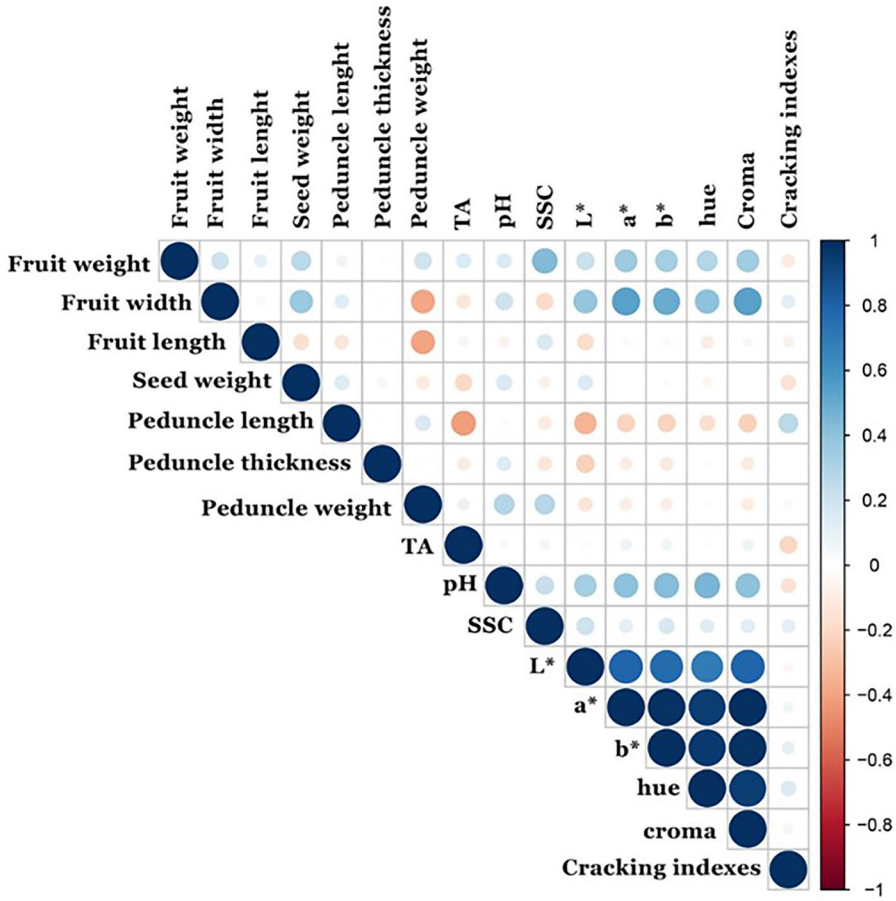

Fig. 4 Relationships between quantitative characteristics of local sweet cherry cultivars and genotypes

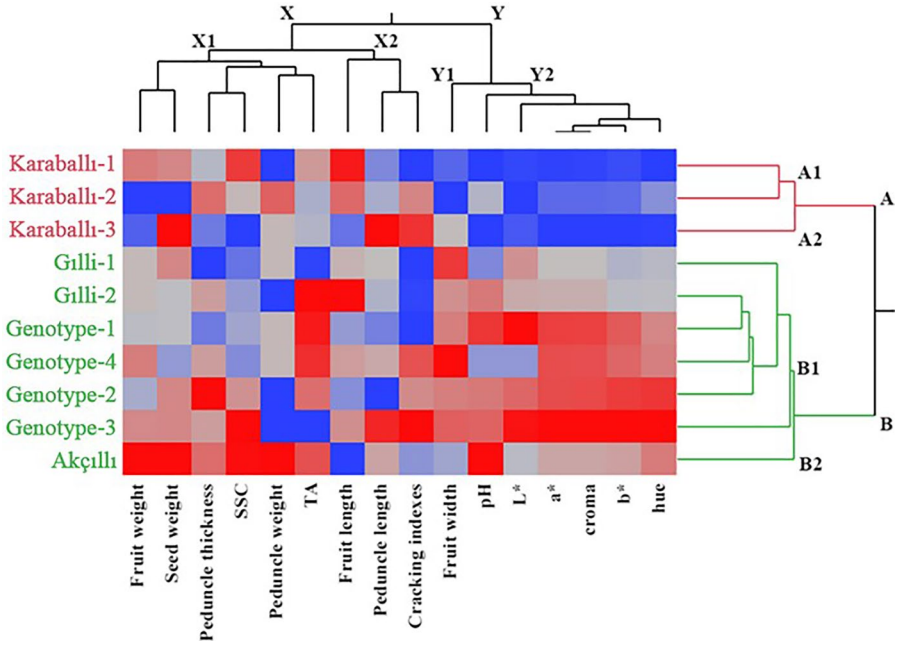

Fig. 5 Hierarchical clustering, heatmap analysis between local sweet cherry cultivars and genotypes, and the quantitative characteristics examined (on the temperature scale, colours shifting to red indicate an increase, and colours shifting to blue show a decrease)

Discussion

Qualitative characteristics

All of the local sweet cherry cultivars and genotypes examined have 'medium' fruit weight, 'medium' fruit length and 'broad' fruit width. Previous research by Simon (2006), Ganopoulos et al. (2015), Farsad and Esna-Ashari (2016) and Dangi et al. (2024) showed a similar variation in fruit size, which is in agreement with our findings. Although sweet cherries have a variety of fruit forms, according to Perez-Sanchez et al. (2010), cherry cultivars with large fruit width appear more attractive than those with long fruit length. Of the local sweet cherry cultivars and genotypes included in the study, 6 had 'oblate', 3 had 'reniform' fruit shapes, while only 1 had 'circular' fruit shapes. Gjamovski et al. (2016) and Dangi et al. (2024) reported cordate, reniform, oblate, circular and elliptic fruit shapes. 'Strongly conspicuous' suture was observed in one of the local cultivars, while 'absent or very weakly conspicuous' suture was observed in the others. Baba (2015) reported that most of the genotypes examined had either no (55.55%) or weak (44.44%) sutures, while Dangi et al. (2024) reported that most of the cherry cultivars examined (60%) had 'weakly conspicuous', 25% had 'strongly conspicuous' and 15% had 'absent or very weakly conspicuous' sutures. The present research is similar to previous research.

There is considerable variation among local sweet cherry cultivars and genotypes in fruit characteristics such as skin, flesh, and juice colour. This difference is widely used to discriminate between different cherry cultivars (Antonius et al. 2012; Petruccelli et al. 2013). Fruit skin and fruit flesh colour are the characteristics considered in fruit marketing regarding consumer appeal. According to previous research, sweet cherry consumers are most influenced by the dark colour of the skin (Ruiz and Egea 2008; Perez-Sanchez et al. 2010; Petruccelli et al. 2013) and the attractive taste of the fruit (Dangi et al. 2021). Apart from that, fruit peel colour is used to determine the ripeness stage of sweet cherries (Chockchaisawasdee et al. 2016). Our findings are consistent with the results of Patzak et al. (2019) and Dangi et al. (2024).

Our findings showed variability in fruit skin, fruit flesh and fruit juice colour. Similar variations in characteristics such as fruit skin colour, fruit flesh colour and juice colour have been reported in previous research (Rakonjac et al. 2014; Simeon and Dimitar 2022; Dangi et al. 2024). Another indicator of fruit freshness is the fruit stem (Dangi et al. 2021). Consumers and growers desire medium to long fruit stem lengths for convenient hand-picking of fruits (Bujdoso et al. 2020). Our findings regarding fruit stem are consistent with the findings of Matteo et al. (2017) and Dangi et al. (2024).

Since sweet cherry fruits are mainly used for fresh consumption, their appearance (fruit shape, shiny fruit skin, red fruit skin, length of fruit stem and eating quality) are the parameters used to determine how good quality they are (Dangi et al. 2021). It was determined that the analysed cherry fruits had two juice forms as 'medium' and 'strong'. This is similar to the findings of Dangi et al. (2024). Matteo et al. (2017) reported four juice forms: very weak, weak, medium, and strong.

Sweetness is the most prominent characteristic for cherry consumers, but fruits with a less sweet taste are really appreciated in many countries (Bujdoso et al. 2020). Our study determined 'excellent' and 'good' eating quality. Sweetness (^{o}Brix) was recorded as 'medium' and stone weight as 'large' in all local cultivars and genotypes. The differences in the results of the present and previous research may be attributed to variations in agro-climatic conditions in fruit development. Regarding core shape, 'broad elliptic' and 'circular' core shapes were determined. Our findings are similar to Matteo et al. (2017) and Dangi et al. (2024).

Cluster analysis groups similar and dissimilar cherries according to various characteristics and helps to classify and select cultivars with different characteristics needed for quality assessment and breeding programmes. This claim finds support in the work of previous researchers (Farsad and Esna-Ashari 2016; Ranga et al. 2021; Akin et al. 2022; Dangi et al. 2024) who have used this approach to select superior genotypes in breeding programmes. Many researchers have obtained similar results with the findings of this study (Khadivi-Khub 2014; Ganopoulos et al. 2018; Dangi et al. 2024).

Quantitative characteristics

Genotype, cultivar, rootstock, cultural practices, environmental factors and harvest time affect fruit

size. (Olmstead and Lezzoni 2007; Nacouzi et al. 2023; Martins et al. 2021; Singh et al. 2020). The most significant increase in fruit size and weight of cherries occurs just before harvest. Up to 25% of the final fruit yield is added in the last week before harvest (Blažková et al. 2002). Our study's fruit weight values varied significantly according to local cultivars and genotypes. The average fruit weights of local cherry cultivars and genotypes varied between 4.20 and 5.14 g. Although, according to Olmstead et al. (2007), the fruit weights of the cultivated cultivars varied between 6 and 13 g, the genotypes, and local cultivars we examined were below these figures. This is thought to be due to the lack of any cultural intervention on the trees and their late incompatibility with the *P. mahaleb* rootstock. From a commercial point of view, the main quality characteristics of cherry fruit are fruit size, colour, firmness and sweetness (Kazantzis et al. 2011). Therefore, the price of a cherry varies according to its size, firmness, fruit colour and sweetness. In breeding, a fruit width of 28 mm and above is one of the most sought-after characteristics for cherry cultivars (Csihon et al. 2018). In this study, there was a significant difference between local cultivars and genotypes regarding fruit width, but no difference was detected in fruit length. The average fruit width values varied between 20.47and 22.80 mm. These values are below the export values. Menzies (2004) reported that a 24 mm fruit width is acceptable by consumers. It is thought that "Genotype 3", "Genotype 4" and "Gilli 1" local cultivars and genotypes will have larger fruit widths under good care conditions.

In this study, significant differences were found between local cherry cultivars and genotypes in terms of seed weight. The seed weight of local cherry cultivars and genotypes varied between 0.58 and 0.68 g. Bolsu and Akça (2011a) reported that the seed weight of "0900 Ziraat", "Vista", "Stella", "Lambert", and "Salihli" cultivars grafted on *P. mahaleb* rootstock varied between 0.47 and 0.62 g. In another study conducted on *P. mahaleb* rootstock with "Bing", "Early Burlat", "Early Lory", "Napoleon", "Sapıkısa", "Stella", "Regina" and "0900 Ziraat" cultivars, it was measured between 0.19 and 0.67 g (Eroğul 2016). Our results are similar to the literature.

Due to the increase in cherry production and trade in recent years, prevention of quality losses during storage and marketing, preservation of shelf life and road saturation are of great importance. Due to these issues, thick and green stem colour expresses freshness, while fruit stem length and mass play an important role (Sarısu et al. 2019). In addition, stem length is desirable in cherries because it reduces labour costs. In our study, the fruit stem length of local cherry cultivars and genotypes varied between 31.79 and 36.44 mm, fruit stem thickness between 1.09 and 1.17 mm and fruit stem weight between 0.08 and 0.11 g. These results were consistent with the literature. Bolsu and Akça (2011a) reported a fruit stem length of 29.16–54.36 mm, a fruit stem thickness of 0.62–0.94 mm and a fruit stem weight of 0.06–1.12 g for 5 cherry cultivars grafted on *P. mahaleb*.

The deep red colour is an important characteristic for consumer appeal (Crisosto et al. 2002). For the consumer, this colour is associated with cherries that are ripe and ready to eat, whereas a pale colour is less preferred by the consumer (Kappel et al. 1996). However, lighter shades of red have also been included in consumer preferences in recent years. L*, a* and b* values were significant among local cultivars and genotypes. The L*, a* and b* values varied between 28.55–33.05, 9.44–22.92 and 2.18–8.23, respectively. Similarly, the croma value was measured between 9.71 and 24.26, and the hue° was 11.98–20.15. Çelik and Hepaksoy (2021) reported fruit colour values of L* 24.54–32.69, a* 21.38–37.29, b* 7.18–28.86, C* 22.56–41.16 and hue° as 17.65–25.58 in the "0900 Ziraat" cultivar grafted on *P. mahaleb* rootstock. Eroğul (2016) reported that the croma value varied between 22.81 and 40.27, and the hue° value varied between 16.44 and 24.07 in his study with 8 cherry cultivars grafted on *P. mahaleb*. Similarly, Göksel and Aksoy (2014) determined the C* value of "0900 Ziraat" cherry fruits as 24.82 and, the h° value as 21.84, and the C* value of the "Regina" cultivar as 25.85 and the hue° value as 22.02. It is thought that these differences in fruit colour parameters of cherry cultivars and genotypes are due to environmental and growing conditions.

SSC, pH and titratable acidity are important fruit quality characteristics that affect consumer preferences. These characteristics are highly influenced by ecological and growing conditions (Wang 2006). Cherries are considered slightly acidic fruits with pH values between 3.7 and 4.2 (Serradilla et al. 2016). Acidity plays an important role in the formation of flavour and taste in products and is one of

the ripeness criteria of fruits (Karaçalı 2009). In our study, the effect of local cultivars and genotypes on SSC, pH and TA was significant. SSC values ranged between 13.53 and 15.05%, pH between 4.20 and 4.37% and TA between 7.66 and 9.37%. Our results were consistent with previous research. The SSC content in cherry cultivars was 13–20% depending on the cultivar and maintenance conditions (Moing et al. 2004; Muskovics et al. 2006; Bolsu and Akça 2011a; Stojanović et al. 2012; Çetinbaş et al. 2012; Sarısu et al. 2016). Again, Eroğul (2016) reported SSC between 9.86 and 16.13%, TA between 0.43 and 1.11% and pH between 3.68 and 4.52, Bolsu and Akça (2011b) reported SSC content of "0900 Ziraat" cultivar grafted on *P. mahaleb* as 16.08%, pH as 4.21 and TA as 1.14%.

The causes and mechanisms behind cracking have been investigated for at least 75 years but have not yet been fully elucidated. The process of fruit cracking is generally considered complex and depends on a wide range of different factors. It has been reported that many factors, such as cultivar, rootstock, growing conditions, irrigation and fertilisation regime, fruit size, osmotic potential of the flesh, and anatomy of the fruit skin, are effective in cracking cherry fruit (Khadivi-Khub and Etemadi-Khah 2015; Blanco et al. 2022; Blanco et al. 2019; Devasirvatham and Tan 2022; Quero-García et al. 2021; Michailidis et al. 2021). Generally, harvesting is uneconomical if the tree contains over 25% cracked fruit (Looney 1985). In this study, there were significant differences between local cultivars and genotypes in terms of the cracking index, which ranged between 6.00 and 12.40. In our study, all local cultivars and genotypes showed significantly lower cracking levels than the "0900 Ziraat" cultivar. Yıldırım and Koyuncu (2010) determined the cracking index value of the "0900 Ziraat" cultivar as 25.50. Similarly, Güçlü et al. (2023) reported that the cracking index of the "0900 Ziraat" cultivar grafted on *P. mahaleb* was 15.90. In our study, in terms of cracking sensitivity, 5 of the local cultivars were in the "resistant" group, 1 of them was in the "medium sensitive" group, 2 of the genotypes were in the "resistant" group, and 2 of them were in the "medium sensitive" group.

Conclusion

The local cultivars and genotypes evaluated exhibited significant variability in the qualitative and quantitative traits studied, thus providing a valuable resource for improving sweet cherry cultivation. Significant statistical differences among various traits provide reliable information for selecting genotypes with improved physical and chemical properties. The investigated fruit characteristics may be advantageous for selecting suitable germplasm in regions with similar climates, and the findings obtained may serve as a noteworthy reference point for the molecular characterisation of sweet cherry cultivars. In this context, local cultivars and genotypes emerge as priority choices due to their characteristics, such as fruit size, shape, weight, skin colour, eating quality, fruit juice, and resistance to cracking. In our study, all local cultivars and genotypes showed a significantly lower cracking level than the "0900 Ziraat" cultivar, which is essential in cultivating and exporting cherries in Turkey. Among the local sweet cherry cultivars and genotypes grown in Afyonkarahisar conditions in Turkey, it was determined that "Genotype 1", "Gılli 1", and "Karaballı 1" local cultivars were high in terms of resistance to cracking and "Akçıllı" local cultivar was high in terms of fruit weight. Again, it was determined that "Genotype 1" and "Genotype 3" stood out regarding fruit peel brightness. Their potential as parental candidates in cherry breeding programmes positions these local cultivars and genotypes to offer the opportunity for the development of a new cultivar candidate adapted to the conditions under which they are grown, characterised by acceptable fruit quality, resistance to cracking and adaptability.

Author contributions All authors contributed to this study. LK and AA planned material preparation and study design. LK and AA carried out data collection and analysis. The authors wrote and approved the manuscript together from the first draft to the final draft.

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Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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References

Akin M, Eyduran SP, Gazioglu Sensoy RI, Eyduran E (2022) Defining associations between berry features of wild red currant accessions utilizing various statistical methods. Erwerbs-Obstbau 64:377–386. https://doi.org/10.1007/s10341-022-00660-3

Antonius K, Aaltonen M, Uosukainen M, Hurme T (2012) Genotypic and phenotypic diversity in fnnish cultivated sour cherry (*Prunus cerasus* L.). Genet Resour Crop Evol 59:375–388. https://doi.org/10.1007/s10722-011-9688-3

Baba JA (2015) Survey, identification and documentation of cherry (*Prunus avium* L) genotypes in selected areas of Kashmir. Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu and Kashmir, pp 1–113

Badenes ML, Martinez-Calvo J, Llacer G (2000) Analysis of a germplasm collection of loquat (*Eriobotrya japonica* Lindl.). Euphytica 114:187–194. https://doi.org/10.1023/A:1003950215426

Bandi A, Thiesz R, Ferencz L, Bandi MJ (2010) Some physical and biochemical compositions of the sweet cherry (*Prunus avium* L.) fruit. Acta Univ. Sapientiae. Agricult Environ 2:5–16

Blanco V, Zoffoli JP, Ayala M (2019) High tunnel cultivation of sweet cherry (*Prunus avium* L.): physiological and production variables. Sci Hortic 251:108–117. https://doi.org/10.1016/j.scienta.2019.02.023

Blanco V, Blaya-Ros PJ, Torres-Sánchez R, Domingo R (2022) Irrigation and crop load management lessen rain-induced cherry cracking. Plants 11(23):3249. https://doi.org/10.3390/plants11233249

Blažková J, Hlušičková I, Blažek J (2002) Fruit weight, firmness and soluble solids content during ripening of Karešova cv. sweet cherry. Hortc Sci 29(3):92–98. https://doi.org/10.17221/4470-HORTSCI

Bolsu A, Akça Y (2011a) Some fruit and morphological characteristics of five sweet cherry cultivars grafted on *Prunus mahaleb* L. rootstock. Yuzuncu Yıl Univ J Agric Sci 21(3):152–157

Bolsu A, Akça Y (2011b) Effects of rootstocks on growth, fruit and yielding characters sweet cherry cultivar 0900. J Agric Fac Gaziosmanpaşa Univ (JAFAG) 2011(1):37–43

Brown SK, Lezzoni AF, Fogle HW (1996) Cherries. Fruit Breeding. Tree and Tropical Fruits, USA

Bujdoso G, Hrotko K, Feldmane D, Giovannini D, Demirsoy H, Tao R, Malchev S (2020) What kind of sweet cherries do the final consumers prefer? South-West J Hortic Biol Environ 11:37–48

Castede S, Campoy JA, Le Dantec L, Quero-Garcia J, Barreneche T, Wenden B, Dirlewanger E (2015) Mapping of candidate genes involved in bud dormancy and fowering time in sweet cherry (*Prunus avium* L.). PLoS ONE 10:1–18. https://doi.org/10.1371/journal.pone0143250

Çelik Z, Hepaksoy S (2021) Farklı Lokasyonların Kiraz Meyve Kalitesi Üzerine Etkileri. Biyoloji Bilimleri Araştırma Dergisi 14(2):127–141

Çetinbaş M, Butar S, Koyuncu F (2012) Effects of Aminoethoxyvinylglycine (AVG) on fruit quality of 0900-Ziraat Sweet Cherry. Ege Univ Fac Agric J 49(1):103–106

Chockchaisawasdee S, Golding JB, Vuong QV, Papoutsis K, Stathopoulos CE (2016) Sweet cherry: composition, postharvest preservation, processing and trends for its future use. Trends Food Sci Technol 55:72–83. https://doi.org/10.1016/j.tifs.2016.07.002

Crisosto CH, Crisosto GM, Ritenour MA (2002) Testing the reliability of skin color as an indicator of quality for early season 'Brooks' (*Prunus avium* L.) cherry. Postharvest Biol Technol 24:147–154. https://doi.org/10.1016/S0925-5214(01)00190-9

Csihon Á, Bicskei DK, Dremák P, Gonda I (2018) Performance of sweet cherry cultivars grafted on Colt rootstock. Int J Hortic Sci 24(1–2):7–10. https://doi.org/10.31421/IJHS/24/1-2./1540

Dangi G, Singh D, Chauhan N, Dogra RK, Verma P, Sharma S (2021) characterization of selected sweet cherry (*Prunus avium* L.) varieties using DUS test guidelines. IPJR 34:290–294. https://doi.org/10.5958/0976-1926.2021.00028.0

Dangi G, Singh D, Chauhan N, Dogra RK, Verma P, Chauhan A (2024) Evaluating genetic diversity of morpho-physiological traits in sweet cherry (*Prunus avium* L.) cultivars using multivariate analysis. Genet Res Crop Evol 11:1–36. https://doi.org/10.1007/s10722-023-01809-z

Devasirvatham V, Tan DK (2022) Key determinants of the physiological and fruit quality traits in sweet cherries and their importance in a breeding programme. Horticulturae 8(8):694. https://doi.org/10.3390/horticulturae8080694

El Baji M, Hanine H, En-Nahli S, Socias I, Company R, Kodad O (2021) Morphological and pomological characteristics of sweet cherry (*Prunus avium* L.) grown in-situ under South Mediterranean climate in Morocco. Int J Fruit Sci 21:52–65. https://doi.org/10.1080/15538362.2020.1858468

Eroğul D (2016) Determination of physical and chemical properties of some important cherry cultivars grown in İzmir. Yüzüncü Yıl Univ J Agric Sci 26(4):579–585

Farsad A, Esna-Ashari M (2016) Genetic diversity of some Iranian sweet cherry (*Prunus avium* L.) cultivars using microsatellite markers and morphological traits. Cytol

Genet 50:8–19. https://doi.org/10.3103/S0095452716010059

Ganopoulos I, Moysiadis T, Xanthopoulou A, Ganopoulou M, Avramidou E, Aravanopoulos FA, Tanie E, Madesis P, Tsaftaris A, Kazantzis K (2015) Diversity of morpho-physiological traits in worldwide sweet cherry cultivars of Gene Bank collection using multivariate analysis. Sci Hortic 197:381–391. https://doi.org/10.1016/j.scienta.2015.09.061

Ganopoulos I, Farsakoglou AM, Aravanopoulos F, Molassiotis A, Michailidis M, Malliarou E, Avramidou E, Tsaftaris A, Osanthanunkul M, Madesis P, Kazantzis K (2018) Towards sweet cherry (*Prunus avium* L.) breeding: phenotyping evaluation of newly developed hybrids. Euphytica 214:1–11. https://doi.org/10.1007/s10681-018-2179-2

Gjamovski V, Kiprijanovski M, Arsov T (2016) Morphological and pomological characteristics of some autochthonous sweet cherry cultivars in the Republic of Macedonia. Acta Hortic 26:147–152. https://doi.org/10.17660/ActaHorti.2016.1139.26

Göksel Z, Aksoy U (2014) Physico-chemical characteristics of some table sweet cherry varieties. Turk J Agric Nat Sci Special 2:1856–1862

Greco P, Palasciano M, Mariani R, Pacifico A, Godini A (2008) Susceptibility to cracking of thirty sweet cherry cultivars. Acta Hortc 795:379–382. https://doi.org/10.17660/ActaHortic.2008.795.56

Güçlü SF, Demir M, Koyuncu F, Özüsoy F (2023) Different calcium applications effects on fruit quality of 0900 Ziraat (*Prunus avium*). Anadolu J Agric Sci 38(1):69–80

Jayasankar S, Kappel F, Kappel SJF, Jayasankar S, Kappel F (2011) Recent advances in cherry breeding. Fruit, vegetables and cereal sciences and biotechnology. Global Science Book, UK, pp 63–67

Kappel F, Fisher-Fleming B, Hogue E (1996) Fruit characteristics and sensory attributes of an ideal sweet cherry. HortScience 31(3):443–446. https://doi.org/10.21273/HORTSCI.31.3.443

Karaçalı, İ. (2009). Bahçe Ürünlerinin Muhafaza ve Pazarlanması. Ege Üniversitesi Ziraat Fakültesi Yayınları, No:494, 6. Baskı, Ege Üniversitesi Basımevi, s:482, Bornova/İzmir.

Kazantzis K, Chatzicharissis I, Papachatzis A, Sotiropoulos T, Kalorizou H, Koutinas N (2011) Evaluation of sweet cherry cultivars introduced in Greece. J Univ Kraiova, Seria Hortic 16:293–296

Khadivi-Khub A (2014) Assessment of cultivated cherry germplasm in Iran by multivariate analysis. Trees 28:669–685. https://doi.org/10.1007/s00468-014-0980-7

Khadivi-Khub A, Etemadi-Khah A (2015) Phenotypic diversity and relationships between morphological traits in selected almond (*Prunus amygdalus*) germplasm. Agrofor Syst 89:205–216. https://doi.org/10.1007/s10457-014-9754-x

Looney NE (1985) Benefits of calcium sprays below expectations in BC tests. Good Fruit Grower 36:7–8

Martins V, Silva V, Pereira S, Afonso S, Oliveira I, Santos M, Gonçalves B (2021) Rootstock affects the fruit quality of 'Early Bigi'sweet cherries. Foods 10(10):2317

Matteo AD, Russo R, Graziani G, Ritienib A, Vaioa CD (2017) Characterization of autochthonous sweet cherry cultivars (*Prunus avium* L.) of southern Italy for fruit quality, bioactive compounds and antioxidant activity. J Sci Food Agric 97:2782–2794. https://doi.org/10.1002/jsfa.8106

Mehmood A, Jaskani MJ, Khan IA, Ahmad S, Ahmad R, Luo S, Ahmad NM (2014) Genetic diversity of Pakistani guava (*Psidium guajava* L.) germplasm and its implications for conservation and breeding. Sci Hortic 172:221–232. https://doi.org/10.1016/j.scienta.2014.04.005

Menzies R (2004) Increasing cherry fruit size. https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/138124/Increasing-cherry-fruit-size.pdf (Date of access:15.09.2023)

Michailidis M, Karagiannis E, Bazakos C, Tanou G, Ganopoulos I, Molassiotis A (2021) Genotype-and tissue-specific metabolic networks and hub genes involved in water-induced distinct sweet cherry fruit cracking phenotypes. Comput Struct Biotechnol J 19:5406–5420. https://doi.org/10.1016/j.csbj.2021.09.030

Moing A, Renaud C, Christmann H, Fouilhaux L, Tauzin Y, Zanetto A, Claverie J (2004) Is there a relation between changes in osmolarity of cherry fruit flesh or skin and fruit cracking susceptibility? J Am Soc Hortic Sci 129(5):635–641. https://doi.org/10.21273/JASHS.129.5.0635

Muskovics G, Felfoldi J, Kovacs E, Perlaki R, Kallay T (2006) Changes in physical properties during fruit ripening of hungarian sweet cherry (*Prunus avium* L.) cultivars. Postharvest Biol Technol 40:56–63. https://doi.org/10.1016/j.postharvbio.2005.12.007

Nacouzi D, Masry R, El Kayal W (2023) Quality and phytochemical composition of sweet cherry cultivars can be influenced by altitude. Plants 12(12):2254. https://doi.org/10.3390/plants12122254

Olmstead JW, Iezzoni AF, Whiting MD (2007) Genotypic differences in sweet cherry fruit size are primarily a function of cell number. J Am Soc Hortic Sci 132:697–703. https://doi.org/10.21273/JASHS.132.5.697

Patzak J, Henychova A, Paprstein F, Sedlak J (2019) Evaluation of S-incompatibility locus, genetic diversity and structure of sweet cherry (*Prunus avium* L.) genetic resources by molecular methods and phenotypic characteristics. J Hortic Sci Biotechnol 95:1–9. https://doi.org/10.1080/14620316.2019.1647798

Perez-Sanchez R, Gomez-Sanchez MA, Morales-Corts MR (2010) Description and quality evaluation of sweet cherries culture in Spain. J Food Qual 33:490–506. https://doi.org/10.1111/j.1745-4557.2010.00339.x

Petruccelli R, Ganino T, Ciaccheri L, Maselli F, Mariotti P (2013) Phenotypic diversity of traditional cherry accessions present in the Tuscan region. Sci Hortic 150:334–347. https://doi.org/10.1016/j.scienta.2012.11.034

Quero-García J, Letourmy P, Campoy JA, Branchereau C, Malchev S, Barreneche T, Dirlewanger E (2021) Multi-year analyses on three populations reveal the first stable QTLs for tolerance to rain-induced fruit cracking in sweet cherry (*Prunus avium* L). Hortic Res 8:136. https://doi.org/10.1038/s41438-021-00571-6

Rakonjac V, Aksic MF, Nikolic D, Milatovic D, Colic S (2010) Morphological characterization of 'Oblacinska' sour cherry by multivariate analysis. Sci Hortic 125:679–684. https://doi.org/10.1016/j.scienta.2010.05.029

Rakonjac V, Mratinic E, Jovkovic R, Aksic MF (2014) Analysis of morphological variability in wild cherry (*Prunus*

avium L.) genetic resources from Central Serbia. J Agric Sci Technol 16:151–162

Ranga AD, Kumar S, Darvhankar MS (2021) Variability among different yield and yield contributing traits of Okra (*Abelmoschus esculentus* L Moench) genotypes. Electron J Plant Breed 12:74–81. https://doi.org/10.37992/2021.1201.011

Ruiz D, Egea J (2008) Phenotypic diversity and relationships of fruit quality traits in apricot (*Prunus armeniaca* L.) germplasm. Euphytica 163:143–158. https://doi.org/10.1007/s10681-007-9640-y

Sarısu HC, Karamürsel ÖF, Öztürk FP, Demirtaş İ, Koçal H, Gür İ, Yürekli Ö, Şevik İ (2016) Fruit characteristics, phenology and yield of six sweet cherry cultivars. Yüzüncü Yıl Univ Fac Agric J Agric Sci 26(4):547–555

Sarısu HC, Karamürsel ÖF, Öztürk FP, Demirtaş İ, Koçal H, Gür İ, Cengiz Ö, Şevik İ (2019) Introducing different cherry cultivars to inner and crossover areas. J Agric Sci 25:11–20

Saunier R (1996) Sweet cherry breeding at the research station in Bordeaux. Acta Hort 41:35–40

Schuller E, Fernandez FF, Antanaviciute L, Anhalt-Bruderl U, Spornberger A, Forneck A (2021) Autochthonous Austrian varieties of *Prunus avium* L. represent a regional gene pool, assessed using SSR and AFLP markers. Genes 12:1–19. https://doi.org/10.3390/genes12030322

Serradilla MJ, Hernández A, López-Corrales M, Ruiz-Moyano S, de Guía Córdoba M, Martín A (2016) Composition of the cherry (*Prunus avium* L. and *Prunus cerasus* L. Rosaceae). Nutritional composition of fruit cultivars. Academic Press, USA, pp 127–147. https://doi.org/10.1016/B978-0-12-408117-8.00006-4

Simon G (2006) Review on rain induced fruit cracking of sweet cherries (*Prunus avium* L.), its causes and the possibilities of prevention. Int J Hortic Sci 12:27–35. https://doi.org/10.31421/IJHS/12/3/654

Singh A, Shukla AK, Meghwal PR (2020) Fruit cracking in pomegranate: extent, cause, and management–A review. Int J Fruit Sci 20(sup3):S1234–S1253. https://doi.org/10.1080/15538362.2020.1784074

Stojanović M, Milatović D, Kulina, M, Alić-Džanović Z (2012) Pomological properties of sweet cherry cultivars on Gisela 5 rootstock in the region of Sarajevo. In: Third international scientific symposium" Agrosym Jahorina 2012". Faculty of Agriculture, University of East Sarajevo, Republic of Srpska, Bosnia and Herzegovina. pp 183–187

TSMS (2023). Turkish State Meteorological Service. https://www.mgm.gov.tr/eng/forecast-cit-ies.aspx.

UPOV (2006) Cherry descriptors. International Union for the Protection of New Varieties of Plants, Geneva, pp 1–31

Wang SY (2006) Effect of pre-harvest conditions on antioxidant capacity in fruits. Acta Hort 712:229–305. https://doi.org/10.17660/ActaHortic.2006.712.33

Wickham H (2016) ggplot2: Elegant graphics for data analysis, 2nd edn. Springer, UK. https://doi.org/10.1007/978-3-319-24277-4

Yıldırım AN, Koyuncu F (2010) The effect of gibberellic acid applications on the cracking rate and fruit quality in the '0900 Ziraat' sweet cherry cultivar. Africa J Biotechnol 9(38):6307–6311

Zambounis A, Ganopoulos I, Avramidou E, Aravanopoulos FA, Tsaftaris A, Madesis P (2016) Evidence of extensive positive selection acting on cherry (*Prunus avium* L.) resistance gene analogs (RGAs). Aust J Crop Sci 10:1324

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