Bioactive compounds and physical attributes of *Cornus mas* genotypes through multivariate approaches

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ABSTRACT

Cornelian cherry fruits are quite rich in bioactive compounds. Natural colour, rich flavonoids and anthocyanins and high antioxidant activity have made the fruits a natural drug. In the present study, antioxidant activity, total flavonoids and total phenolics of naturally growing 18 cornelian cherry genotypes with different phenotypic characteristics were determined. Size and shape parameters of the genotypes were also determined with the image-processing method; sphericity, elongation and shape index were calculated and shapes of two-dimensional fruit images were compared with elliptic Fourier analysis. Antioxidant activity, total flavonoid contents and total phenolic amounts of the genotypes were varied between 55.062 and 152.420 mmol TE · kg⁻¹, 286.40 and 2,882.80 mg QE · kg⁻¹, and 2,644.80 and 12,959.00 mg GAE · kg⁻¹, respectively. Multivariate variance analysis conducted based on physical characteristics revealed that six genotypes were different from the others. Shape analysis with Elliptic Fourier method revealed that the majority of present cornelian cherry genotypes had an oval appearance and a small portion of them had a drop-like appearance. According to discriminant analysis and Hotelling's pair-wise comparison tests, there were five different shape groups for present genotypes. A single genotype was placed into one of these groups, thus it was determined that this genotype was totally different in shape from the others.

Keywords: cranberry genotypes, elliptic Fourier analysis, shape features, shape index

INTRODUCTION

Fruits are a very diverse group and have been evaluated in industrial crops besides their fresh consumption for centuries (Ersoy et al., 2018a; Colak et al., 2019; Gundesli et al., 2019; Mertoglu et al., 2019; Okan et al., 2019). One of them, *Cornus* genus of Cornaceae family has about 65 species. These species are widespread in

the northern hemisphere, southern and central Europe, southwestern Asia, America and eastern Africa (Eyde, 1988). Majority of species in *Cornus* genus are grown as ornamental plants and *Cornus mas* L. is the most significant of these species economically (Ercişli et al., 2008; Bijelic et al., 2011). Cornelian cherry (*Cornus*

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mas L.) has been cultured for about 4,000 years and has a natural spread over the large range of geographies extending from Caucasus, Turkey, Bulgaria, Romania and Italy to Europe (Klimenko, 2004; Brindza et al., 2009; Szot et al., 2019a). In Turkey, cornelian cherry naturally grows under suitable climate conditions of Mediterranean, Aegean, Marmora and Black Sea regions within mountains, forests and valleys of several provinces (TUBİVES, 2020).

World annual cornelian cherry production is around 722.684 tons and the USA with an annual production of 404.880 tons is the leading producer of the world. The USA is, respectively, followed by Canada (195.196 tons), Chile (106.180 tons), Turkey (11.481 tons), Azerbaijan (2.874 tons) and Romania (581 tons) (FAOSTAT, 2018).

Horticulturally, cornelian cherry is classified under stone fruits group. It is a self-incompatible species, thus foreign-pollinated. With the aid of foreign-pollination, seed-propagated cornelian cherry genotypes with different genetic characteristics generated quite a rich population adapted to different conditions of different regions of Turkey. With such a rich population, cornelian cherry fruits exhibit great variations based on the regions as well as in shape, size, quality and colouration attributes. Shapes of cornelian cherry fruits vary from elliptical to cylindrical (Selçuk and Özrenk, 2011); fruit skin colours vary from yellow and cream to pink, red and dark red; fruit flesh colour is red, fruits are juicy with acid, sour-sweetish taste (Didin et al., 2000; Klimenko, 2004; Tural and Koca, 2008).

Phenolics give an acid taste to cornelian cherry fruits, thus they are not consumed much in fresh forms, unless its maturation is complete, but fresh forms are used in fruit juice, fruit-flavoured yoghurt, compote, marmalade, jam, jelly, tarhana, dried fruit roll-up and alcoholic and non-alcoholic beverages; dried forms are either consumed directly or used in local meals, salads and compote (Tural and Koca, 2008; Celep et al., 2013; Ozgen, 2015; Bozdogan, 2017). Cornelian cherry plants are not only used for fruits but also for landscape arrangements as an ornamental plant because of long flowering durations and yellow colour tone of the flowers (Da Ronch et al., 2016). Woods of cornelian cherry trees are also used in the furniture industry and especially in the manufacture of walking sticks (Mohsenin, 1986).

With the knowledge and consciousness about the health effects of fruit substances, fruits are either consumed directly or processed into different forms by the food industry. Besides direct consumptions, cornelian cherry fruits are also used as preservative or colourant in foodstuffs (Akpunar, 2015; Coksoyler, 2018; Ergezer et al., 2018; Elgin, 2019). While cornelian cherry fruits are used in the food industry, the other parts of the plants are used in the health sector against various diseases (Mikaili et al., 2013). With the specific aroma and colour substances, fruits are also used in cosmetics and dye industry (Akpunar, 2015; Coksoyler, 2018).

Previous researches revealed that cornelian cherry fruits were rich in vitamin C, organic acids, phenolics,

antioxidants, minerals and the other bioactive compounds (Kucharska, 2012; West et al., 2012; Deng et al., 2013; Akpunar, 2015). Thanks to its rich and diverse bioactive compounds, cornelian cherry fruit and its products have various health benefits, especially in obesity, cardiovascular disorders, diarrhoea and diabetes (West et al., 2012; Deng et al., 2013; Mikaili et al., 2013; Kucharska et al., 2015).

Several types of research pointed out the prominence of cornelian cherry fruits in terms of fruit composition. The nutritional values reported by the USDA clearly indicate such a prominence of cornelian cherry fruits. 100 g cornelian cherry fruits contain abundant quantities, especially, of vitamin C (14 mg), other vitamins, carbohydrate (11.97 g), sugar (4.27 g) and total dietary fibre (3.6 g). Cornelian cherry fruits also contain remarkable potassium (80 mg), phosphorus (11 mg), magnesium (6 mg) and other element contents (FoodData Central, 2019).

The objectives of the present study for 18 cornelian cherry genotypes exhibiting quite different phenotypic characteristics within narrow geography such as Mesudiye town of Ordu province were set as to:

- assess variations with some biochemical characteristics,
- identify superior genotypes with high antioxidant activity and phenolic compounds, thus, providing material for further breeding studies,
- determine physical attributes (size, surface area, elongation, sphericity) of cornelian cherry genotypes for design and development of postharvest processing systems,
- put forth and compare shape attributes with the aid of elliptic Fourier analysis.

MATERIALS AND METHODS

Cornelian cherry genotypes

Seed-propagated cornelian cherry genotypes in Mesudiye town of Ordu province constituted the material of the present study. A total of 100 fruits were taken from each genotype. Collected fruits were placed into plastic boxes and transported to the laboratory in cooling thermos bottles.

Nutritional attributes

Experiments were conducted in 5 replicates with 20 fruits in each replicate. Stones of fruits were taken out with a stainless-steel knife and resultant flesh was homogenized in a blender. Homogenized fruit samples were placed into falcon tubes (about 50 g) and preserved at -20°C until bioactive compound analyses.

DPPH antioxidant activity (free radical scavenging activity)

Fruit 1.1-diphenyl-2-picryl-hydrazyl (DPPH) antioxidant activity was determined with the aid of modified method of Brand-Williams et al., (1995). For analysis,

0.26 mM DPPH solution was prepared. Then, 100 μ L fruit extract was supplemented with 2,900 μ L ethyl alcohol and 1 mL DPPH solution. The resultant mixture was vortexed for 30 min and kept at dark. Sample absorbance readings were performed in a spectrophotometer at 517 nm wavelength. Results were expressed in μ mol Trolox equivalent (TE) $\cdot$ kg⁻¹ mmol of fresh weight.

Total flavonoid content

Sample total flavonoid content was determined with the aid of the method recommended in Chang et al., (2002). Fruit extracts (1,000 μ L) were supplemented with 3.3 mL methanol, then with 0.1 mL 10% AlCl₃·6H₂O and 0.1 mL of 1 M potassium acetate (CH₃COOK). Spectrophotometer readings were performed at 415 nm wavelength and total flavonoid contents were expressed in quercetin equivalent (mg QE $\cdot$ kg⁻¹) of fresh weight.

Total phenolics

Folin-Ciocalteu's method was used to determine total phenolics of the samples. Initially, 500 μ L fresh fruit extract was supplemented with 4.2 mL distilled water, then with 100 μ L Folin-Ciocalteu reagent and 2% sodium carbonate (Na₂CO₃). The resultant solution was incubated for 2 h. Following the incubation, spectrophotometer readings were performed at 760 nm wavelength and the results were expressed in gallic acid equivalent (mg GAE $\cdot$ kg⁻¹) of fresh weight (Beyhan et al., 2010).

Imaging methodology

Samples were named between G1 and G18 for 18 genotypes (Figure 1). To determine the size and the shape attributes of each genotype, 75 cornelian cherry samples were placed over a lightbox in 5 $\times$ 15 matrix arrangement. Nikon D90 model camera was used to take the images of fruits at horizontal and vertical

Figure 1. Images of cornelian cherry genotypes at horizontal and vertical orientations.

orientations. Imaging was performed from standard height of 50 cm.

Physical characteristics

Physical characteristics of cornelian cherry fruits were determined with the aid of the image processing method. SigmaScan Pro v.5.0 software was used to determine the size and shape parameters. Length (L), width (W), thickness (T), projection area (PA), equivalent diameter (ED) and perimeter (P) measurements of cornelian cherry samples imaged at horizontal and vertical orientations were directly made with the aid of the software (Figure 2). The other size and shape parameters of cornelian cherry fruits and equations used to determine these parameters are provided in Table 1.

Elliptic Fourier analysis

Elliptic Fourier analysis (EFA) includes the stages of (i) formation of the points defining the closed contour of two-dimensional geometry, (ii) determination of x and y coordinates of each point over the contour and

(iii) transformation of coordinates into a mathematical function and obtaining function coefficients defining the shape (Sayıncı, 2016). Function coefficients are generated based on the number of harmonics and each harmonic generates four Fourier coefficients (a_n , b_n , c_n and d_n). The a_n and b_n coefficients correspond to x coordinates and c_n and d_n coefficients correspond to y coordinates of the contour (Neto et al., 2006; Özkan-Koca, 2012).

SHAPE (version 1.03) software was used to compare the geometry of cornelian cherry genotypes identified through the EF method (Iwata and Ukai, 2002). For analysis in software, fruit images were converted into 24-bit *bmp files. EFA and statistical assessments were performed with the use of four sub-modules; (i) 'ChainCoder' module was used for image processing and shape contour generation, (ii) 'Chc2Nef' module was used to normalize contour codes and to get elliptic Fourier descriptors, (iii) 'PrinComp' module was used for principal component analysis (PCA) of descriptors and to generate component scores and (iv) 'PrinPrint'

Figure 2. Basic sizes and notations for any cornelian cherry genotypes.

Table 1. Some size and shape parameters of cornelian cherry fruits

Physical features	Equation	Reference
Geom. mean diameter (mm)	$D_g = \sqrt[3]{L \cdot W \cdot T}$	Kara (2017)
Surface area (cm ²)	$SA = \pi \cdot D_g^2$	Olajide and Ade-Omowaye (1999)
Sphericity (%)	$\phi = (D_g^2 / L) \cdot 100$	Mohsenin (1986)
Shape index	$SI = 2 \cdot L / (W + T)$	Ercisli et al. (2012)
Shape factor	$SF = 4 \cdot \pi \cdot PA / P^2$	Sayıncı et al. (2015a)
Elongation at horizontal	$E_h = L / W$	Fıratlıgil-Durmuş et al. (2010)
Elongation at vertical	$E_v = W / T$	—
Coating rate (%) at horizontal	$CR_h = (4 \cdot PA / \pi \cdot L^2) \cdot 100$	—
Coating rate (%) at vertical	$CR_v = (4 \cdot PA / \pi \cdot W^2) \cdot 100$	—

module was used to visualise shape variations of fruit image contours. Analyses were conducted over 20 harmonics.

Statistical analysis

Nutritional attributes of cornelian genotypes were subjected to analysis of variance at 95% significance level by using one-way ANOVA procedure and statistically significant differences among the genotypes were revealed with the aid of Duncan's multiple comparison test. Statistical analyses were performed with the use of SPSS v.23.0 software.

One-way ANOVA was used to test the differences in size and shape parameters of cornelian cherry genotypes. Significant means were compared with the use of Tukey's multiple comparison test at 95% significance level. PCA was performed to elucidate the relationships between size and shape parameters of the cornelian cherry genotypes. Eigen statistics were provided for principle components presenting the relationships between the genotypes. Factor loads were used to present the differences between the genotypes over a scatter chart.

Shape contours of cornelian cherry images were normalised to get elliptic Fourier scores presenting common variance. The components explaining the variance between these scores were visualised and differences between the genotypes were determined with the aid of multivariate analysis of variance (MANOVA). In the significance test of variance,

'Wilks's Lambda' and 'Pillai Trace' statistics were used. Pair-wise comparisons were made with the aid of Bonferroni-correction test (Bonferroni corrected *P* values). Statistical analyses were conducted with the use of PAST v.3.25 software (Hammer et al., 2001).

For a visual comparison of differences between the genotypes, PC scores obtained from elliptic Fourier descriptors were used and these scores were subjected to discriminant analysis. At the end of this analysis, centroid coordinates of each genotype were determined, and visual similarities of the genotypes were presented over a scatter chart.

RESULTS AND DISCUSSION

Biochemical characteristics of cornelian cherry genotypes

There were significant differences in antioxidant activity, total flavonoids and total phenolics of the seed-propagated cornelian cherry genotypes ($p < 0.05$) (Table 2).

The greatest antioxidant activity was obtained from G13 (152.420 mmol TE · kg⁻¹), G14 (152.180 mmol TE · kg⁻¹) and G11 (151.943 mmol TE · kg⁻¹), which were all placed into the same statistical group. The lowest antioxidant activity was obtained from G10 (55.062 mmol TE · kg⁻¹) and G18 (59.670 mmol TE · kg⁻¹) genotypes that have yellow fruits.

Table 2. Biochemical characteristics of cornelian cherry genotypes

Genotypes	Antioxidant activity (DPPH) (mmol TE · kg ⁻¹)	Total flavonoids (mg QE · kg ⁻¹)	Total phenolics (mg GAE · kg ⁻¹)
G1	94.786 ± 0.681 g*	391.80 ± 11.77 m*	3,603.20 ± 13.78 m*
G2	77.316 ± 0.931 j	484.60 ± 21.05 kl	2,644.80 ± 26.99 p
G3	96.669 ± 0.475 g	819.20 ± 17.38 i	6,124.40 ± 17.80 h
G4	88.026 ± 0.731 h	537.00 ± 11.73 jk	4,167.00 ± 41.35 j
G5	89.938 ± 1.196 h	497.80 ± 9.98 jkl	4,159.20 ± 24.58 j
G6	70.661 ± 0.333 k	451.20 ± 11.42 lm	3,865.00 ± 16.63 l
G7	144.861 ± 0.546 c	2,882.80 ± 27.38 a	10,609.40 ± 84.28 c
G8	138.114 ± 0.592 e	1,263.60 ± 19.88 f	5,248.40 ± 24.19 i
G9	96.310 ± 1.009 g	503.40 ± 33.37 jkl	3,987.00 ± 13.74 k
G10	55.062 ± 0.505 m	286.40 ± 12.35 n	3,463.60 ± 25.68 n
G11	151.943 ± 0.429 a	1,571.80 ± 21.46 e	9,374.20 ± 42.80 d
G12	147.095 ± 0.244 b	1,889.80 ± 16.56 c	8,719.40 ± 61.75 e
G13	152.420 ± 0.423 a	1,818.20 ± 28.98 d	11,355.00 ± 48.58 b
G14	152.180 ± 0.289 a	2,070.40 ± 47.00 b	12,959.00 ± 33.09 a
G15	140.656 ± 0.566 d	1,083.40 ± 23.64 h	8,513.80 ± 31.80 f
G16	120.470 ± 0.969 f	1,160.60 ± 25.62 g	7,498.60 ± 40.08 g
G17	82.401 ± 0.751 i	459.00 ± 12.42 l	4,216.60 ± 50.07 j
G18	59.670 ± 0.718 l	556.80 ± 20.12 j	3,233.60 ± 30.07 o

*Means followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level.

Present findings on antioxidant capacity of seed-propagated cornelian cherry genotypes were found higher than the values reported in previous studies. Dragovic-Uzelac et al. (2007) conducted a study in Croatia and reported DPPH-free radical scavenging activity of fruit extracts of two cornelian cherry genotypes as between 33.41 and 39.89 mmol Trolox $\cdot$ kg⁻¹; Cosmulescu et al. (2019) conducted a study in Romania and reported the antioxidant activity of 6 genotypes as between 1.24 and 2.71 μ mol Trolox 100 g⁻¹; Klymenko et al. (2019) in Ukraine, reported antioxidant activity of 20 genotypes as between 5.94 and 16.56 μ mol Trolox $\cdot$ g⁻¹. On the other hand, Kucharska et al. (2011) conducted a study in Poland on cornelian cherry gene sources and reported the greatest antioxidant activity for Dublany cultivar (20.72 μ mol Trolox $\cdot$ g⁻¹) and the lowest value for Juliusz cultivar (10.85 μ mol Trolox $\cdot$ g⁻¹).

Total flavonoids of the present genotypes varied between 286.40 mg QE $\cdot$ kg⁻¹ (G10) and 2,882.80 mg QE $\cdot$ kg⁻¹ (G7) and a large variation was observed in total flavonoid contents of the genotypes.

Hassanpour et al. (2011) reported total flavonoids of cornelian cherry fruits in Iran as between 321.27 and 669.00 mg QE $\cdot$ 100 g⁻¹; Cosmulescu et al. (2019) reported total flavonoids of 6 cornelian cherry genotypes collected from different regions of Romania in the range of 12.14–64.48 mg QE $\cdot$ 100 g⁻¹. Present findings on total flavonoids were lower than the values of Hassanpour et al. (2011) and greater than the values of Cosmulescu et al. (2019).

Total phenolics of the present genotypes varied between 2,644.80 mg GAE $\cdot$ kg⁻¹ (G2) and 12,959.00 mg GAE $\cdot$ kg⁻¹ (G14).

In previous studies conducted with cornelian cherry fruits, Tural and Koca (2008) reported total phenolics of 24 genotypes selected from Black Sea region of Turkey as between 2.81 and 5.79 mg GAE $\cdot$ g⁻¹; Yilmaz et al. (2009) reported total phenolics of 16 genotypes collected from Western Black Sea and Inner Anatolia of Turkey range from 26.59 to 74.83 mg GAE $\cdot$ g⁻¹; Hassanpour et al. (2011) reported total phenolics of cornelian cherry genotypes grown in Iran varied between 1,097.19 and 2,695.75 mg GAE $\cdot$ 100 g⁻¹; Dragovic-Uzelac et al. (2007) reported total phenolics in Croatia as between 2,095 and 3,055 mg GAE $\cdot$ kg⁻¹. Present findings on total phenolics were greater than the values of Tural and Koca (2008), Yilmaz et al. (2009) and Dragovic-Uzelac et al. (2007) and lower than the values of Hassanpour et al. (2011).

Considering the bioactive components of the genotypes, it was observed that yellow fruits generally had lower antioxidant activity and total phenolics; there were significant variations among the genotypes and present values were mostly greater than earlier reports. Although the differences are thought to be mainly caused by the variation of the examined varieties, differences in climate and soil

characteristics, the geographical situation of the area where the cultivation is made, the type and time of harvest, the storage or processing of the crop, the method or periodic differences of the applied cultural processes, crop load, tree ages and fruit ripening levels cause significant differences on the final form and the amount of the phytochemical composition (Benvenuti et al., 2004; Yilmaz et al., 2009; Ercisli et al., 2011; Gündüz et al., 2013; Ersoy et al., 2018b; Sochorova et al., 2019; Szot et al., 2019b; Bolat and İkinci, 2020; Mertoglu et al., 2020).

Physical characteristics of cornelian cherry genotypes

The greatest fruit lengths were obtained from G9 and G14 genotypes whereas the greatest geometric mean diameters and surface areas were observed in G3, G4, G9 and G18 genotypes (Table 3). The lowest surface areas were observed in G2, G5 and G8 genotypes. On the other hand, G12 and G18 genotypes had the closest geometry to sphere, thus had the lowest shape index values.

The greatest projected area, equivalent diameter and perimeter values at horizontal orientation were observed in G9 and G14 genotypes, whereas the lowest values were observed in G2 and G8 genotypes (Table 4). The greatest values at vertical orientation were observed in G18 genotype and the lowest values were observed in G14 genotype.

Some shape parameters were calculated with the use of dimensional attributes of cornelian cherry fruit and the results are given in Table 5. According to elongation averages at horizontal orientation, the difference between fruit length and widths were greater in G5, G9, G14 and G17 genotypes than the others. Therefore, relevant genotypes had more ellipsoidal form than the other genotypes. Coating ratio of these genotypes to a circular sieve opening was also lower in these genotypes than the others. The fruits with a full circle geometry had a shape factor of 1. At horizontal orientation, genotypes G1, G3 and G15 had the closest geometry to a circle. According to the elongation values at vertical orientation, all genotypes, except for G18, had close geometry to a circle and were able to largely cover a circular opening. The greatest shape factors at vertical orientation were observed in G2, G3, G8 and G14 genotypes.

PCA results are provided in Table 6. Two principle components (PC1 and PC2) were able to explain 92.56% of total variation in size and shape parameters of cornelian cherry genotypes. The variance elements explained by PC1 included size and shape parameters of cornelian cherry fruits. PC2 directly explained the variance in size parameters.

Based on the size and the shape parameters, factor scores identified for each genotype were presented in a scatter plot (Figure 3). Based on variance elements, the genotypes different in terms of size and shape

Table 3. Size and shape parameters of cornelian cherry genotypes

Types	Length (L, mm)	Width (W, mm)	Thickness (T, mm)	Geo. mean diam. (D _g , mm)	Surface area (SA, cm ²)	Sphericity (φ, %)	Shape index (SI)
G1	17.94 ± 0.97 efgh	14.02 ± 0.91 ab	14.06 ± 0.86 bcd	15.23 ± 0.76 bcd	7.30 ± 0.74 bcd	84.9 ± 3.2 abc	1.28 ± 0.07 hij
G2	15.63 ± 0.89 j	10.93 ± 0.71 h	11.08 ± 0.97 h	12.36 ± 0.76 h	4.82 ± 0.59 h	79.1 ± 3.2 fg	1.42 ± 0.09 de
G3	18.93 ± 1.18 cdef	14.12 ± 0.92 a	14.95 ± 1.15 b	15.86 ± 0.95 ab	7.93 ± 0.96 ab	83.8 ± 2.7 bc	1.30 ± 0.06 hi
G4	20.73 ± 0.98 b	14.03 ± 1.02 ab	14.21 ± 1.31 bc	16.04 ± 0.98 a	8.10 ± 0.99 a	77.3 ± 2.8 gh	1.47 ± 0.08 cd
G5	18.48 ± 1.12 defg	10.99 ± 0.75 h	10.85 ± 1.18 h	13.00 ± 0.89 gh	5.33 ± 0.73 fgh	70.4 ± 2.9 i	1.70 ± 0.10 b
G6	17.93 ± 1.23 fgh	13.55 ± 0.95 abcd	13.65 ± 1.19 cde	14.90 ± 1.00 cd	7.00 ± 0.93 cd	83.2 ± 2.8 cd	1.32 ± 0.07 ghi
G7	18.77 ± 0.92 defg	13.00 ± 0.69 de	13.01 ± 0.73 efg	14.69 ± 0.56 d	6.78 ± 0.53 d	78.3 ± 3.1 fg	1.45 ± 0.09 de
G8	16.20 ± 0.74 ij	11.22 ± 0.68 gh	11.32 ± 0.78 h	12.71 ± 0.63 h	5.09 ± 0.50 gh	78.5 ± 2.4 fg	1.44 ± 0.07 de
G9	22.23 ± 1.25 a	13.81 ± 0.88 abc	13.30 ± 1.05 def	15.97 ± 0.89 ab	8.04 ± 0.90 a	71.9 ± 2.0 i	1.64 ± 0.07 b
G10	17.76 ± 1.15 gh	12.74 ± 0.83 e	14.04 ± 1.03 cd	14.70 ± 0.93 d	6.81 ± 0.86 d	82.8 ± 2.0 cde	1.33 ± 0.05 fgh
G11	17.84 ± 1.24 gh	11.92 ± 0.82 fg	12.35 ± 0.99 g	13.79 ± 0.88 ef	6.00 ± 0.80 ef	77.4 ± 2.7 gh	1.47 ± 0.08 cd
G12	16.90 ± 1.09 hi	13.09 ± 1.01 cde	13.97 ± 1.04 cd	14.56 ± 0.96 de	6.69 ± 0.88 de	86.2 ± 3.1 ab	1.25 ± 0.07 ij
G13	19.01 ± 1.09 cde	13.18 ± 0.76 cde	12.44 ± 0.85 fg	14.60 ± 0.67 d	6.70 ± 0.62 de	76.9 ± 3.0 gh	1.49 ± 0.09 cd
G14	22.10 ± 1.18 a	13.77 ± 0.84 abcd	8.23 ± 0.58 i	13.57 ± 0.77 fg	5.80 ± 0.66 fg	61.4 ± 1.8 j	2.01 ± 0.09 a
G15	18.68 ± 1.49 defg	14.15 ± 0.82 a	12.94 ± 0.72 efg	15.06 ± 0.84 cd	7.14 ± 0.79 cd	80.8 ± 3.8 def	1.38 ± 0.10 efg
G16	19.51 ± 1.73 cd	14.18 ± 0.88 a	13.83 ± 0.89 cde	15.63 ± 0.95 abc	7.69 ± 0.92 abc	80.4 ± 4.2 ef	1.39 ± 0.11 ef
G17	19.98 ± 1.38 bc	12.63 ± 0.92 ef	13.53 ± 1.24 cde	15.05 ± 1.11 cd	7.15 ± 1.05 cd	75.3 ± 1.6 h	1.53 ± 0.05 c
G18	18.70 ± 1.17 defg	13.30 ± 0.56 bcde	17.22 ± 0.84 a	16.23 ± 0.65 a	8.29 ± 0.67 a	87.0 ± 3.7 a	1.23 ± 0.08 j
Mean ± SD	18.68 ± 2.05	12.99 ± 1.35	13.07 ± 2.09	14.64 ± 1.41	6.79 ± 1.29	78.8 ± 6.7	1.45 ± 0.20
Min–max	13.50–25.76	9.44–16.22	7.04–18.82	10.66–18.17	3.57–10.37	57.3–97.2	1.03–2.23
Sigma (<i>p</i>)	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
<i>F</i> value	67.228	51.509	110.223	55.281	51.716	137.417	166.002

**Means followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level.

Table 4. Size and area parameters of cornelian cherry genotypes at horizontal and vertical orientations

Types	Projected area (mm ²)		Equivalent diameter (mm)		Perimeter (mm)	
	Horizontal (PA _h)	Vertical (PA _v)	Horizontal (ED _h)	Vertical (ED _v)	Horizontal (P _h)	Vertical (P _v)
G1	198.7 ± 19.3 def	153.3 ± 17.5 bc	15.9 ± 0.8 cde	13.9 ± 0.8 bc	54.1 ± 2.6 de	47.2 ± 3.1 cdef
G2	135.8 ± 15.0 j	94.1 ± 13.2 h	13.1 ± 0.7 h	10.9 ± 0.8 g	45.2 ± 2.7 g	36.5 ± 2.6 i
G3	213.5 ± 24.6 cd	166.0 ± 20.4 ab	16.5 ± 0.9 bcd	14.5 ± 0.9 ab	56.0 ± 3.2 cd	48.6 ± 2.9 bcd
G4	234.4 ± 26.0 ab	150.9 ± 20.5 bc	17.3 ± 1.0 ab	13.8 ± 0.9 bc	61.1 ± 4.0 ab	48.6 ± 3.6 bcd
G5	163.5 ± 19.0 hi	90.9 ± 14.1 h	14.4 ± 0.8 g	10.7 ± 0.8 g	50.7 ± 3.2 f	38.7 ± 3.6 hi
G6	193.1 ± 24.0 efg	142.7 ± 21.0 cd	15.7 ± 1.0 def	13.4 ± 1.0 cd	53.4 ± 3.4 def	47.8 ± 6.0 cde
G7	193.1 ± 17.4 efg	130.2 ± 12.1 de	15.7 ± 0.7 def	12.9 ± 0.6 de	54.0 ± 2.5 de	43.8 ± 2.3 fg
G8	144.9 ± 13.6 ij	98.7 ± 11.3 gh	13.6 ± 0.6 h	11.2 ± 0.6 g	47.3 ± 2.5 g	37.4 ± 2.2 i
G9	245.6 ± 27.7 a	140.8 ± 17.1 cd	17.7 ± 1.0 a	13.4 ± 0.8 cd	61.9 ± 3.6 a	47.4 ± 3.3 cde
G10	182.0 ± 22.4 fgh	143.9 ± 19.9 cd	15.2 ± 0.9 efg	13.5 ± 0.9 cd	52.0 ± 3.2 ef	51.8 ± 6.4 ab
G11	170.6 ± 21.7 h	113.8 ± 16.5 fg	14.7 ± 0.9 g	12.0 ± 0.8 f	52.3 ± 4.5 ef	41.9 ± 3.4 gh
G12	175.1 ± 23.3 gh	145.2 ± 20.6 cd	14.9 ± 1.0 fg	13.6 ± 1.0 cd	52.0 ± 3.2 ef	46.4 ± 3.3 cdef
G13	199.7 ± 19.8 cdef	123.9 ± 13.4 ef	15.9 ± 0.8 cde	12.5 ± 0.7 ef	54.6 ± 2.7 de	45.4 ± 4.5 defg
G14	245.2 ± 25.4 a	57.6 ± 8.1 i	17.6 ± 0.9 a	8.5 ± 0.6 h	61.4 ± 3.1 ab	28.5 ± 2.0 k
G15	209.1 ± 24.6 cde	140.2 ± 17.3 cd	16.3 ± 1.0 cd	13.3 ± 0.8 cd	55.4 ± 3.6 d	49.5 ± 4.0 bc
G16	219.5 ± 26.5 bc	151.7 ± 18.2 bc	16.7 ± 1.0 bc	13.9 ± 0.8 bc	58.7 ± 4.1 bc	49.7 ± 5.2 bc
G17	203.0 ± 26.2 cde	133.0 ± 21.6 de	16.0 ± 1.0 cd	13.0 ± 1.1 de	55.8 ± 3.7 cd	44.4 ± 4.8 efg
G18	198.0 ± 17.2 def	174.0 ± 14.7 a	15.9 ± 0.7 de	14.9 ± 0.6 a	54.4 ± 2.8 de	53.5 ± 3.5 a
Mean ± SD	194.5 ± 36.9	130.5 ± 33.0	15.7 ± 1.5	12.8 ± 1.7	54.3 ± 5.4	44.8 ± 7.1
Min–max	106.5–318.9	42.1–212.7	11.6–20.1	7.3–16.5	39.7–71.3	24.3–72.5
Sigma (<i>p</i>)	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
<i>F</i> value	56.941	88.199	59.775	105.217	53.947	74.787

**Significant at *p* < 0.01.

Means followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level.

Table 5. Shape parameters of cornelian cherry fruits at horizontal and vertical orientations

Types	Shape factor		Elongation		Coating ratio (%)	
	Horizontal (SF _h)	Vertical (SF _v)	Horizontal (E _h)	Vertical (E _v)	Horizontal (CR _h)	Vertical (CR _v)
G1	0.850 ± 0.013 ab	0.865 ± 0.041 abc	1.28 ± 0.09 h	1.05 ± 0.03 b	78.63 ± 5.01 a	94.6 ± 2.4 a
G2	0.832 ± 0.024 abcd	0.882 ± 0.019 ab	1.43 ± 0.07 cd	1.06 ± 0.03 b	70.65 ± 3.57 defg	93.6 ± 2.7 ab
G3	0.851 ± 0.014 a	0.881 ± 0.010 ab	1.34 ± 0.08 efg	1.07 ± 0.05 b	75.79 ± 3.92 abc	93.1 ± 3.6 ab
G4	0.791 ± 0.069 e	0.808 ± 0.106 cdef	1.48 ± 0.08 c	1.08 ± 0.08 b	69.31 ± 3.78 fg	90.9 ± 5.3 b
G5	0.798 ± 0.028 de	0.768 ± 0.097 fg	1.68 ± 0.07 a	1.09 ± 0.05 b	60.89 ± 2.84 j	90.9 ± 4.0 b
G6	0.847 ± 0.016 abc	0.794 ± 0.102 def	1.32 ± 0.07 fgh	1.06 ± 0.04 b	76.42 ± 3.91 ab	93.2 ± 3.6 ab
G7	0.830 ± 0.015 abcd	0.854 ± 0.048 abcd	1.45 ± 0.08 cd	1.06 ± 0.05 b	69.80 ± 4.02 efg	93.2 ± 3.8 ab
G8	0.813 ± 0.050 cde	0.886 ± 0.008 a	1.45 ± 0.07 cd	1.06 ± 0.04 b	70.26 ± 3.23 defg	93.4 ± 3.4 ab
G9	0.803 ± 0.015 de	0.787 ± 0.061 defg	1.61 ± 0.06 b	1.09 ± 0.05 b	63.17 ± 2.54 ij	91.2 ± 4.2 b
G10	0.842 ± 0.015 abc	0.693 ± 0.142 h	1.40 ± 0.05 def	1.06 ± 0.04 b	73.32 ± 2.55 bcde	92.7 ± 2.9 ab
G11	0.788 ± 0.082 e	0.815 ± 0.078 bcdef	1.50 ± 0.08 c	1.07 ± 0.04 b	68.18 ± 4.23 gh	92.3 ± 3.6 ab
G12	0.814 ± 0.076 bcde	0.845 ± 0.063 abcde	1.29 ± 0.07 h	1.05 ± 0.04 b	77.84 ± 4.23 a	94.1 ± 3.1 ab
G13	0.840 ± 0.013 abc	0.766 ± 0.108 fg	1.44 ± 0.07 cd	1.06 ± 0.04 b	70.40 ± 3.63 defg	93.4 ± 3.2 ab
G14	0.816 ± 0.014 bcde	0.884 ± 0.013 ab	1.61 ± 0.08 b	1.08 ± 0.05 b	63.89 ± 2.98 ij	91.9 ± 4.3 ab
G15	0.853 ± 0.018 a	0.722 ± 0.078 gh	1.32 ± 0.10 gh	1.08 ± 0.03 b	76.50 ± 5.56 ab	91.5 ± 2.8 ab
G16	0.799 ± 0.053 de	0.782 ± 0.101 efg	1.38 ± 0.12 defg	1.05 ± 0.03 b	73.80 ± 6.77 bcd	94.1 ± 2.4 ab
G17	0.815 ± 0.017 bcde	0.852 ± 0.076 abcde	1.58 ± 0.06 b	1.08 ± 0.05 b	64.58 ± 2.32 hi	91.6 ± 3.9 ab
G18	0.839 ± 0.020 abc	0.769 ± 0.076 fg	1.41 ± 0.09 de	1.32 ± 0.06 a	72.30 ± 4.47 cdef	74.7 ± 3.3 c
Mean ± SD	0.824 ± 0.043	0.815 ± 0.095	1.44 ± 0.14	1.08 ± 0.08	70.88 ± 6.47	91.62 ± 5.57
Min–max	0.443–0.890	0.338–0.907	1.15–1.85	1.00–1.51	55.14–87.61	66.49–99.13
Sigma (<i>p</i>)	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
<i>F</i> value	9.870	17.217	68.204	55.580	54.083	47.072

**Significant at *p* < 0.01.

Means followed by the same letter in the same column are not different as determined by the Tukey test at 5% significance level.

parameters were indicated within a coloured frame. While the genotypes G2 and G8 with a negative factor score on PC2 had the smallest size, the genotypes G4 and G9 had greater size data than the others. The genotype G14 with the lowest sphericity was placed on the left side of PC1 axis and apart from the

Table 6. Eigen statistics and vectors for two principle components

Size and shape features	PC1	PC2
Sphericity	0.956	
Shape index	-0.953	
Projected area at vertical	0.927	
Thickness	0.915	
Perimeter at vertical	0.891	
Elongation at horizontal	-0.805	
Projected area at horizontal		0.990
Perimeter at horizontal		0.988
Length		0.932
Width		0.826
Geometric mean diameter		0.767
Eigenvalue	5.788	4.395
Proportion (%)	52.614	39.950
Cumulative (%)	52.614	92.564

others. The genotype G5 exhibited a difference in elongation parameter.

When the physical attributes of 18 cornelian cherry genotypes were tested with PCA, it was observed that two principle components were able to explain a large portion of the variance in size and shape parameters. The physical characteristics of the genotypes G2, G4, G5, G8, G9 and G14, placed apart from the other genotypes on scatter plot, were remarkably different from the others.

Visual comparison of cornelian cherry genotypes with elliptic Fourier analysis

Two principle components identified based on shape descriptors explained 86.65% of total variance in cornelian cherry genotypes (Figure 4). According to PC1, the greatest shape difference (explained variance of 80.05%) was attributed to genotypes with oval and circular geometry. Based on average shape geometry, it can be stated that cornelian cherry genotypes had an oval geometry. However, based on ± 2 SD variations, it is possible to mention about pointed or spherical forms. According to PC2, shape differences were slightly (explained variance of 6.60%) attributed to the drop-like image of the fruits. According to elliptic Fourier analysis results, it can be stated that cornelian cherry genotypes had an oval appearance in shape geometry. However, there were some genotypes with a shape

Figure 3. PCA scatter plot for the first two PCs explaining variations in size and shape parameters of cornelian cherry genotypes.

Figure 4. Variations in shape geometry of cornelian cherry geometry based on principle component scores obtained from elliptic Fourier descriptors (orifice contours from left to right: mean–2 SS, mean, mean+2 SS).

geometry close to a spherical form. Such a finding is especially significant for the geometry of sieve openings in size-based separation.

Results of multivariate variance analysis conducted to put forth the shape differences between cornelian cherry genotypes with the aid of EF method are provided in Table 7. The first two functions obtained from the discriminant analysis clearly put forth the shape differences of cornelian cherry genotypes and the entire variance was explained by these discriminant functions. Accordingly, the first function explained 78.6% and the second function explained 21.4% of the variation. According to Wilks' Lambda and Pillai Trace statistics, there were significant shape differences between the genotypes. Pair-wise comparisons were made in the Hotelling test and the genotypes with insignificant differences between them were indicated in coloured format. In shape assessments based on fruit contours, there were not any genotypes similar to G12 genotype.

Among the cornelian cherry genotypes, the groups with similar shapes were presented in coloured fashion in the scatter plot (Figure 5). Accordingly, 18 cornelian cherry genotypes were divided into 5 main shape groups. The first group included the genotypes G5, G9, G14 and G17; the second group included genotypes G4, G7, G8, G11 and G18; the third group included genotypes G2 and G13; the fourth group included genotypes G1, G3, G6, G10, G15 and G16; the fifth group included genotype G12.

In the present study, differences in physical characteristics of cornelian cherry genotypes were determined with PCA. Physical characteristics included size parameters and some shape parameters calculated accordingly. Elliptic Fourier method allowed comparisons based only on the shape, without considering size parameters. When common assessments were made based on two methods, it was observed that the genotypes G5, G9 and G14 with different size parameters have a similar appearance in shape.

CONCLUSION

Present findings revealed that 18 cornelian cherry genotypes collected from natural flora were quite rich in bioactive compounds. Antioxidant activity ($55.062\text{--}152.420\text{ mmol TE} \cdot \text{kg}^{-1}$), total flavonoids (286.40--

$2,882.80\text{ mg QE} \cdot \text{kg}^{-1}$) and total phenolics ($2,644.80\text{--}1,2959.00\text{ mg GAE} \cdot \text{kg}^{-1}$) of the genotypes exhibited variations in a broad range. Such findings indicated that self-incompatible, foreign-pollinating (Akçay and Yalçinkaya, 2003) cornelian cherry genotypes exhibited quite a large phenotypic variation even in narrow geography. Therefore, in selection studies mostly applied in breeding programmes for superior genotypes, precise and deep assessments should be made to reach expedient individuals, thus point-selection method should be applied for this purpose.

Physical characteristics of 18 cornelian cherry genotypes constitute a significant source of data for the design of new processing systems. Shape differences in biological products require product-specific processing technologies. In terms of postharvest processing technologies, the genotypes with similar shape contours are processed in the same machine, but special systems should be designed for different genotypes. Classification, drying, transportation and packaging systems are generally designed based on physical characteristics of the fruits. As sieves are used in size classification systems, sieve opening geometry and size are arranged based on physical characteristics. While sieve opening geometry is oval in walnut classification systems (Ercisli et al., 2012; Demir et al., 2018), circular geometry is used hazelnut classification systems (Sayıncı et al., 2015b). In drying systems, the surface area of the product designates drying durations. For instance, average surface area of *Prunus laurocerasus* (cherry laurel) fruits (Sayıncı et al., 2015a) is about twice as much of *Cornus mas* (cornelian cherry) fruits, thus such greater surface areas prolong drying durations. Product physical characteristics also designate the design of conveyor and elevator systems used for product transportation. Product characteristics should also be well-known in the design of pneumatic and mechanical systems of packaging units or the manufacture of moulds for packages.

It was concluded based on the present findings that cornelian cherry gene sources were quite rich in bioactive compounds. Geometric shapes and size parameters of 18 cornelian cherry genotypes were precisely determined and shape differences were determined with elliptic Fourier analysis and physical parameters were successfully compared with the multivariate statistical approaches.

Table 7. Differences among the genotypes based on *Cornus mas* contours

A. Discriminant analysis results (computed in SPSS version 22.0)																		
Function	Eigenvalue	% of variance		Cumulative, %		Canonical correlation												
1	1.623	78.6		78.6		0.787												
2	0.443	21.4		100.00		0.554												
B. MANOVA results (computed in PAST version 3.25)																		
Effect	Statistics		Value	Hypothesis df		Error df		F										
Genotypes	Wilks' Lambda		0.2336	102		7,281		20.74		1.334E-322								
	Pillai Trace		1.04	102		7,686		15.80		1.248E-241								
C. The results of the Hotelling's pairwise comparisons. Bonferroni corrected <i>P</i> values (computed in PAST version 3.25) <<																		
Genotypes	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18
G1		1.55E-15	9.5926 ^{ns}	9.45E-20	2.92E-48	0.036667	2.58E-22	1.45E-19	3.11E-41	3.21E-09	5.22E-26	4.24E-07	1.95E-20	7.93E-42	2.39E-05	0.02048	6.08E-37	1.19E-19
G2	1.55E-15		4.72E-09	4.08E-05	1.79E-24	1.85E-06	5.51E-11	1.35E-08	2.03E-15	0.003698	2.26E-05	1.48E-22	0.4005 ^{ns}	1.39E-18	4.27E-13	0.000604	7.72E-14	2.72E-14
G3	9.5926 ^{ns}	4.72E-09		2.81E-12	1.15E-41	97.041 ^{ns}	6.80E-14	6.47E-11	1.98E-34	0.002757	1.84E-17	7.76E-06	1.75E-14	6.01E-35	1.99E-07	0.127 ^{ns}	4.02E-29	4.75E-12
G4	9.45E-20	4.08E-05	2.81E-12		9.01E-18	1.23E-08	0.3484 ^{ns}	1.7195 ^{ns}	1.01E-12	1.22E-06	4.0958 ^{ns}	1.09E-18	1.82E-07	2.64E-11	3.74E-23	7.59E-12	7.64E-06	0.001629
G5	2.92E-48	1.79E-24	1.15E-41	9.01E-18		1.55E-38	4.50E-27	2.16E-26	1.6665 ^{ns}	3.07E-31	2.47E-16	4.97E-50	1.27E-20	35.967 ^{ns}	1.14E-45	2.87E-31	0.000166	2.95E-33
G6	0.036667	1.85E-06	97.041 ^{ns}	1.23E-08	1.55E-38		5.65E-10	3.16E-07	3.55E-31	0.1924 ^{ns}	3.50E-13	1.70E-06	5.11E-13	1.46E-31	7.19E-10	0.010843	2.22E-25	7.75E-08
G7	2.58E-22	5.51E-11	6.80E-14	0.3484 ^{ns}	4.50E-27	5.65E-10		44.441 ^{ns}	7.19E-22	1.06E-10	0.0782 ^{ns}	7.20E-16	2.42E-15	1.56E-19	4.71E-30	5.66E-16	1.56E-13	0.24842 ^{ns}
G8	1.45E-19	1.35E-08	6.47E-11	1.7195 ^{ns}	2.16E-26	3.16E-07	44.441 ^{ns}		4.56E-21	1.27E-06	0.2898 ^{ns}	1.34E-15	3.81E-13	6.59E-19	2.79E-26	1.32E-13	2.07E-11	0.9258 ^{ns}
G9	3.11E-41	2.03E-15	1.98E-34	1.01E-12	1.6665 ^{ns}	3.55E-31	7.19E-22	4.56E-21		2.97E-23	1.51E-10	2.02E-44	1.57E-12	13.625 ^{ns}	4.88E-38	9.10E-25	0.004326	2.51E-28
G10	3.21E-09	0.003698	0.002757	1.22E-06	3.07E-31	0.1924 ^{ns}	1.06E-10	1.27E-06	2.97E-23		3.10E-09	2.34E-17	2.87E-09	2.24E-24	4.59E-11	6.40E-05	7.03E-18	1.24E-09
G11	5.22E-26	2.26E-05	1.84E-17	4.0958 ^{ns}	2.47E-16	3.50E-13	0.07817 ^{ns}	0.2898 ^{ns}	1.51E-10	3.10E-09		4.97E-25	4.21E-09	1.73E-09	1.50E-28	2.46E-15	0.000546	6.40E-07
G12	4.24E-07	1.48E-22	7.76E-06	1.09E-18	4.97E-50	1.70E-06	7.20E-16	1.34E-15	2.02E-44	2.34E-17	4.97E-25		2.30E-27	3.93E-43	6.07E-23	2.12E-12	4.14E-38	5.90E-13
G13	1.95E-20	0.4005 ^{ns}	1.75E-14	1.82E-07	1.27E-20	5.11E-13	2.42E-15	3.81E-13	1.57E-12	2.87E-09	4.21E-09	2.30E-27		2.54E-16	6.88E-16	6.58E-06	3.19E-13	7.43E-21
G14	7.93E-42	1.39E-18	6.01E-35	2.64E-11	35.967 ^{ns}	1.46E-31	1.56E-19	6.59E-19	13.625 ^{ns}	2.24E-24	1.73E-09	3.93E-43	2.54E-16		2.83E-40	1.03E-26	2.1106 ^{ns}	2.02E-25
G15	2.39E-05	4.27E-13	1.99E-07	3.74E-23	1.14E-45	7.19E-10	4.71E-30	2.79E-26	4.88E-38	4.59E-11	1.50E-28	6.07E-23	6.88E-16	2.83E-40		2.217 ^{ns}	4.21E-36	6.95E-29
G16	0.02048	0.000604	0.127 ^{ns}	7.59E-12	2.87E-31	0.010843	5.66E-16	1.32E-13	9.10E-25	6.40E-05	2.46E-15	2.12E-12	6.58E-06	1.03E-26	2.217 ^{ns}		4.85E-23	1.17E-16
G17	6.08E-37	7.72E-14	4.02E-29	7.64E-06	0.000166	2.22E-25	1.56E-13	2.07E-11	0.004326	7.03E-18	0.000546	4.14E-38	3.19E-13	2.1106 ^{ns}	4.21E-36	4.85E-23		2.49E-18
G18	1.19E-19	2.72E-14	4.75E-12	0.001629	2.95E-33	7.75E-08	0.2484 ^{ns}	0.9258 ^{ns}	2.51E-28	1.24E-09	6.40E-07	5.90E-13	7.43E-21	2.02E-25	6.95E-29	1.17E-16	2.49E-18	

ns, insignificant.

p < 0.01 highly significant and p < 0.05 significant.

Figure 5. Group centroids of *Cornus mas* genotypes at canonical discriminant functions.

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All the authors contributed equally to all aspects of this manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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