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RESEARCH ARTICLE

Pomological, bioactive compounds, and antioxidant activity of selected superior genotypes from a highly diversified loquat population

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Abstract The study's main objective was to assess the fruit characteristics, total phenolics, total flavonoids, individual phenolic compounds, and antioxidant activity of superior loquat genotypes, which were selected from the coastal area of the Black Sea in 2020 and 2021. The highest seed weight, seed volume, and fruit skin color were obtained in GN 10; fruit weight, shape index, fruit volume, fruit pulp/seed ratio, and flesh weight observed in GN 14; fruit stalk length, calyx core diameter, taste, and juiciness were found in the GN 50; fruit width, fruit length, fruit stalk thickness, seed number, fruit number in cluster, and fruit cluster weight were determined in GN 69. Leaf area varied from 147.59 to 312.92 cm^2 the highest in GN 50 and lowest in GN 10. Total phenolics, total flavonoids, antioxidant activities, and all individual phenolic compounds were observed to have a statistically significant effect among superior genotypes. Total phenolics ranged between 137.69 and 297.83 mg GAE kg^{-1}, total flavonoids recorded 109.00–232.15 mg QE kg^{-1}, and antioxidant activities ranged between 1.52 and 2.73 mmol TE kg^{-1} in the case of DPPH and 4.39–10.28 mmol TE kg^{-1} in case of FRAP. Chlorogenic acid and aminobenzoic acid were the major phenolic compounds in the genotypes. In conclusion, the examined characteristics revealed that GN 69 and GN 14 are ideal in pomological characteristics, GN 10 in antioxidant activities, and GN 69 and GN 10 in the contents of individual phenolics. So, the superior genotypes based on their ideal performances could be used in future breeding.

Keywords Antioxidant · Chlorogenic acid · *Eriobotrya japonica* · Flavonoids · Fruit quality · Genetic resources

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Introduction

Loquat (*Eriobotrya japonica* Lindl.) is a pome fruit belonging to the Rosales order, Pomoideae subfamily, and Rosaceae family. About 30 species native to the eastern parts of Asia include the genus *Eriobotrya* (Hussain et al. 2011). Loquat is a common fruit in China, Pakistan, Korea, Japan, Philippines, Sri Lanka, Spain, Italy, and Türkiye (Ullah et al. 2018). Loquat is mainly a subtropical fruit that can be grown in warm, temperate climates. This fruit is a rich resource of carbohydrates, proteins, potassium, minerals, vitamins, phenolics, flavonoids, anthocyanins, antioxidants, ideal aroma and sweet agreeable taste (Ullah et al. 2018). Loquat can be characterized by its high amount of sugar, acid, and pectin content compared to the other pome fruits. It has over

10% of sugar content and is very rich in carotenoids, especially vitamin A, so it is preferred by consumers (Gupta et al. 2020).

Due to cross-pollination, each loquat plant obtained from seed and chance seedlings can be a genetic resource with many desirable features. Most of the loquat cultivars in the world have been revealed due to selective breeding, and research continues to acquire new cultivars (Badenes et al. 2013). In recent years, consumers have wanted to consume fruits with rich phenolic compounds. Breeders are intensifying their development of cultivars with high bioactive content. Thus, the selection and maintenance of superior genotypes have great importance in loquat fruit production. The loquat originates in China (Jing et al. 2023) and has about 30 species in the eastern regions of Asia (Özçağıran et al. 2005). It is stated that it was brought to Turkiye in the early 1900s (Badenes et al. 2013). Loquat fruit is grown in Turkiye, where the climatic conditions are suitable, in the coastal regions of the Mediterranean and Aegean Regions, and in the coastal areas of the Black Sea. Generally, it is grown naturally from seed in the coastal areas of the Black Sea and has valuable genetic resources in this region that adapt to marginal environments and has gain specific characteristics such as larger fruit size, larger fruit clusters and superior stress tolerance (Öztürk et al. 2023).

The study's main objective was to assess the fruit characteristics, total phenolics, total flavonoids, individual phenolic compounds and antioxidant activity of superior loquat genotypes selected from the coastal area of the Black Sea.

Material and methods

Plant materials

The research was carried out on superior loquat genotypes (Fig. 1), previously selected from a diversified population during 2020 and 2021. In the research population, nearly 1000 loquat genotypes were grown from seeds with different fruit sizes in the Atakum district, which spreads over an area of approximately 20 km long in the Black Sea coast of Samsun province of Türkiye. A selection was made from the genotypes having fruit weight over 20 g, taking into

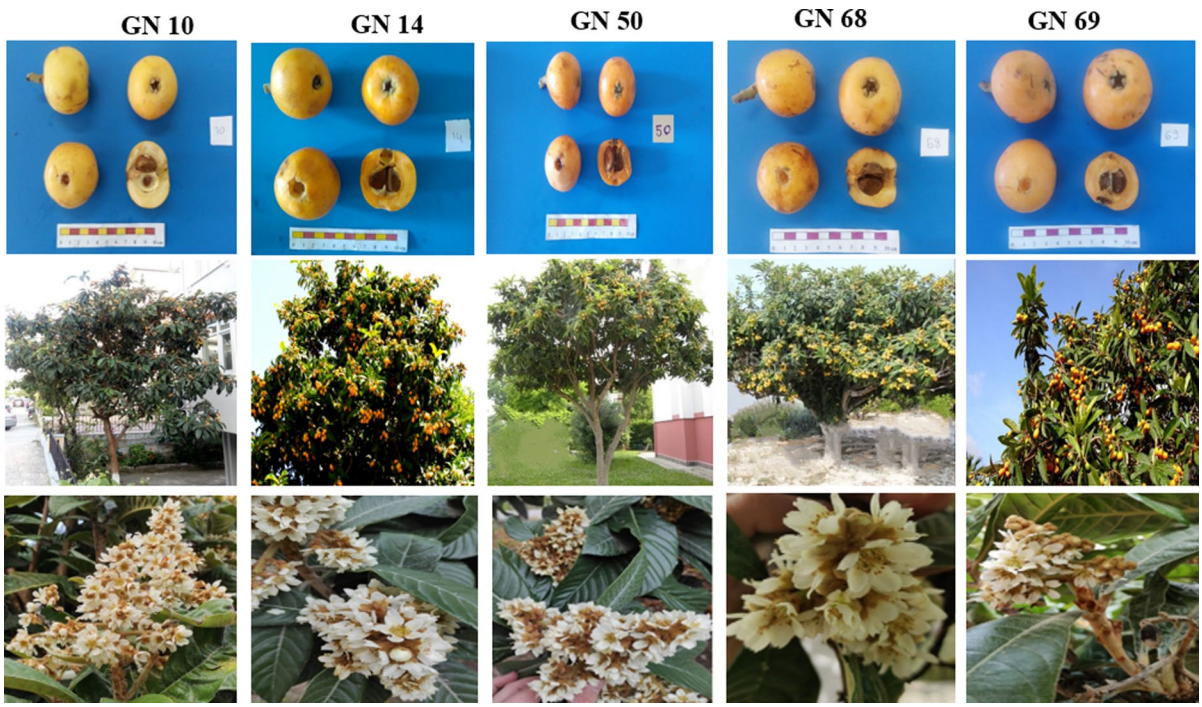

Fig. 1 Fruit, tree, and flower illustration of superior loquat genotypes

account the marketing quality. The superior genotypes were selected, considering characteristics such as fruit weight, soluble solids contents, soluble solids content/titratable acidity ratio, pulp/seed ratio, low seed number (seedless) and high external quality (Badenes et al. 2013). The research area is generally rainy-hot in the summer and rainy-cool in the winter. Precipitation between the area's driest and wettest months of the year was 55 mm, and the annual average precipitation was 936 mm. The annual average temperature was 18.1 °C, the average relative humidity was 76.3%, the highest temperature was 38.5 °C in July, and the lowest was − 5 °C in January (TSMS 2023).

Pomological evaluation

During the fruit ripening period, the fruit was harvested randomly together with their clusters as representing the tree from each of five superior genotypes; then, pomological research was conducted according to previous protocols (Karadeniz and Şenyurt 2007; Balcı, 2015; Yarılgaç et al. 2017; Öztürk and Öztürk, 2018). Ten fruit clusters from each genotype were use to determine cluster weight (g), and 30 fruit for fruit weight (g) from each genotype with the help of precision scales sensitive (Dikomsan KD-TBC) to 0.01 g were weighed. For fruit width (mm), length (mm), and flower pit width (mm), 30 fruit from each genotype were used for measuring them with the help of a digital caliper (Max-Ekstra) with a precision of 0.01 mm. The number of seeds (pieces/fruit) was determined by counting the seeds of 15 randomly selected fruit from each genotype. Seed weight (g) was determined with a precision balance sensitive to 0.01 g. The weight of seeds were obtained from 15 randomly selected fruit from each genotype. The number of fruit (pieces/cluster) was determined by counting the fruit in the 15 fruit clusters from each genotype during harvest. For fruit and seed volume (cm^3), 30 fruit were randomly taken from each genotype, and then, fruit and seeds were dipped separately in a measured cylindrical container containing a certain level of water, then the amount of overflow was counted as volume (Çakır and Öztürk 2019). The fruit pulp ratio (%) was determined by subtracting the seed weight from the fresh weight of each fruit and dividing it by the fresh weight of each fruit, then multiplying it by 100. In each genotype, 15 fruit samples were used. The seed ratio (%) was calculated by dividing the weight of the seeds extracted in 15 fruit samples of each genotype by the fruit weight and multiplying by 100. For pulp/seed ratio (%), flesh weight of 15 fruit belonging to each genotype was divided by seed weight and multiplied with 100. For taste, the fruit was grouped as very sweet, moderately sweet, and slightly sweet in the taste evaluation performed from each genotype by five different persons. The juiciness of genotypes was evaluated on the fruit taken from each genotype; then, the genotypes were grouped as very juicy, moderately juicy, and less juicy. External quality such as fruit skin color of the genotypes were visually scored from 1 to 5. The fresh weight of the fruit pulp (g) was determined by weighing 15 from each genotype on a 0.01 g sensitive balance after removing their seeds.

Color characteristics

Color of the fruit skin and flesh, L*, a*, b*, chroma, and hue angle were determined on both sides of the equatorial part of 10 fruit randomly from each genotype with a colorimeter (Minolta CR-300, Japan). The fruit was longitudinally cut into two parts for fruit flesh color and immediately measured before the color changed.

TSS, titratable acidity, and pH

For total soluble solids (TSS, %), the seeds of 10 randomly harvested fruit from each genotype were removed, and juice was extracted, then the juice was filtered through cheesecloth, and TSS from the obtained fruit juice was determined with the help of a digital hand refractometer (Atago PAL-1, Japan). Also, the pH of the extracted juice was evaluated with the pH meter (PHSJ-4A, Shanghai, China). For titratable acidity (%), the juice extracted from ten randomly selected fruit from each genotype for TSS also used for acidity determination, 5 ml of fruit juice was taken and made up to 50 ml with 45 ml of distilled water and titrated with 0.1 N NaOH. The acidity value was stated as % malic acid based on the amount of NaOH spent.

Morphological evaluations

Leaf width and length (cm) were evaluated by measuring the distance between the widest leaf blade

between the bottom and tip points of the leaf in 100 leaf samples of different sizes taken from trees belonging to each genotype that had completed their development. Leaf stalk length and thickness (mm) were determined from 100 leaves with the help of a 0.01 mm sensitive digital caliper. For leaf area (cm^2), 100 leaves with different sizes were taken from trees belonging to each genotype, and their width and length were determined. Leaf area was calculated according to Teobaldelli et al. (2019).

Total phenolics, total flavonoids, and antioxidant activity

Seeds of 5 fruit were separated from the pulp in each replication. Fruit pulp was homogenized with a blender (Promix HR2653, Philips, Türkiye) and homogenizer (Model PRO 200, PRO Scientific Inc. Oxford, CT, USA). Homogenized loquat samples were placed in 50-ml falcon tubes and stored at -20 °C until bioactive analysis [total phenolic compounds, total flavonoid, and antioxidant activities (DPPH and FRAP)]. Then, frozen samples were dissolved at 21 °C and 1.0 g of sample was taken; after that, 10 ml of methanol was added to each sample. Bioactive compounds such as total flavonoids, total phenolics, and antioxidant activity were read by UV–Vis spectrophotometer (Shimadzu, Japan). Total phenolics were stated in mg gallic acid equivalent (GAE) kg^{-1} fresh weight (fw), while total flavonoids were stated in mg quercetin equivalent (QE) kg^{-1} fw. The antioxidant activity of loquat fruit was detected in two different procedures of DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) and FRAP (Ferric Ions (Fe+3) Reducing Antioxidant Power), and the results were stated as mmol trolox equivalent (TE) kg^{-1} fw as described by (Ozturk et al. 2019).

Individual phenolic compounds

Four-aminobenzoic acid, protocatechuic acid, four-hydroxybenzoic acid, catechin, chlorogenic acid, caffeic acid, epicatechin, *p*-coumaric acid, ferulic acid, and rutin were measured. A DAD detector (DAD-3000, USA) was used for the chromatographic separation in high-performance liquid chromatography (HPLC, Thermo Scientific, Ultimate 3000, USA) following the technique of Karaman et al. (2013). Samples were diluted with distilled water at a ratio of 1:1 after centrifuging at 15 000 × g for 15 min. The supernatant was allocated with 0.45 µm filters, then injected into HPLC. Analytes separated by 250 × 4.6 mm, 5 µm Acclaim™ 120 C18 column (Thermo Scientific, made of USA) with 30 °C temperature set. Solvent A (aqueous 2.5% sulfuric acid) and Solvent B (100 percent acetonitrile) were the elution solvents. At 254 nm, separation was performed. The injection volume was 20 µL, and the flow rate of the mobile phase was 1.0 ml min^{-1}. Results were stated as mg kg^{-1}.

Statistical analysis

Analysis of the obtained data were done, based on a randomized complete block design, with IBM SPSS 21.0 program (SPSS Inc. Chicago, ABD). The means were compared by Duncan's multiple range test at a significance level of 0.05. Pearson correlation and principal component analysis (PCA) were determined by MVApp (Julkowska et al. 2019) and XLSTAT 2022 statistical software.

Results

Pomological characteristics of superior genotypes

Except for fruit pulp ratio and peeling of the skin, all other pomological characteristics had statistically significant ($P < 0.05$) differences. We found the highest seed weight of 2.41 g, seed volume of 1.92 cm^3, and fruit skin color of 4.86 in the GN 10; fruit weight of 46.70 g, shape index of 1.04, fruit volume of 41.50 cm^3, fruit pulp/seed ratio 25.07%, and flesh weight 44.90 g in GN 14; fruit width 43.12 mm, fruit length 41.30 mm, fruit stalk thickness 7.12 mm, seed number 4.43 pieces, fruit number in cluster 8.79 pieces, and fruit cluster weight 409.10 g in GN 69 (Table 1).

Color characteristics of superior genotypes

Except for chroma in fruit flesh, remaining all other color characteristics were statistically significant ($P < 0.05$). In the case of fruit skin color, the highest L*, a*, b*, chroma, and hue angle were 62.92 in GN 69, 49.66 in GN 69, 97.01 in GN 50, 106.28 in GN 69, and 67.81 in GN 50, respectively; while the

Table 1 Pomological characteristics of selected superior genotypes from a highly diversified loquat population

Fruit characteristics	Superior loquat genotypes					Sig	St.Er	CV%
	GN 10	GN 14	GN 50	GN 68	GN 69			
Fruit weight (g)	42.0 b *	46.7 a	38.7 c	32.9 d	40.1 c	0.001	1.21	12.12
Fruit width (mm)	37.81 b	39.65 ab	39.22 b	33.81 c	43.12 a	0.001	0.80	8.30
Fruit length (mm)	33.57 c	41.09 a	40.40 b	34.47 c	41.30 a	0.001	1.17	11.95
Shape index	0.89 c	1.04 a	1.03 a	1.02 a	0.96 b	0.001	0.17	6.2
Fruit stalk length (mm)	30.64 c	34.45 b	39.74 a	38.31 a	34.12 b	0.001	0.92	10.02
Fruit stalk thickness (mm)	5.66 b	5.12 b	5.45 b	5.35 b	7.12 a	0.001	0.21	13.99
Fruit volume (cm^3)	35.38 bc	41.50 a	35.25 c	27.88 d	39.25 b	0.001	1.37	15.02
Calyx core diameter (mm)	9.41 ab	7.62 c	9.78 a	9.35 ab	9.18 b	0.001	0.25	11.00
Seed number (piece)	3.70 b	2.43 d	3.08 bc	3.23 c	4.43 a	0.001	0.19	23.50
Seed weight (g)	2.41 a	1.81 b	1.93 b	2.01 b	1.71 c	0.001	0.79	14.15
Fruit number in cluster (piece)	3.54 c	3.41 d	5.85 b	5.26 b	8.79 a	0.001	0.53	19.37
Fruit cluster weight (g)	164.88 b	132.57 c	125.36 c	172.2 b	409.10 a	0.001	22.36	25.40
Seed volume (cm^3)	1.92 a	1.53 c	1.78 b	1.54 c	1.40 d	0.001	0.06	12.40
Fruit pulp ratio (%)	94.23 ns	96.08	94.97	93.86	95.69	0.325	0.37	1.54
Seed ratio (%)	5.77 a	3.92 d	5.03 ab	6.14 a	4.31 c	0.006	0.16	11.13
Fruit pulp/Seed ratio (%)	16.71 b	25.07 a	19.63 ab	15.55 b	22.76 a	0.048	0.45	15.98
Flesh weight (g)	39.59 ab	44.90 a	36.80 b	30.92 c	38.39 ab	0.001	2.21	14.78
Taste	4.78 a	3.23 b	4.95 a	4.80 a	4.82 a	0.001	0.18	15.33
Juiciness	2.80 b	4.43 a	4.82 a	4.38 a	4.70 a	0.001	0.21	17.48
Fruit skin color	4.86 a	4.66 a	2.88 b	2.84 b	2.96 b	0.001	0.25	25.68
Peeling of skin	5.00 ns	5.00	4.65	5.00	5.00	0.451	0.10	7.55

*Means in the lines with the different letter are significant according to Duncan's test at $P < 0.05$

ns Non-significant, *Sig* Significant, *St. Er* Standard error, *CV* Coefficient of variation

lowest were 56.15 in GN 50, 39.56 in GN 50, 91.37 in GN 14, 100.11 in GN 14, and 62.15 in GN 69 (Table 2).

TSS, titratable acidity, and pH of superior genotypes

Out of TSS (10.30–12.30%), other chemical characteristics were statistically significant ($P < 0.05$). Acidity ranged between 0.35 and 0.65%, being the highest in GN 10 and the lowest in GN 68. pH variation was from 2.45 to 3.96, being the highest in GN 69 and the lowest in GN 50 (Table 3).

Morphological characteristics of superior genotypes

All the leaf characteristics were statistically significant ($P < 0.05$). Leaf width ranged between 7.80 and 11.32 cm, being the highest in GN 50 and the lowest in GN 14. Leaf length range was 23.99–41.22 cm, being the highest in GN 50 and the lowest in GN 68. Petiole diameter varied between 5.29 and 7.19 mm, being the highest in GN 69 and the lowest in GN 68. Petiole length range was 10.49–21.62 mm, being the highest in GN 68 and the lowest in GN 69. Leaf area varied from 147.59 to 312.92 cm^2, being the highest in GN 50 and the lowest in GN 10 (Table 4).

Total phenolics, total flavonoids, and antioxidant activity of superior genotypes

All the phenolic compounds were statistically significant ($P < 0.05$). Total phenolics ranged between 137.69 and 297.83 mg GAE kg^{-1}, being the highest in GN 68 while the lowest was in GN 14. Total flavonoids varied from 109.00 to 232.15 mg QE kg^{-1}, being the highest in GN 68, while the lowest was in GN 50. DPPH ranged between 1.52 and 2.73 mmol TE kg^{-1}, being the highest in GN 10 and the lowest in GN 14. FRAP varied between 4.39 and 10.28 mmol

Table 2 Color characteristics of superior loquat genotypes

Color Characteristics		Superior loquat genotypes					Sig	St.Er	CV%
		GN 10	GN 14	GN 50	GN 68	GN 69			
Skin	L*	60.84^{b*}	61.24 b	56.15 c	59.43 b	64.92 a	0.001	0.82	5.22
	a*	43.59^{b}	40.91 cd	39.56 d	42.19 bc	49.66 a	0.001	0.98	8.83
	a*	94.14^{b}	91.37 c	97.01 a	93.63 bc	93.97 bc	0.008	0.57	2.33
	Chroma	103.74^{ab}	100.11 c	104.77 ab	102.70 b	106.28 a	0.003	0.63	2.36
	Hue angle	65.15^{a}	65.88 a	67.81 a	65.74 a	62.15 b	0.001	0.57	3.40
Flesh	L*	43.45^{c}	51.58 a	46.49 b	41.26 c	47.22 b	0.001	0.99	8.31
	a*	21.95^{b}	23.54 ab	16.79 c	17.76 c	25.33 a	0.001	0.93	17.10
	a*	94.38^{bc}	94.38 bc	97.68 a	96.93 ab	93.56 c	0.017	0.53	2.13
	Chroma	96.90^{ns}	97.27	99.11	98.54	96.93	0.245	0.39	1.53
	Hue angle	76.91^{b}	76.00 b	80.25 a	79.62 a	74.85 b	0.003	0.63	3.16

*Means in rows with the different letter are significant according to Duncan's test at $p < 0.05$. *ns* non-significant

*L** Brightness (0 = white, 100 = black). a* = red (if +) and green (if –). b* = yellowness (if +) and blueness (if –). Chroma = saturation level of the color (0 = neutral color, while higher chroma values means higher saturation). Hue angle (h°) = red (0°), yellow (90°), green (180°), and blue (270°)

Sig Significant, *St. Er* Standard error, *CV* Coefficient of variation

Table 3 Biochemical characteristics of superior loquat genotypes

Biochemical characteristics	Superior loquat genotypes					Sig	St.Er	CV%
	GN 10	GN 14	GN 50	GN 68	GN 69			
TSS (%)	12.30^{ns}	10.80	10.30	11.00	11.50	0.495	0.35	12.17
Acidity (%)	0.65^{a}*	0.60 b	0.60 b	0.35 d	0.47 c	0.001	0.03	21.35
pH	3.85^{a}	3.06 bc	2.45 c	3.56 ab	3.96 a	0.004	0.17	19.58

*Means in rows with the different letter are significant according to Duncan's test at $P < 0.05$

TSS Total soluble solids, *ns* Non-significant. *Sig* Significant, *St. Er* Standard error, *CV* Coefficient of variation

Table 4 Leaf characteristics of superior loquat genotypes

*Means in rows with the different letter are significant according to Duncan's test at $P < 0.05$

sig Significant, *St. Er* Standard error, *CV* Coefficient of variation

Leaf characteristics	Superior loquat genotypes					Sig	St.Er	CV%
	GN 10	GN 14	GN 50	GN 68	GN 69			
Leaf width (cm)	8.21^{b}*	7.8^{b}	11.32^{a}	10.19^{ab}	10.49^{ab}	0.044	0.47	19.05
Leaf length (cm)	27.05^{b}	29.16^{b}	41.22^{a}	23.99^{c}	27.44^{b}	0.001	1.62	21.10
Petiole diameter (mm)	5.46^{b}	5.33^{b}	6.95^{a}	5.29^{b}	7.19^{a}	0.001	0.24	15.37
Petiole length (mm)	17.69^{b}	18.61^{b}	11.32^{c}	21.62^{a}	10.49^{c}	0.001	1.19	22.73
Leaf area (cm^2)	147.59c	151.29^{c}	312.92^{a}	163.09^{c}	188.03^{b}	0.001	16.64	25.68

TE kg^{-1}, being the highest in GN 10, while the lowest was in GN 50 (Table 5).

Individual phenolic compounds of superior genotypes

All the individual phenolic compounds in the superior loquat genotypes were statistically significant ($P < 0.05$). 4-aminobenzoic acid and protocatechuic acid ranges were between 16.43–24.84 mg kg^{-1} and 0.22–0.01 mg kg^{-1}, respectively, being the highest in GN 69 and the lowest in GN 50. 4-hydroxybenzoic acid ranged from 0.44 to 0.76 mg kg^{-1}, being the highest in GN 69 and the lowest in GN 68. Catechin varied from 4.30 to 9.15 mg kg^{-1}, being the highest

Table 5 Total phenolics, total flavonoids, and antioxidant activities (DPPH and FRAP assays) of superior loquat genotypes

Bioactive compounds	Superior loquat genotypes					Sig	St.Er	CV%
	GN 10	GN 14	GN 50	GN 68	GN 69			
Total phenolics (mg GAE kg^{-1})	241.90 c *	137.69 e	144.09 d	297.83 a	287.63 b	0.001	18.37	24.42
Total flavonoids (mg QE kg^{-1})	222.86 b	114.89 d	109.00 e	232.15 a	216.64 c	0.001	14.72	20.67
DPPH (mmol TE kg^{-1})	2.73 a	1.52 b	1.74 b	2.67 a	2.59 a	0.001	0.14	24.53
FRAP (mmol TE kg^{-1})	10.28 a	5.44 bc	4.39 c	9.35 a	7.73 ab	0.001	0.67	20.85

*Means in rows with the different letter are significant according to Duncan's test at $P < 0.05$

sig Significant, *St. Er* Standard error, *CV* Coefficient of variation

in GN 50 and the lowest in GN 68. Chlorogenic acid ranged between 1.73 and 38.43 mg kg^{-1}, while the range for caffeic acid was 0.31–1.76 mg kg^{-1}, for epicatechin 6.07–13.89 mg kg^{-1}, for *p*-coumaric acid 0.55–8.92 mg kg^{-1}, for ferulic acid 0.27–4.60 mg kg^{-1}, and for rutin 0.17–7.98 mg kg^{-1} (Table 6).

Correlation and PCA of evaluated characteristics

A highly significant positive correlation between FWe and FWi ($r=0.747$**), FV ($r=0.945$**), Aci ($r=0.760$**), SR ($r=0.630$**), and FruSC ($r=0.816$**) was observed, while a strongly negative correlation was noted between FPD ($r=-0.723$**) and taste ($r=-0.655$**). In the case of FV, a highly positive significant correlation was acquired with Aci ($r=0.652$**), FruSC ($r=0.600$**), and Cha ($r=0.596$**), however showed a highly negative correlation with FPD ($r=$-0.668**) and taste ($r=-0.619$**). A highly significant correlation was obtained between SN with FNC ($r=0.713$**), FCW ($r=0.865$**), taste ($r=0.740$**), ToPhe ($r=0.629$**), DPPH ($r=0.667$**), Proto ($r=0.655$**), and Hydro ($r=0.863$**). A significantly strong correlation between TSS and pH ($r=0.802$**), DPPH ($r=0.605$**), FRAP ($r=0.771$**), Proto ($r=0.616$**), and Epi ($r=0.632$**) was also obtained. LA had a positive significant correlation with individual phenolic compounds such as Cha ($r=0.670$**), Pcu ($r=0.754$**), Fer ($r=0.962$**), and Ru ($r=0.953$**). From Pearson correlation analysis, we found that ToPhe, ToFla, DPPH, and FRAP had a highly significant positive correlation with each other (Fig. 2).

PCA of evaluated characteristics is illustrated in Fig. 3. The contribution to PC 1 (28.04%) is shown on the *x*-axis, and the contribution to PC 2 (25.10%) is on the y-axis. The length and color of the arrows indicate each character's contribution to the selected principle component.

Eigenvalues of component 1 to component 5 were obtained the following: 11.91, 10.56, 8.00, 7.53, and 3.17, The Scree plot of eigenvectors and their

Table 6 Individual phenolic compounds of selected superior loquat genotypes

Individual phenolic compounds (mg kg^{-1})	Superior loquat genotypes					Sig	St.Er	CV%
	GN 10	GN 14	GN 50	GN 68	GN 69			
4-aminobenzoic acid	19.69 b *	24.45 a	16.43 c	20.80 b	24.84 a	0.001	0.89	16.21
Protocatechuic acid	0.14 b	0.06 c	0.01 d	0.13 b	0.22 a	0.001	0.02	23.64
4-hydroxybenzoic acid	0.62 b	0.45 d	0.52 c	0.44 d	0.76 a	0.001	0.03	22.58
Catechin	6.10 d	7.50 c	9.15 a	4.30 e	8.34 b	0.001	0.47	25.50
Chlorogenic acid	38.43 a	6.58 d	1.73 e	8.25 c	13.10 b	0.001	3.45	24.82
Caffeic acid	1.61 ab	0.31 c	1.76 a	0.96 bc	1.09 ab	0.006	0.16	24.26
Epicatechin	13.89 a	6.07 d	10.08 b	6.78 cd	9.16 bc	0.001	0.80	22.80
p-coumaric acid	5.18 b	1.32 c	8.92 a	1.10 d	0.55 e	0.001	0.86	29.61
Ferulic acid	0.86 b	0.27 e	4.60 a	0.43 d	0.59 c	0.001	0.44	25.70
Rutin	0.56 d	0.65 c	7.98 a	0.72 b	0.17 e	0.001	0.80	24.90

*Means in rows with the different letter are significant according to Duncan's test at $p < 0.05$

sig Significant, *St. Er* Standard error, *CV* Coefficient of variation

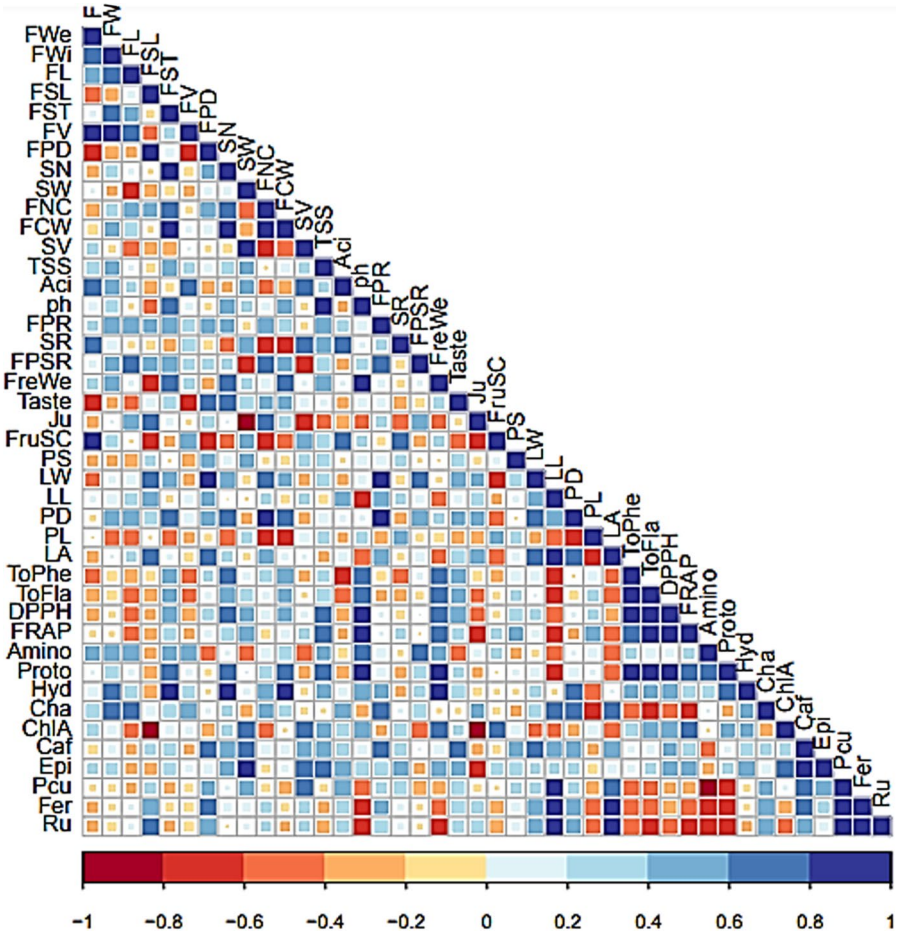

Fig. 2 Correlation between pomological, morphological, and bioactive compounds of superior loquat genotypes. The color and size of the circle reflect the strength of the correlation. *FWe* Fruit weight, *FWi* Fruit width, *FL* Fruit length, *FSL* Fruit stalk length, *FST* Fruit stalk thickness, *FV* Fruit volume, *FPD* Flower pit diameter, *SN* Seed number, *SW* Seed weight, *FNC* Fruit number in cluster, *FCW* Fruit cluster weight, *SV* Seed volume, *TSS* Total soluble solids, *Aci* Acidity, *FPR* Fruit pulp ratio, *SR* Seed ratio, *FPSR* Fruit pulp/seed ratio, *FreWe* Fresh weight, *Ju* Juiciness, *FruSC* Fruit skin color, *PS* Peeling of skin, *LW* Leaf width, *LL* Leaf length, *PD* Petiole diameter, *PL* Petiole length, *LA* Leaf area, *ToPhe* Total phenolics, *ToFla* Total flavonoids, Antioxidant Activities *DPPH and FRAP*, *Amino* Aminobenzoic acid, *Proto* Protocatechuic acid, *Hyd* Hydroxybenzoic acid, *Cha* Catechin, *Chla* Chlorogenic acid, *Caf* Caffeic acid, *Epi* Epicatechin, *Pcu* P-coumaric Acid, *Fer* Ferrulic acid, *Ru* Rutin

percentage of variances is illustrated in Fig. 4. The percentage of variation explained by each principle component is shown from the most significant to the least, respectively; i.e., 28.35%, 25.14%, 19.07%, 17.94%, and 7.56%, which totally equals to 97.08%, and being the remaining percentage related to the components 6 to component 9.

Discussion

Pomological characteristics of selected superior loquat genotypes

Based on the examined characteristics, GN 69 and GN 14 performed better than other superior

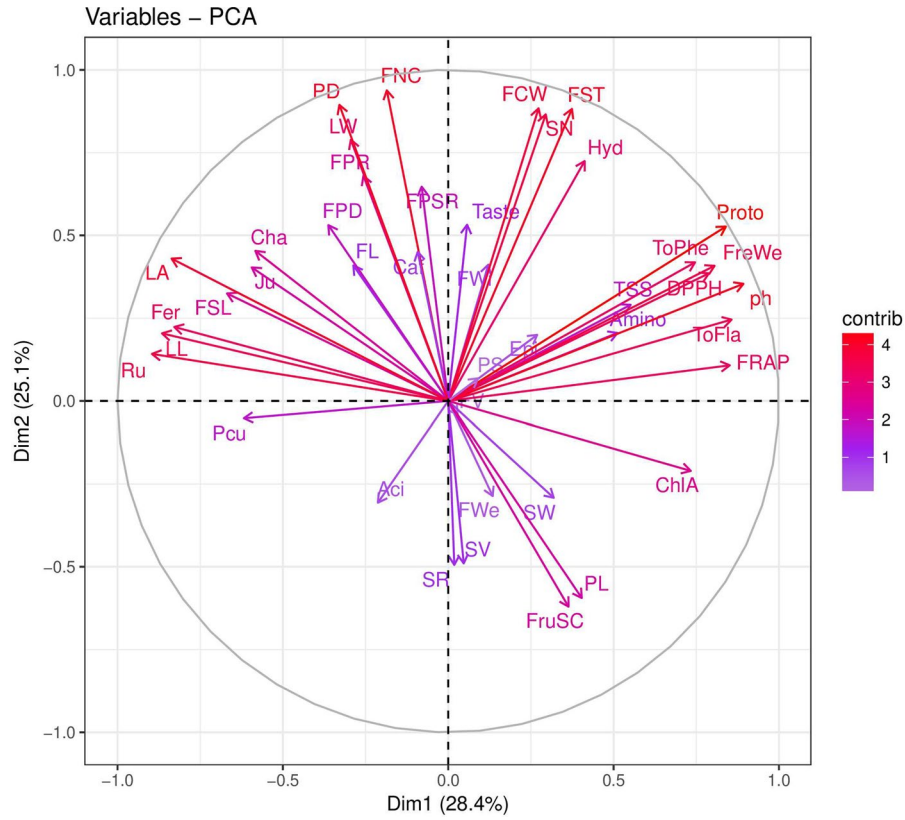

Fig. 3 Principle component analysis of pomological, morphological, bioactive compounds of superior loquat genotypes

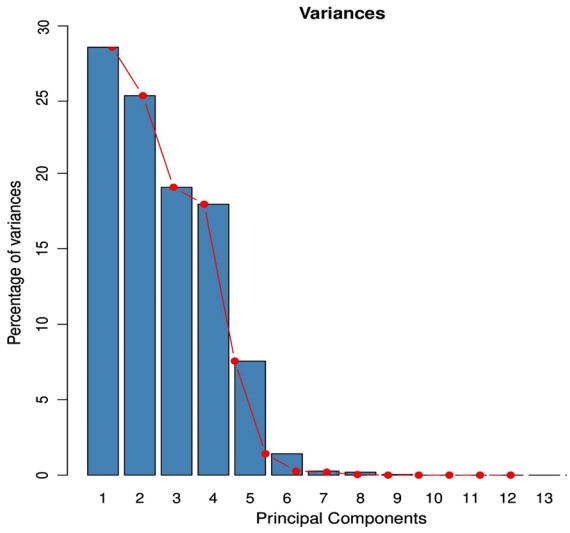

Fig. 4 Eigenvectors and their variances percentage of pomological, morphological, bioactive compounds of superior loquat genotypes

genotypes in the case of pomological characteristics. Among the pomological traits, fruit weight is a withstand attribute in loquat, which is directly related to the requisition of consumers IT was observed previously to range between 30 and 70 g, while fruit diameter ranged between 2 and 5 cm (Badenes et al. 2013). One of the critical attributes for selection of the superior genotypes in our previous research was fruit weight beside the other traits. The range for fruit weight of loquat was 18.65–44.33 g as observed by Balcı (2015); 29.8–47.5 g by Polat and Turunç (2016); 40.43—44.33 g by Yarılgaç et al. (2017); and between 16.02 and 35.52 g by Öztürk and Öztürk (2018). Şenyurt (2006) mentioned that fruit width was 35.45–48.53 mm and fruit length ranged between 35.02 and 47.25 mm. Hussain et al. (2007) noted a fruit width of 2.60–3.87 cm and fruit length of 2.68–5.10 cm; Karadeniz and Şenyurt (2007) indicated a the fruit width range of 26.80–49.92 mm and fruit length range of 29.08–48.02 mm. Balcı (2015) recorded a fruit width range of 25.71–44.60 mm and fruit length of 26.96–44.66 mm; while Polat and Turunç (2016) noticed a fruit width range of 34.1–42.7 mm and fruit length range of 39.3–46.5 mm. Yarılgaç et al. (2017) observed a fruit width range of 39.20–45.20 mm and

fruit length range of 38.72–43.63 mm; while Öztürk and Öztürk (2018) found the fruit width range of 30.86–41.80 mm and fruit length range of 31.13 and 41.91 mm. Fruit stalk length ranged between 8.93 and 49.96 mm, and fruit stalk thickness varied between 4.11 and 7.71 mm in loquat genotypes according to Karadeniz and Şenyurt (2007). The length of the fruit stalk range was 13.03–45.28 mm and thickness of the fruit stalk range was 4.16–6.65 mm as noticed by Balcı (2015). Fruit volume varied from 11 to 62 cm^3 according to Karadeniz and Şenyurt (2007) and 17.95–49.45 cm^3 as observed Balcı (2015). Flower pit diameter of the loquat ranged from 4.27 to 10.70 mm as indicated by Karadeniz and Şenyurt (2007) and 4.27–10.70 mm diameter with a flower pit depth of 3.80–8.46 mm according to Balcı (2015). The differences between above research results and ours could be due to genetics and environmental conditions where the genotypes were grown. Indeed, it has been previously indicated that many factors such as cultivar, growing region, climatic conditions, soil structure, and harvest time affect the pomological characteristics of loquat (Toker et al. 2010).

Seedless fruits or fruits with few and small seeds in the loquat are among the most important preferences of consumers and breeders. Seed weight range was 1.2–3.6 g in loquat, partially large, and generally 3–5 pieces found per fruit (Badenes et al. 2013). Hussain et al. (2009) stated that the number of seeds range was 2.14–3.64, and the seed weight range was 0.99–1.89 g in eight loquat genotypes; while Polat et al. (2010) observed a seed number range of 2.3–3.9 and a seed weight range of 3.2–6.7 g. The number of seeds varied between 1.75 and 4.06, and the seed weight range was 3.00–8.54 g as by Balcı (2015)- Polat and Turunç (2016) stated that the range for number of seeds was 2.37–3.94 and the seed weight range was 1.64–2.38 g. The lesser seed weight and seed number in our superior genotypes as compared to previous research findings, are ideal attributes that should be further evaluated by the breeding programs.

The range of the number of fruit per cluster was 3–15 in loquat (Badenes et al. 2013). The number of fruit per cluster varied between 3.6 and 7.8 according to Insero et al. (2003); while fruit cluster weight range was 69.75–404.90 g, and the number of fruit in a cluster varied between 5 and 21 as observed by Karadeniz and Şenyurt (2007). Hussain et al. (2009) indicated a range of number of fruit per cluster of 8.83–16.27, while fruit cluster weight varied between 47.82 and 237.42 g. Harsimrat et al. (2016) observed that the number of fruit in a cluster ranged between 10.0 and 12. Our study findings revealed lesser number of fruit per cluster than most of the above results. The lower number of fruit per cluster result in a the higher fruit weight and volume.

Fruit pulp ratio is an accepted criterion to consider the amount of fruit pulp in loquat, and it is desired that the fruit pulp ratio and the fruit pulp/seed ratio be high, while a low seed ratio is preferred (Badenes et al. 2013; Balcı, 2015). Cultivar, years, and agroecozones according to research on similar subjects in loquats are reported to have an important effect on fruit flesh ratio, fruit flesh/seed ratio, and seed ratio. Fruit pulp ratio was 62.0–86.0% by Liang et al. (2011) and between 74.3 and 83.8% by Polat et al. (2010); Elsabagh and Haeikl (2012) acquired seed/fruit weight ratio of 12.84–18.77% in four cultivars of loquat; Balcı (2015) stated the pulp ratio between 74.96 and 85.79%, seed ratio between 15.02 and 24.99%, and seed/pulp ratio ranged between 30.36–56.80%; Polat and Turunç (2016) obtained pulp/seed ratio 4.61 to 6.60%; Yarılgaç et al. (2017) mentioned pulp ratio varied 73.28–80.74%; Öztürk and Öztürk (2018) observed pulp/seed ratio between 2.70 to 5.04%; Tepe ve Koyuncu (2019) mentioned that seed ratio varied 15.03–27.12% in 'Akko XIII' cultivar. It can be said that the fruit pulp ratio, seed ratio, and fruit pulp/seed ratio obtained in the genotypes are similar and better than the findings of previous studies.

Llácer et al. (2003) mentioned that the fruit flavor of loquat cultivars they evaluated were low, medium, good, and very good, and they were juicy and aromatic. Fruit taste was stated from sour to very sweet in the loquat genotypes according to Şenyurt (2006), while Balcı (2015) noted that fruit taste varied from tart to sweet in oquat genotypes. Our results are similart with thoseobtained in similar agro-ecozones.

Color characteristics of superior genotypes

Fruit skin color varies from whitish-yellow to orange, and the peeling status of the fruit varies from easy to difficult in the loquat (Badenes et al. 2013). Llácer et al. (2003) stated the fruit's skin color was yellow to orange, while Hussain et al. (2009) observed that

the fruit's skin color was yellowish-white and orange-yellow, and fruit flesh color was yellowish-white and orange. Balcı (2015) noticed that flesh color was yellow and dark-yellow,; while Yosoulkanian et al. (2016) observed fruit skin color being orange, yellow, and yellow-orange. The skin color of a particular cultivar has an impact on customer interest as a fruit quality indicator. Zhou et al. (2007), in 23 cultivars of loquat, got range for L* value of 57.62–67.15, for a* value of 6.92–26.17, for b* value 28.84–49.93, for chroma value 57.54–81.51, and for the hue angle value 32.97–51.86. Toker et al. (2010) on the other hand, got L* value between 61.78 and 67.77, and ranges being for a* 6.29–20.31, b* 43.21–55.49, chroma 44.29–57.10, and hue angle 69.07–83.55 and reported that the fruit flesh color L* value varied between 39.85 and 46.70, and ranges being for a* 6.14–13.19, for b* 21.61–32.75, for chroma 22.46–35.31, and for hue angle 67.63–74.16. The ranges of the fruit skin color of the 'Akko XIII' cultivar were 50.91–52.22 for L*, 15.60–17.04 (a*), 39.20–40.29 (b*), 40.94–43.74 (chroma), and 66.47–68.30 (hue angle) by Tepe and Koyuncu (2019). The fruit skin and flesh color attributes of our study were higher than those available in relevant literature, the higher values obtained from our study. Also, the variation in the color characteristics between our superior genotypes were lower than in previous research. This result was due to the similar ideal attributes while selecting the superior genotypes form a highly diversified population. The hue angle (h°) indicates red (0°), yellow (90°), green (180°), and blue (270°) colors. Hence, our superior genotypes have yellow to yellowish-orange color.

TSS, acidity, and pH of superior genotypes

The TSS is a crucial breeding characteristic that should be high in loquat, whose aromatic flavor is a favorable trait. The perfect taste of the loquat fruit depends on the balance of TSS and acidity. TSS in loquats ranges between 7.0 and 20.0% (Badenes et al. 2013). According to previous researchs in loquats, TSS, acidity,and pH depend on cultivars, years, and agroeozones. Durgaç et al. (2006) noted ranges for TSS of 9.09–11.77%, for pH of 3.45–3.60, and for titratable acidity of 0.73–0.88% in some cultivars of loquat. Polat and Caliskan (2006) observed ranges for TSS between 10.0 and 13.2%, for pH of 3.3–3.6, and for titratable acidity of 0.5–1.1%. Karadeniz and Şenyurt (2007) stated that TSS ranged from 9.5 to 18.5%, while the ranges were for pH 3.23–5.32, and for acidity 0.87–16.41. Polat et al. (2010) observed range for TSS of 10.5–12.8%, for pH of 3.5–4.5, and for acidity of 0.32–1.06%. Toker et al. (2010) determined ranges for TSS of 10.25–17.15%, for pH of 3.46–4.58, and for acidity of 0.21–0.81%. Polat et al. (2010) mentioned that range for TSS was 8.7–13.3%, for pH was 3.16–3.63, and for acidity was 0.53–1.16%; while Balcı (2015) noted that TSS ranged between 7.00 and 12.60%, and ranges for pH of 2.68–4.6, and for acidity of 7.42–14.08%. Polat and Turunç (2016) recorded ranges forTSSof 8.8–13.4%, for pH of 3.08–3.83, and for acidity of 0.47–1.16%; Öztürk ve Öztürk (2018) got ranges for TSS of 5.70–14.50%, for pH of 3.18–6.00, and for acidity 0.33–2.27%. Our results are consistent with those of earlier research, while changes with some references were due to ecological factors and genetic variability in phenotype and cultivars.

Morphological characteristics of superior genotypes

Loquat leaves were tall, lanceolate, evergreen, wavy on the surface (like hard leather), pointed at the tip, and have strongly saw-toothed edges. The leaf measured 12–25 cm in length, 5–8 cm in breadth, has a short petiole, and has a lustrous, dark-green upper surface. The lowest portion is matte and hairy green (Özçağıran et al. 2005). Leaf width ranges between 48.25 and 121.96 mm, leaf length 82.40–367.94 mm, petiole length 8.5–19.24 mm, petiole thickness 3.3–8.5 mm according to Karadeniz and Şenyurt (2007) in 78 loquat genotypes; Hussain et al. (2009) observed ranges for leaf width of 4.18–9.67 cm, for leaf length 13.43–28.14 cm, and leaf area 39.47-167.7 cm^2; Teobaldelli et al. (2019) noticed that leaf width ranged between 2.5–12.1 cm, ranges for leaf length of 10.0–33.3 cm, for leaf length/width ratio of 3.25, and leaf area Ford 25.35–274.0 cm^2 in ten loquat cultivars. The results obtained in our study regarding the leaf characteristics are similar to those of previous research.

Total phenolics, total flavonoids, and antioxidant activity of superior genotypes

Numerous secondary metabolites that are produced carry out vital physiological and biochemical roles.

During development and postharvest storage, these metabolites are crucial for interacting with the environment and overcoming biotic and abiotic disturbances. Secondary metabolites play a crucial role in fruit quality from the perspective of customer acceptance since they influence the fruit's color, flavor, and nutritional qualities (Sanchez-Ballesta et al. 2022). Total phenolics of some loquat cultivars reported 240.5–572.3 mg GAE kg^{-1}, total flavonoids content 21.2–77.5 mg RE kg^{-1}, antioxidant based on DPPH method between 1.45 and 4.24 mmol TE kg^{-1}, and for the FRAP method obtained in the range of 2.17–3.72 mmol TE kg^{-1} (Xu and Chen 2011). Also, some other researchers observed profound changes in the total phenolics in different loquat cultivars, for example, between 818 and 1738 mg GAE kg^{-1} (Ding et al. 2001), 125.7–2603.3 mg GAE kg^{-1} (Ferreres et al. 2009), 129–578 mg GAE kg^{-1} (Polat et al. 2010), 140–753 mg GAE kg^{-1} (Ercisli et al. 2012), and 394.67–664.53 mg GAE kg^{-1} (Delfanian et al. 2015). In previous research, the total flavonoids of loquat fruit ranged between 16.3 and 38.7 mg kg^{-1} (Ercisli et al. 2012). Antioxidants can be changed by several factors, such as cultivars, biotic and abiotic stresses, and plant growth regulators (2.91–4.93 mmol TE kg^{-1}) as noted by Hong-Xia et al. (2014). Similar to previous research, significant differences were found between the superior genotypes of our study in case of total phenolics, total flavonoids, and antioxidant activities. The GN 10 was determined to be the best genotype in the case of antioxidants, while the total phenolics and total flavonoids were found higher in the GN 68 as compare to the others. Antioxidants of our superior genotypes were found in line with the previous research. However, there were differences in the case of phenolic compounds. The differences could be due to stressless climatic situations in the growing area of our superior genotypes. As the increase in the phenolic compounds, is a response to the stressors (Hong-Xia et al. 2014).

Individual phenolic compounds of superior genotypes

In our study, GN 69 and GN 10 were better in the contents of individual phenolics than others. Individual phenolics in the loquat fruit were determined as 5-caffeoylquinic acid (chlorogenic acid), neochlorogenic acid, hydroxybenzoic acid, 5-p-feruloylquinic acid, protocatechuic acid, 4-caffeoylquinic acid, epicatechin, p-coumaric acid, ferulic acid, and o-coumaric acid by Ding et al. (2001). They reported high content of neochlorogenic acid in the early development stages of loquat fruit, while the concentration of chlorogenic acid was higher during ripening and became dominant in ripe fruit. In our study, similar findings were observed in case of GN 10 that has higher content of chlorogenic acid in the ripe stage as compared to the other phenolics. Wang et al. (2020) determined the individual phenolics of different loquat cultivars,; i.e., chlorogenic acid between 197.88 and 304.47 mg kg^{-1}, epicatechin from 8.26 to 19.26 mg kg^{-1}, caffeic acid between 4.22 and 4.66 mg kg^{-1}, and ferulic acid in the range of 5.67–6.68 mg kg^{-1}. They found higher content of individual phenolics as compared to our results. This could be due to the favorable climate situation of China for loquat as its origin, or due to the maturity stages that the fruit were harvested and used for determining phenolic compounds (Ding et al. 2001). Similar to the other research findings, we found higher amount of chlorogenic acid, epicatechin and caffeic acid in the superior genotypes used in the study than other individual phenolic compounds (Ding et al. 2001; Wang et al. 2020).

Conclusion

All the superior genotypes (GN 10, GN 14, GN 50, GN 68, and GN 69) of loquat, which were previously selected from a wide varied chance seedling population, performed ideally in the case of bioactive compounds, antioxidants, biochemical, pomological, and morphological characteristics. To make a final decision regarding whether the chosen superior genotypes would consistently exhibit outstanding features and be recorded as new cultivars, they should be evaluated over an extended period across various climatic conditions. Additionally, these superior loquat genotypes have the potential to be used in future breeding.

Author contributions Research and data collection were done by OCK. Project design, research, reviewing, and data analysis were done by AO. Writing and editing the manuscript draft and preparing tables and graphs were done by ZAF. Analysis of total phenolics, flavonoids, antioxidants, and individual phenolic compounds was carried out by UA. Analysis of total phenolics, flavonoids, antioxidants, and individual phenolic compounds and editing the manuscript draft were done by BO.

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Data availability The manuscript has no associated data. All data are presented in the article.

Declarations

Conflict of interest The authors declare that they do not have conflict of interest.

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