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Full Length Article

Phenotypic and Physicochemical Assessment of Loquat (*Eriobotrya japonica*) Genotypes Grown in Moroccan Zegzel Valley

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Abstract

Loquat [*Eriobotrya japonica* (Thunb.) Lindl] is a very important commercial crop in Morocco, which request a considerable interest in its genetic improvement. In this context, the phenotypic and physicochemical parameters of 34 genotypes, belonging to the main loquat crop area, were analyzed. Indeed, the results obtained showed a large phenotypic and physicochemical variability of loquat genotypes studied. The fruit weight fluctuated between 17.1–68.07 g, while the average weight of seed varied from 1.5 to 3.62 g. These criteria are considered suitable for the market and the breeding program. Concerning the pH, the total soluble solids and the titratable acidity results, they were 2.69–4.15, 6.55–15.7 °Brix and 2.18–14.91 g.L^{-1} of malic acid respectively. In addition, the correlation analysis revealed that the fruit weight is positively correlated with the fruit length (r = 0.77), the fruit width (r = 0. 97) and the fruit thickness (r = 0.95). The PCA results showed that the traits related to fruit weight and size are the most discriminant. Moreover, the cluster analysis allowed to classify the 34 genotypes into 4 homogeneous groups independently of their geographic origin. In this study the loquat genotypes exhibited a great richness which opens the way for the conservation strategies and selection of efficient genotypes with the desired characteristics to be propagated vegetatively. © 2022 Friends Science Publishers

Keywords: *Eriobotrya japonica*; Variability; Phenotypic; Physicochemical; Genotypes

Introduction

The loquat [*Eriobotrya japonica* (Thunb.) Lindl], belonging to *Rosaceae* family, is an important sub-tropical tree native to southeastern China (Baljinder *et al*. 2010). The main producer countries of this fruit are China, followed by Spain, Japan, Turkey, India, and Pakistan (Badenes *et al*. 2013). This species is cultivated as a commercial crop due to its edible yellow fruits as well as an ornamental tree (Hussain *et al*. 2011).

In Morocco, the loquat was introduced from Algeria by the French colonization at the beginning of the last century (Rhomari 2013). The valley of zegzel located in the north-west of Morocco represents 85% of the loquat national area (Skiredj and Elmacane 2003). In 2021, the national production of loquat exceeded 10,000 tons with an improvement in size and gustative quality of this excellent local product. The identity of the Moroccan loquat cultivated is unknown and the distinction between the most genotypes is established by referring to phenotypic characters such as fruit shape (ORMVA 2015).

The assessment of the plant variability involves attributes which are easily perceived by the human senses and other attributes that require sophisticated measurement tools such as safety and nutrition. These attributes could include chemical components, mechanical properties and sensory parameters (Shewfelt 1999). In this regard, the present study aims (i) to evaluate the genetic variability of loquat using phenotypic and physicochemical traits, (ii) look for major discriminate characteristics in this variability (iii) and also to investigate a possible spatial structuration of these genotypes according to their phenotypic and physicochemical similarities. Indeed, the germplasm management and genetic resource conservation and improvement could be accomplished if detailed identification of plant material was available.

Materials and Methods

Plant material

During September 2016, fresh leaves and mature fruits were collected from 34 loquat genotypes belonging to four sites namely Takerboust, Taghsrout, Tazaghin and Zegzel, located in the Zegzel valley of Berkane, with an altitude level of 700–1000 m (Fig. 1; Table 1). From each genotype, 20 developed leaves and 25 healthy fruits were randomly sampled to be subjected to the observations and analyses programmed in this study.

Phenotypic traits

The evaluation of the phenotypic traits related to fruit, seed and leaf was carried out according to 27 characters figured in UPOV descriptors (UPOV 1998; Table 2). The measurements carried out using a scale sensitive to 0.01 g (Precisa XB 2200 C, Precisa, UK) and digital caliper (0–150 mm; BTS Tools, Malaysia). In addition, the firmness was determined by twice measurements with a digital penetrometer. For each use the calibration of the apparatus is necessary.

Fruit physicochemical parameters

Soluble solid content: Total soluble solids were determined by a refractometer (ATAGO Co. Ltd.; Model PR-1) graduated by 0.2 °Brix. Briefly, two drops of loquat fruit juice were placed on the prism of the equipment surface (Viera *et al.* 2022). The analyses were carried out in triplicate and the total soluble solids were expressed in term of °Brix.

Titratable acidity: The acidity was assessed with the dilution of a 10 mL of fruit juice in 50 mL of distilled water and posterior titration with a sodium hydroxide solution (NaOH, 0.1 *N*) was carried out to attain a pH of 8.1. The analyses were performed in three time and the volume of NaOH added was multiplied by the coefficient 0.67 (Serrano *et al.* 2003). The titratable acidity is expressed per g of malic acid L^{-1}.

pH value: Regarding the pH values of the fruit juice, they were recorded using an electronic pH meter (PH211R, HANNA®) with three replicates for each sample.

Statistical analysis

The result of all parameters was expressed as interval of variability and general mean. The association between the traits was carried out using Pearson's correlation coefficient ($\alpha = 0.05$). In addition, the genotype ordination and structuration were performed using principal component analysis (PCA) and hierarchical cluster analysis based on Euclidean distances. All analyses were performed using SPSS v. 22.

Results

Phenotypic and physicochemical traits

The results obtained from the analysis of phenotypic and physicochemical characteristics of 34 Moroccan loquat genotypes showed a great genetic variability (Table 3). Indeed, the fruit weight varied from 17.1 to 68.07 g with an average of 42.73. Moreover, the geometric traits of the fruits such as the geometric diameter, sphericity index, surface and volume recorded a large variation with values ranging from 30.28 to 48.98 mm, 0.75 to 0.98, cm^3, 28.79 to 75.33 mm^2 and 14.53 to 61.5, respectively. In addition, the weight and ratio of the pulp oscillated from 13.30 to 56.33 g and 0.78 to 0.88% respectively. Concerning the firmness character, which is a determinant factor of the fruit quality and refers to the resistance of the fruit to manipulation and transport, it ranged from 4.21 to 7.82 kg/cm^2, with an average of 6.02. For the seed traits, the average weight, number per fruit and the moisture level varied from 1.5 to 3.62 g, 1.1–6.2 and 16.82–33.8% respectively. The leaf traits results revealed that the leaf length of the genotypes studied varied from 15.77 to 29.17 cm with an average of 23.72, while the width of the blade oscillated between 4.48 and 10.41 cm. Similarly, the physicochemical characteristics studied registered a great variation. In fact, the titratable acidity varied from 2.18 to 14.91 g. L^{-1} of malic acid with an average of 8.26. The soluble solids content ranged between 6.55 and 15.7 °Brix with an average of 9.72. Regarding the pH parameter, it recorded values fluctuating from 2.69 to 4.15 with an average of 3.18.

Correlation analysis

The correlation matrix showed a strong and pertinent association between the variables analysed (Table 4). In fact, the fruit weight recorded a strong and positive correlation with fruit length (FL, r = 0.77), fruit width (FWth, r = 0. 97), fruit thickness (FTh, r = 0.95), fruit geometric diameter (GDF, r = 0.97), fruit volume (FV, r = 0.98), fruit surface (FS, r = 0.98), skin weight (SkW r = 0.55) and seed number per fruit (SNF, r = 0.64). Moreover, significant correlations were revealed between fruit dimensions and their geometric characters. The Fruit width Repetition appeared to be positively and strongly correlated with fruit thickness (FTh), fruit volume (FV), fruit geometric diameter (GDF) and fruit surface (FS) with respective coefficients of r = 0.98; r = 0.95; r = 0.96; r = 0.96 respectively. Regarding the characters related to the leaf such as the leaf length, it is significantly and positively correlated with petiole thickness as well as the length and width of blade (PTh r = 0.62, BL r = 0.99, BWth r = 0.74 respectively). Furthermore, the number of seeds per fruit is positively correlated with fruit weight (FW, r = 0.64), fruit size (FL r = 0.50, FWth r = 0.70 and FTh r = 0.68) and the fruit geometric characteristics (GDF r = 0.68, FV r = 0.66, FS r = 0.67). For physicochemical parameters, the soluble solids content is negatively correlated with skin and seed moisture (SkM r = -0.90, SM r = -0.44 respectively), meaning that the lower the moisture content, the more sugars are concentrated in the fruit.

Table 1: List of loquat genotypes subjected to assessments

Geographical origin	Genotypes codes	Numbre of samples
Takerboust	T1, T2, T3, T4, T6, T7, T8, T5, T10, T11, T12, TA1, TA2	13
Taghsrout	TA2, TA5, TA6, TA7, TA8, TA9, TA13, TA14	8
Tazaghin	TZN1, TZN2, TZN3, TZN4	4
Zegzel	Z1, Z16, Z17, Z2, Z3, Z5, Z6, Z7, Z8	9
Total		34

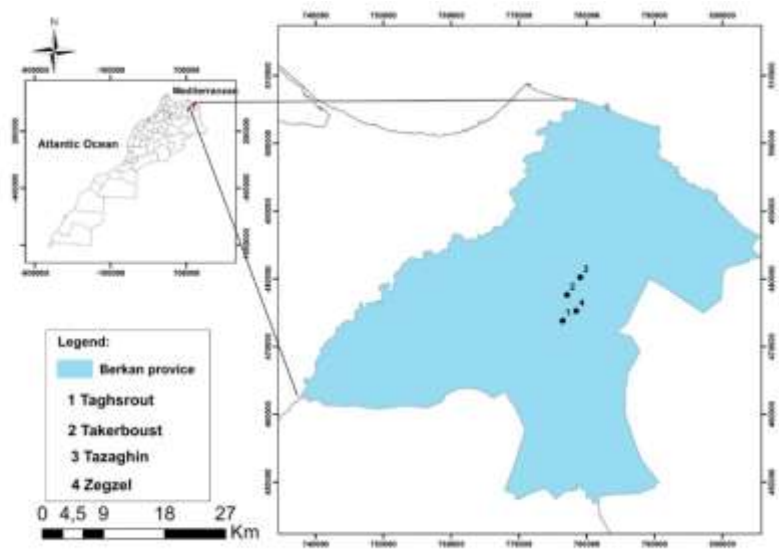

Fig. 1: Sampling location of loquat genotypes studied

Multivariate analysis

According to the PCA results, the first three components explain 37.49, 21.51 and 12.39% respectively for a total variation of 71.4% (Table 5). The first component (PC1) explained positively by weight, length, width, thickness, geometric diameter, volume and surface of fruit as well as the number of seeds per fruit, meaning that the PC1 mainly reflects fruit weight and size. For PC2, it contributed positively by thickness of the petiole, blade length, blade width, skin moisture and seed moisture, while it is contributed negatively by the soluble solids content, peduncle length and average weigh of seed. Regarding PC3, it is positively associated to leaf length, blade length, blade width, number of veins, soluble solids content and fruit sphericity index, but it is negatively associated to skin moisture, suggesting that this axis mainly reflects leaf dimensions. As result, the fruit weight and size traits are the strongest contributors to the explanation of the observed variability between genotypes. Figure 2 illustrates the distribution of the genotypes on the spatial plot formed by the first three components. The results showed a different and extended dispersion of 34 genotypes, indicating a typically continuous genetic diversity of the loquat genotypes studied. Furthermore, the hierarchical cluster analysis divided the 34 genotypes into 4 different groups according to their phenotypic and physicochemical similarity (Fig. 2). The first group (G1) composed by Z17 and Z16 genotypes, which are located on the negative side of PC1 and PC2, meaning that these genotypes are characterized by a weak value of weight, length, width, thickness, volume, geometric diameter and surface of fruit as well as a medium to high values of peduncle length and average weight of seed. On PC3, the genotype Z16 is placed in the negative side, while the genotype Z17 in the positive side. The genotypes Z16 and Z17 are distinguished by sweet fruits and a small leaf. Concerning the second group (G2), it formed by T3 and TA7 genotypes, which are situated in the positive side of the PC1 and in the negative side of the PC2. These genotypes exhibited high values of fruit weight, fruit length, fruit width, fruit thickness, fruit geometrical diameters, peduncle length and skin weight. In addition, they characterised by low values of petiole thickness, seed moisture, average weight of seed and skin moisture. In PC3, these genotypes are located on the negative part of this axis, showing a medium value for the soluble solids content and sphericity index of fruit and a low value for leaf length, blade length and blade width. The individual TA7 demonstrates a high sugar level. The third group (G3) formed by the genotypes TA13, TZN4, T6, T7 and TA14, which are scattered along the PC1 and PC2 leading to the formation of two subgroups (Fig. 3). The first one (G3.1) contained the genotypes TA13, TZN4 and T6 which have negative coordinates on the PC1,

Table 2: Phenotypic and physicochemical parameters analysed in this study

Phenotypic traits	Code
Fruit	
Fruit weight (g)	FW
Fruit length (cm)	FL
Fruit width (cm)	FWth
Fruit Thickness (cm)	FTh
Geometric diameter of the fruit (mm)	GDF
Sphericity index (cm)	SIF
Surface of the fruit (mm^2)	SAF
Volume of the fruit (cm^3)	FV
Pulp weight (g)	PW
Pulp ratio (%)	PR
Skin weight (g)	SkW
Skin moisture (%)	SkM
Length of the peduncle (mm)	LP
Firmness of the fruits (Kg/cm^2)	FF
Seed	
Number of seeds per fruit	SNF
Average weight of the seed (g)	AWS
Sphericity index of seed (cm)	SIS
Geometric diameter of seed (mm)	GDS
Seed surface (mm^2)	SS
Seed volume (cm^3)	SV
The moisture of seed (%)	SM
Leaf	
Leaf Length (cm)	LL
Length of the petiole (cm)	PL
Thickness of the petiole (cm)	PTth
Length of the blade (cm)	BL
Width of the blade (cm)	BWth
Number of veins	NR
Physicochemical Parameters	
Titratable acidity (g/L malic acid)	
The total soluble solids level (°Brix)	
pH	

Table 3: phenotypic and physicochemical characters of loquat analysed

Trait	Mean	Interval of variability
Phenotypic traits		
Fruit weight (g)	42.74	17.10 – 68.07
Fruit length (cm)	42.37	32.81 – 63.38
Fruit width (cm)	39.65	29.98 – 46.40
Fruit Thickness (cm)	37.94	28.26 – 44.79
Geometric diameter of the fruit (mm)	41.62	30.28 – 48.98
Sphericity index (cm)	0.87	0.75 – 0.98
Surface of the fruit (mm^2)	54.86	28.79 – 75.33
Volume of the fruit (cm3)	38.70	14.53 – 61.5
Pulp weight (g)	35.55	13.30 – 56.33
Pulp ratio (%)	0.83	0.78 – 0.88
Skin moisture (%)	78.69	16.82 – 33.8
Skin weight (g)	0.79	0.34 – 1.51
Length of the peduncle (mm)	27.77	11.99 – 43.15
Firmness of the fruits (kg/cm^2)	6.02	4.21 – 7.82
Average wight of the seed (g)	2.37	1.50 – 3.62
Number of seeds per fruit	3.34	1.10 – 6.2
Geometric diameter of seed (mm)	14.43	11.58 – 22.24
Sphericity index of seed (cm)	0.72	0.62 – 0.98
Seed surface (mm^2)	6.37	4.38 – 8.65
Seed volume (cm^3)	1.54	0.90 – 2.42
The moisture of seed (%)	24.13	16.82 – 33.8
Leaf length (cm)	23.72	15.77 – 29.17
Length of the blade (cm)	22.51	14.80 – 27.82
Width of the blade (cm)	7.35	4.48 – 10.41
Length of petiole (cm)	1.21	0.77 – 1.66
Thickness of petiole (cm)	0.44	0.25 – 0.54
Number of veins	28.81	18.30 – 40.80
Physicochemical parameters		
Titratable acidity (g /L malic acid)	8.26	2.18 – 14.91
The total soluble solids level (°Brix)	9.72	6.55 – 15.7
pH	3.18	2.69 – 4.15

indicating a low value of the weight, the length, the width, the thickness, the geometric diameter and the surface of fruit for these genotypes. Moreover, they have a positive coordinate on PC2 and PC3, except for T6 and TZN4 which have negative coordinates on PC 3. On both axes these individuals characterized by medium to high values of parameters contribute to these components. The second subgroup (G3.2) composed by T7 and TA14 genotypes that have negative coordinates on the PC1 with a weak value for the traits related to fruit such as the weight, the length, the width, the geometrical diameter, the volume and the surface. On PC2, the T7 and TA14, with positive coordinates, differentiated by high values of petiole thickness, skin moisture and seed moisture as well as a low value for the peduncle length and average weight of seed. In PC3, the T7 is located in the negative side, while TA14 is located in the positive side of this axis. This situation indicates that these genotypes provide high values of leaf parameters specially the leaves length and the width of the blade. The T7 and TA14 genotypes have less sweet fruits compared to the other genotypes. The last group (G4) formed by 23 genotypes such as Z7, TA9, T12, T11, TA5, T10, Z4, TA1, T5, T4, Z8, Z5, Z3, T8, TZN1, TA2, TZN2, T1, Z6, TA8, TZN3, T2 and Z2, which were bifurcated into 3 subgroups (Fig. 3). The first one (G4.1) included Z7, TA9, T12, T11, TA5, T10 and Z4 which are situated in the negative parts of PC1 and PC2 with medium to low values of fruit weight and size. Regarding PC3, these individuals are scattered in the positive and negative sides of this component with medium to low values of leaf parameters. The T12 and TA9 genotypes have the highest soluble solids content. The second subgroup (G4.2) composed by genotypes of TA1, T5, T4, Z8, Z5, Z3, T8, TZN1, TA2, TZN2 and T1. These individuals are placed on the both sides of PC1, revealing a medium to high values of weight, length, width, thickness, geometric diameter, volume and surface of fruit. On PC 2, these genotypes presented a positive coordinate, reflecting its medium to high values for petiole thickness, peduncle length, the average weight of the seed, moisture of seed and skin. For PC 3, these genotypes recorded positive and negative coordinates with high leaf size. The last Subgroup (G4.3) included individuals Z6, TA8, TZN3, T2 and Z2 that are positively correlated to PC1 with a high value for weight, volume, geometric diameter, surface, length, width and thickness of fruit. On the other hand, these genotypes, except TZN3, are negatively correlated to PC3, meaning high values of leaf length, blade width and sphericity index of fruit.

Table 4: Matrix of correlations (*r*) between several characters analysed in Moroccan loquat

Variable	LL	PTth	BL	BWth	Brix	FW	FL	FWth	FTh	GDF	FV	FS	SIF	SkW	LP	SNF	AWS	SkM
PTth	**0.62**																	
BL	**0.99**	**0.63**																
BWth	**0.74**	**0.66**	**0.73**															
Brix	-0.20	-0.27	-0.20	0														
FW	0.19	0.16	0.19	0.36	0.04													
FL	0.22	0.05	0.20	0.30	-0.34	**0.77**												
FWth	0.12	0.16	0.12	0.27	0.01	**0.97**	**0.70**											
FTh	0.13	0.18	0.14	0.29	0.09	**0.95**	**0.60**	**0.98**										
GDF	0.17	0.14	0.17	0.31	-0.11	**0.97**	**0.86**	**0.96**	**0.93**									
FV	0.16	0.10	0.16	0.31	-0.08	**0.98**	**0.86**	**0.95**	**0.92**	**0.99**								
FS	0.17	0.12	0.17	0.31	-0.09	**0.98**	**0.86**	**0.96**	**0.92**	**0.99**	**0.99**							
SIF	-0.17	0.11	-0.14	-0.09	**0.53**	0.04	**-0.59**	0.16	0.28	-0.09	-0.10	-0.10						
SkW	0.06	-0.41	0.04	0.06	0.37	**0.55**	**0.47**	**0.50**	**0.49**	**0.53**	**0.56**	**0.55**	-0.06					
LP	-0.05	-0.41	-0.07	-0.11	0.24	0.38	0.35	0.37	0.38	0.40	0.41	0.41	-0.07	**0.86**				
SNF	0.01	0.34	0.01	0.13	-0.16	**0.64**	**0.50**	**0.70**	**0.68**	**0.68**	**0.66**	**0.67**	0.09	0.10	0.07			
AWS	-0.11	**-0.45**	-0.11	-0.09	0.33	0.01	-0.15	-0.04	-0.01	-0.08	-0.05	-0.06	0.19	0.32	0.18	**-0.60**		
SkM	0.33	0.3	0.33	0.12	**-0.9**	0.10	0.39	0.09	0.01	0.2	0.19	0.19	**-0.50**	-0.31	-0.27	0.09	-0.12	
SM	0.44	0.39	**0.45**	0.17	**-0.44**	-0.09	-0.02	-0.03	-0.03	-0.03	-0.05	-0.04	-0.05	-0.31	-0.34	0.13	-0.38	0.41

The significant correlations ($P \leqslant 0.05$) are shown in bold

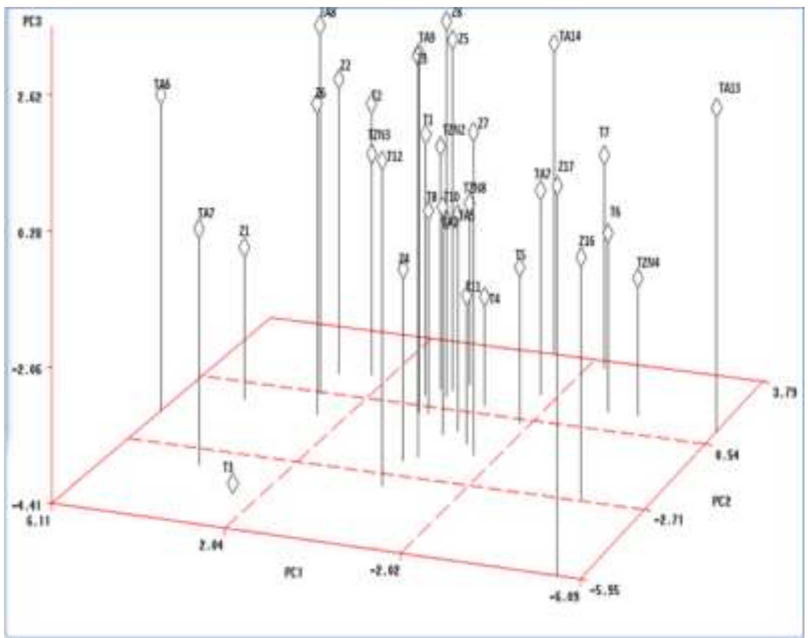

Fig. 2: Plot of the first three principal components of 34 loquat genotypes based on phenotypic and physicochemical traits

Discussion

The results of this study show that the genotypes studied could be a very interesting source of loquat genetic diversity. The fruit weight registered in this study varied between 17.1 and 68.07 g, which were in agreement with those reported by Chalak *et al.* (2014), in loquat genotypes and varieties grown in Lebanon (16.28 to 76.77 g). Moreover, these weights are moderately high compared to levels recorded in some Egyptian and Pakistani varieties (Hussain *et al.* 2011), while they are lower of the average fruit weight of Spanish varieties and genotypes (95 g) (Martínez-Calvo *et al.* 2000; Llacer *et al.* 2003). The genotypes studied in the present work are grown under a traditional management system, with an inadequate orchard technical itinerary, including the absence of pruning and thinning operations that affect significantly the fruit size (ORMVAM 2015). Concerning volume, geometric diameter, sphericity index and surface of fruit, the results obtained showed a wide variation, with ranges of 14.53–61.5 cm^3, 30.28–48.98 mm, 0.75–0.98, 28.79–75.33 mm^2, respectively.

These findings are restricted in comparison to those recorded in local loquat varieties from Turkey with a range of 1.64–83.01 cm^3 for fruit volume, 35.20–92.02 mm^2 for fruit surface, 0.7–1 for Sphericity index and 33.47–53.08 mm for geometric diameter (Boydas *et al.* 2012). The weight and pulp ratio, which are important criteria in commercial terms, ranged from 13.30 to 56.33 g and 0.78 and 0.88

Table 5: Contribution of the quantitative variables to the explanation of the three axes

Variables	PC 1	PC 2	PC 3
Length of the leaf	0.11	0.05	0.31
Petiole thickness	0.09	0.35	0.22
Blade length	0.11	0.3	0.32
Blade width	0.15	0.22	0.34
Number of veins	0.04	0.15	0.32
Brix	-0.05	-0.31	0.38
Weight of the fruit	0.34	-0.08	0.04
Length of the fruit	0.3	0.01	-0.21
Fruit width	0.33	-0.09	0.02
Fruit thickness	0.32	-0.1	0.09
Geometric diameter of the fruit	0.35	-0.05	-0.04
Volume of the fruit	0.34	-0.07	-0.04
Surface of the fruit	0.35	-0.06	-0.04
Sphericity index of the fruit	-0.04	-0.14	0.34
Length of peduncle	0.13	-0.27	0.03
Number of seeds per fruit	0.24	0.02	-0.1
Average weight of the seed	-0.04	-0.25	0.12
Moisture of the skin	0.08	0.31	-0.3
Moisture of the seed	0.01	0.3	0.0
Eigen value	7.87	4.51	2.6
Percentage variation	37.49	21.51	12.39
Cumulative variation	37.49	59.01	71.4

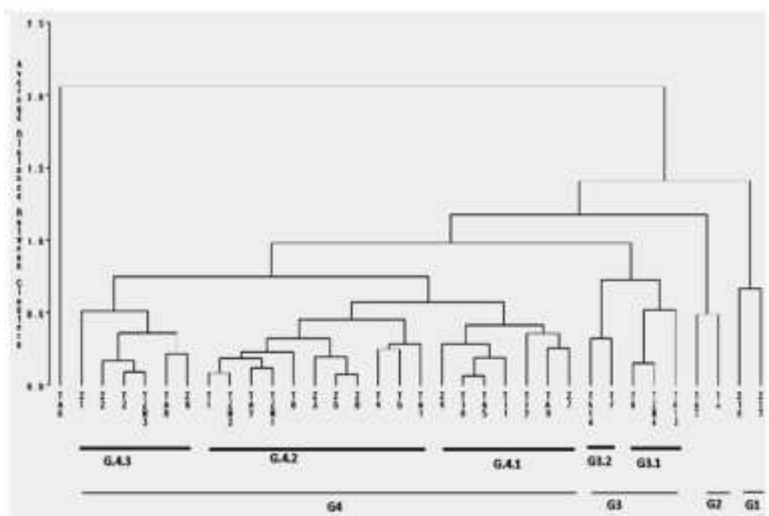

Fig. 3: Dendrogram of 34 loquat genotypes based based on phenotypic and physicochemical traits

respectively. The pulp ratio obtained in this study coincides with the most preferred level by consumer (0.80 and 0.86 g), meaning the most suitable for the market (Ercisli *et al*. 2012). Regarding the average weight of seed, it ranged from 1.5 to 3.62 g and it seems to be higher in comparison with those published in other loquat genotypes (Hussain *et al*. 2011). Furthermore, the results obtained for the leaf revealed a leaf length and a blade width ranging from 15.77 to 29.17 cm and 4.48 to 10.41cm respectively. These results are in agreement with the levels registered by Elsabagh and Haeikl (2012) (19.5–25.25, 6.13–9.85 cm respectively). In addition, the titratable acidity level varied from 2.18 to 14.91 g.L^{-1} of malic acid, which is in accordance with the results registered by Martínez-Calvo *et al*. (2000) (2.5–17 g.L^{-1} malic acid). According to Amorós *et al*. (2003), the variation of the acidity values of the genotypes is mainly due to the stage of maturity and the earliness of production of the varieties. As regards the soluble solids content, the range of variability is between 6.55 and 15.7 °Brix, which is comparable to the range revealed by Elsabagh and Haeikl (2012) (10.86–11.89). Nevertheless, these amounts are considered lower than the amount revealed by Martínez-Calvo *et al.* (2000). The sweet loquat fruit has the highest soluble solids content, meaning that the genotypes T12, Z16, Z17 and TA9 are the richest in sugar and this richness can be explained by tardiness fructification of these genotypes. Indeed, the fruits of tardiness fructification varieties are sweeter than those of earliest varieties (Pareek *et al.* 2014). Regarding the pH parameter, the recorded values ranged from 2.69 to 4.15, while Abozeid and Nadir (2012) reported a pH value around

4.32. Consequently, loquat genotypes analyzed in the present study have an acidic fruit. These variations could be due to genetic, agronomic, and climatic factors (Ercisli *et al*. 2012).

In order to deepen the understanding of Moroccan loquat variability, the knowledge of the relationships between variables is crucial because it helps to identify a primary variable with low heritability and/or difficult to measure based on one or more other variables (Matias *et al*. 2016). Indeed, the correlation matrix between the different characters studied showed a positive correlation of fruit weight with fruit length ($r = 0.77$), fruit width ($r = 0.97$) and fruit thickness ($r = 0.95$), which is similar to correlation result of Martínez-Calvo *et al*. (2000). Furthermore, fruit width was significantly correlated with thickness, volume, geometric diameter and surface of fruit with coefficients of $r = 0.98$; $r = 0.95$; $r = 0.96$; $r = 0.96$ respectively. Moreover, the seed number was positively correlated with fruit weight, fruit dimensions and fruit geometric characters. These correlations are concordant with those reported by Elsabagh and Haeikl (2012). According to the PCA results, the characters related to the fruit weight and size are the most discriminant. In addition, hierarchical analysis based on phenotypic and physicochemical parameters classified the Moroccan loquat genotypes into four homogeneous groups independently of their geographical origin. The similarities detected between the genotypes can be explained by the propagation methods used by the farmers, especially by grafting of genotypes with good quality fruits.

Conclusion

The results of the analyses applied on the phenotypic and physicochemical characters of the 34 genotypes studied showed the existence of a large variability of the loquat genotypes. Fruit weight and size of genotypes showed medium to high values and are the most powerful to distinguish genotypes. This genetic variability may be a basis for this species to survive over the long term and adapt to environmental changes, especially climate change.

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Author Contributions

All authors participated in the elaboration, discussion of the results, and writing of this paper and they assume responsibility for the content of the manuscript.

Conflicts of Interest

The Authors declare that there is no conflict of interests that could possibly arise.

Data Availability

Data is available with the corresponding author.

References

Abozeid WM, AS Nadir (2012). Physicochemical and organoleptic characteristics of loquat fruit and its processing. *Nat Sci* 10:108–113

Amorós A, P Zapata, MT Pretel, MA Botella, M Serrano (2003). Physicochemical and physiological changes during fruit development and ripening of five loquat (*Eriobotrya japonica* Lindl.) cultivars. *Food Sci Technol Intl* 9:43–51

Badenes ML, J Janick, S Lin, Z Zhang, GL Liang, W Wang (2013). Breeding loquat. *Plant Breed Rev* 37:259–284

Baljinder S, G Seema, K Dharmendra, GV Ikas, B Parveen (2010). Pharmacological potential of Eriobotrya japonica – an overview. *Intl Res J Pharm* 1:95–99

Boydas M, B Sayinci, S Gozlekci, I Ozturk, S Ercisli (2012). Basic physical properties of fruits in loquat (*Eriobotrya Japonica* (Thunb. Lindl.) Cultivars and genotypes determined by both classical method and digital image processing. *Afr J Agric Res* 7:4171–4181

Chalak L, A Noun, H Youssef, B Hamadeh (2014). Diversity of loquats (*Eriobotrya japonica* Lindl.) cultivated in Lebanon as assessed by morphological traits. *Sci Hortic* 167:135–144

Elsabagh AS, AM Haeikl (2012). Fruit characteristics Evaluation of four new loquat genotypes grown in Egypt. *J Agric Biol Sci* 8:197–200

Ercisli S, S Gozlekcib, M Sengulc, A Hegedusd, S Tepee (2012). Some physicochemical characteristics, bioactive content and antioxidant capacity of loquat (*Eriobotrya japonica* (Thunb.) Lindl.). *Fruits Turk* 148:185–189

Hussain A, NA Abbasi, IA Hafiz, A Shakor, SMS Naqvi (2011). Performance of loquat (*Eriobotrya japonica*) genotypes under agro-ecological conditions of Khyber Pakhtunkhwa province of Pakistan. *Intl J Agric Biol* 13:746–750

Llacer G, ML Badenes, JM Calvo (2003). Plant material of loquat in Mediterranean countries. *In: Proceedings of the First International Loquat Symposium*, Vol. 58, pp:45–52. Options Mediterraneennes

Martínez-Calvo J, ML Badenes, G Llácer (2000). *Descripción de variedades de Níspero japonés.* Generalitat Valenciana, Consellería de Agricultura, Pesca y Alimentación, IVIA, Valencia, Spain

Matias R, D Silva, P Miranda, J Oliveira, L Pimentel, CH Bruckner (2016). Relationship between fruit traits and contents of ascorbic acid and carotenoids in peach. *Crop Breed Appl Biotechnol* 16:348–354

ORMVAM – Regional Office of Agricultural Value of Moulouya 2015. Published on Map News (https://www.mapnews.ma/fr)

Pareek S, N Benkeblia, J Janick, S Caod, E Yahia (2014). Postharvest physiology and technology of loquat (*Eriobotrya japonica* Lindl.) fruit. *J Sci Food Agric* 94:1495–1504

Rhomari Y (2013). le néflier de Zegzel. *In: Agriculture du Maghreb*. *n°67*, pp: 148–152. ORMVA of Moulouya. Morocco

Serrano M, PJ Zapata, M Pretel, MS Almansa, MA Botella, A Amorós (2003). Changes in organic acids and sugar levels durong ripening of five loquat (*Eriobotrya japonica* Lindl.) cultivars. *Opt Mediterr* 58:157–160

Shewfelt RL (1999). What is quality? *Postharv Biol Technol* 15:197−200

Skiredj A, WLD Elmacane (2003). LE cognassier, le néflier, le fraisier, le pêcher et le figuier de barbarie. *In: Transfert de Technologie*, pp:1−2. Institut Agronomique et Vétérinaire Hassan II, Rabat, Morocco

UPOV (1998). *Guidelines for the conduct of tests for distinctness, uniformity and stability of loquat (Eriobotrya japonica (Thunb.) Lindl.)* International Union for the Protection of New Varieties of Plants. Geneva, Switzerland

Viera W, I Samaniego, D Camacho, N Habibi, L Ron, N Sediqui, J Álvarez, P Viteri, A Sotomayor, J Merino, W Vasquez-Castillo, B Brito (2022). Phytochemical characterization of a tree tomato (*Solanum Betaceum* Cav.) breeding population grown in the Inter-Andean Valley of Ecuador. *Plants* 11:268–273