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Original Research Paper

Assessment of physico-biochemical parameters of Moroccan loquat (*Eriobotrya japonica* Lindl.) genotypes using multivariate analysis

Kabiri G.[1], Kodad O.[2], Hernandez F.[3], Lachkham F.[1] and Hanine H.[1*]

[1]Laboratory of Industrial Engineering and Surface Engineering, Faculty of Sciences and Techniques, University of Sultan Moulay Slimane Beni Mellal, Morocco;
[2]Department of Horticulture and Viticulture, National School of Agriculture, Meknes, Morocco;
[3]Fruit Growing and Production Techniques Research Group, Institute for Agri-food and Agri-environmental Research and Innovation (CIAGRO-UMH), Miguel Hernández University, Carretera de Beniel, km 3.2, 03312 Orihuela, Spain
*Corresponding author Email: h.hanine@usms.ma

ABSTRACT

The present study was conducted to assess the physico-biochemical variability in 35 genotypes of loquat using multivariate analyses, in order to provide efficient criteria and promising genotypes for the loquat genetic breeding program. Mature fruits were collected from 35 loquat genotypes, belonging to the Zegzel valley, were subjected to physico-biochemical analyses. The results revealed a juice yield ranging from 0.21 to 0.65 g/g FW, and a polyphenols content fluctuating from 322.8 to 366.89 µg GAE. g-1 DM. Regarding DPPH test, with a range of 3.35 and 7.6 µmol TE. g^{-1} DM, showed a positive correlation with total polyphenol content (r^2= 0.76) and flavonoid content (r^2= 0.72). Moreover, a negative correlation was recorded between the total soluble solids content and juice yield (r^2=- 0.47), which was moderately correlated with vitamin C (r^2= 0.59). In addition, the components analysis results revealed a significant and independent contribution of bio-physicochemical characteristics in the loquat variation. Indeed, biochemical characteristics contribute to PC1, while, physicochemical parameters contribute to PC2 and PC3. Furthermore, the hierarchical clustering analysis classified the 35 genotypes into four homogeneous groups independently of their geographic origin. According to these findings, the genotypes T9, T12, Z16, Z17 and TA9 exhibited high total sugar content, while, genotypes T9 and T11 provide high carotenoids, flavonoids, total polyphenols and antioxidant activity level. As results, these genotypes can be directly recommended for the vegetative propagation as well as applied along with the efficient characters in future loquat breeding programs.

Keywords: Biochemical, Loquat, multivariate, physicochemical, variability

INTRODUCTION

Loquat (*Eriobotrya japonica* Lindl.) is an evergreen tree belonging to the Rosaceae family. The plant is native to China and was extensively cultivated for commercial purposes since the 19th century (Gariglio et al., 2002). The most prominent loquat producers are China and Japan. Regarding the Mediterranean region, Spain and Turkey are the countries where this crop has progressed spectacularly over the last 20 years (Virginia et al., 2011). The loquat fruit is consumed as fresh fruit due to its excellent flavor, abundant nutritional values and medical applications (Sun et al., 2020). In Morocco, this plant is cultivated as a commercial fruit crop as well as an ornamental crop for its yellow fruits (Hussain, 2011). This crop occupies very specific locations throughout the country, such as the region of Berkane, especially the Zegzel valley which produces more than 10,000 tons in 2021. In this year, fruit production is increased with a significant improvement in the size and taste quality of this local product. These positive results are due to an accompanying program that was initiated during 2016 and concerned the development and valorization of loquat fruits through the purchase of technical materials (ORMVAM, 2021). These programs can be added to the application of various statistical tools which is considered as efficient strategy for analysis of genetic association among breeding materials and germplasm classification (Mohammadi & Prasanna, 2003). Indeed, the multivariate data analysis (MVDA) is used to better understand the structure of germplasm collections to reveal the most pertinent variables and to identify relationships between accessions. As a result, these analyses will help to elaborate a “core collection”, which is very important in terms of

Table 1 : Plant material studied and corresponding codes

Geographical origin	Distance from Berkane (km)	Loquat area (H)	Genotypes codes	Number of samples
Takerboust	8	150	T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12,	12
Taghsrout	12	50	TA1, TA2, TA5, TA6, TA7, TA8, TA9, TA13, TA14	9
Tazaghin	16	35	TZN1, TZN2, TZN3, TZN4	4
Zegzel	20	150	Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z16, Z17	10
			Total	35

germplasm conservation (Leguizamón & Badenes, 2003). In Morocco, the limited research on this plant requires further investigations to provide efficient information and recommendations to obtain a deeper comprehension of the loquat chemical variation and improve the genotype identification. In this regard, the objective of this study was the application of multivariate analysis to effectually explore the loquat physicochemical and biochemical variation and relationships between these two important aspects as well as to identify promising traits and genotypes which could be manipulated in future loquat breeding programs.

MATERIALS AND METHODS

Plant material

In April-May 2015, a survey performed on loquat plantations of the Zegzel valley belonging to the Berkane region. This valley is characterized by a warm and sunny microclimate, an average annual rainfall of 466 mm and well-drained fertile soils. The density of the plantation in the large hydraulic perimeters varied from 260 to 280 trees per hectare (ORMVAM, 2015). This prospection led to identify 35 loquat genotypes from Zegzel, Takerboust, Taghsrout and Tazaghin region. (Table 1, Fig. 1). The choice of these genotypes based on number of agronomic and economic criteria, such as tardiness and earliness, shape, size and fruit color, leaves shape as well as the good physical condition of the tree. From each genotype, a healthy fruit were randomly collected and placed in a cooler and transported immediately to the laboratory for physicochemical and biochemical analysis.

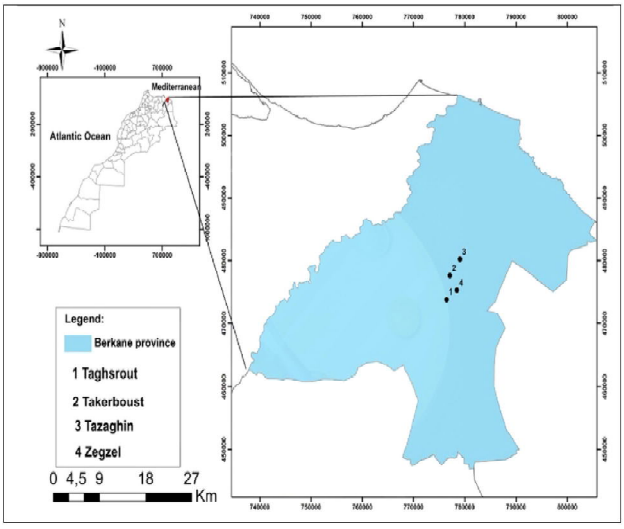

Fig. 1 : Sampling sites of loquat genotypes studied

Determination of juice yield

The loquat fruits were washed, cut into pieces and pulped. Subsequently, the pulp was maintained at 20±1 °C for 3 h and then centrifuged at 12000× g/10 min at 4 æ%C. The supernatant was collected as loquat juice. The juice yield was calculated using the following formula:

$$\text{Juice yield} = \frac{\text{Mjuice}}{\text{Mpulp}}$$

Mjuice: the weight of loquat juice

Mpulp: the weight of loquat pulp

Where,

The juice yield is expressed as *g* of *juice* per *g* of fresh weight (*FW*).

Determination of physicochemical parameters

Soluble solid content

Total soluble solids were determined by a refractometer (ATAGO C.O 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 total soluble solids were expressed in term of °Brix.

Titratable acidity

The titratable acidity was measured by potentiometric titration using a standardized alkaline solution (Serrano et al., 2003). An amount of 10 ml of fruit juice was diluted in 50 ml of distilled water and then titrated with a 0.1 NaOH solution until pH=8.2 was reached. Titratable acidity was expressed per g of malic acid L^{-1}.

pH value

The pH values of the fruit juice were recorded using an electronic pH meter (PH211R, HANNA®).

Determination of biochemical parameters

Extraction procedure

The extraction was performed according to the method described by Xu & Chen (2011). An amount of 10 g of lyophilized fruit was homogenized in 25 ml of absolute methanol using vortex apparatus. The homogenates were kept at 4 °C for 12 hours and then centrifuged at 6000 rpm for 20 min. The supernatants were collected and the extraction of the residue was repeated three times under the same conditions. The collected supernatants were combined and stored at -20 æ%C until further analysis.

Total polyphenols

Total polyphenols were determined using the Folin-Ciocalteu method (Singleton & Rossi, 1965). A 0.1 ml of the loquat extract was mixed with 5 ml of Folin-Ciocalteu (0.2 mol/l). After a 5 min, 4 ml of sodium carbonate (150 g/l) were added. The incubation was performed for 90 min in the dark and followed by the absorbance measurement at 765 nm. The results expressed as µg gallic acid equivalent per g of DW.

Total flavonoids

The determination of flavonoids was determined using the Xu & Chen (2011) protocol. Indeed, 2 ml of the methanolic extract were mixed with 3 ml of distilled water as well as 0.3 ml of sodium nitrate (0.72 mol/L). After 5 min, 0.6 ml of aluminum trichloride at 0.41 mol/L was added. After another 6 min, 2 ml of sodium hydroxide (1M) and 2.1 ml of distilled water were added to the mixture. The absorbance was measured at 510 nm and the results were reported as µg Rutin equivalent per g of DW.

Ascorbic acid content

The ascorbic acid content of the fruit extracts was measured by titration with the *2,6-dichlorophenolindophenol* (*DPIP*) (AOAC, 2000). Following this protocol, 1 g of lyophilized fruit was mixed with 40 ml of buffer consisting of 1 g/l oxalic acid as well as 4 g/l anhydrous sodium acetate. Then, the mixture was titrated with a solution comprising 295 mg/l DPIP and 100 mg/l sodium bicarbonate. The standard L-ascorbic acid AnalaR (BDH, Buffalo, NY USA) was used to prepare a standard curve. The results expressed as g ascorbic acid equivalent (AAE) per g of DW.

Carotenoids

Carotenoids amounts were analyzed with the method provided by Xu & Chen (2011). Briefly, 2 g of lyophilized fruit was mixed with 25 ml of acetone / ethanol mixture (1: 1 v / v) including 200 mg / l butylated hydroxytoluene. The homogenate was filtered under vacuum, then the residue was washed with extraction solvent and was completed to 100 ml with the same solvent. The extracts were transferred to decanting ampoule with 50 ml of hexane. The container was shaken and kept to stand for 15 min. Then, 25 ml of distilled water were introduced and the mixture was agitated again and allowed to separate in order to recover the organic phase after 30 minutes. The spectrophotometer was calibrated with hexane and the absorbance of the samples was measured at 470 nm. The carotenoids results were presented as µg β carotene equivalent per g.

Antioxidant activity

The antioxidant activity of the extracts evaluated according to the protocol of Xu & Chen (2011) using DPPH assay. In fact, 3 ml of DPPH solution (0.1mmol/l) was added to 0.1 ml of the methanolic extract. After 30 min of incubation in the dark and at room temperature the absorbance was measured at 517 nm. The anti-radical activity estimated as percentage of inhibition by the following formula:

$$\text{Percentage Inhibition (\%)} = \frac{Ab_{517\ sample}\ nm - Ab_{517 controle}\ nm}{Ab_{517\ sample}\ nm} \times 100$$

Results were expressed as µmol Trolox equivalent (TE) per g of DW.

Statistical analysis

The obtained data were submitted to several statistical analyses, such as descriptive analysis as well a correlation test using Pearson's correlation coefficient ($\alpha = 0.05$). Furthermore, Principal Components Analysis (PCA) and the hierarchical cluster analysis, were applied. These analyses were carried out using SAS Version 10.0 software (SAS Institute Inc., 1988). All experiments were evaluated in triplicate.

RESULTS AND DISCUSSION

Physicochemical and biochemical variation

The results of physico-biochemical parameters analyzed, are presented in Table 2. The juice yield, which is the most important index for juice production, ranged from 0.21 to 0.65 g/ g FW with an average of 0.44. The titratable acidity showed a level of 2.18-4.91 g/L of malic acid with an average of 5.69. As for the total soluble solids, the recorded values were between 6.55 and 15.7 °Brix, with an average of 7.17. For pH, the highest registered value is 4.15 while the lowest is 2.69 with an average of 3.18. The titratable acidity obtained in this work coincide slightly with the results of Martinez-Calvo et al. (2000), with values varied from 2.5 to 17g/L of malic acid. Amoros et al. (2003) indicated that the difference of acidity values among loquat genotypes is mainly due to the maturity stage and earliness production. For pH parameter, the achieved values are weak revealing an acidic fruit of the genotypes studied. Similarly, Abozeid & Nadir (2012) reported that the loquat pH is about 4.32. Regarding the biochemical parameters, the polyphenols varied from 322.8 to 366.89 µg GAE. g^{-1} DM, as well as the flavonoids ranged from of 71.39 to 76.81 µg RE. g^{-1} DM with an average of 343.67 and 73.34, respectively. The ascorbic acid content showed an amount of 42.04 -153.99 µg AAE. g^{-1} DM, with an average of 96.43. As for the carotenoids, the maximum content registered is 13.76 µg of β-carotene. g^{-1}, while, the minimum is 2.3 µg β-carotene g^{-1}, with an average of 7.17. In addition, the result of antioxidant activity evaluation, using the DPPH test, oscillated between 3.35 and 7.6 µmol TE g-1 DM. These findings are in agreement with the results of Hong-Xia et al. (2014), who previously showed that total phenolic, total flavonoids and total antioxidant activity (DPPH) ranged from 0.66 to 0.96 mg g^{1} GAE, 0.09 to 0.21 mg g^{-1} and 2.91 to 4.93 µmol TE g^{-1}, respectively in six loquat cultivars.

Correlation between the physico-biochemical parameters

Correlation analyses are commonly used in breeding programs to determine traits that are difficult or expensive to measure. The knowledge of the relationships between variables allows a breeder to identify a primary variable with low heritability and/ or difficult to measure based on another variable(s), thus allowing for faster progress than direct selection (Matias et al., 2016). The correlations matrix of fruit physicochemical and biochemical characteristics (Table 3) recorded pertinent associations.

Table 2 : Physico-biochemical parameters analyzed

Parameter	Min.	Max.	Mean	SD
Juice yield (g/g FW)	0.206	0.645	0.444	0.089
Titratable acidity (g / L malic acid)	2.18	14.91	5.69	2.90
The total soluble solids (°Brix)	6.55	15.7	7.17	2.25
pH	2.69	4.15	3.18	0.34
Polyphenol (µg GAE. g^{-1} DM)	322.8	366.89	343.67	11.01
Flavonoids (µg RE. g^{-1} DM)	71.39	76.81	73.34	1.18
Ascorbic acid (µg AAE. g^{-1} DM)	42.04	153.99	96.43	24.24
Carotenoids (µg β carotene. g^{-1})	2.3	13.76	7.17	2.73
DPPH (µmol TE. g^{-1} DM)	3.35	7.6	5.35	1.04

Table 3 : Correlation matrix between physico-biochemical parameters of loguat genotypes

Variable	Juice yield	TSS	TA	pH	DPPH	Carotenoids	Flavonoids	Polyphenols
Juice yield	1							
TSS	-0.34*	1						
TA	0.03	-0.14	1					
pH	0.08	0.003	-0.63***	1				
DPPH	0.03	0.001	0.27	0.005	1			
Carotenoids	-0.04	0.20	-0.36*	0.08	0.21	1		
Flavonoids	-0.11	-0.05	0.24	-0.06	0.72***	0.26	1	
Polyphenols	0.1	-0.06	0.35*	-0.08	0.75***	0.18	0.69***	1
Ascorbic acid	0.49**	-0.21	0.001	0.18	0.13	0.05	0.04	0.09

TSS: total soluble solids, TA: titratable acidity; Significance level *: $p < 0.05$; **: $p < 0.01$ ***: $p < 0.001$

The antioxidant activity is positively correlated with the total polyphenol content (r^2= 0.76) and the flavonoid content (r^2= 0.72). Similarly, flavonoids were positively correlated with total polyphenols (r^2= 0.69). Numerous studies, reported a high correlation of antioxidant activity with polyphenol and flavonoid content (Becerril-Saìnchez et al., 2021). Indeed, these findings are in accordance with the results of loquat study conducted by Xu & Chen (2011), which recorded on the hand a positive and significant correlations of polyphenols with flavonoids ($r = 0.92$, $P < 0.01$) and DPPH ($r = 0.70$, $P < 0.05$) and on the other hand a positive and significant correlations of flavonoids with DPPH ($r = 0.75$, $P < 0.01$). The antioxidant activity is due to the presence of different antioxidant components in plant tissues. In fact, previous studies have reported that the antioxidant activity of bioactive components such as TPC, tannin, anthocyanin, TFC, phenols, alkaloids, and pro-anthocyanins is mainly promoted by their unusual redox properties (Muflihah et al., 2021). In addition, a negative correlation was registered between titratable acidity and pH as well as carotenoids (r^2= -0.63; r^2= -0.36 respectively). Moreover, a negative correlation was revealed between the total soluble solids content and juice yield (r^2=- 0.34) which was strongly and positively correlated to ascorbic acid (r^2= 0.49), which mean that the sweeter fruits provide a lower juice yield.

Physico-biochemical characteristics contributing to genotypes variation

The PCA was applied to identify the parameters that constitute the main source of variation in Moroccan loquat tree. The first three principal components explain 73.45% of the total variance with 30.83%, 25.74% and 16.88%, respectively (Table 4). The flavonoid, carotenoids, polyphenols and DPPH test contribute positively to the PC1, conferring to this latter, an axis of biochemical traits. Moreover, the highest contribution to PC2 corresponded negatively to the total soluble solids content and pH, while it corresponded positively to juice yield, titratable acidity, ascorbic acid and polyphenols. This axis mainly reflects physicochemical parameters. Regarding the PC3, the values indicated that ascorbic acid, pH, and juice yield had the greatest positive contribution, while titratable acidity had the strong negative contribution to this component (Table 5). Based on the results obtained, the physico-biochemical parameters analyzed are potentially useful as discriminant criteria. These results are in agreement with those reported by Arantino et al. (2022), which found that chemical parameters namely juice yield, pH, total soluble solids,

Table 4 : Eigen values and proportion of total variability explained by the first three principal components

Components	Eigen value	Variance (%)	Cumulative variance (%)
PC1	2.77	30.83	30.83
PC2	2.31	25.74	56.57
PC3	1.51	16.88	73.45

Table 5 : Contribution of physico-biochemical parameters to the formation of the three components

Variables	PC1	PC2	PC 3
Juice yield	-0.27	0.33	0.44
Total soluble solids	0.25	-0.36	-0.23
Titratable acidity	-0.05	0.52	-0.41
pH	0.14	-0.35	0.51
DPPH	0.51	0.21	0.1
Carotenoids	0.36	-0.23	0.21
Flavonoids	0.47	0.27	0.04
Total polyphenols	0.45	0.34	0.07
Ascorbic acid	-0.18	0.3	0.52

titratable acidity and antioxidant activity allowed for a significant differentiation among the pomegranate cultivars studied.

Genotypes characterization and identification of potential groups

The PCA plot constructed on the three first components, allowed to reveal a distinct and extended distribution of the 35 genotypes studied (Fig. 2). In addition, the hierarchical cluster analysis led to classify these individuals, according to their physicochemical and biochemical content (Table 6), into four main homogeneous groups independently of their geographic origin (Fig. 3). The first group, formed by T9 and Z17 genotypes, revealed with coordinate that are positive on PC1 and negative on PC 2 and PC3. On the hand, the genotype T9 is located on the positive side of PC1 with high values of antioxidant activity (7.60 µmol TE/g), carotenoids (13.76 µg β carotene/g), flavonoids (74.32 µg RE/g), and total polyphenols (355.66 µg EAG/ g). The genotype Z17, positioned in the positive median part of PC1, exhibiting low to medium values of biochemical traits (DPPH, carotenoids, flavonoids and polyphenols). On the other hand, both are characterized by very high values of the total soluble solids content (15.7 and 15.2 °Brix, respectively), low juice yield (0.20 and 0.28 g/g FW, respectively), very low ascorbic acid content (42.04 and 57.6 µg AAE/ 100g, respectively), high pH value and low titratable acidity. These results are consistent with the correlation matrix showing that juice yield correlated negatively with the total soluble solids content and positively with ascorbic acid, meaning that the sweet fruit produce a low juice yield. Regarding the second group, it included genotypes T4, T1, T5, T11, T3, Z5, T8 and T2. On PC1, these genotypes are located in the positive side distinguished by high values of polyphenols and flavonoids (344.7 to 366.8 µg EAG/ g; 74.02 to 76.81 µg ER/g respectively) as well as a medium values of carotenoids, providing a great level of antioxidant activity.

For PC2, these genotypes are located on the positive side and revealed medium to high values for titratable acidity and the total soluble solids content. In PC3, they are distributed along the axis with positive and negative coordinates and characterized by medium to high values for juice yield, ascorbic acid content and medium to low values for pH. The large third group containing Z2, T7, TA5, TA2, Z3, Z4, Z16, TA13, T12, TA7, Z1, Z6, Z7, Z8, TZN2, TA6, T6, TA1, TA8, TA9, TA14, T10 and TZN1 genotypes, can be divided into four subgroups. The first subgroup composed by genotypes Z2, T7, TA5 and TA2 which were located on the negative part of PC1, exhibiting a medium to high values of flavonoids, carotenoids, total polyphenols and DPPH. On PC2, these genotypes are located on its positive median part, with lower values of the total soluble solids and titratable acidity. As for PC3, these individuals are located at its positive side with a high juice yield rich in ascorbic acid. Concerning the second subgroup formed by genotypes Z3, Z4, Z16, TA13, T12 and TA7, presenting positive coordinates on PC1 and negative coordinates on PC2, showed medium amounts of flavonoids, carotenoids, total polyphenols and antioxidants (DPPH). In general, the fruits of these genotypes are rich in total soluble solids (9.95 to 13.20 °Brix). The third subgroup, including Z1, Z6, Z7, Z8, TZN2, TA6 and T6, recorded negative coordinates on PC1 as well as positive coordinates on PC2. These individuals, rich in flavonoids, total polyphenols and ascorbic acid,

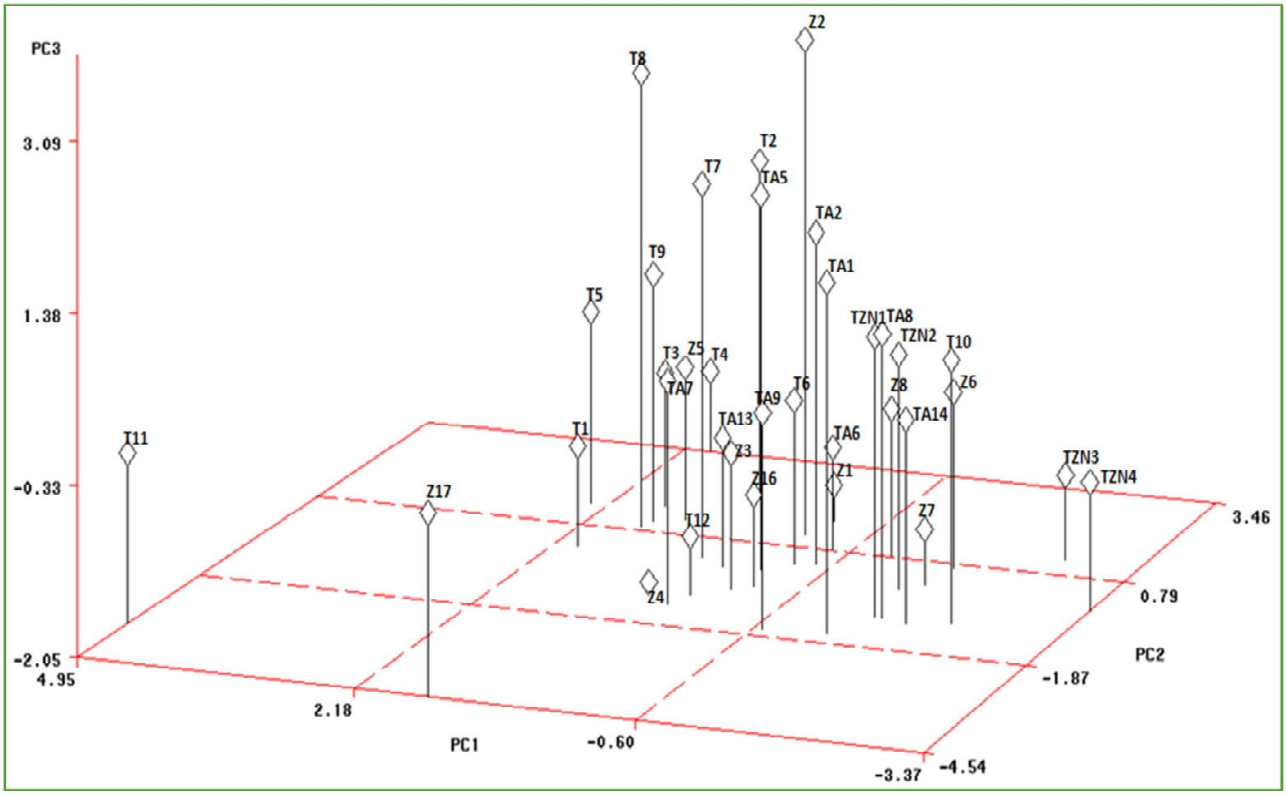

Fig. 2 : Distribution of the 35 loquat genotypes on the first three principal component

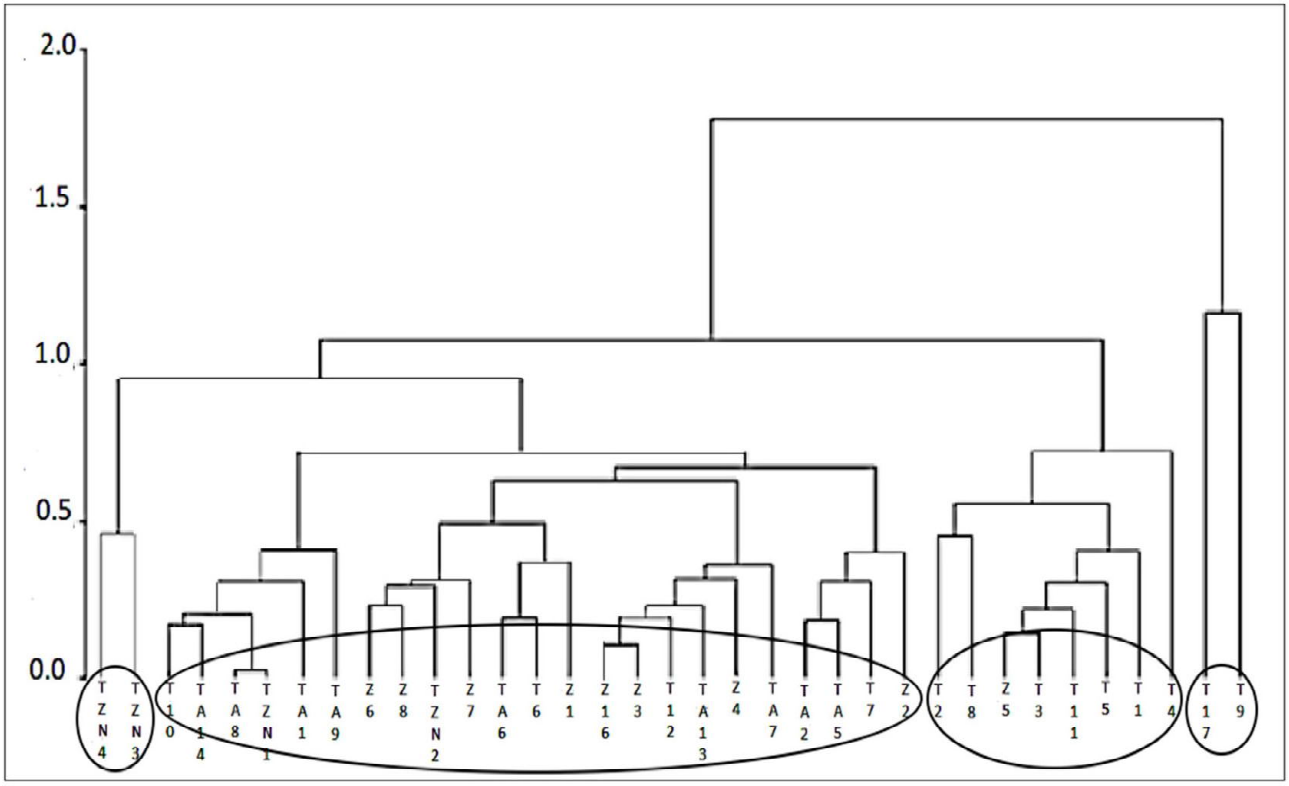

Fig. 3: Dendrogram of the 35 loquat genotypes based on physico-biochemical parameters

Table 6 : Means and SD of the physico-biochemical parameters

Genotype	Juice yield (g/ g FW)	Carotenoids (µg β carotene. g^{-1})	Flavonoids (µg RE. g^{-1})	Polyphenol (µg GAE. g^{-1})	Ascorbic acid (µg AAE. g^{-1})	DPPH (µmol TE. g^{-1})	TSS (°Brix)	TA (g / L malic acid)	pH
T1	0.339±0.06	8.9±0.85	76.81±2.59	344.71±2.42	76.96±2.77	5.01±0.30	10.15±0.92	8.61±1.15	3.04±0.34
T10	0.503±0.02	7.27±0.54	72.13±1.57	322.8±3.96	111.37±1.94	4.05±0.21	9.05±0.45	6.87±0.25	3.2±0.71
T11	0.443±0.05	11.82±0.28	74.33±0.66	353.34±4.72	112.65±5.16	6.43±0.18	8.5±0.57	8.91±0.24	2.91±0.44
T12	0.403±0.02	7.64±0.93	73.32±1.44	331.47±0.76	75.33±0.89	5.82±1.46	13.2±1.06	9.05±0.10	2.95±0.86
T2	0.538±0.07	8.48±0.54	74.45±0.92	355.04±2.88	141.91±2.70	6.54±0.48	8.75±1.09	9.65±0.44	3.07±0.07
T3	0.394±0.01	9.79±0.66	74.39±1.26	362.31±4.13	105.36±1.07	5.97±1.40	9.3±0.41	10.45±0.74	2.69±0.81
T4	0.425±0.04	4.3±0.45	76.07±1.06	366.89±3.92	89.32±2.01	6.58±0.61	7.55±0.81	14.91±1.24	2.94±0.41
T5	0.454±0.06	6.79±0.92	74.73±2.94	363.89±3.10	77.01±0.82	7.48±0.83	8.8±1.12	8.71±0.51	3.15±0.17
T6	0.411±0.03	5.68±0.75	73.66±3.35	342.99±1.12	100.33±2.19	5.29±0.27	9.00±0.62	7.47±0.31	2.95±0.38
T7	0.5±0.01	9.31±0.75	74.89±2.35	344.23±6.76	105.9±1.64	5.68±0.64	7.00±1.43	5.16±0.25	3.42±0.85
T8	0.558±0.07	8.11±0.14	74.5±1.95	353.97±3.10	126.78±1.30	7.29±0.71	9.35±0.93	7.17±0.99	3.78±0.93
T9	0.206±0.02	13.76±1.54	74.32±1.15	355.66±5.80	42.04±2.18	7.6±0.72	15.2±0.31	3.69±0.10	3.89±0.32
TA1	0.338±0.04	2.77±0.17	72.64±3.34	331.68±1.15	108.92±4.55	4.77±0.76	6.65±0.95	5.03±0.35	4.15±0.37
TA13	0.381±0.10	6.59±0.78	73±1.41	351.02±1.51	100.28±0.71	5.35±0.45	11.5±0.72	8.94±0.54	3.04±0.13
TA14	0.461±0.04	2.77±0.48	72.07±0.81	335.2±3.73	85.54±3.31	4.29±0.08	9.15±0.89	4.99±0.69	3.31±0.30
TA2	0.585±0.11	10.96±0.88	72.99±2.47	345.56±4.84	94.73±1.81	5.04±0.08	6.85±0.83	7.1±1.03	3.18±0.08
TA5	0.517±0.04	7.28±0.21	73.29±2.45	346.53±7.48	115.75±4.82	5.81±0.24	8.6±0.99	5.39±0.11	3.47±0.14
TA6	0.445±0.02	4.03±0.07	72.92±2.08	345.18±1.19	97.23±7.18	5.46±0.33	11.05±0.25	12.46±0.72	3.15±1.16
TA7	0.493±0.06	9.53±0.30	73.07±1.02	342.16±1.00	64.44±0.93	5.35±0.31	10.6±0.21	5.76±0.21	3.34±0.28
TA8	0.383±0.09	8.65±0.59	72.41±0.74	324.58±3.13	145.25±1.91	4.38±0.21	9.5±0.74	6.47±0.34	3.13±0.61
TA9	0.448±0.03	7.8±0.99	72.59±2.28	333.98±4.00	93.74±0.79	4.56±0.62	11.9±1.30	5.03±0.08	3.21±0.65
TZN1	0.488±0.07	8.54±0.27	72.09±2.62	335.51±0.86	88.5±3.96	4.15±0.04	6.85±0.96	5.53±0.42	3.3±0.28
TZN2	0.464±0.05	5.88±1.03	72.26±0.24	341.71±1.29	104.42±1.16	4.59±0.35	7.6±0.71	6.03±0.20	3.03±1.19
TZN3	0.551±0.06	2.3±0.40	71.96±0.82	338.83±2.90	75.68±1.39	4.21±0.13	6.95±0.23	12.16±1.16	2.91±0.16
TZN4	0.5±0.04	5.29±0.04	71.39±0.92	324.21±1.43	86.21±0.52	3.35±0.14	6.55±0.45	10.16±0.10	2.97±0.89
Z1	0.382±0.09	5±0.16	73.66±0.59	341.39±0.83	91.13±0.47	6.12±0.49	8±0.48	13.84±1.34	2.82±0.37
Z16	0.416±0.02	6.12±0.20	73.1±2.26	331.41±1.15	85.02±2.06	6.02±1.07	11.8±1.58	8.48±0.35	2.92±0.66
Z17	0.287±0.08	11.16±0.18	72.68±1.58	339.2±3.82	57.6±0.47	4.48±0.66	15.7±1.05	2.18±0.54	3.8±0.28
Z2	0.645±0.02	7.04±0.08	73.7±1.60	355.54±1.39	153.99±0.30	5.6±0.14	10.55±0.61	7.84±0.85	3.71±0.37
Z3	0.415±0.02	10.03±0.82	72.56±0.62	345.12±0.48	92.73±0.82	4.7±0.28	11.6±0.81	8.94±1.10	2.98±0.59
Z4	0.277±0.04	7.19±0.07	73.2±0.42	347.07±1.17	57.04±0.74	5.42±0.25	9.95±0.11	9.48±0.49	3.04±0.10
Z5	0.435±0.02	6.94±0.85	74.02±0.45	356.14±2.08	93.9±1.98	6.44±0.45	10.05±0.41	11.29±0.38	3.12±0.20
Z6	0.503±0.02	6.24±0.16	72.22±0.27	337.17±0.71	122.87±1.37	4.42±0.27	10.55±0.59	12.23±1.06	3.04±0.08
Z7	0.454±0.03	2.86±0.42	72.58±1.53	338.99±0.76	90.06±0.40	4.14±0.17	11.35±0.89	9.48±0.20	2.82±0.52
Z8	0.523±0.04	4.23±0.82	73.03±0.59	343.14±2.33	105.09±3.89	5.02±1.23	11.1±0.10	9.72±0.42	2.86±0.05

provide fruit with high juice contents and a slight acidity compared with the other genotypes. Indeed, the genotypes TA6, Z6, Z7, Z8 achieved total soluble solids content values higher than 10 °Brix (11.05; 10.55; 11.35; 11.10 °Brix), while T6, T1 and TZN2 had values lower than 10 °Brix (Table 6). The last subgroup constituted by 7 genotypes namely TA1, TA8, TA9, TA14, T10 and TZN1. These individuals are positioned on the negative part of axes 1 and 2, and on the positive part of PC3. This position reflects a high ascorbic acid content, ranging from 88.5 and 145.25 mg EAA/100g. Finally, the fourth group, included TZN3 and TZN4 genotypes, are located on the negative side of PC1 and PC3 with low values of the parameters contributing to the explanation of PC1. In PC2, the TZN3 located on the positive side, whereas the TZN4 located on the negative side with acidic fruits and a high juice level as well as very low total soluble solids content (TZN3= 6.95 °Brix and TZN4= 6.55 °Brix). The variation within the genotypes can be probably due to the stage of maturity and the earliness of production (Amoros et al., 2003). In addition, environmental factors including soil, moisture, temperature, light intensity, humidity, precipitation, photoperiod and cultural practices can influence gene regulation which, in turn, affects the expression of genes controlling the trait of interest leading to different phenotypic expression from one location to another (Garen et al., 2016).

CONCLUSION

The results showed large variability of physico-biochemical parameters analyzed which were efficient to classify the genotypes studied into four homogenous group independently of their geographic origin. In general, Zegzel Valley trees are characterized by acidic fruit with medium to low sugar levels, but they can considered a very important source of antioxidant. The T9, T12, Z16, Z17 and TA9 genotypes produce fruit with great total sugars level, while, genotypes T9 and T11 produce fruit rich of carotenoids, flavonoids, total polyphenols with high antioxidant activity. These results provide very useful information for loquat breeding programs to improve the Moroccan loquat crop.

REFERENCES

Abozeid, W.M., & Nadir, AS. (2012). Physico-chemical and organoleptic characteristics of loquat fruit and its processing. *Natural Sciences*, *10*, 108–113.

Amoros, A., Zapata, P., Pretel, M.T., Botella, M.A., & Serrano, M. (2003). Physico-chemical and physiological changes during fruit development and ripening of five loquat (*Eriobotrya Japonica* Lindl.) cultivars. *Food Science and Technology International*, *9*, 43-51. https:// doi.org//10.1177/1082013203009001007.

AOAC. (2000). *Official Methods of Analysis of AOAC International*. Gaithersburg, MD, USA.

Arantino, A., Frabboni, L., Mazzeo, A., Ferrara, G., & Disciglio, G.)2022(. Comparative Evaluation of yield and fruit physico chemical characteristics of five commercial cultivars of pomegranate grown in southeastern italy in two consecutive years. *Horticulturae*, *8*, 497.

Becerril-Saìnchez, A. L., Quintero-Salazar, B., Dublaìn-Garciìa, O., & Escalona-Buendiìa, H. B. (2021). Phenolic compounds in honey and their relationship with antioxidant activity, botanical origin, and color. *Antioxidants*, *10*, 1700. https:// doi.org/10.3390/antiox10111700

Garen, Y., Chalak, L., Fadel, D., Rizkallah, J., Assadi, F., Georges, A., & Chahine, H.)2016(. Physical and biochemical characterisation of loquat fruit (*Eriobotrya Japonica* lindl.) varieties in southern Lebanese areas. *International Journal of Plant*, *Animal and Environmental Sciences*, *6*, 239-356.

Gariglio, N., Castillo, Á., Juan, M., Almela, V., & Agustí, M. (2002). Nispero Japonés. Técnica para mejorar la calidad del fruto'. Divulgació Tècnica nº52, Generalidad Valenciana. C.A.P.A., Valencia, pp. 61.

Hong-Xia, X., Xiao-Ying, L., & Jun-Wei, C. (2014). Comparison of phenolic compound contents and antioxidant capacities of loquat (*Eriobotrya japonica* Lindl.) fruits. *Food Science and Biotechnology*, *23*, 2013-2020.

Hussain, A. N. A., Abbasi, I. A., Hafiz, A., & Shakor Naqvi, S. M. S. (2011). Performance of loquat (*Eriobotrya japonica*) genotypes under agro-ecological conditions of Khyber Pakhtunkhwa province of Pakistan'. *International Journal of Agriculture and Biology, 13*(5), 746–750.

Leguizamón, J. E. & Badenes, M. L. (2003). Multivariate analysis as a tool for germplasm studies, example of analysis of germplasm loquat data. *Acta Horticulturae*, *606*, 29-34.

Matias, R., Silva, D., Miranda, P., Oliveira, J., Pimentel, L., & Bruckner, C.H. (2016). Relationship between fruit traits and contents of ascorbic acid and carotenoids in peach'. *Crop Breeding and Applied Biotechnology*, *16*(04), 348-354.

Mohammadi, S. A. & Prasanna, B. M. (2003). Analysis of genetic diversity in crop plants-salient statistical tools and considerations. *Crop Sciences*, *43*(4), 1235-1248.

Muflihah, Y., Gollavelli, G., & Ling, Y. (2021). Correlation Study of antioxidant activity with phenolic and flavonoid compounds in 12 Indonesian indigenous herbs. *Antioxidants*, *10*, 1530. https:// doi.org/10.3390/antiox10101530.

ORMVAM (Regional Office of Agricultural Value of Moulouya). (2021). Published on *MapNews* (https://www.mapnews.ma/fr.)

Serrano, M., Zapata, P.J., Pretel, M.T., Almansa, M.S., Botella, M.A., & Amorós A. (2003). Changes in organic acids and sugar levels during ripening of five loquat (*Eriobotrya japonica* Lindl.) cultivars. *Options Mediterranea*, *58*, 157-160.

Singleton, V.L. & Rossi J.A. (1965). Colorimetry of total phenolics with phosphomolybdic – phosphotungstic acid reagents. *American Journal of Enology and Viticulture, 16*, 144–158.

Sun, H., Chen, W., Jiang, Y., He, Q., Li, X., Guo, Q., Xiang, S., Xi, W., & Liang, G. (2020). Characterization of volatiles in red- and white-fleshed loquat (*Eriobotrya japonica*) fruits by electronic nose and headspace solid-phase microextraction with gas chromatography-mass spectrometry. *Food Science and Technology, 40*, 10.

Viera, W., Samaniego, I., Camacho, D., Habibi, N., Ron, L., Sediqui, N., Álvarez, J., Viteri, P., Sotomayor, & A., Merino, J., et al. (2022). Phytochemical Characterization of a tree tomato (*Solanum Betaceum* Cav.) Breeding population grown in the inter-andean valley of Ecuador'. *Plants*, *11*, 268.

Virginia, P.V. & Juan José, H.M. (2011). Maduración Del Níspero Japonés (*Eriobotrya Japonica* Lindl.) Cv. Algerie: Carácter Climatérico E Índices De Recolección. pp. 100.

Xu, H.X. & Chen, J.W. (2011). Commercial quality, major bioactive compound content and antioxidant capacity of 12 cultivars of loquat (*Eriobotrya japonica* Lindl.) fruits. *Journal of the Science of Food* and *Agriculture*, *91*(6), 1057–1063.

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