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PHENOTYPIC DIVERSITY ASSESSMENT OF MOROCCAN LOQUAT USING MULTIPLE CORRESPONDENCE ANALYSIS

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Abstract: The loquat fruit has a very important commercial value due to its benefits for human health. However, there is very limited scientific research on this species in Morocco. In this regard, a set of 35 genotypes was collected from the Zegzel valley (Berkane). The phenotypic variability was evaluated using nine traits related to fruit and leaf. The results revealed a coefficient of variation ranging from 13.02 to 42.21%, implying a large phenotypic variation in Moroccan loquat, especially for the characteristics associated to the fruit shape. Regarding the multiple correspondence analysis, the first two axes explained 62.57% of the total variance. The major traits that made it possible to distinguish between the genotypes were those related to fruit size. Therefore, the Mekerkba genotype in the Zegzel region is not a single variety, but rather genotypes with a round fruit shape. In addition, the 35 genotypes studied were divided into three main groups regardless of their geographical origin. The results indicate that the geographical proximity did not play an important role in the structure of genotypes, implying a weak adaptation of the genotypes to the environment. The findings of this study could be used in conventional breeding and in situ conservation programs for Moroccan loquat.

Key words: *Eriobotrya japonica*, phenotypic variability, quantitative traits, coefficient of variation, multiple correspondence analysis.

Introduction

Loquat (*Eriobotrya japonica* Lindil.), belonging to the *Rosaceae* family, is an evergreen tree native to China. Since the 19th century, the loquat tree has been

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widely cultivated throughout the world for commercial and health purposes (Gariglio et al., 2002). The loquat fruit is consumed as fresh fruit or juice due to its excellent flavor and high nutritional values (Sun et al., 2020). Globally, China and Japan are the leading loquat producers, while Spain and Turkey have been the most important producers in the Mediterranean region over the last 20 years (Pinillos Villatoro and Hueso Martin, 2011).

In Morocco, the loquat is cultivated both as a commercial food crop and an ornamental crop for its yellow fruits (Hussain et al., 2011). This species is found in several areas throughout the country, but it is practically concentrated in the Berkane region, especially in the Zegzel valley, producing over 10,000 tons in 2021. The genotypes planted are unknown and the distinction between the most planted individuals in this region is based on the shape of the fruit, considering that the fruits of round shape and large size (called mkerkeba) are the most appreciated by the consumer (ORMVAM, 2021).

When evaluating plant germplasm, it is crucial to measure the extent of available genetic diversity (Zubair et al., 2007). In this regard, the application of various statistical tools is an efficient strategy for classifying germplasm and analyzing genetic association among breeding materials (Mohammadi and Prasanna, 2003). The multiple component analysis (MCA) was applied to study the qualitative characteristics of 35 loquat genotypes from the Zegzel valley in order to improve the identification of the loquat genotypes and contribute to their selection and conservation in Morocco.

Material and Methods

Plant material

During April and May 2016, a total of 5 healthy fruits and 10 well-developed leaves of 35 genotypes were randomly selected from the Zegzel valley, the main growing area of loquat in Morocco (Table 1, Figure 1).

Table 1. Plant material studied and corresponding codes.

Geographical origin	Genotype codes	Number of samples
Takerboust	T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12,	12
Taghsrout	TA1, TA2, TA5, TA6, TA7, TA8, TA9, TA13, TA14	9
Tazaghin	TZN1, TZN2, TZN3, TZN4	4
Zegzel	Z1, Z2, Z3, Z4, Z5, Z6, Z7, Z8, Z16, Z17	10
Total		35

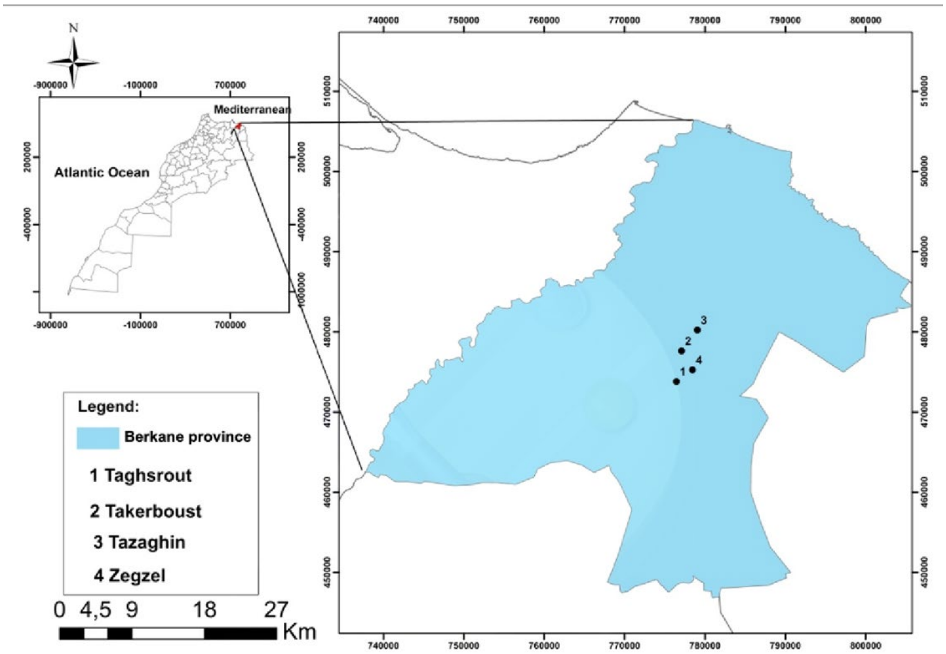

Figure 1. The sampling location of the studied loquat genotypes.

Phenotypic analysis

Nine qualitative traits related to fruit and leaf were analyzed according to the descriptor of the International Union for the Protection of Plants (UPOV, 1998) (Table 2). The selection of the studied traits was based on their economic importance as well as the possibility of their introduction in the improvement programs of this species.

Table 2. Phenotypic parameters analyzed in this study.

Traits	Code	Phenotype
Fruit shape in longitudinal section	FFL	1. Elliptic, 2. Broad elliptic, 3. Round, 4. Oblate, 5. Broad obovate, 6. Obovate
Fruit shape in transverse section	FFT	1. Round, 2. Slightly angular, 3. Strongly angular
Fruit shape at the stalk end	FPP	1. Acute, 2. Obtuse, 3. Round
Shape of the leaf apex	FS	1. Sharp acute, 2. Blunt acute, 3. Rounded
Shape of the seed	FG	1. Elliptic, 2. Round, 3. Obovate
Color of flesh	CCH	1. White 2. Yellowish white 3. Yellow 4. Orange yellow 5. Orange
Green color of leaf's upper side	CVFS	3. Light, 5. Medium, 7. Dark
Attitude of leaf in relation to shoot	PPP	1. Upwards, 2. Outwards, 3. Downward
Density of margin serrations	DD	3. Loose, 5. Medium, 7. Dense

Statistical analysis

The data obtained were subjected to several measurements, such as the general mean, standard deviation and coefficient of variation (CV). This latter was calculated using the following formula: CV (%) $= \frac{SD}{\bar{X}} \times 100$. Moreover, the multiple correspondence analysis (MCA) and the hierarchical cluster analysis were performed according to the quantitative traits related to fruits and leaves to determine the most discriminant variables and modalities and to assess the genetic structure of the loquat genotypes. This analysis was performed using the XLSTAT software.

Results and Discussion

Phenotypic variation

The mean values, standard deviation and coefficient of variation of nine traits related to loquat fruit and leaf are shown in Table 3. The CV parameter is independent of a unit of measurement, meaning that it is more powerful when comparing measured characteristics (Khadivi-Khub and Etemadi-Khah, 2015). The results obtained revealed a wide range of CV with the values ranging from 13.02 to 42.21%. Pomological characteristics, especially those related to the fruit shape, showed the greatest variation, with a CV of 42.21% for fruit shape at the stalk end (FPP) and 40.20% for fruit shape in transverse section (FFT). In contrast, the lowest variation in leaves was found in the density of the serration of margin (DD) (13.2%). The remaining traits showed a CV of over 17%, indicating high levels of phenotypic variation. In the Moroccan loquat, the acute and obtuse shapes were the most frequent for the fruit shape at the stalk end trait and the slightly angled shape was the most dominant trait in the fruit shape in transverse section. In addition, the color of the flesh varied between orange-yellow and orange. Similarly, the results of the morphological observation of loquat in Karo, Dairi and Simalungun districts showed uniform leaf morphology, while the fruit and seed showed diverse characters within the genotypes studied (Elimasni and Nasution, 2021). This variability could be explained by propagation by the seeds used by the farmers, which causes very high polymorphism. In addition, the woody species, the outcrossing reproductive system and wind dispersal show greater genetic diversity within the species and the population (Hamrick et al., 1991). The occurrence of the same characters between varieties is caused by the presence of genes composing the same phenotype, although they are influenced by different environments (Jayanti, 2018).

Table 3. The mean values, standard deviation and coefficient of variation of the traits measured in the 35 genotypes.

Genotypes	FFL	FFT	FPP	CCH	FG	PPP	CVFS	FS	DD
T1	6	2	1	5	1	1	5	2	7
T10	5	1	1	5	1	1	3	2	5
T11	4	1	2	3	2	1	5	1	7
T12	4	1	3	3	1	2	3	1	7
T2	6	1	2	4	1	1	3	1	7
T3	6	3	1	5	1	1	7	1	7
T4	6	2	1	3	1	1	5	1	7
T5	6	3	1	5	1	1	3	1	7
T6	6	1	1	4	2	1	5	1	7
T7	6	2	1	4	1	1	3	2	7
T8	6	3	2	5	1	1	5	2	7
T9	4	1	2	4	2	2	3	1	7
TA1	4	2	2	5	2	2	7	1	7
TA13	4	2	3	5	2	1	5	1	7
TA14	5	2	3	3	1	1	3	2	5
TA2	6	2	2	4	1	1	5	2	7
TA5	6	2	1	4	2	2	7	1	7
TA6	5	3	1	3	1	2	5	1	5
TA7	5	1	2	4	1	1	7	1	7
TA8	4	3	2	5	1	1	7	2	5
TA9	4	3	3	5	2	1	7	1	7
TZN1	5	2	1	4	1	1	7	1	7
TZN2	5	3	2	4	1	1	7	2	5
TZN3	5	2	2	3	1	1	7	1	5
TZN4	5	2	1	5	1	1	7	1	7
Z1	6	2	1	4	1	1	7	1	7
Z16	4	1	3	5	2	2	7	1	7
Z17	4	1	3	5	2	2	7	1	7
Z2	6	2	2	3	1	2	7	1	7
Z3	6	2	1	5	1	1	7	1	7
Z4	6	2	2	4	2	1	5	1	5
Z5	4	3	2	4	1	1	7	2	7
Z6	4	1	3	3	1	1	7	1	7
Z7	6	1	3	4	1	1	7	2	7
Z8	4	1	3	3	1	1	5	2	5
Mean	5.09	1.89	1.89	4.11	1.29	1.23	5.63	1,31	6.54
SD	0.89	0.76	0.80	0.80	0.46	0.43	1.59	0,47	0.85
CV (%)	17.44	40.20	42.21	19.35	35.65	34.68	28.28	35,84	13.02

Multiple correspondence analysis

Eigenvalues and percentage of variance

According to the MCA applied to the qualitative characters of the fruit and the leaf, the first two axes explained 45.02 and 17.54% of the variance, respectively, corresponding to a total explanation of 62.57% (Table 4). The contributions of each modality to the total variance are summarized in Table 5. The traits that mainly contributed to the formation of axis 1 were modalities 4 and 5 of the fruit shape on longitudinal section (FFL), modality 1 of the fruit shape on transverse section (FFT), modalities 1 and 3 of the fruit shape at the stalk end (FPP), modality 2 of the seed shape (FG), modality 5 of the density of margin serrations, modalities 1 and 2 of the shape of the leaf apex (FS), and modality 2 of the leaf attitude in relation to the shoot (PPP). Regarding axis 2, it was mostly explained by modalities 5 and 6 of the shape of the fruit on longitudinal section (FFL), modality 2 of the shape of the fruit on transverse section (FFT), modalities 1 and 3 of the shape of the fruit at the stalk end (FPP), modality 3 of the color of the flesh (CCH), modality 2 of the shape of the leaf apex (FS), and modalities 5 and 7 of the density of margin serration (DD). According to this explanation, the characteristics related to fruit size were the major traits allowing the distinction between the loquat genotypes.

Table 4. The percentage of total variance explained by the two axes.

Axis	F1	F2
Eigenvalue	0.29	0.22
Variance %	45.02	17.54
Cumulative	45.02	62.57

Table 5. The contribution of the variables in the first two axes.

Modality	F1	F2
FFL-4	1.08	0.46
FFL-5	-0.79	0.77
FFL-6	-0.45	-0.78
FFT-1	0.72	0.39
FFT-2	-0.34	-0.5
FFT-3	-0.45	0.35
FPP-1	-0.57	-0.67
FPP-2	-0.1	0.19
FPP-3	0.97	0.7
CCH-3	0.15	0.87
CCH-4	-0.31	-0.41
CCH-5	0.21	-0.2
FG-1	-0.46	0.16
FG-2	1.14	-0.4
PPP-1	-0.34	0.02
PPP-2	1.15	-0.07
CVFS-3	-0.12	0.4
CVFS-5	-0.17	-0.05
CVFS-7	0.14	-0.12
FS-1	0.34	-0.28
FS-2	-0.74	0.62
DD-5	-0.66	1.31
DD-7	0.2	-0.39

Therefore, the Mekerkba genotype in the Zegzel region, which is highly appreciated by the consumer, is not a variety but a genotype with round fruits, yellow-orange flesh and a sweet taste. In contrast, many authors have noted that morphological and agronomic characteristics used to measure genetic diversity in some populations often do not allow the identification of discrete taxonomic groups since most plant characteristics are influenced by environmental factors and exhibit continuous variation and a high degree of phenotypic plasticity (Rabelo et al., 2020).

The multiple correspondence analysis (MCA) results showed a large dispersion of genotypes along axes 1 and 2. The bi-dimensional graph of the genotypes and the modalities (Figure 2) as well as the dendrogram (Figure 3) classified the genotypes studied into three main groups regardless of their geographical origin. The MCA results indicate that geographical proximity did not play an important role in the differentiation and structure of the genotypes, suggesting a weak adaptation of genotypes to their environment. The first group (G1) was divided into two subgroups. The first (G1.1) contained the following genotypes: T7, T2, T5, T10, T6, T4, T8, T1 and TA2. These genotypes, located on the negative part of axes 1 and 2, were characterized by fruits with a slightly angular, obovate shape, an acute fruit shape at the stalk end, orange-yellow flesh, and leaves of medium green color on the upper side. The second subgroup (G1.2) consisted of four genotypes such as TA13, T11, T12 and T9. The genotypes of this group were located on the positive part of axis 1. The fruits had an acute fruit shape at the stalk end and orange flesh. The leaves of these specimens were dark green with densely serrated margins. The second group (G2) included the genotypes TA14, Z8, TA6, Z4, TA8, TZN2 and TZN3. These genotypes were characterized by broad obovate and strongly angular fruits, with an obtuse fruit shape at the stalk end. The leaves were blunt acute, light green and directed upwards in relation to the shoot, while the shape of the seed seemed to be elliptical. The last group (G3) was bifurcated into two subgroups. The first set (G 3.1) included genotypes TA9, Z5, Z17, Z16, TA1, TA7, Z6 and Z7. The genotypes of this group were located on the positive part of axis 2 with round oblate fruits, yellow flesh and a rounded fruit shape at the stalk end. The second subgroup (G 3.2) consisted of TA5, Z2, Z3, Z1, T3, TZN4, TZN1. These genotypes were located on the negative part of axes 1 and 2 and were characterized by fruits oblate with a slight angular shape, an acute fruit shape at the stalk end, yellow-orange flesh and a medium green color of the upper side of the leaf. According to these results, the genotypes studied show a great differentiation, particularly in the shape and color of the fruit. In addition, the 35 Moroccan loquat genotypes were classified into three different groups even though they belonged to the sites which are geographically close to each other and have similar climatic conditions, indicating a weak effect of environmental conditions on the loquat genotypes. However, several studies have shown considerable plasticity and adaptability of the species to various environmental conditions (Drobná, 2010). The genetic diversity observed in the Moroccan loquat could be due to the seed propagation practiced by farmers, which can generate a large polymorphism.

Figure 2. The graphical representation of the 35 genotypes and modalities.

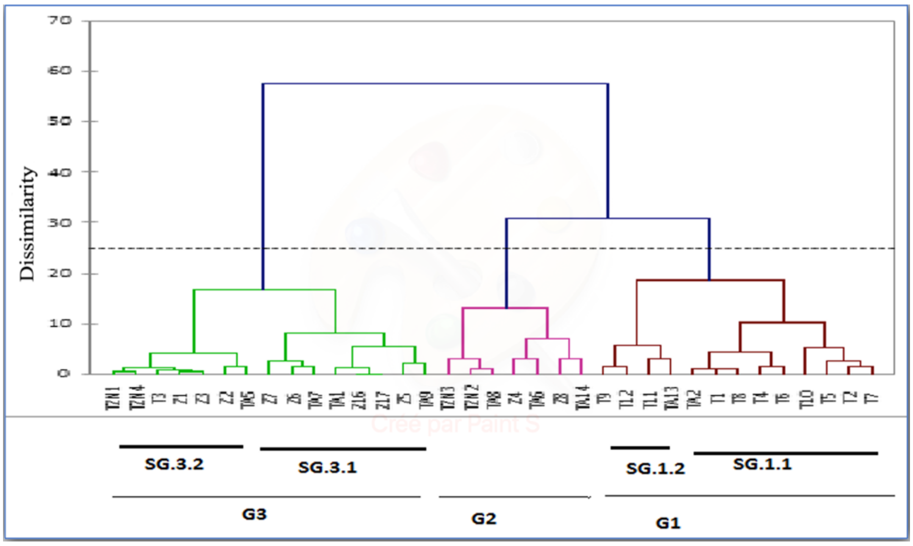

Figure 3. The dendrogram of the 35 genotypes based on nine qualitative traits.

Conclusion

Based on the results of the phenotypic characterization of Moroccan loquat, the studied genotypes showed a great diversity, especially in terms of fruit shape and color. In addition, the Mekerkba genotype in the Zegzel valley is just a set of genotypes with round fruits and orange-yellow flesh. The high phenotypic variability of the genotypes should be exploited to develop strategies for the conservation and improvement of the Moroccan loquat crop to satisfy the needs of farmers, producers and consumers.

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PROCENA FENOTIPSKE RAZNOLIKOSTI MAROKANSKOG LOKVATA KORIŠĆENJEM VIŠESTRUKE KORESPONDENTNE ANALIZE

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R e z i m e

Plod lokvata ima veoma važnu komercijalnu vrednost zbog njegove koristi za ljudsko zdravlje. Međutim, postoje vrlo ograničena naučna istraživanja o ovoj vrsti u Maroku. S tim u vezi, skup od 35 genotipova prikupljen je iz doline Zegzel (Berkane). Fenotipska varijabilnost je procenjena korišćenjem devet osobina koje se odnose na plod i list. Rezultati su pokazali koeficijent varijacije u rasponu od 13,02 do 42,21%, što implicira veliku fenotipsku varijaciju kod marokanskog lokvata, posebno kada je reč o karakteristikama koje su povezane sa oblikom ploda. Koristeči metodu višestruke korespondentne analize, prve dve ose su objasnile 62,57% ukupne varijanse. Glavne osobine koje su omogućile razlikovanje između genotipova bile su one koje su povezane sa veličinom ploda. Dakle, genotip mekerkba u regionu Zegzel nije jedna pojedinačna sorta, već genotipovi sa okruglim oblikom ploda. Pored toga, 35 proučavanih genotipova podeljeni su u tri glavne grupe bez obzira na njihovo geografsko poreklo. Rezultati pokazuju da geografska blizina nije imala značajnu ulogu u strukturi genotipova, što implicira slabu prilagodljivost genotipova životnoj sredini. Nalazi ovog istraživanja mogli bi se koristiti u konvencionalnom oplemenivanju i programima *in situ* očuvanja za marokanski lokvat.

Ključne reči: *Eriobotrya japonica*, fenotipska varijabilnost, kvantitativne osobine, koeficijent varijacije, višestruka korespondentna analiza.

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