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Genetic diversity of Algerian fig (*Ficus carica* L.) cultivars based on morphological and quality traits

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ABSTRACT

Assessment of the genetic diversity of 11 fig (*Ficus carica* L.) cultivars using 45 traits using international morphological descriptors was undertaken. The results show that 20 quantitative variables and 7 qualitative variables were useful for discrimination of cultivars. Skin thickness, length and fruit width were the more discriminating pomological variables. In terms of total soluble solids, the levels obtained (13.56-25.12%), constitute an index of high quality for all cultivars. The principal component analysis indicates that 61.38% of the total variability involve the first three components. Cluster analysis divided the 11 cultivars into 4 sub-groups characterized by a narrow genetic base. The colour of the fruit was not sufficient for their differentiation, while the cultivars Bakor Blanc and Bakor Noir present a case of homonymy. Some cultivars (Chetoui, Benacer, Taranimt, Toudjente, Bakor Blanc and Meroudji) are attractive to growers due to the good fruit quality traits. The use of morphological descriptors has proved a more suitable means to assess the genetic diversity in Algerian fig genotypes.

Key words: Clusters analysis, cultivars, descriptors, fig.

INTRODUCTION

The common fig (*Ficus carica* L., 2n = 26) is one of the oldest plants to be grown by man, even before wheat (Kislev *et al.*, 8). This species grows in a wide range of soils and adapts very well to Mediterranean basin. Fig is ubiquitous in Algeria, especially in the center of the country where it is found in abundance and in different cultivars. The names of the cultivars are often associated with the location of culture or to the fruit characteristics and some of them produce excellent quality fruits. Despite its importance, the cultivation of the tree is still considered as a secondary interest and local cultivars face recurrent problems of confusion in their names and genetic vulnerability. Currently, 1 caprifig, 6 local and 16 foreign cultivars are recorded, authorized in the market and grown in the country (ITAFV, 7). However, these figures are not sure as the identification of the genetic resources of the fig in Algeria and the exchange of data between the different operators are non-existent. Moreover, apart from some preliminary studies, the local germplasm of this species did not attract the interest of researchers and still remains unexplored. In this context, surveys and research are needed to identify and characterize the genetic resources of this fruit crop. Different methods of analysis exist, but in the lack of molecular tools, the use of phenotypic markers becomes an appropriate alternative. This research aims to analyze the genetic diversity of 11 local fig cultivars using international descriptors.

MATERIALS AND METHODS

This study concerns an *ex situ* fig collection located at the agricultural farm of Hassiba Benbouali, University of Chlef, Algeria (altitude 109 m, latitude 36°10'N, longitude 01°14'E). The climate of Chlef is a typical Mediterranean climate, with relatively wet and cold winters and hot, dry summers. The average annual temperature is 19.3°C. Thermal amplitudes are 30.80°C in summer and 9.40°C in winter. The average annual rainfall is 552 mm and occurs mainly from November to April. The orchard floor is a clay-loam texture with a pH of 8.3.

Eleven cultivars (Taranimt, R'dani, Toudjente, Kadota, Chetoui, Benacer, Enk El H'mam, Bezoult Rhadem, Bakor blanc, Bakor noir, Meroudji), each one represented by a tree, have been studied over two years (2013 and 2014). Trees were planted in 2009 at a spacing of 6 m × 6 m. They were conducted in a free form and received the same cultural maintenance. For the analyses, we collected data from each tree 36 adults leaves and 36 mature fruits (2nd crop). There were three replicates each consisting of 12 fruits. Sampling was carried out at various sites on the tree periphery on 1-year-old shoots.

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A set of 45 traits (25 quantitative and 20 qualitative) were measured or classified according to the fig descriptors of IPGRI and CIHEAM (6) including three additional traits related to leaf apex shape, beginning of defoliation and internal pulp thickness (Basheer-Salimia *et al*., 2). Quantitative characters analyzed include the leaf length, the fruit weight, the number of leaves and fruits per shoot and the ostiole width. Qualitative character such as tree vigour, beginning of maturity, harvest time, colour of the internal pulp, and fruit shape index were determined. Dimensional properties were performed with a scale sensitive to 0.01 g (Precisa XB 2200 C, UK) and with digital calipers (0-150 mm; BTS Tools, Malaysia). The total soluble solids were determined by a hand-held refractometer (NOW, 0-32% Brix). The titratable acidity, and TSS : acid ratio were calculated.

The analysis of variance (one-way ANOVA) was performed to assess the variations between the 11 cultivars. The mean values were separated by Duncan's multiple range test at a level of $p \leq 0.05$. To establish multivariate analyzes among cultivars a principal component analysis (PCA) was performed. The PCA factor was accepted when the means values were superior than 1. Recorded factors equal or greater than 0.7 were considered as a strong correlation between the principal component and the descriptive characters. To assess the similarity among cultivars, a hierarchical cluster analysis was performed by measuring the Euclidean distance using the Ward's method. The software used was SPSS 10.0.

RESULTS AND DISCUSSION

The Analysis of variance revealed significant differences at a threshold of 95% level among cultivars for most characters. The average values of characters related to trees, branches and leaves are shown in Table 1. Our results show that tree vigour, the relative degree of branching, the colour of the terminal bud and the beginning of fruits maturity depended on cultivar. The average values of pomological variables are summarized in Table 2. They show that the skin thickness, the length and the width of fruits were more discriminating among all the analyzed parameters.

The principal component analysis concerns the branches characters, buds, leaves and fruits (Table 3, Fig. 1). It indicates that the first three axes concern 61.38% of the total variability. The first axis (PC1) shows 3 game variables positively correlated (the tendency to form suckers; the leaf shape apex; the width, the shape and the fruit weight; the length and the width of the neck; the stalk width; the ease of peeling; the pulp internal thickness) and 3 negatives (the tree vigour; the length and the shape of the fruit).

Table 1. Mean values and significance degree of differences between eleven fig cultivars for morphological traits.

Genotype	PLL	SLB	RDB	LM	LC	BOD	DLL	NFS	TFS	LAS	TV	LLN	HP	TGH	PT (mm)	TBC	BFM	LCL (cm)	NLS	LW (cm)	LL (cm)	PL (mm)	LA (cm^2)
Taranimt	0,34a	2ab	2,5abc	2,5abc	3abc	3abc	3abc	3,355abc	3,5abc	3,5abc	3,5abc	3,54abc	4abc	5abc	5,25abc	5,5abc	5,5abc	8,38abcd	16,1bcd	17,105cd	19,485d	66,4e	338,81f
R'dani	0,355a	2,5a	4ab	3,5a	3,5a	2a	3,5a	3,135a	3,5a	4,5ab	3,5a	4,3ab	4ab	4.....cccc, 4, 5ab	5,645abc	3,5a	5ab	10,48bc	11,65c	18,35d	21,61d	77,005e	399,06f
Toudjente	0,3a	4ab	2,5ab	3,5ab	3,5ab	3ab	4,5ab	3,315ab	3,5ab	2,5ab	2ab	4,17ab	5b	4,5ab	5,96bc	2ab	3ab	9,36c	15,385d	18,075de	19,915e	59,49f	367,215f
Kadota	0,385a	2a	4a	3a	2,5a	3a	3a	5,46a	3,5a	3,5a	3,5a	2,765a	5a	5a	5,56a	3,5a	5,5a	8,385a	13,175a	18,53a	20,675a	80,79b	401,28c
Chetoui	0,405a	3ab	5abc	4,5abc	2,5ab	3ab	3ab	3,625ab	3,5ab	2a	3,5ab	4,715abc	3,5ab	4,5abc	4,775abc	5,5abc	4ab	9,87abc	11,58c	18,075d	19,35d	78,43e	355,95f
Benacer Enk El H'mam	0,345a	3,5a	2,5a	3,5a	3a	3a	5,5a	7,885a	2,5a	4a	4a	4,94a	4a	4,5a	4,875a	2a	2a	9,05a	16,065a	17,07a	17,935a	62,935b	315,195c
Bezoult Rhadem	0,33a	2,5a	4ab	2a	3a	3a	3a	3,25ab	3,5ab	3,5ab	3,5ab	3,455ab	4ab	5ab	5,305ab	3,5ab	3a	10,635ab	12,05ab	18,015ab	21,295b	70,315c	390,97d
Bakor noir	0,34a	3a	5a	4a	3,5a	2a	3,5a	2,175a	3,5a	4a	4,5a	4,715a	4a	4a	4,635a	3,5a	5a	9,685a	14,285a	17,045a	19,8a	68,15b	346,585c
Bakor blanc	0,375a	4ab	2,5ab	4ab	2a	3ab	4ab	3,37ab	2a	2,5ab	4ab	4,225ab	2a	3,5ab	5ab	2,5ab	2a	10,965ab	7,28ab	15,35ab	20,695b	79,59c	380,185c
Meroudji	0,325a	2abc	5bc	3abc	3abc	2abc	3abc	1,675ab	3,5abc	3,5abc	4,5bc	4,26bc	4abc	3abc	4,385bc	5,5c	5,5c	11,035d	5,05bc	16,975e	19,885e	65,735f	344,72g
F-Value	0,27a	3,5abc	4abc	4,5abc	3,5abc	3abc	4abc	0,27ab	3,5abc	4abc	3,5abc	3,57abc	3,5abc	4abc	4,305abc	4,5abc	4abc	8,59c	7,5bc	16,64d	18,08d	48,65e	304,65f
	6,496**	1,625NS	12,300**	1,053NS	1,100NS	0,436NS	0,800*	6,291**	0,655NS	1,230NS	0,7143*	2,703**	0,6714*	0,180NS	3,505*	8,644**	1,753*	4,679**	2,452*	0,873*	1,233NS	11,772**	0,842*

Means within column followed by the same letters are not significantly different at P<0.05
NS: not significant; * and ** are statistically significant at P<0.05 and P<0.01 respectively, according to Duncan's multiple range test.
PLL: Petiole length / Length of leaf; **SLB**: Shape of leaf base; **RDB**: Relative degree of branching; **LM**: Leaf margin; **LC**: Leaf colour; **BOD**: Beginning of defoliation; **DLL**: Degree of leaf lobation / incision; NFS: Number of fruits per shoot; **TFS**: Tendency to form suckers; **LAS**: Leaf apex shape; **TV**: Tree vigour; **LLN**: Leaf lobes number; **HP**: Harvesting period; **TGH**: Tree growth habit; **PT**: Petiole thickness; **TBC**: Terminal bud colour; **BFM**: Beginning of fruit maturation; **LCL**: Length of central lobe; **NLS**: Number of leaves per shoot; **LW**: Leaf width; **LL**: Leaf length; **PL**: Petiole length; **LA**: Leaf area.

Table 2. Mean values and significance degree of differences between eleven fig cultivars for pomologial traits.

Genotype	TAC (%)	FSI	FSCK	OW (mm)	FSF	FST (mm)	FS	EPE	FFC	FC	ASFT	FSC	FSW (mm)	FNL (mm)	FNW (mm)	FSL (mm)	TSS (%)	FWG (g)	FPT (mm)	FW (mm)	FL (mm)	TTST (%)
Taranimt	0,25a	0,92a	2a	2,15a	2,5a	2,78ab	3ab	3ab	3,5ab	3,5ab	4ab	4ab	4,685ab	5,575ab	6ab	9,19b	19,75c	26,84d	33,62e	36,4e	39,895e	79,065f
R'dani	0,255a	0,845ab	2abcd	2,57abcd	2,5abcd	3,005abcd	2,5abcd	2abc	4,5cd	4,5cd	3abcd	2abc	5,25d	4,985cd	5,17cd	4,005bcd	25,125e	28,74f	33,28g	36,285h	42,9i	98,54k
Toudjente	0,275a	0,91ab	3cde	2,15bc	3cde	2,875cde	2,5cd	4def	3cde	4,5efg	3,5cdef	5fgh	6,005gh	6,36h	7,96i	8,38i	13,745k	25,96l	33,205m	36,08n	39,755o	49,975p
Kadota	0,19a	0,9ab	2abc	3,01abcd	2,5abc	3,265abcd	3abcd	4bcde	5cde	4,5bcde	3abcd	5cde	5,475cde	3,935abcde	7,055e	6,74de	19,12f	30,965g	34,4h	37,665h	41,88i	100,985k
Chetoui	0,25a	1,01ab	2abc	2,025abc	2,5abc	3,13abc	2,5abc	3abc	2abc	4,5bcd	3abc	2abc	5,665cd	5,73cd	7,645d	8d	22,26e	33,22f	36,525f	39,655f	39,34f	89,04g
Benacer Enk El H'mam	0,24a	0,905a	2a	2,53a	4,5a	2,615a	3a	3a	5a	5,5a	2,5a	3a	5,23a	6,515a	6,58a	5,13a	23,75b	31,66c	36,485cd	39,1de	43,345e	99,085f
Bezoult Rhadem	0,23a	0,75a	2a	4,125a	2,5a	3,635a	3,5a	4,5a	3,5a	4,5a	4a	6a	7,22a	21,47b	10,945ab	6,61a	21,485b	43,345c	46,98c	51,065c	62,845d	94,845d
Bakor noir	0,195a	0,95a	2a	2,5a	2,5a	2,48a	2,5a	3a	5a	4,5a	4a	2a	5,185a	2,555a	5,75a	5,3a	21,5ab	25,345ab	33,71b	36,19b	38,1b	118,33c
Bakor blanc	0,17a	0,8a	3a	2,695a	3,5a	3,205a	3,5a	4,5a	4a	2a	2a	2a	6,555a	7,76a	9,345a	5,985a	13,56a	51,045b	39,415ab	44,755b	56,25b	82,77c
Meroudji	0,23a	0,84a	2ab	1,62ab	3,5abc	3,75abc	3,5abc	3abc	5abc	4,5abc	2ab	5abc	5,74abc	9,98c	8,71bc	4,87abc	20,5d	31,25e	34,29ef	45,38g	38,04f	88,505h
F-Value	0,29a	0,98ab	2abc	2,595abc	4,5abc	4,01abc	2,5abc	4abc	2abc	4,5abc	3abc	6bcd	6,295cd	4,405abc	6,325cd	9,435d	17e	44,025fg	39,98f	43,99fg	45,07g	58,26h
	3,22*	5,911**	1,800 NS	3,64*	2,014 NS	8,522***	0,525 NS	1,957NS	3,136*	1,877 NS	1,700 NS	5,527 NS	15,55**	9,134**	2,586*	2,968*	4,261*	6,71*	8,21**	8,973***	13,87***	1,857 NS

Means within column followed by the same letters are not significantly different at P<0.05
NS: not significant; *,** and *** are statistically significant at P<0.05 and P<0.01 respectively, according to Duncan's multiple range test.
TAC: Titratable acidity; **FSI**: Fruit shape; index; **FSCK**: Fruit skin cracks; **OW**: Ostiole width; **FSF**: Fruit skin firmness; **FST**: Fruit skin thickness; FS: Fruit shape; **EPE**: Ease of peeling; **FFC**: Fruit flesh colour; **FC**: Fruit cavity; **ASFT:** Abscission of the stalk from the twig; **FSC**: Fruit skin colour; **FSW**: Fruit stalk width; **FNL**: Fruit neck length; **FNW**: Fruit neck width; **FSL**: fruit stalk length; **TSS**: Total soluble solids; **FWG**: Fruit weight; **FPT**: Fruit pulp thickness; **FW**: Fruit width; **FL**: Fruit length; **TTST**: TSS / Titrable acidity.

Table 3. Principal component analysis based on morphological traits in fig.

Principal component	PC1	PC2	PC3
Variance (%)	30.080	16.810	14.492
Cumulative variance (%)	30.080	46.890	61.382
Eigen value	13.36	7.565	6.521
Traits			
TGH (Tree growth habit)	-0.133	0.435	-0.772
TV (Tree vigour)	-0.842	0.077	0.125
TFS (Tendency to form suckers)	0.710	-0.124	0.567
RDB (Relative degree of branching)	-0.593	0.107	-0.083
TBC (Terminal bud colour)	0.668	-0.335	-0.033
NFS (No. of fruits per shoot)	-0.291	-0.120	0.033
BFM (Beginning of fruit maturation)	0.138	-0.711	0.138
HPD (Harvesting period)	0.512	0.328	0.015
NLS (No. of leaves per shoot)	-0.576	-0.062	0.517
LLN (Leaf lobes No.)	-0.159	0.238	-0.544
DLL (Degree of leaf lobation / incision)	0.325	0.433	-0.712
SLB (Shape of leaf base)	0.619	-0.388	0.155
LC (Leaf colour)	0.168	0.525	-0.359
LL (Leaf length)	0.338	0.528	0.518
LW (Leaf width)	-0.298	-0.007	0.593
LA (Leaf area)	0.278	0.594	0.532
LCL (Length of central lobe)	0.633	0.515	-0.158
LAS (Leaf apex shape)	0.725	0.327	-0.325
PLL (Petiole length/Length of leaf)	-0.078	0.338	-0.093
LM (Leaf margin)	0.138	-0.344	-0.723
PL (Petiole length)	0.082	0.763	0.134
PT (Petiole thickness)	-0.093	0.173	0.721
BOD (Beginning of defoliation)	0.199	-0.551	0.065
FW (Fruit width)	0.886	-0.273	0.129
FL (Fruit length)	-0.947	0.017	0.115
FS (Fruit shape)	0.806	0.372	-0.189
FSI (Fruit shape index)	-0.815	-0.360	-0.254
FWG (Fruit weight)	0.904	-0.175	0.043
FNL (Fruit neck length)	0.811	0.013	0.357
FNW (Fruit neck width)	0.885	0.279	0.155
FSL (Fruit stalk length)	-0.141	-0.533	0.074
FSW (Fruit stalk width)	0.936	-0.120	0.015
ASFT (Abscission of the stalk from the twig)	-0.090	-0.406	0.217
OW (Ostiole width)	0.578	-0.186	0.521

Contd...

Table 1 Contd...

Principal component	PC1	PC2	PC3
EPE (Ease of peeling)	0.777	-0.529	0.041
FSCK (Fruit skin cracks)	0.418	0.314	-0.578
FST (Fruit skin thickness)	0.595	-0.305	0.004
FSF (Fruit skin firmness)	0.073	-0.385	-0.751
FPT (Fruit pulp thickness)	0.875	-0.253	0.128
FSC (Fruit skin colour)	0.304	-0.432	0.075
FFC (Fruit flesh colour)	-0.445	0.441	-0.201
FC (Fruit cavity)	-0.546	-0.088	0.557
TSS (Total soluble solids)	-0.290	0.024	0.607
TAC (Titratable acidity)	-0.134	-0.726	-0.103
TSST (TSS: acid ratio)	-0.181	0.482	0.528

The second axis (PC2) corresponds to the length of the stalk which is negatively correlated with 2 other variables (the beginning of fruit ripening and the titratable acidity). The third axis (PC3) represents the petiole thickness which is negatively correlated with 4 variables (the tree growth habit; the degree of leaf lobation; the leaf margin and the fruit skin firmness).

Cluster analysis, based on the Euclidean distance separated the cultivars into 2 groups, *i.e.* I and II, at the level of 40% similarity (Fig. 2). The first group (I) contains 4 cultivars, which are separated into 2 sub-groups, I.I and I.II. The first subgroup (I.I) includes 2 cultivars Enk El H'mam and Bakor Noir (d=27.7), which are mainly characterized by high vigour, fruit shape oblong and high fruit weight. The second sub-group (I.II) consists of R'dani and Kadota (d = 16), the fruits of which have small length and neck's width. The second group (II) comprises 7 cultivars and is divided into 2 sub-groups, II.I and II.II. The first sub-group (II.I) is represented by Meroudji, which has a long harvest period, a globular fruit shape, a heavy weight, a thick pulp and is rich in sugars. The second sub-group (II.II) is broader and includes Chetoui, Benacer, Bezoult Rhadem, Toudjente, Bakor blanc and Taranimt. This second sub-group is mainly characterized by a long harvest period and very high sugar content.

The present study revealed that the variability of the tree vigour, the degree of leaf lobation, the relative degree of branching, the terminal bud colour, the beginning of fruit maturity and the harvest period, was in agreement with those of Kuden *et al.* (9) but can change with the environmental conditions (Gaaliche *et al.*, 5). Therefore, we could speculate that the vegetative characters of the relatively young trees and their architectural forms do not remain constant and could evolve over time.

The values of leaf area recorded in this study were lower than those obtained by Abo-El-Ez *et al.*

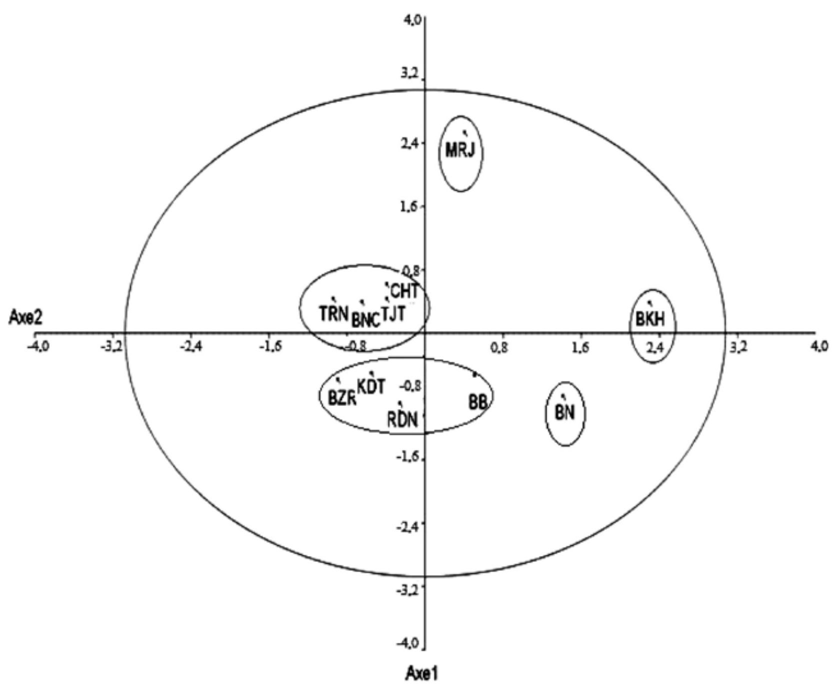

Fig. 1. Plot of the first and the second principal components resulting from a PCA using phenotypic traits in fig. MRJ = Meroudji; BZR = Bezoult Rhadem; RDN = R'dani; EKH = Enk El H'mam; TRN = Taranimt; BNC = Benacer; CHT = Chetoui; TJT = Toudjente; KDT = Kadota; BB = Bakor Blanc; BN = Bakor Noir.

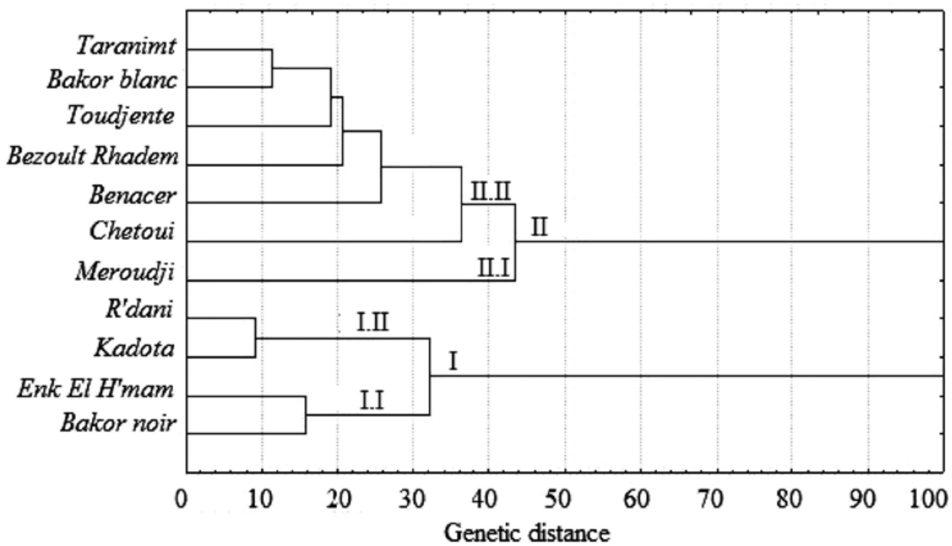

Fig. 2. Dendrogramm of the 11 fig cultivars based on phenotypic traits using Ward's method.

(1), whereas in terms of leaves number our results were higher than those reported by Simsek (11) who attributed the variability of the leaf surface and the number of leaves to genetic characteristics and environmental conditions. Furthermore, since the leaves number and the leaf size are expected to evolve with the trees growth, we suggest that it is better to evaluate these vegetative characteristics beyond 6 or 7-year-old age. The harvesting period recorded in this study coincides with that observed by Simsek and Yildirim (12), however it could last longer. The cultivars Chetoui, Benacer and Enk El H'mam are interesting in terms of fruit ripening (very late) and can be used in a programme to improve the duration of fruit ripening.

The shape and the index of the fruits are very important for their trade. Practically, it is assumed that the globose shape is the most suitable especially for packaging and fruits transportation. Our data show that 7 cultivars (Taranimt, Toudjente, Kadota, Chetoui, Bezoult Rhadem, Benacer and Meroudji) fulfil this commercial criterion. The others cultivars have an oblong shape and are more appropriate for confectionery or jam preparation. The fruit size is considered as an important qualitative trait for the consumption of fresh figs. A good fruit size is also a quality index that reflects the proper maintenance of the tree (Tamboli *et al.*, 13). However, this character is known to be negatively influenced by the fruit load on the trees (Radivojevic *et al.*, 10). It is noteworthy that besides the genetic effect, fruit weight depends also on the growing location as well as the interaction between the genotype and the maturity stage.

This study revealed that the maximum length of the neck and the stalk is different from that reported by Vrhovnik *et al*. (15). Simsek and Yildirim (12) consider that, contrary to a long stalk, a short neck is undesirable because it makes the picking difficult and is damaging to the fruits. Moreover, the fruits with a too long neck or with a large ostiole opening are a major problem to the fresh fig industry. In this study, the cultivars R'dani, Kadota, Bezoult Rhadem and Meroudji have the shortest fruit necks and therefore are less attractive to fig producers. On the other hand, the figs of the cultivar Enk El H'mam, which have the longest neck and a large ostiole opening, is also not very well appreciated by the industry. The results of chemical properties of the fruits show significant variability of soluble solids among cultivars and confirm previous reports (Crisosto *et al.*, 4; Trad *et al.*, 14). In Algeria, fresh figs with globular shape and rich in sugars are well sought by consumers. Most of these sugars are in the form of soluble solids and are involved with organic acids, particularly citric acid, in the fruit flavour. In this context, Basheer-Salimia *et al.* (2) consider that high quality table figs must have a solid soluble extract ranging from 13.0 to 25.1%. In our study, levels varying between 13.56% (Bakor Noir) and 25.12% (R'dani) constitute an index of high quality for all cultivars in terms of total soluble solids.

The results of the principal component analysis show that the total variability is expressed by the first three components, *i.e.* 30.08, 16.81 and 14.49%, respectively. The Euclidean distances indicate that Kadota has the closest similarity with R'dani and the furthest with Meroudji. On the other side Bakor Blanc and Bakor Noir are significantly dissimilar, even though they have the same name, which implies a case of homonymy. The inclusion of cultivars with different fruit colours in the same group demonstrate that this character is not sufficiently discriminatory. The presence of 4 cultivars (Enk El H'mam, Bakor Noir, R'dani and Kadota) in group I and 7 cultivars (Meroudji, Chetoui, Benacer, Bezoult Rhadem, Toudjente, Bakor Blanc and Taranimt) in group II, reveals also that they are phenotypically similar. This similarity is probably due to the same mode of propagation.

According to Caliskan and Polat (3), the random selection from natural populations decreases the genetic diversity. However, due to vegetative multiplication, which probably uses the same propagation material, the fig has a narrow genetic base. This work demonstrated that the assessment of genetic diversity by morphological descriptors is an appropriate tool, and showed the richness of the fig genetic resources and their characteristics. It also revealed some promising cultivars that can offer new opportunities to growers. Their conservation can be used for future research works as well as for the constitution of a fig database.

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