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Evaluation of phenotypic variability of fig (*Ficus carica* L.) cultivars in Atlas Mountains and oases of Morocco

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ABSTRACT

The fig tree (*Ficus carica* L.) is one of the most economically important fruit species in Morocco. Nevertheless, little research has focused on the genetic diversity of total fig genetic material, and there is no comprehensive inventory of Moroccan fig cultivars. Therefore, this study focused on unstudied cropping zones, namely Atlas Mountains and oases of the South of Morocco. 28 pomological traits were used to characterize 75 cultivars of autumn figs. The results revealed significant pomological variation among studied cultivars, with high levels of variation for most measured parameters, as indicated by the overall mean values and high coefficients of variation. Furthermore, the analysis of variance showed significant differences between cultivars for the majority of the examined traits, demonstrating high phenotypic heterogeneity among these cultivars. Size, weight, length, width, and flesh thickness of fruit were found to be the most discriminatory variables between cultivars. The Principal coordinate analysis and Hierarchical Cluster Analysis placed the accessions in two separate groups. Hypotheses of homonymy and synonymy were suggested for some cultivars. The results indicated that the cultivars in this region provide a rich genetic resource; in addition, pomological markers were informative for genetic variability detection of this species. These results should be exploited to resolve the mislabeling problem of some cultivars which could be useful to identify the exact number of fig cultivars in Morocco in order to establish a national core collection.

Keywords: *Ficus carica*, pomological trait, cultivars, phenotypic diversity.

INTRODUCTION

The fig species (*Ficus Carica* L.) is a tree belonging to the Moraceae family in which a very large number of species are grouped into 40 genera (Marcotuli et al., 2020; Ergül et al., 2021). It is one of the oldest traditional crops and a sacred fruit tree recognized since ancient time and utilized for fruit production. It was originated from a region in western Asia, between the Caspian Sea and Northeast Turkey, and has been spread through the Mediterranean basin (Caliskan et al. 2012) and the Middle East (Madrigal-santillán et al., 2024; Bakewell-stone, 2022). It is a subtropical deciduous fruit which is suitable for high temperatures and inadequate water regimes (Chithiraichelvan et al., 2017). The majority of fig acreage is found in the Mediterranean Basin and Middle East area (AYAR et al., 2023 ; Badgujar et al., 2014). According to FAOSTAT Database, total global fig harvested area reached 286 197 hectares and the fig production reached 1 315 588 tons in 2019. Morocco with around 137 930 tons is ranked third among the most important fig-producing countries in the world. Figs can be eaten fresh as a table fruit, but the greater quantity is dried for preservation, since figs are highly perishable and cannot be stored for long periods under ambient conditions (Saltveit et al., 2016).

Botanists distinguish between two types of fig trees: wild fig trees, known as caprifig, whose figs never ripen (morphologically, these fruits differ from edible fruits in that they are often small, bitter and of a whitish flesh color, containing no achenes); and fig trees that produce edible fruit. To schematize this ecosystem, it can be imagined that the caprifig provide the male function, while the others play the female role (Marcotuli et al., 2023; Hiwale, 2015). For the cultivars that produce edible fruit, a distinction is made between cultivated populations and spontaneous populations, which are difficult to distinguish from one another. From a practical point of view, in surveys, geneticists rely mainly on the characteristics of the natural habitat (Bakewell-stone, 2022; Khadari et al., 2005) to differentiate the spontaneous forms that would be closest to the wild forms, that is: natural sites with rocky soils, located on watercourses or open vegetation on steep slopes. However, this work does not take into account the dispersal distances of cultivated fig tree seeds or the spatio-temporal framework of the historical occupation of fig orchards.

In Morocco, fig cultivation is very traditional (Haddou and Damme, 2013), and considerable efforts are being made nationwide to promote fig production as an alternative to other traditional crops (Tikent et al., 2022 ; Messaoudi and Boughida, 2008). For instance, fig is widely spread in all the climatic stages. The plant material used is heterogeneous and made up of varieties with local names attributed according to cultivation areas or fruit criteria like color, shape, etc., (El Oualkadi; Hajjaj, 2019; Oukabli and Khadari, 2005). Numerous fig cultivars are grown in many niches all over the country, and well adapted to the local agroecological conditions. In the southern and south-eastern oases, given the climatic constraints, the lack of modern means of food preservation, the remoteness of these oases from the towns and markets that supply them with food, and their limited financial resources, the inhabitants of these oases resort to drying figs. Other regions even use the inedible fruit of the caprifig tree (male fig tree), and the small edible figs before ripening, in Moroccan meals such as couscous. However, diverse abiotic and biotic stresses (urbanization, rainfall irregularities, plagues...) are currently threatening the germplasm resources.

It should be stressed that some studies have reported the use of pomological traits and molecular markers in a limited cultivars collected in the North and Eastern of Morocco (Khadari et al., 2005; Ater and Hmimsa, 2008). However, no research results have been reported on cultivars in Atlas Mountains and oases of Morocco. Thus, the objective of this study was to investigate and characterize the morphological variations among different fig cultivars, specifically grown in those regions. This study can help to identify the accessions that can potentially serve as genetic resources for future conservation and breeding programs.

MATERIALS AND METHODS

Plant material and characterization parameters

During June - September 2022, the fruits of 75 fig trees were collected from 4 regions in center and South of Morocco: Khénifra-Beni Mellal, Marrakech-Safi, South East and South west (Figure 1). Well-maintained mature trees were selected at random for each site, and for each tree, 10 ripe figs were taken at random from each side. Geographical characteristics of the studied areas are summarized in Table 1. In total, 28 pomological traits were used to evaluate the morphological variation of the studied cultivars. Those traits were performed using IPGRI (IPGRI, 2010) and UPOV (Upov, 2010) descriptors. These traits are largely used to identify fig genotypes (Barakat and Draie, 2023; Aljane et al., 2012) and most of them are of economic interest, particularly those related to fruit quality, and therefore serve as suitable traits for fig selectors and producers.

Quantitative traits, such as fruit width, fruit length, pulp length, achenes diameter, internal cavity, stalk width, stalk length, neck length, ostiole diameter, fruit size, fruit weight (Table 2), were measured using a digital caliper and a precision scales. Also, qualitative traits (shape, fruit apex shape, fruit symmetry, ground color of skin, over color of skin, crackling of skin, crackling around ostiole, density of lenticels, lenticels color, attachment of stalk to stem, shape of stalk, bracted color, color of liquid drop at the ostiole, ease of peeling, color of pulp, number of achenes, juiciness), were assessed using rating, scoring, and coding methods (Table 3).

Statistical analysis

The numerical values obtained from the different traits measured were subjected to various statistical analyses. For all parameters, the averages and coefficients of variation were determined using Excel software. Analysis of variance (one-way ANOVA) was used to determine differences between cultivars and comparison of the mean values was made using the Duncan's multiple range test ($P < 0.05$). Further**,** Pearson's correlation test was used to measure the association between all variables. These analyses were realized using SPSS software (SPSS, 2020). Multivariate relationships among cultivars were revealed through a Principal coordinate analysis (PCoA) using a correlation matrix derived from the significant characters. The squared Euclidean distance was used to perform cluster analysis. This analysis was realized with XLSTAT software version 2018.

RESULTS AND DISCUSSION

Means and ranges of quantitative variables

The global average values for all quantitative parameters measured are shown in Table 2. Analysis of variance showed highly significant differences between cultivars for all parameters. Additionally, several traits also showed high

Table 1. Geographical and meteorological conditions of *Ficus carica* L. cultivars used in the study

Cultivars	Code	Region	Geographic origin	Latitude N	Longitude W	Altitude (m)	Rainfall (mm)
Chetoui	CH1	Beni Mellal-Khenifra	Ain Kaicher	388830.29	238217.63	603.76	346.26
Kahalia	KH1						
Chetoui	CH2		Sidi Jaber	397695.75	197376.80	498.42	402.39
Kahla	KA1						
Chetoui	CH3		Oulad Si Mimoune	397703.1	197433.65	494.9	402.39
Kahla	KA2		Ain Aserdoun	412367.64	191058.92	1000.5	402.39
Khadou	KD2						
Chetoui	CH4						
Chetoui	CH5		Dahra	393015.1	186677.61	494.75	402.39
Kahla	KA10						
Benaxi	BX		El Ksiba	438261.36	217843.43	1084.3	596
Tahjajt	TA1						
Ain Hajla	AH1			438487.61	217897.92	1079.5	596
Khadou	KD1						
Beida Bakor	BB		Afourar	460263.96	233905.19	812.84	426.37
Chetoui	CH6						
Tahjajt	TA2		Ouaouizeght	408775.24	177362.53	1213.4	426.37
Otaamran	OT						
Alkhmi	AL			408456.28	177128.96	1169.5	
Akidoun	AK						
Chetoui	CH7						
Lharcha	HA		Bzou	684726.97	3549745.86	582.8	358.99
Beida	BD18		Foum Jemaa	689038.32	3537742.06	799.74	358.99
Chetoui	CH8		Tanant	693051.42	3527673.99	893.46	358.99
Tahjajt	TA3						
Marrakchia	MA						
Beida	BD10		Azilal	728226.50	3537739.41	1376.3	358.99
Fechtalia	FC2		Demnate	357490.65	124689.33	1108.4	328.1
Beida	BD9			349301.96	126591.93	1022.8	
Kahla	KA15		Ait Bouguemez	313837.64	62744.40	2007.8	341
Beida	BD17						
Kahla	KA3		Ouaoumana	460263.96	233905.18	812.84	532.97
Beida	BD1			459702.83	234231.58	823.48	
Kahla	KA4		Talhiente	488509.29	244557.31	998.45	461.62
Ain Hajla	AH2		El Asri	483230.09	235846.57	1167.4	532.97
Beida	BD2			483239.54	235856.01	1203.2	

Ain Hajla	AH3	South East	Rich	580134.63	191635.10	1447.28	211.5
Kahla	KA5						
Beida	BD3		Errachidia	585201.34	146100.46	1110.62	133.9
Kahla	KA6						
Ain Hajla	AH4						
Tawrakht	TW		Aghbalou N'kerdouss	507285.10	130454.56	1652.99	98.93
Tabkhant	TB1						
Aayad	AY			507294.82	130399.78	1648.28	
Tazizawt	TZ			507115.99	130228.67	1625.04	
Beida	BD4		Goulmima	541735.46	122581.13	1085.59	71.1
Ain Hajla	AH5						
Mrotchi	MR1						
Mrotchi	MR2		Imider	529769.23	157410.37	1456.99	104
Beida	BD5		Oudeddi	528797.49	157011.76	1457.25	
Beida	BD6		Azaghar	509872.46	145683.35	1760.19	100
Mrotchi	MR3		Boumalne Dades	443537.31	487899.04	1596.85	341
Beida	BD7						
Kahla	KA7						
Fechtalia	FH1		Skoura	388830.91	453929.78	1324.71	238
Kahla	KA8						
Beida	BD8		Tizerine	313900.22	460004.73	1589.77	213
Kahla	KA9						
Beida	BD11	Marrrakech Safi	Ben Sasi	483480.63	3561040.58	161.45	265
Beida	BD12		Akarkaw	428576.93	3402007.87	448.73	133
Beida	BD16		Siti Fatma	619720.30	3464670.84	1073.5	288
Kahla	KA14						
Variete Algerienne	AL						
Beida	BD13	South West	Tamrout	304048.10	9291.20	358.42	183
Kahla	KA11						
Mrotchi	MR4		Imouzzer	453868.42	3393118.61	1227.4	335
Tasmoumt	TS		Sidi Ali Bouzid Tioughza	403692.22	3254166.96	284.34	235
Toumlit	TM			404039.81	3253547.6	288.97	
Tabkhant	TB2			407726.11	3250878.3	374.02	
Amjoud	AM						
Tasgant	TG		Tasrit	507159.96	3276714.88	1701.0	109
Beida	BD14		Oasis AIT MANSOUR	511541.95	3269093.03	1289.8	109
Kahla	KA12						
Kahla	KA13		Ait Iggass Zawia Ifergan	303255.43	84112.087	382.68	193.3
Beida	BD15						

coefficients of variation (CV), exceeding 34.8% (Internal cavity, Pulp length, Stalk width, Neck length, Ostiole diameter, Fruit size and Fruit weight). This indicates a significant amount of variation or differences in these traits among the studied cultivars.

In terms of fruit weight, ''KH 4'', ''FC 1'' and ''FC 2'' cultivars presented the heaviest fruits 59.3–70 g. However, the lightest fruits were obtained in the "TG", "TB2", "KA14", "MR3", "KA15" and "KA12" cultivars (7.6–12.3 g). These results show a high diversity between cultivars studied in comparison with the results obtained in Moroccan germplasm collection by Hssaini et al. (2020), since they found that the weight of the fruits varied between 14.78

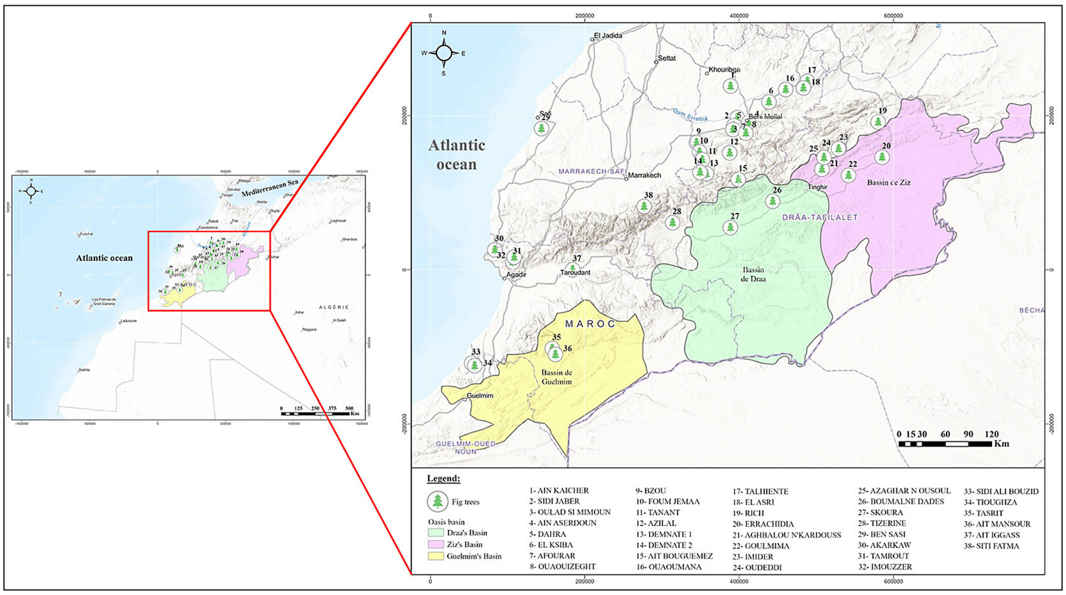

Figure 1. Map of Morocco showing locations of the *Ficus carica*. L cultivars collected in Atlas Mountains and oases of Morocco

g and 34.41 g. This high variability is probably linked to environmental conditions and agricultural practices. According to Sadder and Ateyyeh (2006), Curi et al. (2019) and Khadivi and Mirheidari (2022), fruit sizes are highly appreciated for fresh consumption, and small sizes are generally destined for canning.

Concerning the fruit length, the longest fruits were found in cultivars "KA4", "BD1" and "AL" (57.04 mm, 46.64 mm and 46.13 mm, respectively) and the smallest fruits were detected in cultivars "TB2", "TG" and "MR4" (15.32 mm, 21.25 mm and 21.33 mm, respectively), while the fruit width varied from 15.83 mm to 56.50 mm. The greatest widths were registered in "FC1", "FC2", "KA4" and "BD1". For fruit pulp, the highest values was obtained in "AL" (36.34 mm), followed by "KA8" (36.23 mm), ''BD1'' (34. 59 mm), and ''BD13'' (33.81 mm), while the thinnest pulp were recorded in the "KA11", "TB2", "TW" and "MR1" cultivars (9.3 mm, 11.2 mm, 15.95 mm and 18.33 mm, respectively).

About the diameter of fruit ostiole, the values varied between 2.41 mm (AH4) and 14.42 mm (OT). Indeed, the fruit ostiole is the key to maintaining pollinator-host specificity (Wang et al., 2013; Hu et al., 2020 ; Falistocco, 2020) A large ostiole in the fig is an unwanted trait that allows pests and infections, such as endosepsis, to easily enter the fruit and spread to healthy fruits (Koşar et al., 2022 ; Herre et al., 2008). For stalk dimensions, coefficients of variation of 83.6% and 104.11% were registered for width and length, respectively. Besides, stalk length varied between 0.38 mm (AH4) and 10.87 mm (BD17), while stalk width ranged from 0.59 mm (BD2) to 6.03 mm (KH7). The positive extremes of stalk length were observed in cultivars "BD17" (10.87 mm) and "BD4" (10.32 mm), while the shortest stalks were observed in cultivars "AH4" (0.38 mm) and "BD2" (0.44 mm). In terms of stalk width, the thickest are found in cultivars "AH17" (6.03 mm) and "KA3" (5.43 mm), while the thinnest are found in cultivars "BD2" (0.59 mm) and "BX" (0.66 mm).

The cultivars studied in this work coming from oases and mountainous regions of the Atlas, are distinguished by their large fruit size and weight, compared with the cultivars previously studied in other regions in Morocco (Tikent et al., 2022; Hssaini et al., 2020), and other countries: Tunisia (Aljane et al., 2012) and Jordan (Almajali et al., 2012). However, the results obtained seem to be similar to the cultivars of Turkey (Çalişkan and Polat, 2012).

Ranges of qualitative traits variables

All results obtained from qualitative scoring are presented in Table 3. These results revealed that the majority of cultivars showed spherical fruit shape (57.5%), rounded apex shape (51.2%) and asymmetrical fruits (94.7%). Moreover, lenticels density for fruits cultivars is generally medium (58.5%) and white in color (83.1%). Skin

Table 2. Means, coefficient of variation and "F" values from one-way ANOVA of quantitative morpholoical characters determined of studied fig cultivars. The minimum and maximum values are bolded

Cultivars	Achenes diameter (mm)	Internal cavity (mm)	Pulp length (mm)	Stalk width (mm)	Stalk length (mm)	Neck length (mm)	Ostiole diameter (mm)	Fruit width (mm)	Fruit length (mm)	Fruit size (mm)	Fruit weight (g)
KAHA1	1.29	5.30	26.22	3.96	1.78	1.44	5.01	33.78	29.68	95.43	21.83
CHET1	1.54	4.94	30.37	-	-	1.89	3.54	35.44	30.85	118.10	26.16
BENX	1.38	4.30	28.15	0.66	0.60	7.90	5.34	39.44	35.52	127.60	34.20
AINH1	1.38	-	28.36	-	-	0	7.54	41.70	35.84	13.26	35.45
TAHJ 1	1.35	0.19	32.38	1.23	1.43	4.77	7.85	42.32	36.66	13.44	37.20
KHAD1	1.27	6.83	29.23	-	-	2.69	5.41	38.58	36.10	12.07	31.60
CHET2	1.12	-	30.19	3.84	4.23	7.10	5.01	43.14	40.42	137.50	38.40
KAH1	1.55	2.45	25.18	4.76	4.01	1.17	5.67	39.73	36.91	124.20	29.64
CHET3	1.41	2.09	26.54	3.83	6.17	4.83	5.16	45.71	41.30	14.63	42.49
KAH2	1.48	-	21.58	4.48	2.46	1.04	5.05	34.05	35.18	12.08	28.11
KHAD2	1.32	1.40	22.92	-	-	3.28	3.45	36.25	34.51	11.63	23.75
CHET4	1.42	1.97	24.31	1.22	0.60	1.77	5.31	37.52	32.31	11.79	25.50
BEID1	1.61	-	34.59	-	-	6.59	8.48	51.02	46.13	157.15	55.00
KAH3	1.64	-	27.22	5.43	2.84	6.51	7.89	45.46	42.11	148.25	46.06
KAH4	1.37	-	30.29	1.42	0.73	2.54	9.22	55.06	57.04	171.50	70.00
AINH2	1.55	-	26.98	-	-	0	13.87	45.91	27.01	118.74	38.85
BEID2	1.61	-	28.59	0.59	0.44	2.67	6.31	51.66	42.30	162.75	56.80
AINH3	1.38	-	21.45	3.50	2.65	0	5.17	41.29	30.42	130.15	27.65
KAH5	1.52	-	23.91	4.80	2.00	0	6.08	40.00	32.78	127.40	28.80
BEID3	1.50	-	29.33	1.63	0.64	0.62	5.51	47.40	37.69	153.75	50.00
KAH6	1.55	-	21.23	-	-	0.81	9.20	39.47	34.60	136.95	35.00
AINH4	1.42	-	24.43	0.92	0.38	0	2.41	39.74	31.76	136.00	32.65
TAWR	1.47	0.84	15.95	-	-	0	4.76	29.78	22.21	97.35	13.15
TABKH1	1.46	4.58	22.61	1.35	2.43	3.32	3.72	31.68	30.53	99.45	13.90
AYAD	1.43	-	24.41	-	-	0	5.09	38.24	30.16	122.55	26.65
TAZIZ	1.35	-	27.52	-	-	1.43	4.60	37.71	36.10	120.25	28.45
BEID4	1.40	-	22.77	5.04	10.32	0	4.99	42.29	33.58	143.10	39.10
AINH5	1.46	1.11	27.01	3.63	8.86	0	6.19	42.12	31.51	135.20	32.60
MROT1	1.37	0	18.33	4.79	4.61	2.95	5.77	30.37	25.99	100.90	13.70
MROT2	1.60	4.05	24.36	3.88	8.38	0	4.78	39.12	31.78	127.80	24.80
BEID5	1.37	5.65	20.80	1.11	1.69	0	5.39	44.84	28.48	144.25	32.70
BEID6	1.52	0	30.64	2.01	2.50	4.14	5.43	40.67	43.29	128.60	31.20
BEID7	1.17	3.36	20.45	5.77	5.35	0.50	5.24	39.38	28.16	126.20	25.10
KAH7	1.35	4.27	26.09	6.03	6.41	4.85	5.61	47.27	41.11	152.00	49.50
MROT3	1.40	2.58	26.15	4.51	3.08	1.14	4.72	35.81	31.42	114.80	24.10
FECH1	1.29	-	26.67	5.50	1.89	1.31	7.38	56.50	41.98	175.80	66.78
KAH8	1.59	-	36.23	0.82	0.76	0	3.78	33.89	40.23	110.80	24.20
BEID8	1.39	1.35	31.32	2.52	4.39	3.16	6.58	44.52	40.38	139.90	40.10
KAH9	1.24	3.59	27.03	4.27	5.31	0.83	5.92	39.02	32.42	124.60	28.80
BEID9	1.55	4.95	23.39	2.23	2.37	0	5.58	33.90	28.10	111.10	20.60
FECH2	1.16	1.21	30.55	5.32	3.14	3.98	6.36	50.48	43.70	160.50	59.30
CHET5	1.31	1.37	24.40	1.61	1.81	8.55	4.88	37.93	38.15	121.90	27.50
KAH10	1.65	0	22.94	3.45	4.53	2.15	6.30	38.82	37.76	124.40	32.20
BBAK	1.45	1.09	24.35	1.42	1.07	3.69	5.78	36.99	36.20	116.40	26.70
CHET6	1.76	1.95	22.78	1.00	0.85	1.70	4.72	34.86	32.78	112.90	22.50

BEID 10	1.64	-	24.50	4.44	3.01	0.49	4.53	31.98	27.78	103.20	19.10
BEID 11	1.57	-	31.14	1.19	1.45	0.36	5.65	43.70	37.99	136.40	38.60
BEID 12	1.28	-	27.73	2.25	1.77	0	6.29	36.10	32.10	11.99	28.90
BEID 13	1.38	-	33.81	2.83	4.23	0	6.23	40.15	39.17	13.23	35.90
KAH 11	1.44	21.43	9.3	-	-	0	4.94	27.99	22.83	9.00	14.00
MROT4	1.31	0.41	16.95	1.91	2.68	0	4.38	27.44	21.33	9.26	12.00
TASM	1.51	6.22	29.38	2.89	2.84	5.53	7.84	32.17	37.33	10.84	23.80
TOUM	1.21	8.30	23.03	-	-	1.77	8.32	37.91	34.84	12.28	25.70
TABKH2	1.47	3.32	11.90	2.07	4.10	2.01	3.03	15.83	15.32	88.70	10.30
AMJO	1.16	9.82	28.64	-	-	5.35	6.36	38.25	37.13	12.25	32.10
TASG	1.42	2.48	17.01	1.57	2.15	0.26	3.02	24.68	21.25	79.70	7.60
BEID14	1.53	-	20.26	2.39	2.67	0	5.55	35.92	26.00	116.60	19.85
KAH12	1.37	4.66	21.23	2.23	2.27	0.91	3.87	27.32	24.31	89.00	12.30
BEID15	1.58	4.98	25.30	-	-	1.28	4.86	36.39	35.60	116.60	24.20
KAH13	1.41	4.71	24.48	1.31	7.62	3.11	6.41	36.14	34.54	105.55	21.90
BEID16	1.49	-	27.98	2.17	2.97	1.03	3.75	36.00	36.15	116.20	25.90
ALG	1.38	9.95	36.34	1.30	1.97	2.99	3.79	40.31	46.64	141.70	59.40
KAH14	1.47	1.54	19.90	0.74	0.48	1.55	3.27	25.18	25.27	81.90	10.30
TAH2	1.52	0.52	29.22	-	-	0	4.50	39.73	34.89	126.10	32.70
OUTAA	1.40	4.04	31.47	-	-	0	14.42	48.43	38.47	151.60	47.60
ALKH	1.60	-	26.45	1.12	1.57	0	5.77	38.74	33.10	124.90	29.90
AKID	1.50	-	26.98	2.03	0.85	0	4.96	45.88	32.86	142.20	40.10
CHET7	1.68	3.58	30.76	-	-	1.04	6.79	41.89	37.98	135.60	37.30
KAH15	1.53	-	17.31	3.11	9.11	0	5.11	28.64	22.86	92.60	12.20
BEID17	1.65	4.77	23.22	4.41	10.87	0.45	5.05	32.49	27.75	103.00	17.90
HAR	1.62	-	28.69	2.95	2.64	1.82	4.78	38.63	36.07	124.30	30.30
BEID18	1.59	3.60	23.97	0.84	0.98	1.28	5.67	33.51	31.96	108.20	19.10
CHET8	1.68	1.99	27.48	2.73	6.55	2.12	5.80	36.18	37.61	116.60	27.79
TAH3	1.76	1.00	26.93	4.38	6.61	1.29	9.24	37.69	33.57	117.50	28.60
MAR	1.57	0.85	26.44	4.66	8.00	1.31	5.18	37.20	35.89	76.00	29.00
Mean	1.45	2.26	25.57	2.19	2.64	1.83	5.75	38.44	34.02	102.91	30.57
CV%	9.69	147.82	19.63	83.63	104.11	115.26	34.80	18.10	19.76	46.78	42.81
F value	7.10***	14.07***	13.46***	8.07***	8.74***	10.88***	5.86***	20.34***	14.60***	112.9***	37.26***

Note: *all F values are significant at $p < 0.001$.

color is predominantly green (36.1%), purple (26.6%), yellowish-green (22.8%) and black (6.8%). The over coloration of figs is generally green (42.4%) and black (34%). Indeed, fruit skin color is a trait that seems to be influenced by environmental conditions (Espley and Jaakola, 2023 ; Oukabli. 2005), for example the “Kahla” cultivars illustrate this influence since most oases fruits have a green-black color, while some cultivars from the Agadir region have a violet-black color with the absence of green.

Most of the fruit sampled was juicy (47.2%), easy to peel (47.9%) and rarely showed cracks in the skin, since most of the fruit was crack-free (70.1%). The same for the cracks around the ostiole, only 10.3% had this characteristic. These epidermal cracks are favored, by low temperatures and high humidity (Hayati et al., 2021). This is why the “Chetoui” cultivar, from the Ouaouizeght region (a mountainous region at an altitude of 1213.45 m) has more cracks than the Beni Mellal cultivar, where altitude is low and rainfall is rare, especially during the fruit ripening months (Table 1). Generally, a large number of cultivars (58.8%) have no honeydew in the ostiole (the liquid that comes out of the ostiole), which is generally yellow (22%). The bracts inside the ostiole are generally yellow (52.3%). For 52%

Table 3. Dominant frequencies and analysis of variance of fruit qualitative traits

Descriptor	Evaluation scale	Dominant character	Fréquency (%)	ANOVA Signification
Shape	Spherical-cucurbiform-turbinate-ovoid-pyriform - urceolate	Spherical	57.7%	8.456***
Fruit apex shape	Flat-rounded - acute	Rounded	51.2%	14.094***
Fruit Symmetry	Yes-no		94.7%	2.316***
Ground color of skin	Yellow-green yellow-yellow green-green-yellow and green bands-purple-black	Green	36.1%	207.9***
Over color of skin	Absent-yellow-green-red-purple-black	Green	42.4%	376.99***
Crackling of skin	Absent-lateral - longitudinal	Absent	70.1%	7.30***
Crackling around ostiole	Absent - present	Absent	89.6%	4.85***
Density of lenticels	Sparse-medium-dense	Medium	58.5%	25.14***
Lenticels color	White-pink-green	White	83.1%	44.93***
Attachment of stalk to stem	Weak- medium - strong	Dure	59.3%	8.2***
Shape of stalk	Variously enlarged Long and slender Short and thick	Short and thick	56.9%	74.48***
Bracted color	Yellow-brown-pink-purple - white	Yellow	52.3%	16.55***
Color of liquid drop at the ostiole	Absent -Transparent- pinkish-red - dark red	Absent	58.8%	18.92***
Ease of peeling	Easy-medium - difficult	Easy	47.9%	12.5***
Color of pulp	Yellow white- brown yellow- pink-purple-orange red-red-light brown-dark brown	Purple	28.4%	23.71***
Number of achenes	Few-medium - many	Many	55.1%	12.4***
Juiciness	Low-medium-high	Medium	47.2%	8.45***

of cultivars, the pulp was purple in color, and contained many achenes (55.1% had a very high number of achenes). The taste quality of the fruit, low to average in some cultivars, is generally linked to the absence of seeds, which contribute to improving the taste of the fruit (Veberic and Mikulic-Petkovsek, 2015).

The stalk is generally short and thick (56.9%), and tends to stay attached to the branch at harvest time (59.3% are hard). Size, color and the presence of cracks in the fruit are generally the main criteria desired by consumers. According to farmers' testimonies, consumers prefer the fruits that are larger in size, mature, especially those with a green color and multiple cracks.

Principal coordinate analysis

Principal coordinate analysis (PCoA) was performed taking into account all quantitative parameters measured of fruits. The eigenvalues obtained by PCoA indicate that the first two components provide a good summary of the data. They explained 97.20% of the total variability. The first component (PC1) was strongly linked to fruit size, fruit width, and fruit length, while the second component (PC2) showed strong associations with fruit weight and fruit flesh thickness. The bi-plot axes generated based on principal components PC1 and PC2 showed a high pomological variation among the studied cultivars, and they were distributed into two mains groups (Figure 2). The first group includes 14 cultivars belonging to the Beni Mellal and Agadir-Sidi Ifni regions. These cultivars are mainly characterized by a small fruit size not exceeding 14 mm, a low weight not exceeding 40 g, and a pasty, not very juicy flesh often red in color. The liquid of the ostiole of these cultivars is transparent and often absent. The second group includes the remaining cultivars (61), mainly from mountainous regions characterized by high weight, large size and a small internal cavity of fruits, which is often absent and the size of the flesh is also often large. As for quality criteria, the cultivars in this group are often juicy, with purple flesh, containing many achenes, making the fruit crunchy and giving it a good taste. Within each group of cultivars that

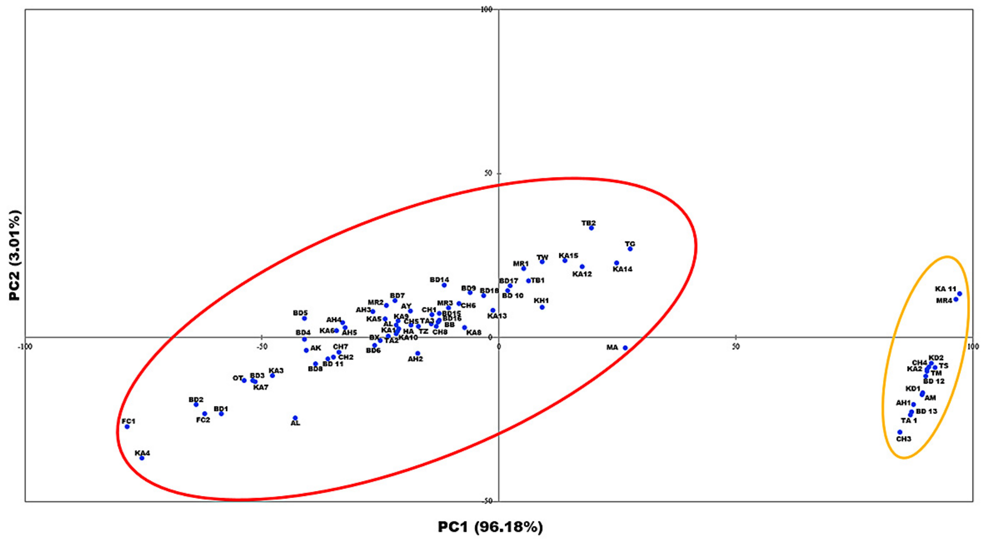

Figure 2. Principal coordinate analysis (PCoA) Plot of studied fig cultivars on the space formed by the first two axes performed on the basis of pomological characters

received the same denomination 'Chetoui', 'Kahalia', 'Kahla', 'Beida', 'Ain hajla' or 'Mrotchi', many differences were observed. However, some genotypes clustered together. Thus, it is possible to consider these groups as 'variety populations' or 'multiclone varieties' as reported for other fruit species (Gaaliche et al., 2012 ; Cao et al., 2019). It is also interesting to note that the geographic origin was not a determinant criterion for cultivar aggregation. This may suggest that there was a wide interchange of plant material between different growing zones in the country.

Cluster analysis

Cluster analysis using the unweighted pair group method with arithmetic mean (UPGMA) based on morphological distance analysis revealed that the 75 cultivars could be divided into 2 main groups (Figure 3). The first group (I) includes 14 cultivars, subdivided into 2 distinct subgroups (A and B). The first subgroup (A) contained two cultivars: "KA11" and "MR4" characterized by black, small and low weight of fruit. The second subgroup (B) is composed of 12 accessions

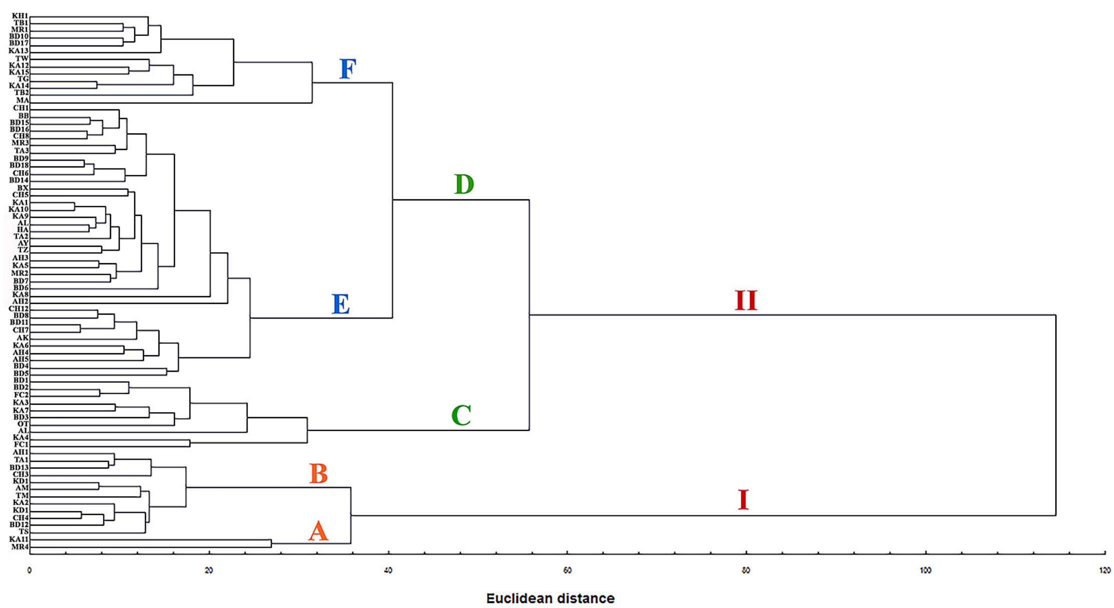

Figure 3. UPGMA dendrogram (based on squared Euclidean distance) of fig cultivars performed using pomological characters

(“TS”, “BD12”, “CH4”, “KA2”, “TM”, ‘AMJO’, “KD 1”, “KD2”, “CH3”, “BEID13”, “TAHJ” and “AINH1”. These accessions are distinguished by a red flesh color that is often pasty, and not very juicy for most cultivars. This group is also characterized by a light weight, but slightly heavier than subgroup A. Their fruits are also small in size. The liquid coming out of the ostiole is transparent and often absent.

The second group II is also subdivided into two subgroups C and D. Subgroup C comprised 10 cultivars (BD 1, BD2, BD3, KA3, KA4, KA7, FC1, FC2, OT and AL). These cultivars are characterized by their heaviest weight and very large size of fruits. They are frequently juicy, with thick purple flesh, and lot of achenes, giving the fruit a crunchy texture and a pleasant taste. The epidermis contains moderately intense white lenticels, whereas their stalks are hard and stay attached to the stem. In addition, this group characterizes accessions with irregular cracks in the skin, which is easy to peel. Subgroup D bifurcated into two sub-subgroups, namely E and F. The first sub sub-group E was constituted with a large number of cultivars, 38 in all. It is characterized by the fruits with significant size, average weight and high length and width. They often have a spherical shape with a rounded apex. The skin is easy to peel, and the flesh, often pink, is juicy and rich in achenes. The sub sub-group F included 13 cultivars (KH1, TW, TB1, TB2, MR1, BD 10, BD17, TG, KA12, KA13, KA14, KA15 and MAR), which are characterized by their spherical shape, often with a rounded apex. Their skin is free of cracks, and the pulp is generally red and juicy. Fruits are a medium-size, the fruit length and width are relatively small.

CONCLUSIONS

This study revealed a high degree of variability between Moroccan fig cultivars and confirms that pomological traits are viable for estimating genetic relationships between fig cultivars. Significant differences between the various fig cultivars studied were obtained in terms of both quantitative and qualitative traits. Although there is a potential effect of the climate, these results show that there is a genetic part in this variability. In assessing the extent of this diversity, all the descriptors can be considered as complementary tools, simplifying the preservation and exploitation of the fruit of this species. Many of the highly discriminating traits (size, weight, length, width, and flesh thickness of fruit) recorded in this study are of great economic importance and generally could serve as target traits for selection by fig growers and breeders, as well as preventing homonymy and synonymy.

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