

Research Article

Phenotypic Diversity of Date Palm Cultivars (*Phoenix dactylifera* L.) from Sudan Estimated by Vegetative and Fruit Characteristics

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The aim of this study was to apply some of the vegetative and fruit traits which are easily recognised to identify the variation and the diversity level of the most famous Sudanese date palm cultivars grown on farm in the northern region of Sudan. Sixteen phenotypic traits consisting of ten quantitative and six qualitative characteristics were used for describing the vegetative and fruit characteristics. The principal components analysis (PCA) and UPGMA clustering were used to analyse the data set. The results revealed high variability among the cultivars according to PCA. Fourteen out of the sixteen quantitative and qualitative traits investigated showed a strong discriminating factor suggesting their possible uses in the initiation of Sudanese date palm morphological descriptor list. UPGMA clustering exhibited strong relationship between some cultivars according to their fruit and vegetative characteristics similarity. Based on morphological traits, cultivars Wad-laggi (Lag) and Wad-khateeb (Kha) formed a distinct group suggesting their close relatedness. Similarly, the cultivars sharing the dry fruit texture such as Gondaila (Gon), Tamoda (Tam), Kolmah (Kol), and Barkawi (Bar) were grouped together according to their vegetative traits. Further investigations on Sudanese date palm using more phenotypic characteristics are recommended in order to shape and complete the set of the morphological descriptor list.

1. Introduction

The date palm (*Phoenix dactylifera* L.) is perennial and diploid ($2n = 2x = 36$) and classified under the genus *Phoenix*, which is the single member of tribe Phoeniceae, monocotyledonous family Palmae. “*Phoenix*,” meaning purple or red in the Greek language, refers to the colour of the fruit and “*dactylifera*” means finger, referring to the fruit shape [1]. *Phoenix* species have two types of growth habit: trunked or clumping. Both forms are common in Sudan where the female trees have both forms depending on the culture where the date palm grows. The trunk height is ranging between 15 and 25 meters [2]. *Phoenix* species can be distinguished from other palms by having feather-type leaves through modification of the basal leaflets into spines, the presence of a terminal leaflet, and a central fold or ridge on the leaflets, which cause the leaflets to remain erect at all

times. *Phoenix* species are dioecious, with the inflorescences arising among the leaves. The small pale yellowish flowers are borne singly, with the sepals being united into a cupule and three petals. Female flowers have three carpels, only one of which matures. The fruits of *Phoenix* species are drupes of variable size, depending on the species, with a single grooved seed [3].

The date palm is mainly propagated vegetatively through offshoots but also by tissue culture or through seed. However, propagation through seeds results in new genotypes or forms of date palm, which are considered the main source of variation in date palms [4]. The distribution of date palms globally is intensively concentrated between latitudes 10° and 35° north and south of the equator. In Sudan, the intensive culture of dates concentrated along River Nile in River Nile and northern states beside separated oases in the Red Sea regions, Kordofan and Darfur [5, 6].

TABLE 1: Name, abbreviation, classification, and coordinates of date palm cultivars evaluated.

Cultivar	Code	Status	<i>E</i>	<i>N</i>	Elevation	Fruit class
Wad-laggi	Lag	Cultivated	602599	1957504	359	Soft
Wad-laggi	Lag	Cultivated	525308	2159709	313	Soft
Wad-laggi	Lag	Cultivated	375234	2043146	261	Soft
Wad-laggi	Lag	Cultivated	559938	2075246	339	Soft
Wad-laggi	Lag	Cultivated	535815	2154538	320	soft
Wad-laggi	Lag	Cultivated	560436	2118716	336	Soft
Wad-khateeb	Kha	Cultivated	377290	2049337	242	Semisoft
Wad-khateeb	Kha	Cultivated	251388	2047859	251	Semisoft
Wad-khateeb	Kha	Cultivated	382560	2052407	222	Semisoft
Wad-khateeb	Kha	Cultivated	602661	1957745	357	Semisoft
Wad-khateeb	Kha	Cultivated	605060	1989032	372	Semisoft
Wad-khateeb	Kha	Cultivated	597121	2013769	343	Semisoft
Kolma	Kol	Seedling	234010	1261482	224	Dry
Kolma	Kol	Seedling	361221	2019949	265	Dry
Kolma	Kol	Seedling	367656	2029199	225	Dry
Kolma	Kol	Seedling	374386	2045858	247	Dry
Kolma	Kol	Seedling	238418	2205990	216	Dry
Kolma	Kol	Seedling	556486	2118163	305	Dry
Jaw	Jaw	Seedling	227703	2171767	220	Soft
Jaw	Jaw	Seedling	348943	2003129	264	Dry
Jaw	Jaw	Seedling	234554	2126176	226	Semisoft
Jaw	Jaw	Seedling	582285	1913899	353	Soft
Jaw	Jaw	Seedling	499466	1828680	389	Dry
Jaw	Jaw	Seedling	596102	1936920	354	Dry
Gondaila	Gon	Cultivated	353171	2013025	268	Dry
Gondaila	Gon	Cultivated	229274	2174614	223	Dry
Gondaila	Gon	Cultivated	283940	1996407	250	Dry
Gondaila	Gon	Cultivated	500033	1828321	365	Dry
Gondaila	Gon	Cultivated	617539	1949686	356	Dry
Gondaila	Gon	Cultivated	548228	1849063	377	Dry
Bet-tamoda	Tam	Cultivated	223931	2175398	225	Dry
Bet-tamoda	Tam	Cultivated	321495	1992480	250	Dry
Bet-tamoda	Tam	Cultivated	273680	2004702	237	Dry
Bet-tamoda	Tam	Cultivated	227711	2168578	226	Dry
Bet-tamoda	Tam	Cultivated	238418	2205990	216	Dry
Bet-tamoda	Tam	Cultivated	556486	2118163	305	Dry
Barkawi	Bar	Cultivated	377290	2049337	242	Dry
Barkawi	Bar	Cultivated	354353	2010453	245	Dry
Barkawi	Bar	Cultivated	261409	2010212	235	Dry
Barkawi	Bar	Cultivated	500033	1828321	365	Dry
Barkawi	Bar	Cultivated	602578	1957878	355	Dry
Barkawi	Bar	Cultivated	524895	2159956	313	Dry

The date palm is considered as one of the main important crops in arid and semiarid areas, especially in North Africa and Middle East [7]. 7.5 million metric tons in 2013 was recorded as the total world production, to which Sudan contributed about 1.1% [8]. The fruit of the date palm is very rich in carbohydrates and provides high value for nutrition. In addition, other parts of the date palm such as timber and leaves have multipurpose uses [9]. The date palm in Sudan

is derived by cultivation of old traditional dry cultivars, soft and semisoft. Several farmer cultivars are also cultivated in Sudan. These include the most common cultivars: Barkawi, Gondaila, Tamoda, and Abde-Rahim, representing the dry cultivars; the soft Mishrig Wad-laggai, the semisoft Mishrig Wad-khateeb, and the Jaw, which are seed propagated cultivars [3]. The use of morphological parameters is one of the common methods implemented to identify the date palm

TABLE 2: Measured characters.

Character	Code
<i>Quantitative</i>	
Frond length (cm)	FL
Leaf width (cm)	LW
Thorn area length (cm)	TL
Pinnae length (cm)	PL
Pinnae width (cm)	PW
Stalk length (cm)	SL
Strand length (cm)	STL
Fruit length (cm)	FRL
Fruit width (cm)	FRW
Pulp thickness (cm)	PT
<i>Qualitative</i>	
Leaf colour	LC
Midrib colour	MC
Fruit colour	FC
Fruit shape	FS
Flesh colour	FLC
Flesh taste	FT

variation and level of diversity. Therefore, it has been strongly assumed that traits related either to the vegetative or to the fruit parameters are useful for date palm characterization [10–13]. The aim of this study was to apply some of the vegetative and fruit traits which are easily recognised to identify the variation and the diversity level of the most famous Sudanese date palm cultivars.

2. Materials and Methods

The study was conducted on seven Sudanese date palm cultivars (Table 1) located in the northern region of Sudan between latitudes 15.5° and 22°N. Every cultivar was represented by replication of six mature trees of each cultivar selected randomly among different geographical coordinates in the region. For morphological characterisation purposes, sixteen estimated designed parameters were used consisting of ten quantitative and six qualitative characteristics (Table 2). The main traits were taken from the descriptor list previously used for the date palm [14].

Mean values for six trees were subjected to principal components analysis (PCA) in order to identify the quantitative and qualitative parameters (separately) that significantly contribute to the variability among the cultivars [15]. The qualitative traits were scored based on scaling (1–6). In addition, Pearson correlation coefficients [16] and correspondence analysis were applied to identify and discriminate the relevant informative traits. Cluster analysis was run for grouping cultivars that showed dissimilarity in several characteristics [17]. Clustering was performed on three fruit quantitative traits and seven quantitative vegetative traits separately, using Euclidean distance matrix and the unweighted pair-group method with arithmetic average (UPGMA) method [18]. All

statistical analyses were performed using XLSTAT software [19].

3. Results

The mean values of quantitative (Table 3) and qualitative (Table 4) traits showed a great variability in the investigated date palm cultivars and this was confirmed by the results of the principle component analysis (PCA) for quantitative parameters, which explained 77.38% of variability by the first and second component (Table 5). The first component explaining 60.27% of variability was mostly correlated to the following traits: FL, LW, TL, PL, PW, FRW, and PT. The second component explaining 17.11% of variability was mainly influenced by the STL and FRL traits. The PCA of the qualitative parameters (Table 6) showed that the first and second component accounted for 82.31% of the total variability among the cultivars. The first component explaining 67.58% of variability was positively correlated to the MC, FC, LC, FS, and FT traits, while the second component explaining 14.73% of variability was directly affected by FLC parameter. In addition, the correlation matrix between the investigated quantitative traits (Table 7) showed strong correlation mainly between LW and FL; TL, FL, and LW; PL, FL, LW, and TL; PW and LW; FRW and PL; and PT and FL. Moreover, the correlation matrix between the qualitative traits (Table 8) exhibited strong correlation mainly between FC and MC; FS, LC, and MC; and FT, LC, and FS. The implication of the studied quantitative characteristics on the plot was defined by the two first principal components PC1 and PC2 (Figure 1), showing a significant relation between Kha and Lag cultivars on the PC1 associated positively with following traits: FL, LW, TL, PL, PW, FRW, and PT. The PC2 recorded grouping between Tam, Bar, and Jaw cultivars associated with STL and FRL traits. The plot of qualitative traits (Figure 2) showed negative contribution of PC1 to total variation with respect to cultivars Tam, Gon, and Bar, which were supported by five characteristics: LC, MC, FC, FS, and FT. The PC2 contributed to the scattering of cultivars Lag and Kha following the FLC trait. Jaw cultivar because of being mixed (soft, semisoft, and dry) had no prominent traits contributing to its grouping but rather an effect of the combined contribution of all traits. Grouping of cultivars was also illustrated in a dendrogram based on UPGMA for seven vegetative quantitative traits (Figure 3). Dissimilarity level pointed in 0.39, delineating the main phenotypically related groups. They were generally two main groupings: the first one for cultivars Kha and Lag and the second for cultivars Bar, Gon, Kol, Jaw, and Tam. The second one could be further grouped into two subclusters of Bar and Gon and of Kol, Jaw, and Tam. UPGMA for three qualitative fruit characteristics produced a dendrogram with grouping cultivars (Figure 4) with dissimilarity level which pointed in 0.44. Two groups were observed; cultivars Bar, Gon, Kol, and Tam were clustered together. Similarly, cultivars Jaw, Lag, and Kha were grouped together. However, for the last group, Jaw cultivar is 0.50 dissimilar to cultivars Lag and Kha, associating itself in the middle of the dendrogram suggesting that it shares some traits with the other group,

TABLE 3: Mean values of 10 quantitative phenotypic characters of date palm cultivars.

Cul.	FL	LW	TL	PL	PW	SL	STL	FRL	FRW	PT
Lag	327.50	74.33	110.17	42.00	3.23	99.00	41.22	3.25	2.37	0.73
Kha	356.00	73.67	127.00	43.00	2.80	98.33	33.00	3.62	2.50	0.67
Kol	312.00	51.50	91.33	38.83	2.23	105.83	32.17	4.55	2.32	0.65
Jaw	264.17	55.17	62.17	35.80	2.53	89.33	33.00	3.57	2.05	0.52
Gon	301.50	65.42	94.50	40.33	2.52	78.33	37.33	4.50	2.45	0.63
Tam	288.17	56.17	61.42	40.17	2.43	96.83	37.08	4.60	2.28	0.57
Bar	277.83	57.67	80.33	38.50	2.37	85.67	34.70	4.30	2.17	0.52

TABLE 4: Mean values of 6 qualitative phenotypic characters of date palm cultivars. Abbreviations are as in Table 2.

Cul.	LC	MC	FC	FS	FLC	FT
Lag	1.00	1.00	1.00	1.50	1.83	1.00
Kha	1.00	1.00	1.00	1.33	2.00	1.00
Kol	1.70	1.17	1.17	2.70	1.83	1.67
Jaw	1.83	1.33	1.50	4.50	1.50	1.83
Gon	1.67	1.00	1.00	4.17	1.83	1.50
Tam	1.67	1.50	2.33	5.00	1.83	1.67
Bar	1.17	1.00	1.67	3.17	1.50	1.33

TABLE 5: Eigenvalues, eigenvectors, and proportion of the quantitative variance explained for the three principal components.

Principal component	Characters	PC1	PC2	PC3
Eigenvectors	FL	0.374	0.281	0.098
	LW	0.373	-0.231	-0.104
	TL	0.367	0.161	0.043
	PL	0.372	0.148	-0.209
	PW	0.328	-0.432	0.152
	SL	0.125	0.340	0.625
	STL	0.188	-0.441	-0.375
	FRL	-0.207	0.463	-0.512
	FRW	0.333	0.314	-0.340
	PT	0.369	0.109	0.038
Eigenvalue		06.027	1.711	1.218
Variability (%)		60.273	17.107	12.183
Cumulative %		60.273	77.38	89.563

given that it has a mixture of soft, semisoft, and dry fruits. The other cultivars forming groups are either soft to semisoft, or dry.

4. Discussion

The present morphological traits (quantitative and qualitative), studied to assess the phenotypic variability in a group of Sudanese date palm cultivars, proved strongly useful. The grouping of the cultivars in PCA plots as well as in UPGMA cluster analysis supported the idea that the investigated cultivars are embodied by a high level of genetic diversity. In addition, significant differences among cultivars have also been detected. Therefore, consideration of the morphological

TABLE 6: Eigenvalues, eigenvector, and proportion of the qualitative variance explained for the three principal components.

Principal component	Characters	PC1	PC2	PC3
Eigenvectors	LC	0.573	-0.317	0.060
	MC	0.537	-0.439	-0.066
	FC	0.187	0.424	0.538
	FS	0.459	0.278	0.372
	FLC	-0.283	-0.198	0.679
	FT	0.241	0.641	-0.323
Eigenvalue		06.027	1.711	1.218
Variability (%)		60.273	17.107	12.183
Cumulative %		60.273	77.38	89.563

traits studied should be taken into account for Sudanese date palm cultivars characterisation. The results mostly agreed with those previously reported for Sudanese date palm by Elshibli and Korpelainen [5] and Elsafty [3] which found that a 79.5% of the morphological diversity existed in the fruits and 60.5% of the diversity in tree vegetative morphology. However, Elshibli and Korpelainen [5] used limited number of morphological characteristics compared with this study. This study highlighted some strong relationship between some cultivars especially between Lag and Kha (Figures 3 and 4) as well as between Gon, Kol, Bar, Tam, and Jaw with regard to some quantitative vegetative and fruit characteristics. The grouping of Lag and Kha cultivars is not surprising since the two types have a well-known single character; the orientation of spines along their base of the leaf either is alternate or opposite arrangement, with two spines or a single spine, that differentiates the growth of the Lag and Kha cultivars. However, in other cultivars, this character is not stable [5]. Furthermore the classification of the respective cultivars according to the fruit texture is quite similar for both soft and semisoft forms, respectively. The other cultivars excluding Jaw only share the fruit texture classification as dry cultivars although this may not suggest that they do not share some vegetative characteristics [7]. According to Zaid and de Wet [20], the mixture of cultivars during sexual propagation by seeds is the main source of variation in the date palm. However, it is expected that the Jaw has evolved as an independent group in the fruit traits cluster (Figure 4) while being close to one group in the vegetative cluster (Figure 3). This is an indication of its mixed group (dry, semisoft, or soft) as a result of seed propagation. Thus, the mixed nature of

TABLE 7: Correlation coefficients between the different quantitative morphological characters of date palm cultivars.

Variables	FL	LW	TL	PL	PW	SL	STL	FRL	FRW	PT
FL	1	0.742	0.933	0.888	0.543	0.476	0.113	-0.329	0.866	0.849
LW	0.742	1	0.811	0.813	0.875	-0.027	0.525	-0.634	0.678	0.696
TL	0.933	0.811	1	0.805	0.584	0.247	0.125	-0.422	0.802	0.805
PL	0.888	0.813	0.805	1	0.597	0.266	0.441	-0.197	0.899	0.776
PW	0.543	0.875	0.584	0.597	1	0.146	0.661	-0.831	0.365	0.663
SL	0.476	-0.027	0.247	0.266	0.146	1	-0.152	-0.167	0.148	0.452
STL	0.113	0.525	0.125	0.441	0.661	-0.152	1	-0.226	0.265	0.450
FRL	-0.329	-0.634	-0.422	-0.197	-0.831	-0.167	-0.226	1	0.027	-0.347
FRW	0.866	0.678	0.802	0.899	0.365	0.148	0.265	0.027	1	0.784
PT	0.849	0.696	0.805	0.776	0.663	0.452	0.450	-0.347	0.784	1

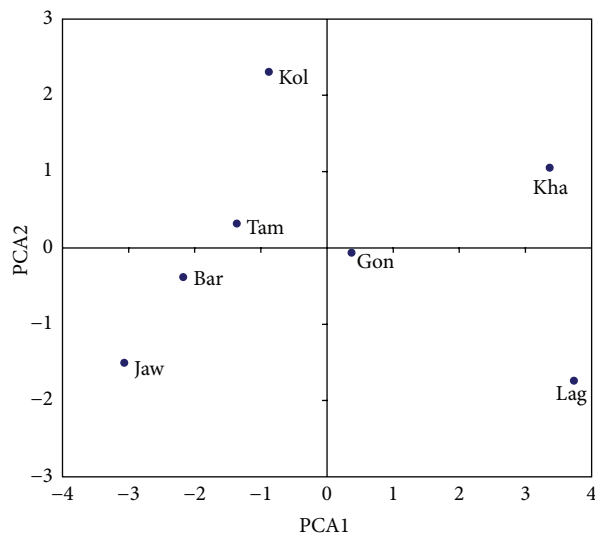


FIGURE 1: Principal component analysis of 7 Sudanese cultivars based on the 10 quantitative morphological traits.

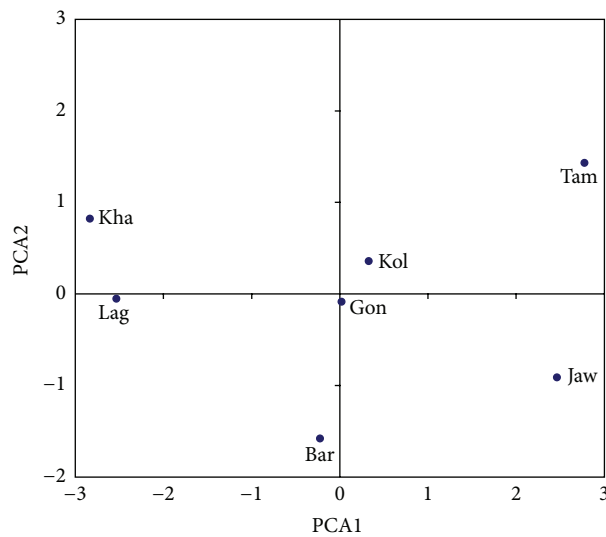


FIGURE 2: Principal component analysis of 7 Sudanese cultivars based on the 6 qualitative morphological traits.

TABLE 8: Correlation coefficients between the different qualitative morphological characters of date palm cultivars.

Variables	LC	MC	FC	FS	FLC	FT
LC	1	0.669	0.352	0.827	-0.287	0.965
MC	0.669	1	0.793	0.713	-0.171	0.732
FC	0.352	0.793	1	0.686	-0.355	0.503
FS	0.827	0.713	0.686	1	-0.453	0.849
FLC	-0.287	-0.171	-0.355	-0.453	1	-0.462
FT	0.965	0.732	0.503	0.849	-0.462	1

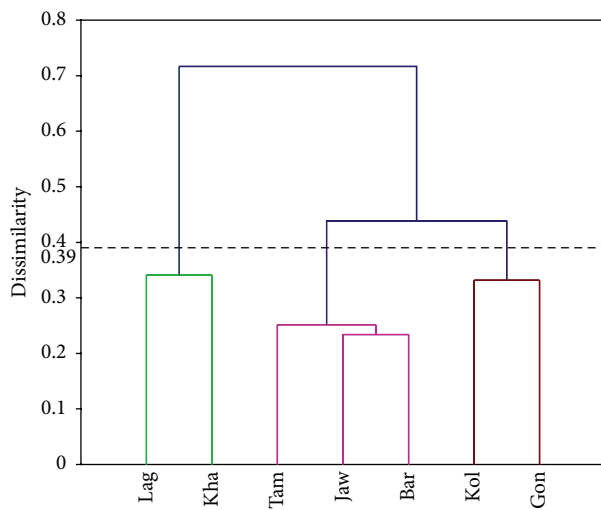


FIGURE 3: UPGMA clustering dendrogram based on 7 quantitative vegetative traits of 7 date palm cultivars.

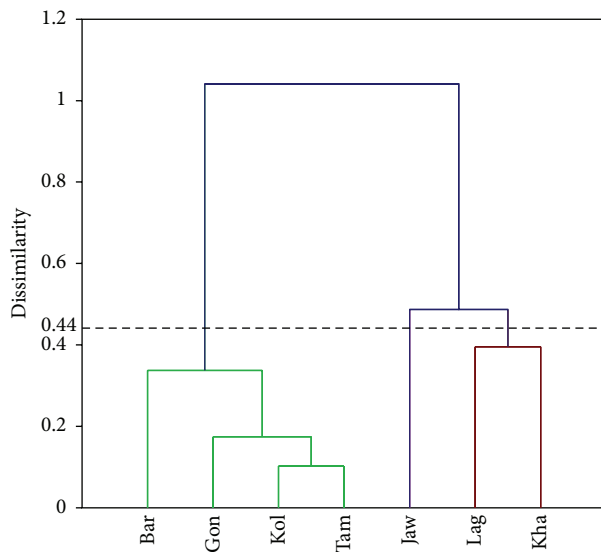


FIGURE 4: UPGMA clustering dendrogram based on 3 quantitative fruit characteristics of 7 date palm cultivars.

the Jaw group could still suggest that it may be segregating into different forms of date palms. There is no information

on how and where these cultivars have been individually domesticated, since date palm in Sudan has traditionally been grown using old, local cultivars, mainly of the dry type, for 3000 years [7]. However, semidry and soft cultivars are also grown in limited areas and numbers. Therefore, such unique dry form of date palm strongly suggests that Sudan could be considered one of the diversity centres of date palm. This study revealed the high genetic diversity level among Sudanese date palm cultivars confirming the previous morphological and molecular studies of Elshibli and Korpelainen [5, 21], Elsafy [3], and Elsafy et al. [4], despite the limited number of studies. Therefore, further investigation on the diversity level of the Sudanese date palm is highly warranted.

Abbreviations

FAO: Food Agriculture Organisation
 PCA: Principal component analysis
 UPGMA: Unweighted pair-group method arithmetic average.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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