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Physico-chemical properties revealed huge diversity in 50 date palm (*Phoenix dactylifera* L.) genotypes

Riaz Ahmad[1], *Muhammad Akbar Anjum*[1], *Sezai Ercisli*[2,3], *Waqas Malik*[4], *Ebru Sakar*[5], *Romina Alina Marc*[6], *Rohini Karunakaran*[7,8]*

[1] Department of Horticulture, Bahauddin Zakariya University, Multan 60800, Pakistan
[2] Department of Horticulture, Faculty of Agriculture, Ataturk University, 25240 Erzurum, Türkiye
[3] HGF Agro, Ata Teknokent, TR-25240 Erzurum, Türkiye
[4] Department of Plant Breeding and Genetics, Bahauddin Zakariya University, Multan 60800, Pakistan
[5] Department of Horticulture, Faculty of Agriculture, Harran University, 63289 Sanliurfa, Türkiye
[6] Food Engineering Department, Faculty of Food Science and Technology, University of Agricultural Sciences and Veterinary Medicine, Cluj-Napoca 400372, Romania
[7] Unit of Biochemistry, Centre of Excellence for Biomaterials Engineering, Faculty of Medicine, AIMST University, Semeling, Bedong 08100, Malaysia
[8] Department of Computational Biology, Institute of Bioinformatics, Saveetha School of Engineering, SIMATS, Thandalam, Chennai, Tamil Nadu 602105, India

ABSTRACT

Date palm has excellent economic value all over the world. Date palm genotypes grown in Pakistan are diverse in nature. The current study aimed to explore the diversity in 50 date palm genotypes collected from two different research stations in Punjab, Pakistan. The study findings are as follows: Dhakki had the highest fruit weight, pulp weight, fruit width and fruit volume. Jaman had a longer fruit length. Eedel Shah and Begum Jangi had greater fruit thickness and fruit perimeter, respectively. Makran showed a higher fruit area. Dedhi showed the highest stone weight, thickness and volume. Halmain had a longer stone length, and Sundari had an extended stone width. Makhi exhibited a higher stone perimeter and area. The Danda genotype had low weight and a small length of the stone. Begum Jangi and Peeli Sundar had small stone width. Seib and Shado had a higher moisture content in their fruits. The fruits of Baidhar and Khudraw-2 genotypes had the highest dry matter and reducing sugars. Champa Kali and Shakri had higher TSS levels in fruits. Halmain had higher juice pH. The fruits of Pathri and Makhi genotypes exhibited higher non-reducing sugars and carotenoids. In this study, a dendrogram was constructed to cluster 50 genotypes into five different clusters based on their physico-chemical characteristics. The correlation matrix and variable plot revealed positive and negative correlations between fruits traits and their biochemical properties conducive to the improvement of desired traits. Principal component analysis (PCA) revealed that Dhakki, Chohara, Baidhar, Karbalaen and Eedel Shah showed a higher genetic diversity; hence, in the scatter plot and biplot, these genotypes deviated from the centre of origin. Physico-chemical characteristics of data palm genotypes indicated a huge diversity among them, which could help select diverse parents, which is important for different breeding purposes.

Keywords: biochemical attributes, biodiversity, date palm germplasm, digital image analysis

INTRODUCTION

Date palm (*Phoenix dactylifera* L.) is a member of the monocot plant family Arecaceae. It grows in arid and semi-arid areas of the world and is known for its nutritious and delicious fruit. It is believed to be originated from the Middle East, North Africa, southwest Asia, Egypt and Arab countries. Approximately 600 cultivars of

*Corresponding author.
e-mail: rohini@aimst.edu.my (Rohini Karunakaran).

date palm have been identified and consumed worldwide (Baliga et al., 2011). It is widely cultivated in arid and semi-arid areas of Pakistan. Date palm fruit is a rich source of glucose and fructose and has an excellent flavour and taste, and it is one of the most affordable nutrition sources to humans (Shahib and Marshall, 2003; Naqvi et al., 2015). Its fruit contains carbohydrates, fats, proteins, minerals, vitamins and dietary fibres, which vary across cultivars and fruit developmental stages (Awan et al., 2018).

Numerous local cultivars have been used by farmers based on their fruit size, colour, taste and several other morpho-physical attributes. Thus, the major problem in the date palm industry of Pakistan is the mis-naming of homonymous and synonymous plants (Ahmed et al., 2011). Date palm reproduces sexually through seeds and asexually through offshoots. However, seed propagation provides new genotypes, which are considered the main source of variability in date palms. The uniqueness in fruit characteristics of each cultivar is designated as a marker because it helps obtain necessary information about the genetics of desired attributes. Since time immemorial, the differences in plant genotypes were evaluated through morphological traits, and this fact cannot be denied (Benjak et al., 2005; Ercisli et al., 2005; Erturk et al., 2012; Haider et al., 2015; Ersoy et al., 2018; Bozhuyuk et al., 2020; Kupe, 2020; Bozhuyuk, 2022). Information about genetic variability in genotypes and association among fruit traits helps plant breeders better use germplasm resources to introduce elite genotypes (Ozkan et al., 2020; Dawadi et al., 2022; Yazici and Sahin Cevik, 2022).

An efficient, quick, simple and reliable method is required for the study of morphological attributes of date palm fruits. The fruit characteristics are evaluated through manual methods in the laboratory for commercial purposes. These methods can be time-consuming and labour-intensive, which may hinder the evaluation of a large number of fruits and in turn limit the selection of excellent cultivars and their utilisation in further breeding programmes. Therefore, there is an urgent need to enhance the efficiency of the characterisation and evaluation of fruits of the date palm cultivars. So, digital imaging along with ImageJ application plays a significant role in the rapid characterisation and evaluation of a huge set of cultivars by reducing experimental error and time (Li et al., 2014). Digital imaging is considered one of the excellent computational methods to determine fruit size traits with high resolution (Wang et al., 2009; Lobet, 2017).

ImageJ is an open-access and Java-based image processing software that measures the actual fruit size from fruit pictures. It can be used online or after downloading its application. A high-throughput method was developed by Tanabata et al. (2012) to evaluate fruit size traits using ImageJ software. Several attributes, such as fruit length (FL), fruit width (FD), fruit thickness (FT), fruit perimeter (FP), fruit area (FA), stone length (SL), stone width (SD), stone thickness (ST), stone perimeter (SP) and stone area (SA), can be measured using ImageJ from fruit and stone images. It is successfully used in several other horticultural crops, for instance, walnut and papaya (Ercisli et al., 2012; Catarina et al., 2018). Currently, plant researchers are using different pieces of sophisticated software for the characterisation and evaluation of different plants all over the world.

For establishing commercial orchards as well as certified nurseries, accurate characterisation of different cultivars is important to identify homogeneity in the germplasm. An accurate description of cultivars through morphological characterisation is also important to provide valuable data on their use in further breeding purposes because improvement in existing cultivars through conventional breeding approaches is very challenging due to a long juvenility period and a dioecious nature of palm (Markhand et al., 2010). Usually, genetically diverse parents with the higher range of variability are selected by plant breeders for hybridisation as this increases the scope of improving target traits. In recent times, the demand for date palm fruits is increasing gradually due to their high nutritional properties. Therefore, it is very important to characterise and evaluate the date palm cultivars available in Pakistan to assess the genetic diversity and identify appropriate indigenous cultivars in a quick and easiest way.

MATERIALS AND METHODS

Plant materials

Trees of 50 date palm cultivars growing at two research stations of Punjab, Pakistan, comprised the plant material (Table 1).

Monthly temperature, humidity, rainfall and wind speed at these research stations were recorded during both years of study (Figure 1). Plants of each genotype were marked for the collection of desired data on morphological characteristics of fruits.

Data collection

The following observations were recorded during the study.

Fruit weight (g), pulp weight (PW) (g) and stone weight (g) were measured by using a digital weighing balance. For this purpose, 30 fruits from each genotype were randomly selected, with 10 fruits in each replication. The pulp-to-stone ratio was calculated by using the following formula:

$$\text{Pulp-to-stone ratio} = \frac{Pulp\,weight}{Stone\,weight}$$

Twelve fruits from each genotype were randomly collected to estimate morpho-physical traits using a digital imaging system. There were three replications,

Table 1. Date palm cultivars collected from 2 different research stations of Punjab, Pakistan.

Genotype code	Genotype name	Collection site
1	Akhrot	Date palm Research Sub-Station, Jhang
2	Angoor	Date palm Research Sub-Station, Jhang
3	Aseel	Date palm Research Sub-Station, Jhang
4	Baidhar	Horticultural Research Station, Bahawalpur
5	Begum Jangi	Date palm Research Sub-Station, Jhang
6	Burhami	Date palm Research Sub-Station, Jhang
7	Champa Kali	Date palm Research Sub-Station, Jhang
8	Chohara	Date palm Research Sub-Station, Jhang
9	Danda	Date palm Research Sub-Station, Jhang
10	Dedhi	Horticultural Research Station, Bahawalpur
11	Deglet Noor	Date palm Research Sub-Station, Jhang
12	Dhakki	Date palm Research Sub-Station, Jhang
13	Eedel Shah	Horticultural Research Station, Bahawalpur
14	Fasli	Horticultural Research Station, Bahawalpur
15	Gajar	Horticultural Research Station, Bahawalpur
16	Gokhna	Date palm Research Sub-Station, Jhang
17	Haleeni	Date palm Research Sub-Station, Jhang
18	Halmain	Horticultural Research Station, Bahawalpur
19	Hamin Wali	Horticultural Research Station, Bahawalpur
20	Hilawi-1	Date palm Research Sub-Station, Jhang
21	Hilawi-2	Date palm Research Sub-Station, Jhang
22	Jaman	Date palm Research Sub-Station, Jhang
23	Jan Sahr	Date palm Research Sub-Station, Jhang
24	Kantar	Date palm Research Sub-Station, Jhang
25	Karbalaen	Date palm Research Sub-Station, Jhang
26	Khudrawi-1	Date palm Research Sub-Station, Jhang
27	Khudrawi-2	Date palm Research Sub-Station, Jhang
28	Kohraba	Date palm Research Sub-Station, Jhang
29	Koznabad	Date palm Research Sub-Station, Jhang
30	Kupra	Horticultural Research Station, Bahawalpur
31	Kur	Horticultural Research Station, Bahawalpur
32	Makhi	Horticultural Research Station, Bahawalpur
33	Makran	Date palm Research Sub-Station, Jhang
34	Neelum	Date palm Research Sub-Station, Jhang
35	Pathri	Horticultural Research Station, Bahawalpur
36	Peela Dhora	Date palm Research Sub-Station, Jhang
37	Peeli Sundar	Date palm Research Sub-Station, Jhang
38	Rachna	Date palm Research Sub-Station, Jhang
39	Seib	Date palm Research Sub-Station, Jhang
40	Shado	Date palm Research Sub-Station, Jhang
41	Shakri	Horticultural Research Station, Bahawalpur
42	Shamran-1	Date palm Research Sub-Station, Jhang
43	Shamran-2	Date palm Research Sub-Station, Jhang
44	Sufaida	Horticultural Research Station, Bahawalpur
45	Sundari	Horticultural Research Station, Bahawalpur
46	Tarmali	Horticultural Research Station, Bahawalpur
47	Wahn Wali	Date palm Research Sub-Station, Jhang
48	Zahidi	Date palm Research Sub-Station, Jhang
49	Zardo	Date palm Research Sub-Station, Jhang
50	Zarin	Date palm Research Sub-Station, Jhang

and each replication contained four fruits. FL (cm), FD (cm), FT (cm), FP (cm) and FA (cm^2) were recorded using a digital imaging system. fruit volume (FV, cm^3) was estimated by using the following formula:

$$\text{Fruit volume } (cm^3) = \left(\frac{4}{3}\right)\pi(\text{Fruit length})(\text{Fruit width})(\text{Fruit thickness})$$

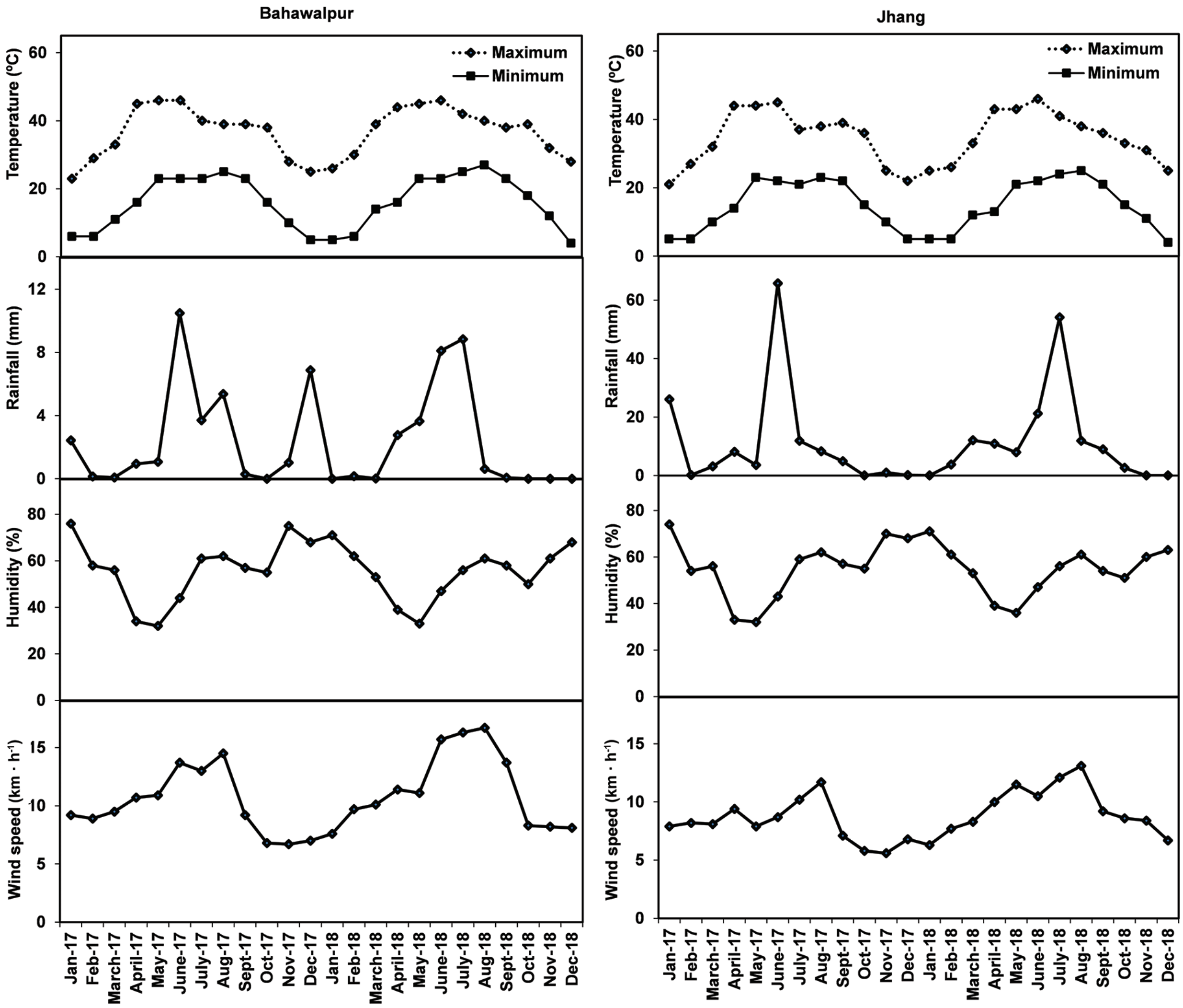

Figure 1. Temperature, humidity, rainfall and wind speed of samples collected areas during both years.

SL (cm), SD (cm), ST (cm), SP (cm) and SA (cm^2) were also recorded by digital imaging. Stone volume (SV, cm^3) was calculated by following the formula:

$$\text{Stone volume } (cm^3) = \left(\frac{4}{3}\right)\pi(\text{Stone length})(\text{Stone width})(\text{Stone thickness})$$

Digital imaging system

Morphological characterisation of fruits of 50 cultivars was performed using a digital imaging system. Pictures of fruits and their stones were captured using a camera (Canon EOS 700D, Canon Inc., Tokyo, Japan) in such a way that these pictures do not have any shadows. Twelve fruits were used from each cultivar. Pictures of fruits and their stones were taken in two directions, that is, horizontal position and vertical position, on a black paper to attain a proper colour background for better imaging analysis. All these pictures were labelled and saved as PNG files (Figures 2–5).

IrfanView was used for image editing and segmentation. ImageJ, an open-access scientific software developed by the National Institute of Health, USA, was used for directly measuring numerous objects from PNG files. The measurement using ImageJ was categorised into three stages: The first stage is collection of date palm fruits, second stage is picture editing and the third stage is the conversion of pictures into numerical data based on advanced mathematical algorithms, as described by Tanabata et al. (2012).

Biochemical traits

Thirty fruits from each genotype were randomly collected to estimate biochemical properties. There were three replications, and each replication comprised 10 fruits. Fruit juice was extracted according to the dilution factor with 30 g of fruit pulp and 70 mL of water. After fine grinding, the supernatant was collected for further biochemical estimations. The moisture content (MO, %)

Figure 2. Original fruit images of date palm genotypes for image analysis.

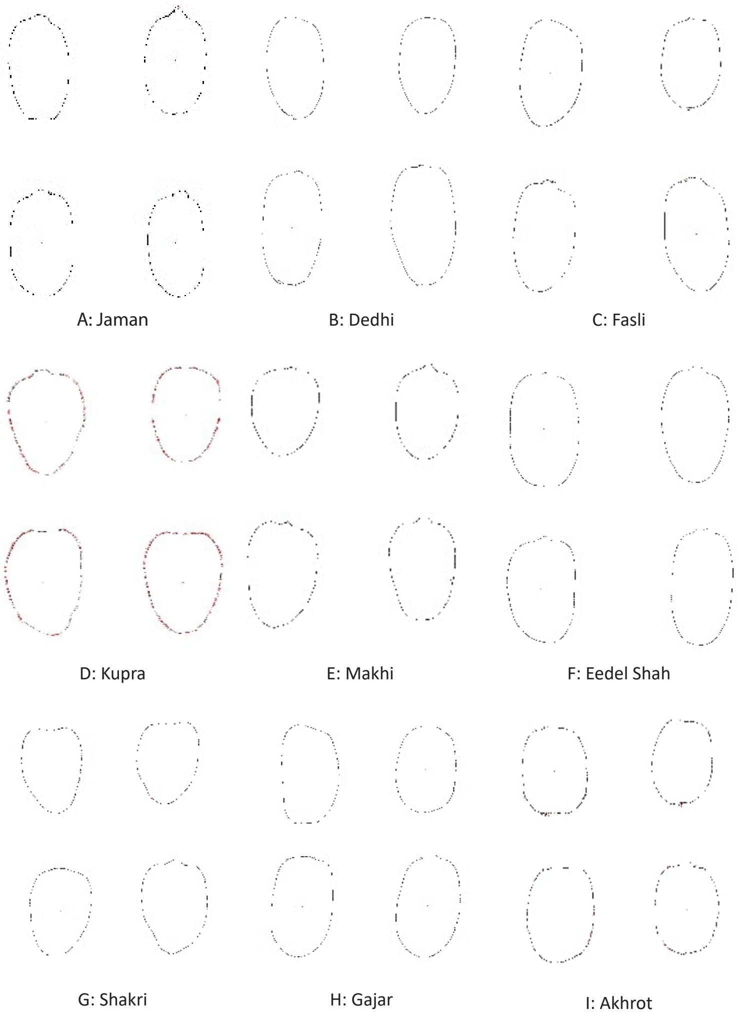

Figure 3. Segmented fruit images of date palm genotypes for image analysis.

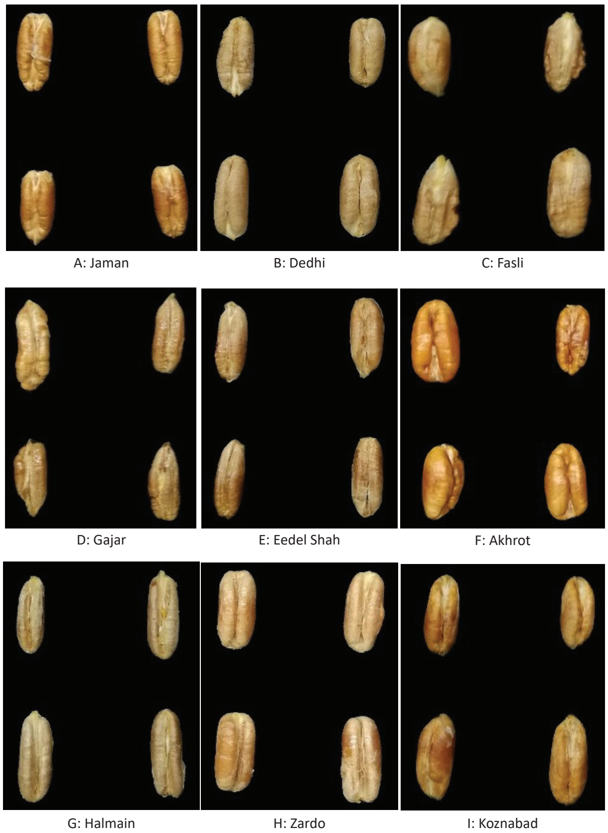

Figure 4. Original stones images of date palm genotypes after image analysis.

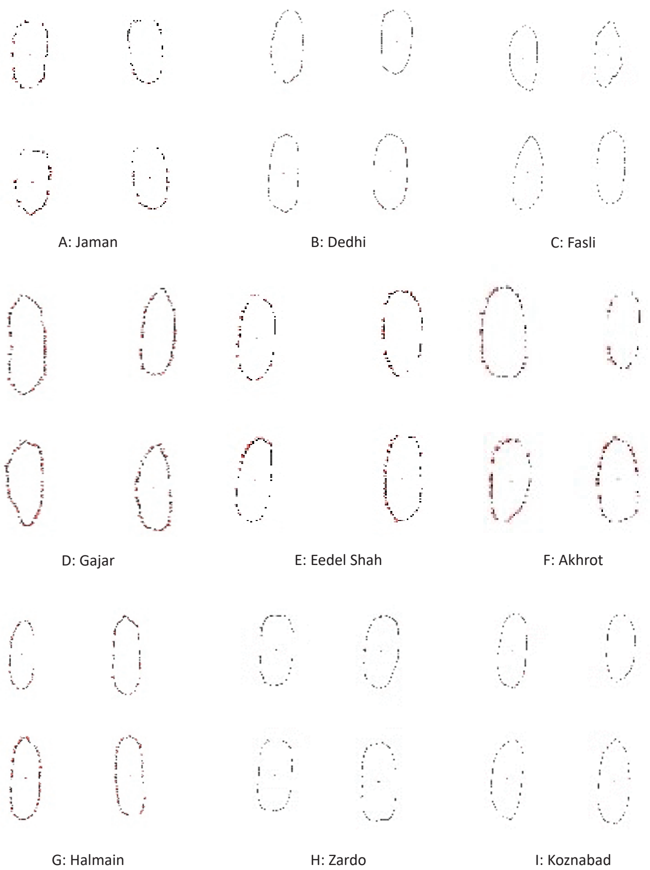

Figure 5. Segmented stones images of date palm genotypes after image analysis.

and dry matter (DM, %) were determined by using the following equations:

Moisture content (%)

$$= \frac{\text{Weight before drying} - \text{Weight after drying}}{\text{Weight before drying}} \times 100$$

$$\text{Dry matter content (\%)} = \frac{\text{Average dry weight}}{\text{Average fresh weight}} \times 100$$

In fruit juices, the total soluble solids (TSS °Brix) content was measured by using a hand-held refractometer. Juice pH was measured by using a pH meter (Milwaukee Instruments, Washington, USA). reducing sugars (RSs, %) and non-reducing sugars (NRSs, %) were recorded by using the method described by Hortwitz (1980). According to this method, 10 mL of the fruit juice sample, 25% lead acetate, 20% potassium oxalate and 100 mL of distilled water were added and homogenised in a 250-mL volumetric flask to determine different sugars. The carotenoid content ($\mu g \cdot g^{-1}$) were estimated using the method described by Farsi et al. (2005). For the estimation of carotenoid, fruit samples (0.5 g) were ground in 80% acetone, and absorbance reading was noted at 470 nm using a spectrophotometer (UV-1900, Hitachi Instruments, Tokyo, Japan).

Data analysis

The collected data were analysed under RCBD through a statistical software package, Statistix 8.1 (Tallahassee, FL, USA) using the two-factor analysis of variance (ANOVA) technique due to genotypes and years of study. However, the effect of years and their interaction with genotypes were non-significant and have not been discussed. Pearson's correlation matrix, principal component analysis (PCA), variable plot, scatter plot and biplot were constructed using XLSTAT, 2021. A dendrogram was developed based on agglomerative hierarchical clustering (AHC) by using clustering program XLSTAT, 2021.

RESULTS AND DISCUSSION

Significant variability was observed in quantitative and qualitative traits of date palm. Statistical analysis of the data revealed that all the studied traits were significant at $p \leq 0.05$.

Variation in fruit traits

Among all the studied genotypes, Dhakki had significantly greater FW, PW, FD and FV. The genotype Jaman had longer FL. The genotype Eedel Shah had greater FT, while the genotypes Begum Jangi and Makran had greater FP. The Makran genotype also showed higher FA among all the studied genotypes. The Shado genotype had significantly lower FW, PW and FT. The Danda genotype had significantly smaller FL and less volume. The Kohraba genotype had the lowest FP. The Makhi genotype had less width and volume of fruits (Table 2).

Variation in stone characteristics

The Dedhi genotype had the maximum stone weight (SW), thickness and volume among all the studied genotypes. The Halmain and Sundari genotypes had longer SL and SD, respectively. The Makhi and Hilawi-2 genotypes had greater SP, and Hilawi-1 and Makhi had higher SA. The Shamran-2 genotype showed a higher pulp-to-stone (P:S) ratio than other genotypes. The Danda genotype had low weight and small length of stone. Begum Jangi and Peeli Sundar genotypes had smaller SD. Hamin Wali and Shado genotypes showed lower ST and a P:S, respectively. The Koznabad genotype had the minimum SP and volume, and the Angoor genotype had a less SA (Table 3).

Variation in biochemical properties

The fruits of Seib and Shado genotypes had greater MO than the other studied genotypes. The fruits of Baidhar and Khudraw-2 genotypes had the highest DM and reducing sugars (RSs). Champa Kali and Shakri genotypes had higher TSS level in fruits. The Halmain genotype had greater juice pH. The fruits of Pathri and Makhi genotypes exhibited higher NRSs and carotenoids. The Baidhar genotype had a lower moisture content and NRSs. The Shado genotype had the highest DM. The Danda genotype had lower TSS in fruits than others. The Seib, Burhami and Baidhar genotypes had lower juice pH, RSs and NRSs than other studied genotypes (Table 4).

Cluster analysis

The Euclidean distance was applied to determine the genetic similarity/differences and relationship among collected genotypes of date palms (Figure 6). A dendrogram was constructed to cluster the studied genotypes into five different clusters (clusters A, B, C, D and E). However, five genotypes, namely, Begum Jangi, Wahn Wali, Makhi, Deglet Noor and Baidhar, did not cluster with other studied genotypes because of their higher dissimilarity and different genetic backgrounds.

Eedel Shah, Hillawi-1 and Makran genotypes showed the highest similarity with each other and were grouped into cluster C. The variability within class and that between classes were found to be nearly 31.52% and 68.48%, respectively, in the studied date palm genotypes (Table 5).

Trait association among physical traits and biochemical properties

FW was significantly and positively correlated with PW, FL, FD, FT, FP, FA, FV, SW, P:S and TSS, while it was

Table 2. Variation in fruit attributes of 50 date palm genotypes.

Genotype name	FW (g)	PW (g)	FL (cm)	FD (cm)	FT (cm)	FP (cm)	FA (cm^2)	FV (cm^3)
Akhrot	13.89 ef	12.85 de	3.56 m–s	3.21 e–g	3.25 d–h	10.81 h–k	9.56 c–e	155.53 gh
Angoor	9.85 lm	8.73 l–o	4.06 h–n	2.31 p–v	2.30 m–r	10.03 l–p	7.68 ij	89.91 n–t
Aseel	9.01 m–o	7.97 o–r	4.46 f–i	2.55 k–r	3.04 d–j	11.57 ef	8.82 g	144.62 hi
Baidhar	11.09 h–j	10.10 gh	3.55 n–s	2.24 r–w	3.01 e–k	10.24 j–o	5.94 no	101.07 m–r
Begum Jangi	8.37 n–q	7.42 r–u	3.75 k–r	1.73 zA	1.80 qr	13.34 a	5.12 q–s	54.34 wx
Burhami	6.73 t–v	5.52 x–z	4.48 f–i	3.58 cd	3.12 d–i	7.61 v	5.49 o–q	208.82 ef
Champa Kali	12.89 g	11.58 f	3.73 l–r	2.49 l–s	2.70 g–o	11.44 e–h	6.97 k	105.22 l–p
Chohara	10.33 j–l	9.03 j–m	3.82 j–r	2.31 p–v	3.61 b–e	9.78 n–q	9.45 c–f	133.3 4 h–l
Danda	4.41 y	3.72 B	2.36 v	1.91 x–A	1.86 qr	6.56 wx	3.85 v–x	34.86 x
Dedhi	13.22 fg	11.52 f	4.34 f–j	2.94 g–j	2.40 k–q	12.31 cd	9.67 cd	128.75 h–m
Deglet Noor	8.02 p–r	6.72 t–v	3.75 k–r	2.36 o–u	3.32 c–h	10.38 i–n	6.72 kl	119.03 i–n
Dhakki	20.93 a	19.62 a	6.62 b	5.23 a	4.22 b	10.72 i–k	9.64 cd	611.99 a
Eedel Shah	13.87 ef	12.95 de	3.70 l–s	2.53 k–r	9.59 a	10.69 i–l	7.64 ij	375.27 b
Fasli	14.08 ef	12.65 e	4.11 g–l	2.46 m–s	2.29 m–r	9.02 r–u	5.32 p–r	96.99 n–s
Gajar	11.85 h	10.43 g	4.52 f–h	2.79 h–l	2.28 n–r	11.66 d–f	8.63 gh	119.63 i–n
Gokhna	9.89 lm	8.52 l–p	3.46 o–t	2.82 h–k	2.67 h–p	9.24 q–s	5.65 n–q	109.13 j–o
Haleeni	7.72 p–s	6.66 t–v	3.37 q–u	2.39 n–u	2.97 e–m	8.55 tu	4.81 r–t	99.90 m–r
Halmain	9.85 lm	8.89 k–n	4.27 f–k	2.64 j–o	2.22 n–r	10.38 i–n	8.68 g	104.80 l–q
Hamin Wali	10.72 i–l	9.40 h–l	3.58 m–s	2.67 j–o	2.13 n–r	8.97 s–u	5.17 q–s	85.56 o–v
Hilawi-1	10.67 i–l	7.13 r–v	5.76 cd	4.99 a	3.04 d–j	10.44 i–n	9.08 d–g	364.33 bc
Hilawi-2	8.57 n–p	7.66 p–s	3.68 l–s	3.00 f–i	2.97 e–m	11.51 e–g	9.92 c	137.07 h–k
Jaman	9.10 mn	7.99 n–r	9.30 a	2.93 g–j	2.01 p–r	6.25 x	2.32 y	231.02 de
Jan Sahr	14.25 de	12.72 de	4.48 f–i	3.50 c–e	3.33 c–h	9.79 n–q	8.95 e–g	219.83 de
Kantar	9.93 sk–m	8.80 k–o	5.21 e	4.53 b	3.70 b–d	9.15 q–t	7.71 ij	365.30 bc
Karbalaen	11.21 h–j	10.25 gh	3.35 r–u	2.57 k–q	2.75 f–n	11.97 de	7.15 jk	99.61 m–r
Khudrawi-1	10.80 i–k	9.65 g–k	3.48 o–s	2.03 v–z	2.35 k–q	9.65 o–r	5.71 n–q	69.30 s–w
Khudrawi-2	5.42 x	4.35 AB	3.56 m–s	1.98 w–A	1.87 qr	9.39 p–s	5.09 q–s	56.19 v–x
Kohraba	8.17 o–r	6.99 s–v	3.45 p–t	2.61 k–p	2.03 o–r	5.21 y	4.68 s–u	77.30 p–w
Koznabad	7.47 q–t	6.39 v–x	3.97 i–p	2.26 q–w	2.31 l–r	10.60 i–m	6.94 k	86.58 o–u
Kupra	15.76 c	14.70 c	4.61 fg	3.27 d–f	3.37 c–g	11.64 ef	10.56 b	214.42 e
Kur	11.30 hi	9.94 g–i	3.98 i–o	2.69 i–n	2.98 e–l	10.90 g–j	8.01 hi	134.04 h–l
Makhi	6.99 s–u	6.24 v–x	2.88 u	1.71 A	1.78 qr	7.10 vw	3.35 x	37.80 x
Makran	17.55 b	15.94 b	6.25 bc	3.27 d–f	4.00 bc	13.03 ab	12.30 a	342.77 c
Neelum	10.47 i–l	9.07 i–m	4.67 f	3.61 c	3.51 c–e	9.70 o–q	9.81 c	247.63 d
Pathri	6.45 u–w	5.74 w–y	2.95 tu	2.35 o–v	1.96 qr	8.87 r–u	4.46 t–v	57.12 u–x
Peela Dhora	7.87 p–s	6.74 s–v	4.62 fg	1.86 y–A	3.95 bc	12.64 bc	5.70 n–q	138.43 h–j
Peeli Sundar	11.04 h–j	10.13 gh	3.55 n–s	2.13 t–y	2.37 j–q	10.23 k–o	6.69 k–m	70.96 r–w
Rachna	15.03 cd	13.59 d	3.45 p–t	2.73 h–m	2.33 k–q	8.87 s–u	5.29 p–s	95.26 n–s
Seib	5.42 x	4.36 AB	3.56 m–s	1.98 w–A	1.87 qr	9.39 p–s	5.09 q–s	56.19 v–x
Shado	3.50 z	2.49 C	3.66 l–s	2.80 h–l	1.64 r	8.91 s–u	3.23 x	71.31 r–w
Shakri	9.88 lm	8.39 m–q	3.89 j–q	2.37 n–u	2.46 i–q	9.71 o–q	6.09 m–o	95.07 n–s
Shamran-1	5.55 wx	4.56 AB	3.69 l–s	2.20 s–x	1.81 qr	8.92 s–u	4.17 u–w	64.75 t–x
Shamran-2	9.85 lm	8.93 k–m	4.08 h–m	3.01 f–h	3.42 c–f	10.99 f–i	7.99 i	179.38 fg
Sufaida	8.32 n–q	7.49 q–t	4.45 f–i	2.44 m–t	2.34 k–q	10.02 m–p	6.15 l–n	108.62 j–o
Sundari	7.41 r–t	6.55 u–w	3.67 l–s	2.38 n–u	2.75 f–n	9.79 n–q	6.07 no	100.13 m–r
Tarmali	5.89 v–x	5.06 y–A	4.43 f–i	2.56 k–q	2.25 n–r	11.96 de	8.87 fg	106.86 k–p
Wahn Wali	5.55 wx	4.61 z–B	3.61 l–s	2.12 u–y	1.85 qr	8.46 u	3.60 wx	61.06 t–x
Zahidi	11.10 h–j	9.87 g–j	5.43 de	4.56 b	3.32 c–h	8.84 s–u	7.3 1 jk	346.34 bc
Zardo	5.42 x	4.35 AB	3.56 m–s	1.98 w–A	1.87 qr	9.39 p–s	5.09 q–s	56.19 v–x
Zarin	7.93 p–r	7.10 r–v	3.19 s–u	2.29 q–w	2.43 j–q	10.50 i–m	5.86 n–p	74.55 q–w
SE	0.46	0.47	0.26	0.16	0.35	0.34	0.31	15.82
SD	3.57	3.44	1.11	0.77	1.19	1.87	2.23	112.50
CV	36.77	40.09	27.13	28.43	42.54	18.95	33.06	77.70
LSD 5%	0.91	0.93	0.52	0.31	0.68	0.67	0.62	31.20
F-value	117.48**	108.41**	33.53**	45.77**	23.37**	47.62**	103.17**	100.88**

Mean values with different letters (s) in a column are statistically significant at $p \leq 0.05$ (LSD test). Means are initially symbolled by small letters and afterwards by capital letters due to great variation in means.

**Significant at $p \leq 0.01$.

CV, coefficient of variation; FA, fruit area; FD, fruit width; FL, fruit length; FP, fruit perimeter; FT, fruit thickness; FV, fruit volume; FW, fruit weight; LSD, least significant difference; PW, pulp weight; SD, stone width; SE, standard error.

Table 3. Variation in stone attributes of 50 date palm genotypes.

Genotype name	SW (g)	SL (cm)	SD (cm)	ST (cm)	SP (cm)	SA (cm^2)	SV (cm^3)	P:S
Akhrot	1.04 l–r	1.68 p–r	0.84 f–k	0.70 j–n	5.05 o–t	0.81 tu	4.15 q–w	12.42 b–e
Angoor	1.12 i–o	1.06 vw	0.59 p–s	0.69 j–n	3.95 t–v	0.35 x	1.80 xy	7.78 d–i
Aseel	1.10 j–p	2.02 i–n	0.57 p–s	2.13 b–d	5.95 j–p	1.02 m–t	10.23 g–i	7.28 e–i
Baidhar	1.00 m–r	1.57 q–s	0.82 g–l	0.60 k–o	4.35 s–v	0.89 q–u	3.23 s–x	10.89 b–f
Begum Jangi	0.95 n–s	1.66 p–r	0.50 s	0.79 jk	7.48 d–h	1.15 k–p	2.92 u–y	7.82 d–i
Burhami	1.22 f–l	2.01 i–n	0.58 p–s	0.71 j–n	4.61 q–u	0.93 p–u	3.43 r–x	4.53 g–i
Champa Kali	1.32 c–i	1.25 t–v	0.69 l–p	0.76 j–l	3.90 t–v	0.48 wx	2.81 u–y	8.71 c–i
Chohara	1.31 d–j	2.42 b–e	0.84 e–k	2.31 b	5.72 k–q	1.42 g–i	19.62 b	6.93 e–i
Danda	0.70 u	0.91 w	0.80 g–l	2.13 b–d	7.90 c–f	1.22 i–m	6.46 k–p	5.29 f–i
Dedhi	1.70 a	2.59 a–c	0.92 c–g	2.88 a	7.23 d–i	1.68 d–f	29.08 a	6.83 e–i
Deglet Noor	1.30 d–j	2.19 e–k	0.91 c–h	1.38 h	7.71 d–g	1.42 g–i	11.52 f–h	5.14 f–i
Dhakki	1.28 d–k	2.51 a–d	0.74 k–o	1.81 fg	7.08 d–j	1.49 f–h	14.00 c–e	15.49 b
Eedel Shah	0.92 o–u	2.68 ab	0.87 d–j	0.72 j–m	8.13 b–d	1.76 c–e	7.01 k–n	14.26 bc
Fasli	1.44 b–e	1.93 j–p	0.84 e–k	1.67 g	5.30 n–s	1.03 m–s	11.75 e–g	8.77 c–i
Gajar	1.43 b–f	1.77 n–r	0.64 o–r	0.50 no	6.40 h–n	0.51 wx	2.41 v–y	7.68 d–i
Gokhna	1.38 c–g	1.17 vw	0.76 j–o	0.73 j–m	6.84 f–k	1.58 e–g	2.86 u–y	6.17 f–i
Haleeni	1.07 k–q	2.32 c–h	0.95 b–f	0.78 j–l	7.94 c–f	1.83 b–d	7.23 j–m	6.19 e–i
Halmain	0.97 n–s	2.70 a	1.02 bc	0.76 j–m	9.03 a–c	2.01 b	8.73 i–k	9.16 c–h
Hamin Wali	1.33 c–i	1.92 k–p	0.65 m–q	0.43 o	5.33 m–s	0.58 vw	2.34 v–y	7.10 e–i
Hilawi-1	0.89 p–u	2.23 d–i	0.99 b–d	0.72 j–m	9.29 ab	2.39 a	6.81 k–o	8.52 c–i
Hilawi-2	0.92 o–u	1.89 l–p	0.86 e–k	0.63 j–o	9.41 a	0.97 n–u	4.40 p–w	8.31 c–i
Jaman	1.12 i–o	2.34 c–g	0.97 b–e	0.81 i–k	8.05 c–e	1.42 g–i	7.58 j–l	7.14 e–i
Jan Sahr	1.53 a–c	1.93 k–p	0.90 c–i	0.75 j–m	5.17 o–s	0.89 q–u	5.52 l–r	8.31 c–i
Kantar	1.13 i–o	2.14 e–l	0.78 h–m	2.19 bc	7.84 d–f	1.07 l–r	15.54 cd	7.80 d–i
Karbalaen	0.97 n–s	2.02 i–n	0.95 b–f	0.70 j–n	6.95 e–j	1.39 g–j	5.69 l–r	10.50 b–g
Khudrawi-1	1.16 h–n	1.29 s–v	0.55 q–s	0.79 jk	6.48 h–m	0.58 vw	2.62 v–y	8.53 c–i
Khudrawi-2	1.07 k–q	1.68 p–r	0.77 i–n	0.67 j–n	6.46 h–n	0.83 s–u	3.63 r–x	4.11 hi
Kohraba	1.19 g–m	2.06 h–m	0.90 c–h	0.67 j–n	4.74 q–u	0.82 s–u	5.24 m–t	5.84 f–i
Koznabad	1.09 j–p	0.54 x	0.54 q–s	0.70 j–n	3.43 v	0.43 wx	0.93 y	5.88 f–i
Kupra	1.07 k–q	1.91 l–p	0.80 g–l	0.68 j–n	5.39 m–s	0.95 o–u	4.37 p–w	13.80 b–d
Kur	1.37 c–h	1.98 i–o	0.74 k–o	0.69 j–n	5.13 o–s	0.93 p–u	4.30 p–w	7.31 e–i
Makhi	0.76 s–u	1.82 m–q	1.08 ab	0.73 j–m	9.72 a	2.36 a	6.08 l–q	8.24 c–i
Makran	1.62 ab	1.83 m–q	0.64 n–r	0.84 ij	4.81 p–u	0.51 wx	4.21 p–w	9.92 b–h
Neelum	1.41 b–g	0.89 w	0.63 o–r	1.91 ef	5.99 j–o	1.23 i–m	4.60 o–v	6.46 e–i
Pathri	0.73 tu	2.01 i–n	0.90 c–j	2.13 b–d	5.56 l–r	1.17 j–o	15.96 c	8.33 c–i
Peela Dhora	1.14 i–o	1.71 o–r	0.63 o–r	0.76 j–m	4.73 q–u	0.44 wx	3.43 r–x	6.07 f–i
Peeli Sundar	0.92 o–u	1.93 k–p	0.50 s	0.57 l–o	9.84 a	0.84 s–u	2.23 w–y	11.15 b–f
Rachna	1.45 b–e	1.72 o–r	0.95 b–f	0.71 j–n	6.63 g–l	0.93 q–u	5.04 m–u	10.84 b–f
Seib	1.07 k–q	1.68 p–r	0.77 i–n	0.67 j–n	6.46 h–n	0.83 s–u	3.63 r–x	4.11 hi
Shado	1.02 l–r	2.07 g–m	0.83 f–k	0.69 j–n	7.95 c–f	1.19 j–n	4.92 n–u	2.55 i
Shakri	1.49 a–d	1.49 r–u	0.60 p–s	0.63 j–o	7.39 d–h	0.85 r–u	2.47 v–y	5.61 f–i
Shamran-1	0.99 m–r	1.52 r–t	0.65 n–q	0.68 j–n	4.34 s–v	0.39 wx	3.02 t–y	4.59 g–i
Shamran-2	0.93 o–t	1.69 p–r	0.87 d–k	2.17 b–d	6.08 i–o	1.10 l–q	13.41 d–f	26.97 a
Sufaida	0.84 r–u	2.13 f–l	0.73 k–o	0.64 j–o	4.56 r–v	0.78 uv	4.26 p–w	9.01 c–h
Sundari	0.87 q–u	2.21 e–j	1.18 a	1.02 i	7.30 d–h	1.74 c–e	10.91 g–i	7.59 d–i
Tarmali	0.83 r–u	1.94 j–p	0.91 c–h	2.08 c–e	5.66 l–r	1.28 h–l	15.30 cd	6.10 f–i
Wahn Wali	0.94 n–t	2.55 a–c	0.92 c–g	0.54 m–o	7.93 c–f	1.92 bc	5.36 l–s	4.95 f–i
Zahidi	1.24 e–l	2.40 b–f	0.51 rs	0.83 ij	3.89 uv	0.85 s–u	4.23 p–w	8.16 c–i
Zardo	1.07 k–q	1.68 p–r	0.77 i–n	0.67 j–n	6.46 h–n	0.83 s–u	3.63 r–x	4.11 hi
Zarin	0.84 r–u	1.22 uv	0.92 c–g	1.98 d–f	5.94 j–p	1.36 g–k	9.40 h–j	8.42 c–i
SE	0.11	0.14	0.07	0.10	0.58	0.11	1.15	3.17
SD	0.24	0.47	0.90	0.63	1.65	0.50	5.579	0.24
CV	21.18	25.35	95.41	59.98	26.06	44.97	77.85	21.18
LSD 5%	0.22	0.28	0.13	0.21	1.16	0.22	2.27	6.24
F-value	9.37**	22.22**	11.30**	15.78**	15.78**	37.81**	43.12**	2.96**

Mean values with different letters (s) in a column are statistically significant at $p \leq 0.05$ (LSD test).

**Significant at $p \leq 0.01$.

CV, coefficient of variation; LSD, least significant difference; P:S, pulp-to- stone ratio; SA, stone area; SD, stone width; SE, standard error; SL, stone length; SP, stone perimeter; ST, stone thickness; SV, stone volume; SW, stone weight.

Table 4. Variation in biochemical properties of 50 date palm cultivars.

Genotype name	MO (%)	DM (%)	TSS (°Brix)	Juice pH	RSs (%)	NRSs (%)	Carotenoids (μg · g^{-1})
Akhrot	61.17 l–p	38.83 g–k	14.57 n–t	6.26 r–t	40.40 l–t	10.99 b–e	0.04 e
Angoor	66.99 h–k	33.01 l–o	15.50 h–o	5.39 wx	38.29 o–u	11.28 b–d	0.03 f
Aseel	62.77 j–o	37.23 h–m	15.07 k–p	7.06 a–e	35.25 s–v	11.50 b	0.04 e
Baidhar	37.41 v	62.59 a	16.50 c–h	6.47 n–r	63.24 a	5.29 k	0.06 c
Begum Jangi	64.77 i–n	35.23 i–n	14.82 l–r	5.55 vw	27.75 x	11.41 bc	0.03 f
Burhami	73.81 d–f	26.19 q–s	14.24 p–u	6.99 b–f	16.30 z	9.48 b–i	0.04 e
Champa Kali	69.36 f–i	30.64 n–q	18.83 a	6.21 st	44.35 i–o	10.38 b–f	0.03 f
Chohara	64.24 i–n	35.76 i–n	17.07 b–d	6.50 l–q	61.81 ab	5.78 jk	0.03 f
Danda	46.73 tu	53.27 bc	13.25 u	5.87 u	27.92 wx	11.41 bc	0.03 f
Dedhi	65.74 h–l	34.26 k–o	16.74 b–f	6.70 h–n	60.26 a–c	7.84 f–k	0.03 f
Deglet Noor	56.89 p–r	43.11 e–g	14.66 m–s	6.65 i–n	29.53 v–x	11.55 b	0.04 e
Dhakki	61.07 l–p	38.93 g–k	16.32 d–i	6.75 g–k	47.22 f–l	9.70 b–i	0.04 e
Eedel Shah	75.54 c–e	24.46 r–t	15.66 g–m	6.51 l–p	46.67 g–m	9.70 b–i	0.03 f
Fasli	57.09 p–r	42.91 e–g	16.00 e–k	6.39 p–t	43.45 j–p	9.70 b–i	0.04 e
Gajar	61.58 k–p	38.42 g–l	16.16 d–j	6.64 i–o	55.93 b–e	6.93 i–k	0.04 e
Gokhna	61.11 l–p	38.89 g–k	15.08 k–p	5.75 uv	29.92 v–x	11.54 b	0.03 f
Haleeni	65.51 h–m	34.49 j–o	14.82 l–r	6.38 p–t	46.13 h–n	9.58 b–i	0.04 e
Halmain	74.11 d–f	25.89 q–s	16.32 d–i	7.22 a	37.66 o–u	11.33 b–d	0.05 d
Hamin Wali	61.00 l–p	39.00 g–k	16.24 d–i	6.48 m–r	25.67 xy	11.32 b–d	0.03 f
Hilawi-1	73.03 d–g	26.97 p–s	15.66 g–m	7.14 a–c	46.56 g–m	9.81 b–h	0.03 f
Hilawi-2	76.69 cd	23.31 st	14.49 o–t	6.94 c–g	35.55 r–v	11.61 b	0.04 e
Jaman	83.34 ab	16.66 uv	13.91 r–u	6.64 i–o	41.99 k–t	10.97 b–e	0.03 f
Jan Sahr	43.22 u	56.78 b	13.58 tu	5.71 uv	57.12 a–d	7.14 h–k	0.05 d
Kantar	70.87 e–h	29.13 o–r	13.9 q–u	6.70 g–m	36.17 q–v	11.45 bc	0.03 f
Karbalaen	47.07 tu	52.93 bc	14.91 l–r	6.41 o–s	38.87 n–u	11.23 b–d	0.03 f
Khudrawi-1	61.47 k–p	38.53 g–l	15.58 g–n	7.1 a–d	38.02 o–u	11.74 b	0.03 f
Khudrawi-2	35.42 v	64.58 a	14.82 l–r	7.18 ab	25.57 xy	11.26 bcd	0.03 f
Kohraba	64.5 i–n	35.49 i–n	14.99 k–q	6.85 e–i	39.55 m–u	11.29 b–d	0.03 f
Koznabad	56.67 p–r	43.33 e–g	14.66 m–s	6.55 k–p	40.83 l–t	11.03 b–e	0.03 f
Kupra	65.94 h–l	34.06 k–o	17.66 b	7.08 a–e	27.45 x	11.38 bc	0.06 c
Kur	62.08 k–p	37.92 g–l	16.58 c–g	6.58 j–p	36.33 p–v	11.44 bc	0.03 f
Makhi	70.53 e–h	29.47 o–r	16.32 d–i	6.91 c–h	54.08 c–f	8.20 e–j	0.09 a
Makran	78.19 b–d	21.81 s–u	14.99 k–q	6.39 p–t	40.56 l–t	11.22 b–d	0.03 f
Neelum	61.50 k–p	38.50 g–l	14.99 k–q	6.34 p–t	53.07 c–h	8.51 d–j	0.04 e
Pathri	66.03 h–l	33.97 k–o	16.91 b–e	6.72 g–l	50.06 d–j	16.85 a	0.06 c
Peela Dhora	66.05 h–l	33.95 k–o	14.75 l–s	6.27 q–t	30.36 v–x	11.59 b	0.03 f
Peeli Sundar	54.63 o–s	45.37 d–f	17.41 bc	6.17 t	26.10 xy	11.29 b–d	0.03 f
Rachna	57.46 o–r	42.54 e–h	15.41 i–o	5.18 xy	43.30 j–q	10.61 b–f	0.05 d
Seib	89.00 a	11.00 v	15.32 i–o	5.11 y	44.70 i–o	10.38 b–f	0.04 e
Shado	87.04 a	12.96 v	15.66 g–m	5.27 xy	32.71 u–x	11.52 b	0.08 b
Shakri	50.81 st	49.19 cd	18.75 a	7.03 a–f	36.07 q–v	11.54 b	0.03 f
Shamran-1	70.58 e–h	29.42 o–r	14.91 l–r	6.69 h–n	51.38 d–i	8.98 b–i	0.03 f
Shamran-2	73.77 d–f	26.23 q–s	15.16 j–p	6.22 st	53.63 c–g	8.62 cj	0.04 e
Sufaida	67.77 g–j	32.23 m–p	15.74 f–l	5.85 u	49.11 e–k	9.32 b–i	0.03 f
Sundari	53.64 rs	46.36 de	17.16 b–d	6.90 d–h	56.70 a–d	7.48 g–k	0.03 f
Tarmali	75.29 c–e	24.71 r–t	15.16 j–p	6.49 l–r	30.17 v–x	11.61 b	0.03 f
Wahn Wali	80.63 bc	19.37 tu	15.00 k–q	6.81 f–j	35.09 t–w	11.58 b	0.03 f
Zahidi	59.47 n–q	40.53 f–i	14.99 k–q	6.90 d–h	42.38 k–s	10.76 b–e	0.03 f
Zardo	59.87 m–q	40.13 f–j	14.74 l–s	6.90 d–h	42.58 k–r	10.72 b–e	0.04 e
Zarin	63.49 j–n	36.51 i–m	13.74 s–u	6.35 p–t	19.47 yz	10.12 b–g	0.03 f
SE	2.11	2.09	0.47	0.10	2.60	1.11	0.02
SD	11.25	11.25	1.20	0.53	11.04	1.87	0.01
CV	17.51	31.48	7.75	8.28	27.16	18.06	25.43
LSD 5%	4.14	4.13	0.93	0.19	5.12	2.18	0.03
F-value	57.60**	58.63**	12.94**	3.96**	36.20**	5.68**	3.90*

Mean values with different letters (s) in a column are statistically significant at $p \leq 0.05$ (LSD test).
**Significant at $p \leq 0.01$ and *significant at $p \leq 0.05$.
DM, dry matter; MO, moisture content; pH, potential acidity; RS, reducing sugar; SD, stone width; TSS, total soluble solids.

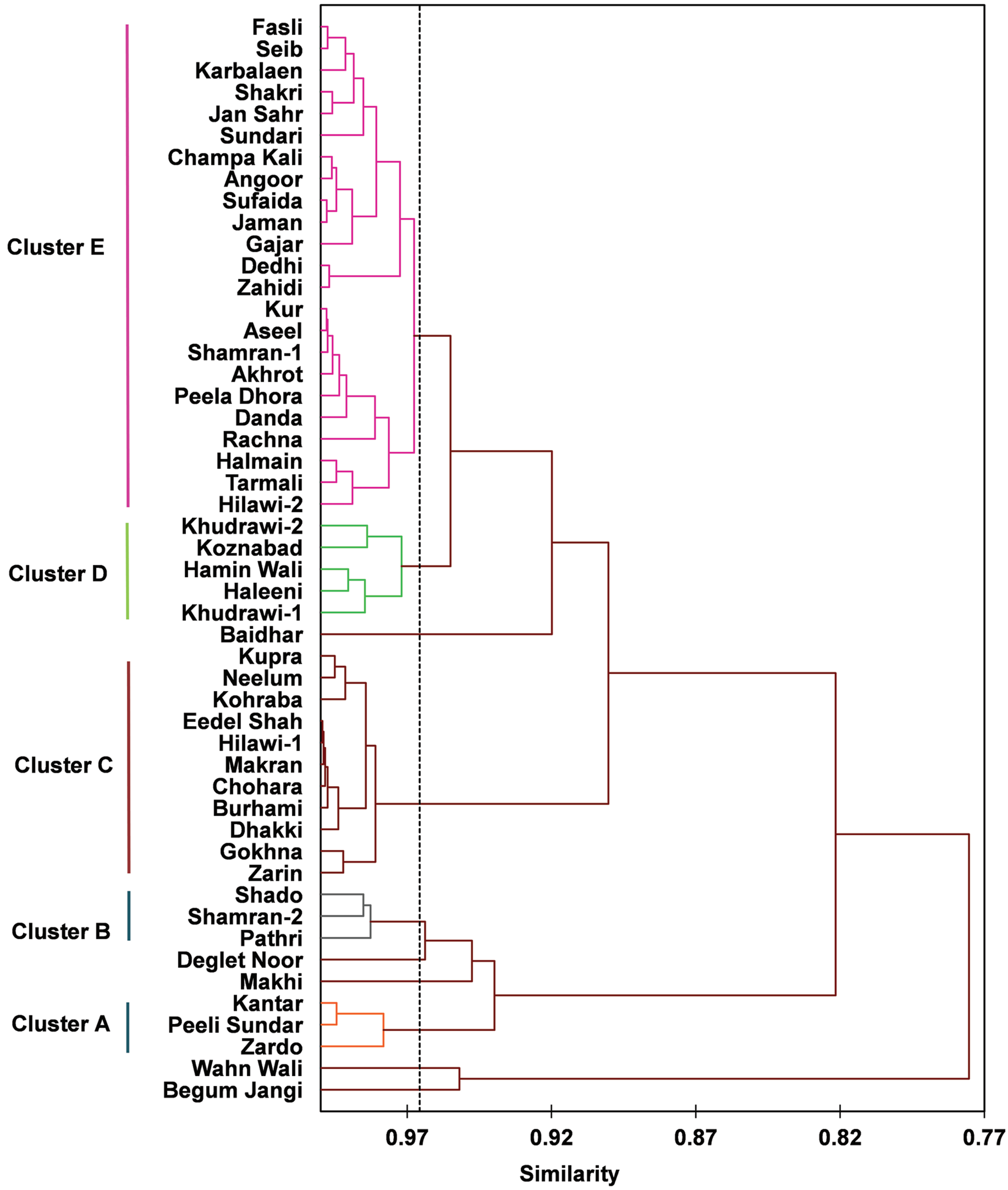

Figure 6. Dendrogram showing similarity among 50 date palm genotypes based on physico-chemical characteristics.

Table 5. Variance decomposition for the optimal classification of studied genotypes.

	Absolute	Percentage (%)
Within-cluster	4,136.636	31.52
Between-clusters	8,985.867	68.48
Total	13,122.504	100.00

non-significantly correlated with SL, SD, ST, SP, SA, SV, MO, dry matter, potential acidity (pH), RSs, NRSs and carotenoids. However, a significant and negative relationship was observed between RSs and NRSs (Table 6).

PCA based on physical traits and biochemical properties

According to PCA, we divided the fruit, stone and biochemical data of date palm genotypes into 21 components. The first eight components revealed a cumulative variation of nearly 77.69% (Table 7).

The two-dimensional variable plot, scatter plot and biplot were constructed based on first two components

Table 6. Pearson correlation matrix among physico-chemical characteristics of 50 date palm genotypes.

Trait	FW	PW	SW	PS	FL	FD	FT	FP	FA	FV	SL	SD	ST	S:P	SA	SV	MO	DM	TSS	pH	RSs	NRSs	CA
FW	**1**																						
PW	**0.99****	**1**																					
SW	**0.56****	**0.51****	**1**																				
PS	**0.61****	**0.64****	−0.09	**1**																			
FL	**0.38****	**0.37****	**0.28***	0.17	**1**																		
FD	**0.47****	**0.46****	0.28	**0.29***	**0.60****	**1**																	
FT	**0.46****	**0.48****	0.10	**0.45****	0.18	**0.31***	**1**																
FP	**0.37****	**0.38****	0.14	**0.32***	0.12	0.05	0.28	**1**															
FA	**0.63****	**0.63****	**0.36***	**0.43***	0.27	**0.51****	**0.43****	**0.57****	**1**														
FV	**0.60****	**0.62****	0.24	**0.42****	**0.68****	**0.86****	**0.64****	0.18	**0.53****	**1**													
SL	0.15	0.15	−0.01	0.11	**0.30***	**0.29***	0.28	−0.03	0.10	**0.35***	**1**												
SD	0.02	0.03	−0.02	0.03	−0.09	−0.13	−0.06	−0.06	−0.09	−0.11	−0.11	**1**											
ST	0.05	0.06	0.03	0.16	0.05	0.16	0.07	0.11	0.25	0.17	0.06	−0.04	**1**										
SP	−0.11	−0.10	**−0.29***	0.05	0.01	0.02	0.04	−0.05	−0.11	0.04	**0.37***	0.08	0.04	**1**									
SA	−0.08	−0.07	**−0.28***	0.09	0.05	0.16	0.14	−0.11	−0.04	0.17	**0.50****	−0.04	0.24	**0.70****	**1**								
SV	0.13	0.16	0.08	0.16	0.09	0.13	0.08	0.10	0.21	0.15	**0.39***	**0.35***	**0.79****	0.19	**0.36***	**1**							
MO	−0.17	−0.16	−0.16	−0.02	**0.29***	0.13	0.07	−0.03	−0.04	0.15	**0.32***	−0.02	0.01	0.18	0.17	0.10	**1**						
DM	0.17	0.16	0.16	0.02	**−0.29***	−0.13	−0.07	0.03	0.04	−0.15	**−0.31***	0.02	−0.01	−0.18	−0.17	−0.10	**−0.99****	**1**					
TSS	**0.29***	**0.30***	0.16	0.18	−0.11	−0.09	0.01	0.21	0.15	−0.07	0.14	0.01	−0.07	0.02	0.02	0.09	−0.05	0.05	**1**				
pH	0.01	0.01	−0.05	0.01	0.19	0.20	0.10	−0.04	0.22	0.21	**0.29**	0.19	0.06	0.13	0.25	0.23	−0.10	0.10	0.18	**1**			
RS	0.23	0.23	0.15	0.24	0.89	0.11	0.14	0.01	0.18	0.15	0.18	0.01	0.17	−0.08	0.15	**0.31***	−0.06	0.06	0.27	0.01	**1**		
NR	−0.20	−0.19	−0.23	−0.16	−0.07	−0.08	−0.17	−0.05	−0.19	−0.12	−0.08	0.08	−0.05	0.07	−0.13	−0.09	0.20	0.20	−0.09	0.03	**−0.62****	**1**	
CA	−0.05	−0.04	−0.18	0.07	−0.18	−0.05	−0.15	−0.15	−0.17	−0.13	0.08	−0.04	−0.07	0.19	0.24	−0.04	0.10	0.10	0.15	0.08	0.20	−0.08	**1**

*Significant at $p \leq 0.05$ and **highly significant at $p \leq 0.01$.

CA, carotenoid; DM, dry matter; FA, fruit area; FD, fruit width; FL, fruit length; FP, fruit perimeter; FT, fruit thickness; FV, fruit volume; FW, fruit weight; MO, moisture content; NRSs, non-reducing sugars; pH, potential acidity; P:S, pulp-to- stone ratio; PW, pulp weight; RSs, reducing sugars; SA, stone area; SD, stone width; SL, stone length; SP, stone perimeter; ST, stone thickness; SV, stone volume; SW, stone weight; TSS, total soluble solids.

Table 7. PCA of the studied traits.

	F1	F2	F3	F4	F5	F6	F7	F8
Eigen value	5.40	3.18	2.27	1.68	1.50	1.49	1.27	1.06
Variability (%)	23.48	13.84	9.86	7.33	6.54	6.49	5.54	4.62
Cumulative%	23.48	37.32	47.18	54.51	61.05	67.53	73.07	77.69

PCA, principal component analysis.

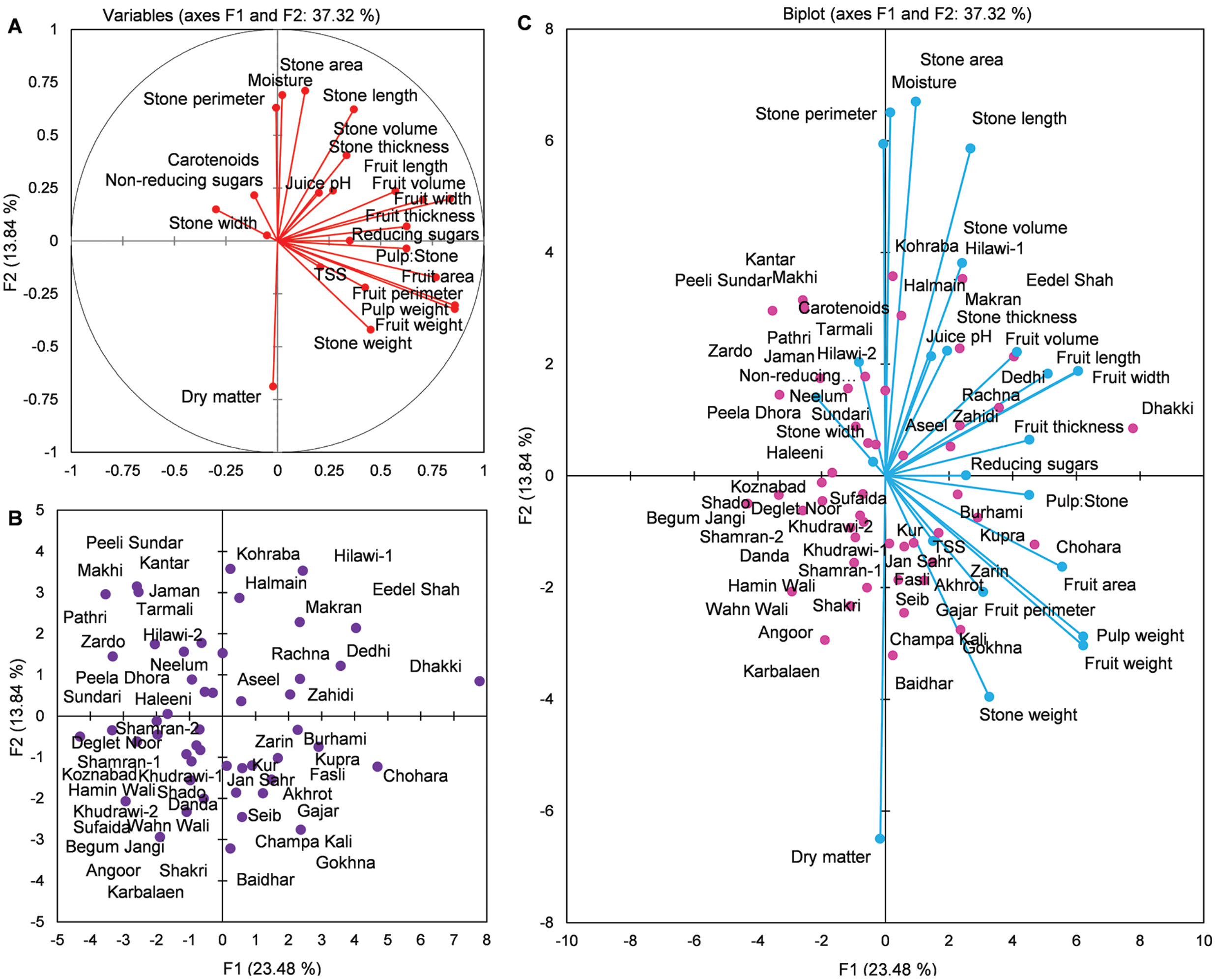

Figure 7. Variable plot (A), scatter plot (B) and biplot (C) analyses of physico-chemical characteristics of 50 date palm genotypes.

of grouped genotypes according to the similarity of physical traits and biochemical properties, which had 37.32% of variability (Figure 7).

DISCUSSION

Variation among 50 date palm genotypes collected from two research stations situated in major date palm-growing areas of Punjab province was studied based on 23 physico-chemical traits. The information on genetic diversity can be helpful in the collection, management and utilisation of germplasm (Din et al., 2020). Physico-chemical properties are more efficient in the characterisation of fruit crops, that is, date palm (Ahmad et al., 2021), Jaman (Din et al., 2020) and Indian jujube (Anjum et al., 2018). Fruit yield and quality-related characteristics have greater economic value (Andrés-Agustín et al., 2006). These are more desired and targeted traits by breeders and growers (Mehmood et al., 2014). The evaluation of biodiversity can be helpful for a population's survival under major turbulences, by making the germplasm less susceptible to inherited as well as environmental hazards (Awasthi and More, 2009).

Current findings are in line with previous work because morpho-physical and biochemical properties are useful in discrimination among date palm genotypes. Physical and biochemical characteristics showed greater reliability in the evaluation of genetic diversity among date palm genotypes because these characteristics revealed significant variation/difference in the studied genotypes. Researchers (Akhtar et al., 2014; Haider et al., 2015) have characterised date palm genotypes, but their research was not wide-ranging. The major strength of the current study is discrimination of the studied genotypes, which increases the scope for further research on date palm breeding and commercialisation.

Diversity found among the studied genotypes based on FW, size, area, perimeter and quality can be utilised as breeding targets (Anjum et al., 2018; Ahmad et al., 2021). In the present study, fruit, stone and pulp weights showed greater diversity among date palm genotypes. This variation possibly occurred due to the unique genetic makeup and climatic conditions (Ahmad et al., 2019, 2020). Similarly, Ahmed et al. (2011) studied significant diversity in date palm fruit, stone and pulp weights, TSS and different sugars, which are governed by additive gene action. This shows that selection based on physical and biochemical properties could be useful. Genotypes with greater fruit and pulp weight are found to be more important and useful for fresh and dried fruit production. In the present study, the Dhakki genotype had greater FW, PW, and FL, which can be further utilised in breeding programmes for improved FW. However, genotypes with smaller fruits had higher biochemical traits; thus, these genotypes could be an important source of nutrition. The current study revealed that phenotypic identification of genotypes is more imperative than farmers' names.

Cluster analysis based on phenotypic traits and biochemical properties of fruits revealed that genotypes collected from two different areas were grouped together and separately based on the similarity of the studied characteristics. The genotypes that grouped together showed higher similarity in the studied traits. The findings of the present study indicated that date palm genotypes had significant variations in their morpho-physical and biochemical characteristics. Our findings proved that cluster analysis is a helpful tool for the differentiation of the studied genotypes. Seed propagation and cross-pollination are major causes of diversity in fruit crops (Ahmad et al., 2020).

Correlation and variable plots revealed positive and negative associations among fruit traits and biochemical characteristics. They also revealed that RSs and NRSs were negatively correlated with each other. Similar relationships were also observed in a previous study (Anjum et al., 2018). The increase in fruit size may result in less nutrient accumulation, which is a cause for the poor quality of fruits (Sharif et al., 2019). The scatter plot showed diversity among the studied genotypes. It was observed that Dhakki and Baidhar genotypes showed higher genetic diversity than other studied genotypes. Therefore, these genotypes deviated from the centre of origin in the scatter plot. The biplot classified the 50 studied genotypes into four groups based on the studied traits. Genotypes close to their trait vectors, such as Dhakki genotype, showed greater mean performance than other genotypes for respective traits. This shows that multivariate approaches can be used to evaluate the genetic diversity of a huge number of genotypes and their traits. Hence, hybridisation might be used among different clusters for higher heterosis and desired genetic recombination.

CONCLUSION

The present study proved that characterisation of physical and biochemical traits is necessary during the selection of diverse parents for evolving new commercial cultivars of date palm. Genotypes with greater fruit size and higher nutritional properties can be further used for breeding purposes. The current work is helpful for taxonomical studies and selection of the suitable plant material for breeding programmes such as development of higher-yielding cultivars with an excellent fruit quality.

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AUTHOR CONTRIBUTIONS

R.A. and M.A.A.: conceptualisation. S.E.; R.A.M. and R.K.: writing – original draft preparation. R.A., M.A.A., S.E. and W.M.: data curation. R.A.: M.A.A., S.E. and W.M.: validation. E.S., R.A., W.M. and R.A.M.: visualisation. R.A., W.M., R.A.M., R.K. and E.S.: writing — review and editing. R.A., M.A.A., S.E. and W.M.: investigation. R.A. and M.A.A.: methodology. M.A.A.: supervision. R.A.: resource. W.M., M.A.A. and S.E.: software. R.A., M.A.A. and W.M.: formal analysis.

CONFLICT OF INTEREST

All authors have read and agreed to the published version of the manuscript and declare that no conflict of interest exists.

DATA AVAILABILITY STATEMENT

Data recorded in the current study are available in all tables and figures of the manuscript.

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