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Research Article

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Evaluation of the Mineral Composition of Fruit of 15 Date Cultivars (*Phoenix dactylifera* L.) Using Univariate and Multivariate Analyses

Mohammadreza Pourghayoumi[1], Kamal Gholamipour Fard[2], Sara Farokhzadeh[3*] and Rahman Yousefi[4]

[1]*Date Palm and Tropical Fruits Research Center, Horticultural Science Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Ahvaz, Iran*

[2]*Department of Plant Production, College of Agriculture and Natural Resources of Darab, Shiraz University, Darab, Iran*

[3]*Field and Horticultural Crops Research Department, Fars Agriculture and Natural Resources Research and Education Center, Agricultural Research, Education and Extension Organization (AREEO), Shiraz, Iran*

[4]*Date Palm and Tropical Fruits Research Center, Horticultural Science Research Institute, Agricultural Research, Education and Extension Organization (AREEO), Ahvaz, Iran*

***Correspondence to:**
Sara Farokhzadeh
Field and Horticultural Crops Research Department,
Fars Agriculture and Natural Resources Research and Education Center,
Agricultural Research,
Education and Extension Organization (AREEO), Shiraz, Iran.
E-mail: Sfarokhzadeh87@gmail.com

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Abstract

Date fruit is renowned for its rich mineral composition and is considered as an important component of the diet in many countries. Therefore, the current study aimed to explore the mineral composition and moisture contents (MC%) of 12 Iranian native cultivars and three imported cultivars, using univariate and multivariate methods. The results showed that the K content in date fruits was higher than other elements, followed by Ca and Na. The predominant micronutrient in all date fruit cultivars was Fe. The 'Hallawi' cultivar exhibited high and considerable concentrations for all mineral elements (Fe, Mn, Cu, Zn, Na, and K), except for Ca. The 'Barhee' date had the lowest Na content, making it suitable for individuals with high blood pressure. The highest positive correlations were observed between Cu-Fe, Cu-Mn, Fe-Mn, Na-Cu, Na-Fe, and K-Ca, respectively. Cluster analysis (CA) of MC% and mineral composition of fruits grouped 15 date cultivars into three and four clusters, respectively. The discriminant function analysis revealed that the accuracy of the CA in grouping date fruits was 100% for MC% and 93.3% for macro- and micro-nutrients. According to principal component analysis (PCA), the first two components explained 36.01% and 24.90% of the total variation in traits, respectively. Overall, the fruits of examined cultivars contained considerable, but highly variable, amounts of minerals. According to the study, it is suggested that the superior cultivars can be potentially used as nutritional supplements or as ingredients in functional food products.

Keywords

Cluster analysis, Correlation, Date fruits, Discrimination function, Macronutrients, Micronutrients, Moisture content, Principal component analysis

Introduction

The date palm (*Phoenix dactylifera* L.) is a long-lived, woody perennial plant classified as a monocotyledon and belonging to the Arecaceae family. It is widely recognized as one of the oldest and most popular fruit trees in arid and semiarid regions worldwide [1]. The date palm has been cultivated since ancient times and is mentioned in the Holy Quran and Christian Bibles. On a global scale, date palm cultivation covers an area of approximately 1.09 million hectares, resulting in a total production of around 8.53 million tons [2]. Date fruit plays a vital role in ensuring food security in many countries, including Iran. The date palm is one of the most important and widely grown commercial tree crops in southern Iran. According to the FAO (2021), Egypt, Saudi Arabia, and Iran are the

leading countries in date production. Additionally, in terms of cultivated area, Iran ranks third globally, following Iraq and Algeria [3]. The escalating global population growth and the rising demand for food, along with the nutritional, industrial, economic, social, and cultural importance of dates, highlight the need for a heightened emphasis on identifying and introducing the most economically viable and high-yielding date palm cultivars. Additionally, the identification and introduction of promising date cultivars to increase date production and improve the current status of date palm groves will help us achieve these goals. Future climate change scenarios foresee a substantial increase in suitable regions for date palm cultivation in Iran, which will lead to the expansion of date palm cultivation due to improved conditions. These predictions offer valuable insights for date palm industry stakeholders and agricultural planners, facilitating informed decisions on cultivation locations and maximizing benefits from this valuable crop [4]. Date fruits are nutritionally rich in carbohydrates, essential vitamins, minerals, and dietary fiber. Furthermore, their bioactive compounds like carotenoids, phenolic compounds, sterols, and anthocyanins offer extra health benefits. At the full maturity stage, date fruits consist of moisture (10 - 30%), dietary fiber (5 - 12% or 6.4 - 11.5%), carbohydrates (total sugars 44 - 88% or 60 - 80%), fats (0.2 - 0.4%), proteins (2.3 - 5.6%), phenolic compounds (up to 4%), and 15 minerals and vitamins. The amount of each mineral varies from 0.1 to 916 mg/100 g of dry date weight, depending on the specific mineral [5-9]. Hence, incorporating date fruit in one's diet is vital for human nutrition due to its nutritional benefits. Soft cultivars are rich in invert sugar (glucose and fructose), semi-dry cultivars have an equal mix of invert sugars and sucrose, and dry cultivars contain a higher proportion of sucrose [10]. The nutritional value of dates is attributed to their high sugar content, alongside other essential macronutrients and micronutrients such as K (over 2.5 times higher than bananas), Ca, Mn, and Fe [6]. Dates are recommended for preventing diseases, particularly in treating blood sugar and controlling blood fat levels in diabetic patients. Their richness in polyphenolic compounds and vitamins also grants them antioxidant properties [11-13]. Minerals play vital roles in human health, contributing to bones and teeth formation, serving as components of enzymes and hormones, regulating heart rate, red blood cell formation, glucose levels, and blood pressure control. Additionally, metabolic reactions rely on precise amounts of each mineral [14]. Researchers are actively involved in analyzing the mineral composition of dates, which is a highly significant topic concerning food safety and its health-promoting properties. Published studies provide valuable information on the essential elements of date like Ca, P, K, Na, Mg, Fe, Mn, Sr, Zn, Co, and Se that are vital for proper human body function [15-18]. Understanding the nutritional content of various date cultivars holds significance for preserving date genetic resources, increasing per capita date consumption, improving the production chain, and facilitating export.

The use of multivariate statistical methods for analyzing food data has significantly increased [10, 19-21]. Multivariate statistical analysis provides greater insights into explaining the sources of variation in the data compared to descriptive statistics or univariate statistical techniques [21, 22]. Techniques such as PCA, CA, and discriminant function analysis (DFA) enable exploring key principles in multivariate data, describing correlations among multiple variables, and categorizing diverse genotypes into distinct groups. Applying multivariate data analysis and machine learning techniques allows for extracting hidden patterns within the data and facilitating the identification of significant characteristics [21-25]. PCA and DFA techniques have been used to examine the variations in size and shape among various species of dates [26]. Overall, our research innovatively investigates the nutritional properties of previously uninvestigated Iranian native and imported date fruit cultivars using univariate and multivariate analyses, emphasizing their importance as a rich source of minerals and their relevance to global dietary practices. The study's novelty lies in its comprehensive analysis of variations in mineral content among these date cultivars and their potential impact on nutrition and functional food development.

The objectives of the present study were to: i) analyze the MC% and mineral composition (including micronutrients and macronutrients) of various date fruit cultivars, ii) evaluate the genetic diversity among various cultivars of date fruit, iii) investigate the relationships between different traits, and iv) estimate the heritability of traits and classify date fruits based on examined characteristics using multivariate analyses.

Materials and Methods

This research was carried out at the research orchard Date Palm and Tropical Fruits Research Center (48° 33´ E, 31° 15´ N, 12 m Altitude) in Ahvaz, Khuzestan, Iran, during 2021 - 2022. For this purpose, the fruits of 15 date cultivars including 'Thoory', 'Hallawi', 'Medjool', 'Barhee', 'Zahidi', 'Sowaidani', 'Deiri', 'Stamaran', 'Piarom', 'Owaydi', 'Ashrasi', 'Deglet Noor', 'Fersi', 'Belyani', and 'Bereim' were collected at the full ripening stage (Tamar) (Figure 1). Table 1 provides the characteristics of selected cultivars of date fruit, including details on cultivar type, origin, ripening time, fruit type, fruit shape, fruit color, consumption stage, and supplementary properties. Notably, some cultivars like 'Ashrasi', 'Piarom', 'Thoory', 'Deglet Noor', and 'Medjool', are not native to the Ahvaz region, and their appearance and quality are superior in their primary growing regions. These foreign cultivars, such as 'Thoory', 'Deglet Noor', and 'Medjool', have been imported to Iran as tissue-cultured seedlings and are only available in limited areas in specific regions like Khuzestan. The quality of these foreign

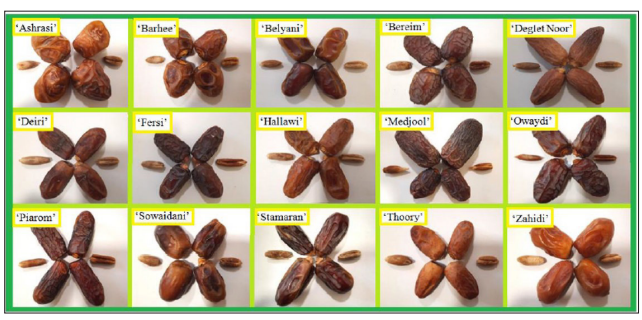


Figure 1: Fruits of 15 date cultivars grown in the Ahvaz region of Iran.

Table 1: Characteristics of selected cultivars of date fruit grown in the Ahvaz region of Iran.

Cultivar	Origin	Ripening time	Fruit type	Fruit shape	Fruit color	Consumption stage	Supplementary properties
Ashrasi	Syria, Iraq, Iran	Medium to late	Semi-dry	Ovoid with shallowly cordate base	Light brown	Ruatb and tamar	It is of excellent quality. It is attractive in appearance, and very delicious.
Barhee	Iran, Iraq	Late	Soft	Broadly ovate to rounded	Amber to deep brown	Khalal, rutab, and tamar	It is internationally well-known. It is highly valued for its attractive appearance and delicate, distinctive flavor. The fruit is firm, smooth, and offers a unique taste.
Belyani	Iran, Iraq	Mid-season	Soft to semi-dry	Oblong	Light brown	Ruatb and tamar	It has acceptable quality, but its cultivation area is low.
Bereim (Braim)	Iran, Iraq	Mid-season	Soft	Ellipsoid with shallowly cordate or oblique base	Transparent amber	Khalal, ruatb, and tamar	It is attractive in appearance and is excellent quality. It is sweet, very delicious, and luscious.
Deglet Noor	Algeria	Late	Semi-dry	Linear-oblong	Slightly deep brown	Ruatb and tamar	It is well-known internationally. It is mechanically pitted. It is attractive in appearance and possesses a delicate, distinctive flavor. The fruit is firm, smooth, with a unique taste.
Deiri (Dayri)	Iran, Iraq	Mid-season	Dry to semidry	Oblong to oblong-elliptical	Dark reddish brown	Rutab and tamar	It is good quality, but its yield is low. It is considered easy to handle and suitable for mechanized harvesting.
Fersi	Iran, Iraq	Medium to late	Semi-dry	Oblong	Dark brown	Ruatb and tamar	It is attractive in appearance, and the fruit has high quality.
Hallawi	Iran, Iraq	Early	Semi-dry	Oblong with a rounded apex	Golden brown	Khalal, rutab and tamar	The fruit has good keeping quality and moisture tolerance. It is sweet, caramel-like, and translucent. It has low fiber and pigments.
Medjool	Morocco	Medium to late	Soft to Semi-dry	Broadly oblong-oval to somewhat ovate	Light brown to dark brown	Rutab and tamar	Fruit has a large size, soft flesh, and attractive appearance. It has high demand in the market and in international trade.
Owaydi	Iran, Iraq	Mid-season	Semi-dry	Oblong to a truncate base	Dark brown	Rutab and tamar	The fruit is large in size and attractive in appearance. However, its cultivation area is low.
Piarom	Iran	late	Semi-dry	Linear-oblong	Dark brown to black	Rutab and tamar	It is one of the most expensive and desirable date cultivars in the world. It is attractive in appearance. This cultivar is known worldwide for its high quality.
So-waidani	Iran	Mid-season	Dry to semi-dry	Oblong with a shallowly cordate base	Brown	Rutab and tamar	It has moderate quality and cultivation area is low.
Stamaran (Sayer)	Iran, Iraq	Mid-season	Semi-dry	Linear-oblong with a truncate base	Dark orange-brown	Rutab and tamar	It is good quality. The fruit is medium in size. It is suitable for fresh consumption and processing purposes.
Thoory	Algeria	Late	Dry	Oblong with a rounded apex	Yellow to light grayish-brown or straw color	Tamar	It has an attractive appearance. The fruit has good flavor, and its astringency is low. The fruit is medium to large and is slightly affected by humid conditions.
Zahidi	Iran, Iraq	Mid-season	Dry to Semi-dry	Obovate	Yellow to brown	Tamar	It is suitable for mechanized harvesting, and its yield is high. The fruit is firm, not very sweet, with a smooth consistency.

cultivars might vary from their original habitat due to the different conditions in our region.

From each cultivar, 30 healthy and disease-free fruits were randomly selected. Each fruit was carefully cleaned to remove any foreign matter and then placed in labeled polyethylene bags. The date fruits were stored in a refrigerator until they were ready for analysis. Subsequently, for the analysis of mineral compositions, the samples were transferred to the College of Agriculture and Natural Resources of Darab, Shiraz University, Iran. The cultivars were evaluated using a completely randomized design (CRD) with three replications. Data for various traits, including the MC% of the fruit and the mineral composition of different date fruit cultivars, including micronutrients such as Fe, Mn, Zn, and Cu, and macronutrients such as Na, K, and Ca were measured as follows:

To measure the MC%, the following steps were taken. Initially, approximately 50 g of fresh fruits (FFW, g) without the stone were chopped to an area of approximately 0.5 cm^2 using a sharp knife, and the precise weight of the chopped fruit was recorded. Next, the chopped fruit was placed in aluminum containers and transferred to an oven set at 75 °C for 5 days. Subsequently, the weight of the dried fruit (FDW, g) was

measured [27, 28]. The MC was calculated using the following formula:

Moisture content of the fruit (MC, %) = [(FFW - FDW)/ FFW] x 100

For mineral analysis, the acid digestion method was investigated for sample preparation, as described below. Date fruit samples were placed in an oven at 75 °C for 5 days. After grinding, the dried samples were homogenized and stored for further analysis. To measure the desired elements, 1 g of the dried samples was placed in porcelain crucibles and heated in an electric furnace at 550 °C for 5 hours. The resulting ash or cooled sample was then boiled in 5 ml of 2 M HCl solution for 2 minutes, followed by filtration using filter paper, and diluted to a volume of 50 ml with distilled water [29, 30].

The concentrations of micronutrients (Fe, Mn, Zn, and Cu) in the obtained extract were analyzed using an atomic absorption spectrometer (AAS; PG 990, PG Instruments Ltd., UK). In contrast, the concentrations of macronutrients (Na, K, and Ca) in the extract were determined using a flame photometer (BWB XP, UK).

Univariate and multivariate statistical analysis

Statistical analyses were conducted using various methods, including the normality test (Shapiro-Wilk test), simple analysis of variance, mean comparisons (MRT: Duncan's new multiple range test), descriptive statistics [Min, Max, Range, Mean, Median, Std.dev, Std Error, Coef.var, Phenotypic (σ^2_p), genotypic (σ^2_g) and environmental (σ^2_e) variances, Phenotypic (PCV) and genotypic (GCV) coefficient of variation, and Broad sense heritability (H^2_b)], correlation, CA, DFA, and PCA. The software programs used for the analyses were SAS 9.2 (SAS Institute, Cary, NC, USA), SPSS 24 (SPSS, Chicago, IL, USA), and Excel.

Results and Discussion

The moisture content and mineral compositions

The results of an analysis of variance (ANOVA) revealed a significant difference among the different date cultivars examined in terms of the amounts of mineral elements such as Fe, Mn, Cu, Zn, Na, K, and Ca, as well as the MC% of fruit (Table 2). These findings suggest a high variation among all date cultivars for different traits and are consistent with the findings of other studies in date cultivars [10, 17, 31, 32]. Genetic variation among cultivars is desirable for effective selection in breeding programs, as breeders utilize it to develop new cultivars with improved characteristics such as biotic and abiotic stress tolerance, higher yield, and higher nutritional value for a growing population [33-35]. Plant breeding investigations and cultivar development play a pivotal role in enhancing food production. Therefore, ensuring the availability and accessibility of diverse genetic sources is crucial for promoting sustainability within the global food production network [36].

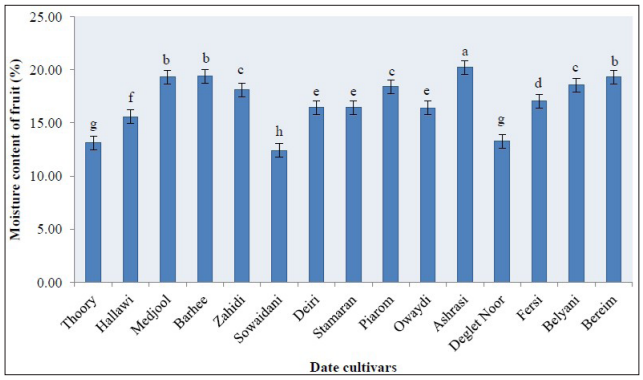


Figure 2: Mean comparison of MC of fruit (%) in selected date cultivars grown in Ahvaz region of Iran. Means with different letters in each column are significantly different (α = 5%), using Duncan's multiple range test.

The results of the mean comparison of the studied traits using the Duncan test are presented in figure 2 and table 3. The moisture content is a crucial factor in categorizing date crops into dry, semi-dry, or soft fruits. In addition to moisture, fiber values, external fruit qualities (texture and pliability), and the ratio of fructose, glucose, and sucrose content are also important in determining fruit types at the tamar stage. By identifying different cultivars of dry, semi-dry, and soft dates, it is possible to recognize and introduce their specific uses. Some cultivars of dates are suitable for export due to the quality of their dry and semi-dry texture, while others are preferred for fresh consumption because of their delightful softness and flavor. In different studies on various types of dates, the moisture content of the fruits ranged from 9.73 to 17.52% [37], from 15.95 to 22.14% [13] and from 14.8% to 20.5% [32]. In the present study, the moisture content of fruit ranged from 12.42 to 20.22% (Figure 2). Figure 2 illustrates that 'Ashrasi' date fruit had a higher moisture content compared to the other cultivars, demonstrating significant differences ($p < 0.01$). Additionally, 'Medjool', 'Barhee', and 'Bereim' date fruits had the highest moisture content, with no significant differences among them. Conversely, 'Sowaidani', 'Thoory', and 'Deglet Noor' had the lowest moisture content, indicating that these dry fruits were firmer than other cultivars, and could be suitable for extended storage [38]. This finding is consistent with the results of Abbasi Bastami et al. [13], and Alghamdi et al. [38] who reported

Table 2: ANOVA analysis for concentrations of micronutrients and macronutrients in the fruit of 15 date cultivars.

		Mean squares							
		MC of fruit	Concentration						
SOV	DF	%	Fe	Mn	Cu	Zn	Na	K	Ca
Cultivar	14	18.28**	718.65**	33.64**	6.45**	6.20*	0.0002**	0.14**	0.03**
Error	30	0.11	8.84	2.29	0.60	2.39	0.00003	0.03	0.0001
CV (%)	-	1.94	17.17	18.15	25.40	15.98	25.78	18.09	13.89

Note: * and **: significant (α = 5%) and highly significant (α = 1%), respectively.

a high moisture content for the 'Barhee' date cultivar. Also, contrary to our results, the 'Piarom' date had a higher moisture content of fruit than the 'Zahidi' date [39]. The average humidity level in common date fruit cultivars is 16.94% (Table 4). Date fruit's low moisture content makes it an ideal, nutrient-rich staple food, storing more calories for fasting periods. Additionally, the dryness of date fruit safeguards them against infestation caused by contamination and nutrient deficiency. The tamer stage of date fruit is especially suitable for storage and consumption, ensuring a healthy one-year lifespan as a nutrient-rich source of energy. Certain cultivars are classified as dry cultivars in specific regions, but variations in climatic conditions lead to different cultivar types in other areas, resulting in fluctuations in moisture levels during the harvest period. Dates contain low concentrations of the micro-elements Zn and Cu, while Fe is present in higher concentrations [40]. In all date fruit cultivars, the highest micronutrient contents were observed for Fe, Zn, Mn, and Cu, respectively (Table 3 and table 4). The most important role of Fe is to facilitate oxygen transport within the body. Fe deficiency is the primary cause of anemia [41]. In the current study, Fe content of different date cultivars ranged from 4.85 to 18.69 mg/kg. The 'Hallawi' and 'Thoory' cultivars had the highest and lowest Fe content, respectively. The Fe content of the 'Hallawi' date being 14 times that of the 'Thoory' date. The recommended daily intake of Fe is 10 mg and 15 mg for men and women, respectively. Dates, especially 'Hallawi', the Fe-rich date cultivar, can be used to meet daily Fe requirements instead of synthetic Fe supplements. Among the examined micronutrients, there was also a significant amount of Zn in various date cultivars. Zn plays a vital role in both the structure and function of cell membranes and helps maintain adequate levels of vitamin A in the body [42]. Zn acts as a strong antioxidant and is necessary for the growth and development of body tissues, proper immune function, and insulin regulation [43]. The recommended daily intake for Zn is 11 mg [44]. The 'Stamaran' date fruit contained the highest amount of Zn (11.98 mg/kg), and it was not significantly different from the 'Ashrasi', 'Piarom', 'Hallawi', 'Fersi', 'Zahidi', 'Belyani', 'Owaydi', 'Deiri', and 'Sowaidani' cultivars. While, the 'Thoory' cultivar had the lowest Zn content in the fruits (7.15 mg/kg), and it did not show any significant difference from 'Medjool', 'Barhee', 'Sowaidani', 'Deiri', 'Owaydi', 'Deglet Noor', 'Belyani', and 'Bereim' cultivars. Mn is essential for brain function and facilitates the metabolism of proteins and carbohydrates. Additionally, it plays a key role in the synthesis of cholesterol, fatty acids, and collagen [45]. The Mn content in the studied date palm cultivars ranged from 22.3 to 48.16 mg/kg. The 'Hallawi' date fruit contained the highest Mn content, while the 'Bereim' date fruit contained the lowest content among the examined cultivars, which were significantly different from the other date cultivars. The 'Hallawi' date had approximately five times more Mn content than the 'Bereim'. The recommended daily intake of Mn for women and men is 1.8 and 2.3 mg, respectively. Daily consumption of dates can easily serve as a supplement to meet the recommended daily amount of Mn [46]. Mn plays several vital roles in the human body, including regulating blood sugar, activating specific enzymes, and acting as an antioxidant [47]. The daily requirement of Mn for the human body is 2 to 5 mg [48]. Incorporating dates into the diet, particularly the 'Hallawi' cultivar, can serve as a valuable Mn supplement, helping to meet a portion of the body's daily Mn requirements. In the present study, the Cu content of examined dates ranged from 2.10 to 8.10 mg/kg. The 'Hallawi' cultivar had the highest Cu content, significantly differing from other cultivars, while the 'Zahidi' cultivar had the lowest Cu content. The Cu content in

Table 3: Mean comparison of concentrations of micronutrients and macronutrients in the fruit of 15 date cultivars.

Cultivar	Concentration						
	Fe (mg.kg^{-1})	Mn (mg.kg^{-1})	Cu (mg.kg^{-1})	Zn (mg.kg^{-1})	Na (%)	K (%)	Ca (%)
Thoory	4.85^{g} ± 0.30	8.25^{d} ± 1.74	3.65^{b} ± 0.75	7.15^{c} ± 0.15	0.022^{c} ± 0.02	1.25^{a} ± 0.06	0.045^{c} ± 0.01
Hallawi	69.18^{a} ± 1.83	16.48^{a} ± 3.12	8.10^{a} ± 1.75	10.70^{ab} ± 0.17	0.035^{ab} ± 0.01	1.10^{abc} ± 0.02	0.063^{b} ± 0.01
Medjool	25.58^{b} ± 3.68	7.62^{de} ± 2.04	2.67^{bc} ± 0.93	8.25^{bc} ± 0.40	0.017^{de} ± 0.003	0.73^{de} ± 0.07	0.027^{de} ± 0.003
Barhee	14.03^{def} ± 2.27	8.83^{cd} ± 0.58	3.08^{bc} ± 1.04	8.48^{bc} ± 1.18	0.007^{e} ± 0.001	0.79^{cde} ± 0.10	0.017^{e} ± 0.001
Zahidi	14.83^{de} ± 3.08	6.47^{de} ± 1.35	2.10^{c} ± 0.78	10.40^{ab} ± 1.23	0.016^{de} ± 0.01	0.73^{de} ± 0.11	0.027^{de} ± 0.01
Sowaidani	17.27^{cd} ± 1.78	8.23^{d} ± 1.48	3.15^{bc} ± 0.58	9.17^{abc} ± 0.83	0.02^{cd} ± 0.0005	1.22^{a} ± 0.09	0.398^{a} ± 0.01
Deiri	12.80^{def} ± 0.05	12.13^{b} ± 1.38	2.85^{bc} ± 0.61	9.67^{abc} ± 0.59	0.023^{cd} ± 0.01	1.13^{ab} ± 0.19	0.034^{cd} ± 0.01
Stamaran	7.03^{g} ± 0.92	11.53^{b} ± 0.62	2.45^{bc} ± 0.25	11.98^{a} ± 0.89	0.019^{cd} ± 0.01	1.01^{abcd} ± 0.06	0.037^{cd} ± 0.01
Piarom	20.28^{c} ± 6.48	11.15^{bc} ± 0.56	2.78^{bc} ± 0.64	10.95^{ab} ± 0.48	0.020^{cd} ± 0.002	1.17^{a} ± 0.27	0.037^{cd} ± 0.005
Owaydi	21.35^{bc} ± 5.40	5.27^{ef} ± 0.55	2.53^{bc} ± 0.33	9.75^{abc} ± 0.26	0.034^{ab} ± 0.001	0.95^{abcde} ± 0.11	0.047^{c} ± 0.001
Ashrasi	13.80^{def} ± 4.31	5.12^{ef} ± 0.72	3.35^{bc} ± 0.05	11.97^{a} ± 2.74	0.037^{a} ± 0.003	0.78^{cde} ± 0.11	0.065^{b} ± 0.01
Deglet Noor	6.78^{g} ± 0.42	6.60^{de} ± 0.20	2.38^{bc} ± 0.02	8.17^{bc} ± 2.47	0.016^{de} ± 0.002	0.82^{bcde} ± 0.07	0.043^{cd} ± 0.02
Fersi	9.68^{efg} ± 1.73	6.15^{de} ± 2.36	2.20^{bc} ± 0.85	10.47^{ab} ± 1.29	0.03^{abc} ± 0.004	1.17^{a} ± 0.24	0.042^{cd} ± 0.01
Belyani	13.83^{def} ± 1.52	7.95^{de} ± 1.84	2.38^{bc} ± 0.83	9.85^{abc} ± 3.22	0.026^{bcd} ± 0.01	0.62^{e} ± 0.38	0.035^{cd} ± 0.01
Bereim	8.47^{fg} ± 1.39	3.22^{f} ± 0.80	2.22^{bc} ± 0.44	8.22^{bc} ± 2.24	0.020^{cd} ± 0.003	1.19^{a} ± 0.29	0.037^{cd} ± 0.01

Note: All the results were reported in the above table as mean value ± SD (standard deviation). Means with similar letter(s) in each column are not significantly different (α = 5%), using Duncan's new multiple range test.

the 'Fersi' cultivar was not significantly different from all cultivars, except for the 'Hallawi' and 'Thoory' cultivars. Cu is an essential mineral required for the proper functioning of organs and metabolic processes [49]. Moreover, it accelerates wound healing by increasing blood flow in the injured area and facilitating the movement of oxygen around the body [50]. The recommended intake for Cu is 1.5 to 3 mg per day [51]. Consuming 100 g of 'Hallawi' dates provides around 25 - 50% of the daily Cu requirement for adults, whereas consuming 100 g of other date cultivars investigated in this research provides approximately 8 - 15% of the daily Cu requirement for adults.

In all date fruit cultivars, the highest amounts of macronutrients were observed for K, Ca, and Na, respectively (Table 3 and table 4). Our results were consistent with the findings of Nadeem et al. [48], who reported that K and Ca were the predominant mineral components in date fruit cultivars, as well as with the results of Rambabu et al. [32], who identified K as the major macroelement in all the date cultivars. The recommended K content for adults is 2000 mg daily. In this study, the K content in the dates ranged from 0.62% ('Belyani') to 1.25% ('Thoory'). The 'Thoory' cultivar had the highest K content, but there was no significant difference in K content between the 'Thoory' date and the 'Sowaidani', 'Bereim', 'Piarom', 'Fersi', 'Deiri', 'Hallawi', 'Stamaran', and 'Owaydi' date fruits. Consuming approximately 100 grams of these date fruits can supply 50% of the daily K requirements. Parvin et al. [11] stated that K was the dominant element in the examined cultivars of date palm in Bangladesh, which is consistent with our findings. The high K content in various date cultivars holds significant nutritional importance, as K acts as an essential electrolyte contributing to kidney function, muscle cell contraction, and nervous system function [52]. The research on three prominent date cultivars ('Barhee, 'Sukri', and 'Rothana') from Saudi Arabia unveiled their substantial amounts of essential macro and micronutrients. Among them, 'Barhee' dates exhibited the highest K content (8171.24 mg/kg). Furthermore, all three date cultivars contained significant levels of Se, Cu, P, Fe, and Mn, which play a crucial role in maintaining normal bodily functions [53].

Ca is the most abundant mineral in the body, regulating numerous cellular processes and playing other vital roles in living organisms [54]. This study revealed variations in Ca content among different date cultivars, ranging from 0.017% to 0.398%. The 'Sowaidani' date exhibited the highest Ca content, which was significantly different from the other cultivars, while the 'Barhee' date had the lowest Ca content. The recommended daily intake of Ca is 800 mg [55]. This study's findings suggest that consuming 100 g of 'Sowaidani' dates fulfills approximately 50% of the daily Ca requirement for adults. However, consuming other date cultivars provides a lower amount of calcium needed by the body. The Na content in the studied cultivars ranged from 0.007% to 0.037%. Generally, the Na content in the examined cultivars was low, and the 'Barhee' date had the lowest Na content, making it suitable for individuals with high blood pressure. Na is essential for the proper functioning of living cells. The recommended daily intake of Na is 500 mg. However, excessive Na consumption can lead to high blood pressure [56]. The results of the present study align with previous research conducted on various date cultivars. Ismail et al. [57] reported that the macronutrients such as K and Na in dates ranged from 524 - 1164 and 8.5 - 69.3 mg/100 g, respectively. Additionally, the content of micronutrients including Mn, Fe, and Zn varied from 0.35 - 0.47, 0.83 - 1.76, and 0.25 - 0.60 mg/100 g, respectively. Additionally, Elleuch et al. [58] observed mineral content variations in two date cultivars, with levels ranging from 823 - 863 mg/100 g for K, 7.47 - 63.10 mg/100 g for Ca, 1.10 - 2.10 mg/100 g for Na, and 2.0 - 5.2 mg/100 g for Fe on a dry weight basis. These differences could be attributed to variations in date cultivars, climatic conditions, and fertilization practices. Nadeem et al. [48] found that different date cultivars are rich in minerals such as K, Ca, and Fe, but have low Na content. They mentioned that the amounts of Na, K, Ca, Fe, Cu, Zn, and Mn in the examined date cultivars are as follows: 0.10 - 1.07, 533 - 1013, 81 - 195,

Table 4: Descriptive statistics of micronutrient and macronutrient concentrations in the fruit of 15 date cultivars.

Traits	MC of fruit	Concentration						
		Fe	Mn	Cu	Zn	Na	K	Ca
	%	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	$mg.kg^{-1}$	%	%	%
Min	12.42	4.85	3.22	2.10	7.15	0.01	0.62	0.02
Max	20.22	69.18	16.48	8.10	11.98	0.04	1.25	0.40
Range	7.80	64.33	13.27	6.00	4.83	0.03	0.63	0.38
Mean	16.94	17.31	8.33	3.06	9.68	0.02	0.98	0.06
Median	17.04	13.83	7.95	2.67	9.75	0.02	1.01	0.04
Std.dev	2.47	15.48	3.35	1.47	1.44	0.01	0.21	0.09
Std Error	0.64	4.00	0.86	0.38	0.37	0.002	0.06	0.02
Coef.var	14.57	89.39	40.19	47.93	14.85	36.56	21.90	146.78
σ^2_e	0.11	8.84	2.29	0.60	2.39	0.00003	0.03	0.0001
σ^2_g	6.06	236.60	10.45	1.95	1.27	0.0001	0.04	0.01
σ^2_P	6.17	245.44	12.74	2.55	3.66	0.00001	0.07	0.01
PCV (%)	14.66	90.49	42.84	52.21	19.77	50.51	26.43	158.49
GCV (%)	14.53	88.84	38.80	45.66	11.64	44.30	19.60	157.70
H^2_b **(%)**	98.22	96.40	82.03	76.47	34.70	76.92	55.00	99.01

Note: σ^2_p, σ^2_g, and σ^2_e: Phenotypic, genotypic, and environmental variances, respectively; PCV and: GCV Phenotypic and genotypic coefficient of variation, respectively; and H^2_b: Broad sense heritability.

46.0 - 52.2, 6.1 - 14.0, 32.0 - 89.1, and 7.1 - 24.0 mg/100 g of fruit dry weight, respectively. Our findings demonstrated that the date cultivars possess substantial mineral contents. Previous studies have consistently reported higher mineral levels in dates compared to grapes, apples, oranges, and bananas, with values ranging from three to five times greater [10, 15, 16].

Heritability, phenotypic, and genotypic variations

The coefficients of variation for different traits were calculated for 15 date fruit cultivars (Table 4), illustrating the levels of variation among all the studied traits. The Fe concentration exhibited the highest variability (89.39), whereas the MC% of the fruit showed the lowest variability (14.57) (Table 4). To identify traits with high variability, it is crucial to consider both GCV and PCV, as coefficients of variation can only indicate the degree of overall variation and cannot distinguish between non-heritable and heritable traits [23, 59, 60]. It is evident from the table 4 that significant diversity presents between the date cultivars for all the recorded traits. GCV showed a similar trend as PCV. The highest PCV and GCV values were observed for Ca (PCV = 158.49%, GCV = 157.70%) and Fe (PCV = 90.49%, GCV = 88.84%) concentrations, respectively. The lowest GCV and PCV values were belonged to MC% of fruit (PCV = 14.66%, GCV = 14.53%) and Zn concentration (PCV = 19.77%, GCV = 11.64%). In the present study, a close correspondence was observed between PCV and GCV for the MC of the fruit (%), Ca and Fe concentrations, respectively, indicating less influence of environment in the expression of these traits and their control through additive effects of genes [23, 61]. Moderate GCV and PCV were observed in the following traits: Cu and Na concentrations (40 - 60%), Mn (PCV = 42.84%, GCV = 38.80%), and K (PCV = 26.43%, GCV = 19.60%) concentrations. As anticipated, our study revealed that the PCV values were higher than the GCV values for all the traits, indicating the environmental interference effects [60]. This result was consistent with the findings of other studies, suggesting a significant difference between GCV and PCV, which implies that the expression of certain traits is greatly influenced by the environment [60].

Heritability reflects the effectiveness with which genotypes selection would be based on phenotypic performance [60]. The broad-sense heritability (H^2_b) ranged from 98.22% to 34.70% for Ca and Zn concentrations, respectively (Table 4). High H^2_b (> 70%) was recorded for fruit moisture content, and for concentrations of Fe, Mn, Na, and Cu, respectively. Other studies have also reported a high heritability coefficient (H^2_b) of > 70% for the traits of the number of secondary branches (at first harvest) and seed yield per plant (in grams) in *Jatropha curcas* L. germplasm [60]. Heritability plays a crucial role in the selection process of an effective population improvement program [23]. Traits with high heritability are particularly advantageous for selection purposes. By accurately assessing the heritability, breeders can identify the necessary resources required to efficiently breed desired traits and achieve optimal results in a shorter time and with reduced resources consumption [61]. Knowing the genetic diversity in plant species is crucial for breeding programs to develop superior genotypes, and recognizing this diversity helps select desirable traits and safeguards ownership rights of indigenous cultivars and genotypes within a country. Genetic diversity is vital for plant resistance to pests and diseases and for preserving valuable genes. Successful breeding programs depend on diversity and selection, with genetic diversity being crucial for achieving high-yielding cultivars with improved quality and stress tolerance. Estimating genetic diversity is foundational in safeguarding genetic materials and implementing effective breeding programs [62, 63].

Correlation between different traits

Correlation coefficient analysis is a commonly utilized method to assess the degree and direction of relationships among different traits. The phenotypic correlations (r_p) between different investigated traits in fruit of fifteen date cultivars are given in table 5. The significant correlation coefficients ranged from 0.294* to 0.778**. The highly significant negative correlations were observed for MC% of the fruit with the concentrations of Ca and K. The study reveals that an increase in fruit MC is associated with a decrease in the concentrations of the macronutrients Ca and K. The relationship between fruit hydration and mineral uptake is likely due to physiological processes, and understanding this interplay is essential for assessing fruit quality and storage stability. Further research is needed to investigate the underlying mechanisms and implications in date fruit production and utilization. The highest significant positive correlations were reported for Cu

Table 5: Pearson's correlation coefficients among the investigated traits in the fruit of 15 date cultivars.

Trait	X_1 = MC of fruit	Concentration						
		X_2 = Fe	X_3 = Mn	X_4 = Cu	X_5 = Zn	X_6 = Na	X_7 = K	X_8 = Ca
	%	mg.kg^{-1}	mg.kg^{-1}	mg.kg^{-1}	mg.kg^{-1}	%	%	%
X_1	1	-0.008	-0.219	-0.199	0.222	0.004	-0.387**	-0.528**
X_2		1	0.590**	0.778**	0.142	0.331*	0.006	0.051
X_3			1	0.622**	0.194	0.083	0.197	0.012
X_4				1	0.138	0.368*	0.272	0.090
X_5					1	0.283	0.079	-0.028
X_6						1	0.146	0.045
X_7							1	0.294*
X_8								1

Note: * and **: Significant (α = 5%), highly significant (α = 1%), respectively.

concentration with the Fe (r_p = 0.778**) and with the Mn (r_p = 0.622**) concentrations, respectively. Additionally, Fe concentration showed the high positive r_p with Mn concentration. This finding suggests a potential relationship among three micronutrient elements (Fe, Mn, and Cu) in the composition of date fruit. The positive correlation implies that an increase in the concentration of one micronutrient corresponds to an increase in the concentration of another micronutrient in the fruit. This association may be attributed to shared physiological processes or pathways involved in mineral uptake, transport, and accumulation in date palms. Understanding the interaction of micronutrient elements in date fruit is crucial for evaluating its nutritional value and potential health benefits. Na concentration indicated significant positive correlation with Fe and Cu concentrations. In this study, the correlation between K and Ca concentrations was also statistically significant and positive, likely due to their role as enzyme activators. However, the other relations were not statistically significant ($p > 0.05$). In contrast to our findings, other studies reported negative relationships between Fe-K and a positive r_p between Cu-Zn, Cu-K in date cultivars, as well as Zn-K and Cu-K in medicinal plants [31, 64]. The significant and positive correlation among the traits indicates that selecting one trait directly influences the expression of another trait, thereby assisting in the selection and advancement of the breeding program. Additionally, Ahmad et al. [65] reported significant positive correlations among the phenological and biochemical traits in date fruit cultivars.

Multivariate analyses

Cluster analysis

To assess the similarity and grouping of the investigated cultivars based on the measured traits, CA was performed using Ward's method with the Euclidean distance squared as the distance criterion [33]. The CA of MC% of fruit, using Ward's method, grouped 15 date cultivars into three clusters, as shown in figure 3. Cluster I consisted of three date cultivars ('Thoory', 'Deglet Noor', and 'Sowaidani'), cluster II consisted of five date cultivars ('Hallawi', 'Deiri', 'Stamaran', 'Owaydi', and 'Fersi'), while cluster III comprised seven date cultivars ('Medjool', 'Bereim', 'Barhee', 'Ashrasi', 'Zahidi', 'Piarom', and 'Belyani'). Furthermore, when considering the mean performance of cultivars, cluster I consisted of date cultivars with low MC% of the fruit, allowing them to be stored for extended periods. Cluster II consisted of date cultivars with medium MC% of fruit, while the highest mean performance for this trait was observed in cluster III (Table 6). Hamad et al. [11] classified 15 date cultivars into two groups using hierarchical cluster analysis. Their research highlighted the significant nutritional value of date fruits and revealed variations in the chemical composition among different cultivars.

Table 6: Mean fruit MC of the date cultivars grouped into different clusters.

Traits	MC of fruit (%)
Total mean	16.94
Cluster I: 3 date cultivars	12.95
Cluster II: 5 date cultivars	16.38
Cluster III: 7 date cultivars	19.05

The CA for seven micronutrient and macronutrient traits in fifteen date cultivars is presented in figure 4. The cultivars were divided into three clusters. Cluster I consisted of six cultivars, representing 40% of the total cultivars. It included 'Thoory', 'Deglet Noor', 'Fersi', Bereim', 'Deiri' and 'Stamaran'. This cluster exhibited high concentration of K (Table 7). Cluster II consisted of seven cultivars, representing 53.33% of the total cultivars. It included 'Medjool', Owaydi', 'Piarom', 'Barhee', 'Belyani', Sowaidani', 'Zahidi', and 'Ashrasi'. This cluster exhibited the highest value for macronutrient Ca compared to other clusters, as well as a high value for Fe. According to Rambabu et al. [32], 'Barhee' dates exhibited a significantly higher content of essential minerals, including Ca (42.39 mg/100 g of DF), K (444.69 mg/100 g of DF), Mg (70.38 mg/100 g of DF), and P (65.84 mg/100 g of DF), compared to other date cultivars. Date cultivars with high Fe content have the potential to be used as supplements for Fe deficiency, offering a side-effect-free alternative to traditional Fe supplements, which often lead to symptoms such as headache, nausea, and anorexia [40]. Cluster III consisted of only one cultivar, namely 'Hallawi' which is characterized by early maturity and usability for all three processing stages: Khalal, rutab, and tamar, in comparison to other cultivars. This cluster exhibited high and considerable concentrations for all mineral elements (Fe, Mn, Cu, Zn, Na, and K), except Ca (Table 7).

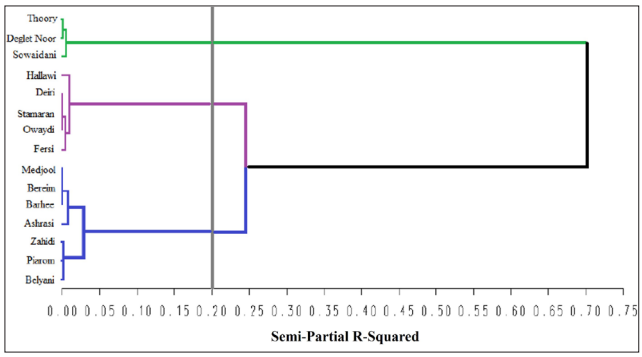


Figure 3: Dendrogram of CA for MC of fruit (%) in 15 date cultivars using Ward's method. The green, purple, and blue colors represent the I, II, and III clusters, respectively.

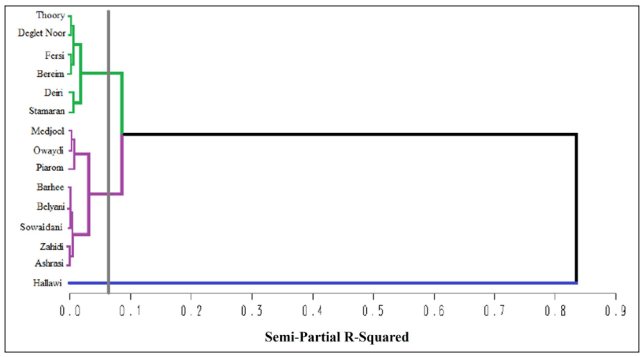


Figure 4: Dendrogram of CA for micronutrient and macronutrient traits in 15 date fruit cultivars using Ward's method. The green, purple, and blue colors represent the I, II, and III clusters, respectively.

Table 7: Mean values of micronutrient and macronutrient concentrations for date cultivars grouped into different clusters.

Traits	Concentration						
	Fe	Mn	Cu	Zn	Na	K	Ca
	mg.kg^{-1}	mg.kg^{-1}	mg.kg^{-1}	mg.kg^{-1}	%	%	%
Total mean	17.31	8.33	3.06	9.68	0.02	0.98	0.06
Cluster I: 6 date cultivars	8.27	7.98	2.62	9.28	0.02	1.10	0.04
Cluster II: 8 date cultivars	17.62	7.58	2.75	9.85	0.02	**0.87**	0.08
Cluster III: 1 date cultivars	69.18	16.48	8.10	10.70	0.03	1.10	0.06

In this study, date cultivars in clusters I and II exhibited low Na content and high K content for micronutrient and macronutrient traits, making them desirable for people suffering from hypertension [17]. Dates are rich in minerals, making them an excellent dietary source. The mineral content in date fruits is influenced by factors such as soil fertility, cultivar, and the stage of ripeness [66]. Dates contain a significant amount of K, Ca, Mg, and P. Also, the flesh of dates is abundant in Fe, Co, Cu, Mg, Na, Br, Zn, S, F, and Se. Consuming 100 g of dates can fulfill approximately 15% of the daily requirements for Se, Cu, K, and Mg [17]. In a study by Hamad et al. [11], it was highlighted that dates from Saudi Arabia have high K content, ranging from 180.7 to 796.7 mg/100 g. Furthermore, notable amounts of P, Mg, and Na (with a range of 4.39 - 9.37 mg/100 g dry mass) were found. The researchers also confirmed that the elemental composition of dates varies depending on their cultivation location. Ahmad et al. [65] employed Ward's method of clustering to group the fifty date fruit cultivars into seven clusters based on both phenological and biochemical traits separately. Although the CA grouped cultivars with greater traits similarities, the clusters do not necessarily consist of all cultivars from a homogeneous origin [67]. Therefore, in date fruit breeding programs, utilizing diversity between groups and cultivars can help achieve desired objectives. Crossbreeding between cultivars with high nutritional value and suitable male cultivars can lead to genotypes with improved nutritional profiles.

Discriminant function analysis

DFA was utilized to evaluate the accuracy of the groupings established through the CA method. This involved determining the correct placement of each genotype in its respective category and identifying the optimal grouping based on the highest confidence percentage (Table 8 and table 9). Based on the results presented in table 8, we obtained one linear DFA for the MC% of the fruit and three functions for macronutrient and micronutrient concentrations. These functions are commonly referred to as canonical functions. The number of canonical functions will be one less than the number of CA groups (Table 8).

According to the results, canonical model 1 can accurately recognize 100.00% of the MC% of the fruit. In terms of macronutrient and micronutrient concentrations, canonical models 1, 2, and 3 can recognize 55%, 39%, and 6%, respectively (Table 8). Furthermore, the canonical correlation coefficient reveals the relationship between discriminating variables and groups in each canonical function. Wilks' Lambda statistic is used to assess the significance of the canonical correlation coefficient (Table 8). The results of the DFA revealed that the accuracy of the CA in grouping date fruit cultivars was 100% for MC% of fruit and 93.3% for macronutrient and micronutrient concentrations. Consequently, the accuracy of the groupings was confirmed through the DFA (Table 9). Abbas et al. [21] conducted a study utilizing multivariate analysis techniques, including MANOVA, discriminant analysis (DA), and PCA, to analyze the data of date cultivars. The results of MANOVA indicated a significant difference among the eight types of dates, which comprised one dried date (DD), three semi-dried dates (SDD), and four soft dates (SD). DA was employed to identify the parameters contributing to distinguishing the dates and successfully identified two functions that effectively differentiated the various date types.

Principal component analysis

PCA is a widely used method that transforms original variables into new components, reducing data dimensionality and explaining observed variances. Its objective is to condense

Table 8: Eigenvalues and percentage of variance explained by discriminant functions for group separation in date fruit cultivars for different traits.

Trait	Function	Eigen value	% of Variance	Cumulative %	Canonical Correlation
MC of fruit (%)	1	17.161[a]	100.00	100.00	0.972
Macronutrient and micronutrient concentrations	1	4.254[a]	54.70	54.70	0.900
	2	3.046[a]	39.20	93.90	0.868
	3	0.471[a]	6.10	100.00	0.566
Trait	**Test of Function(s)**	**Wilks' Lambda**	**Chi-square**	**df**	**Sig.**
MC of fruit (%)	1	0.055	34.792	2	0.000
Macronutrient and micronutrient concentrations	1 through 3	0.032	29.262	21	0.108
	2 through 3	0.168	15.161	12	0.233
	3	0.680	3.281	5	0.657

Table 9: DFA for evaluating the accuracy of grouping in CA of date fruit cultivars for different traits.

Trait	Groups from CA	Groups from DFA									
		1		2		3		4		Total	
		No.	Per.	No.	Per.	No.	Per.	No.	Per.	No.	Per.
MC of fruit (%)	1	3	100							3	100
	2			5	100					5	100
	3					7	100			7	100
Macronutrient and Micronutrient Concentrations [a]	1	6	85.7	1	14.3					7	100
	2			3	100					3	100
	3					4	100			4	100
	4							1	100	1	100

Note: [a]. 93.3% of original grouped cases correctly classified.

correlated variables into interpretable axes of variation, capturing the highest variance with a smaller number of components. Previous studies have recognized PCA as a valuable technique for data analysis, emphasizing its importance in determining high variance with minimal components [10, 23, 68]. PCA was performed to identify important traits associated with the nutritional value of date fruits. The loadings in the principal components (PCs) indicate the variables' influence on the components and reflect their significance. The PCA revealed three major PCs (with eigenvalues greater than one), which collectively accounted for 75.21% of the total variance among the 15 date cultivars (Table 10). An eigenvalue provides a measure of a component's importance. The component with the highest eigenvalue is the most significant and accounts for explaining a substantial amount of variation in the data. Specifically, the first two PCs explained 36.01% and 24.90% of the total variance, respectively, resulting in a cumulative variance of 60.91% (Table 10). The greatest variability in the data was justified by the first PC, in which Fe, Mn, and Zn concentrations had the most positive contribution. Hence, it is concluded that the PC1 was introduced as the superior PC, which can be used to select cultivars with desirable nutritional potential in date breeding programs. In PC2, the MC% of fruit had the most positive contribution, while K and Ca concentrations had the most negative contribution. Furthermore, in PC3, Zn and Na concentrations had the most positive contribution.

Table 10: Results of the PCA for all investigated traits in the fruit of 15 date cultivars.

Traits	PC1	PC2	PC3
X_1 = MC of fruit (%)	-0.180	0.586	-0.025
X_2 = Fe concentration (mg.kg^{-1})	0.509	0.171	-0.213
X_3 = Mn concentration (mg.kg^{-1})	0.462	0.012	-0.349
X_4 = Cu concentration (mg.kg^{-1})	0.543	0.033	-0.217
X_5 = Zn concentration (mg.kg^{-1})	0.203	0.406	0.491
X_6 = Na concentration (%)	0.309	0.217	0.605
X_7 = K concentration (%)	0.212	-0.441	0.235
X_8 = Ca concentration (%)	0.132	-0.468	0.352
Eigenvalue	2.88	1.99	1.14
Proportional variance (%)	36.01	24.90	14.30
Cumulative variance (%)	36.01	60.91	75.21

Due to the highest eigenvalues of the first two components, the cultivars were categorized based on these components (the first two components). The study classified the fifteen date cultivars into four groups (Figure 5). Group 1 consisted of 'Thoory' and 'Sowaidani' dates, while group 2 included 'Belyani', 'Ashrasi', 'Zahidi', 'Medjool', and 'Barhee' dates. Group 3 comprised 'Stamaran', 'Piarom', 'Owaydi', 'Fersi', 'Deiri', 'Bereim', and 'Deglet Noor' dates, and 'Hallawi' date was assigned to group 4. These findings suggest that cultivar ('Hallawi') with the high PC1 score will exhibit higher nutritional quality in terms of micronutrients, while cultivar ('Ashrasi') with a high PC2 score exhibit higher nutritional quality in terms of macronutrients and also the MC% of the fruit. Therefore, selecting date cultivars based on these traits leads to increased nutritional quality.

Hamad et al. [11] demonstrated a distinct separation of the 12 cultivars of date fruits into four distinct groups using PCA. The first cluster included 'Rashodia', 'Sokary', and 'Nabtit Ali', while the second cluster consisted of other tested cultivars. This segregation was attributed to the lower content of certain minerals (Fe, Cu, Zn, and Cd) in the date cultivars of the second cluster. On the other hand, 'Khlas Al Qassim', 'Khlas Al Kharj', 'Khlas Al Ahsa', and 'Khlas Al Shiokh' exhibited high levels of minerals (Mg, Mn, Na, K, and Ca), with 'Khlas

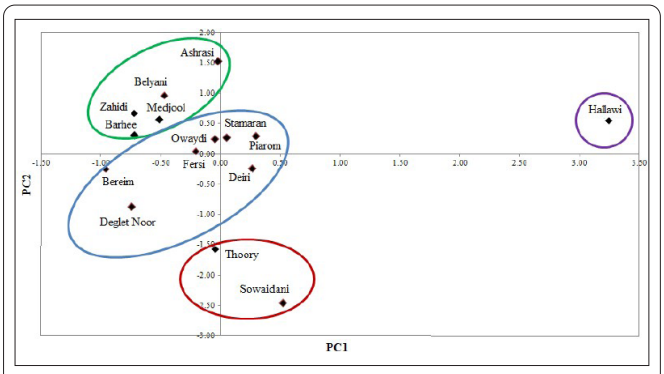


Figure 5: Two-dimensional view of the first component plotted against the second component of PCA in the fruit of 15 date cultivars. Date cultivars are dispersed in different coordinates based on their dissimilarity.

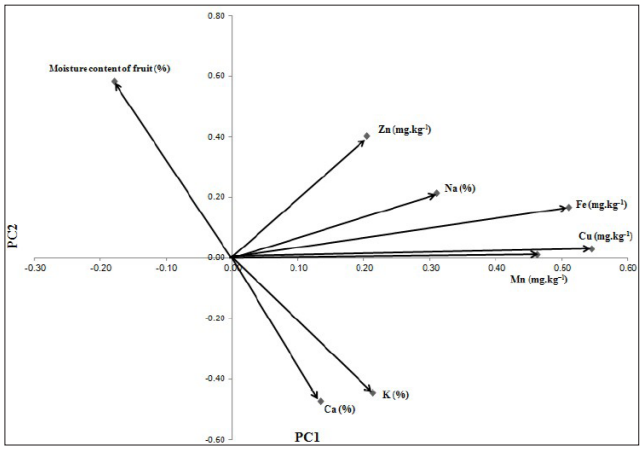


Figure 6: Biplot of the first two PCs for all investigated traits in the fruit of 15 date cultivars.

Al Kharj'displaying the highest levels.

The PCA biplot depicted the relationships among the measured traits in this study (Figure 6). The cosine of the angles between vectors indicates the degree of correlation between the traits. The angles between the vector of MC% of fruit with K and Ca, as well as with Fe, Mn, and Cu, were obtuse, indicating a negative correlation. On the other hand, the vector of MC% of fruit had acute angles with Zn and Na, indicating a positive correlation (Figure 6). Furthermore, the vectors of Fe, Mn, Zn, Cu, and Na exhibited acute angles with each other, indicating a positive correlation among them (Figure 6).

Overall, the PCA results confirmed the correlation coefficient, and the biplot analysis also demonstrated that the correlation matrix is an effective multivariate tool for evaluating the associations among traits in date cultivars. This finding is consistent with the results of Ahmad et al. [65]. In a study conducted by Ebrahimi [63], PCA analysis was performed on 68 important date palm genotypes using the Euclidean square distance matrix. The results revealed that the first ten components accounted for 54.57% of the total variation. Moreover, the PCA plot based on the first two PCs effectively separated the date population into four distinct groups. Additionally, the CA successfully categorized the 68 date genotypes into four clusters. Ahmad et al. [65] conducted a study on fifty date fruit cultivars, examining specific phenological and biochemical traits using PCA. They reported that the first four components, with eigenvalues greater than 1, accounted for 77.04% of the total variance and demonstrated the highest variability among the studied traits of date fruit cultivars.

Conclusion

Our study findings demonstrated that the selected date cultivars possess appreciable amounts of mineral composition. Among the minerals, K was identified as the predominant element in all the date cultivars. In particular, the 'Hallawi' cultivar exhibited superiority over others concerning Fe, Mn, and Cu content. Interestingly, the 'Stamaran' date fruit displayed the highest concentration of Zn, while the 'Thoory' had the lowest Zn content. Regarding K content, the 'Thoory' had the highest concentration. Moreover, Ca content was significantly higher in the 'Sowaidani' cultivar compared to the other cultivars. Our results indicated substantial variations in mineral contents among the date cultivars, suggesting their potential utility in various breeding programs. Negative correlations were found between MC% and Ca, as well as between MC% and K. Conversely, positive correlations were observed between Cu-Fe, Cu-Mn, Fe-Mn, Na-Cu, Na-Fe, and K-Ca. The CA, based on both moisture content and mineral composition, grouped the 15 cultivars into three and four clusters, respectively, indicating distinct differences among the studied cultivars. Additionally, PCA categorized the cultivars into four clusters, and the biplot analysis demonstrated the effectiveness of the correlation matrix in evaluating trait associations among the date cultivars. In conclusion, the date cultivars examined in this study represent potentially valuable gene pools that can be utilized not only for dietary health but also for breeding purposes.

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None.

Conflict of Interest

The authors have declared no conflict of interest.

Credit Author Statement

Mohammadreza Pourghayoumi: Investigation, Resources, Writing - original draft preparation, Writing - review and editing, Manuscript revision, Project administration, Supervision; Kamal Gholamipour Fard: Investigation, Experimentation, Project administration; Sara Farokhzadeh: Conceptualization, Investigation, Experimentation, Data curation, Formal analysis, Data analysis, Data visualization, Validation, Resources, Writing - original draft preparation, Writing - review and editing, Manuscript revision; Rahman Yousefi: Investigation.

References

1. Benouamane O, Vergara-Barberan M, Benaziza A, Garcia-Alvarez-Coque MC, Simo-Alfonso E, et al. 2022. Characterization of different cultivars of Algerian date palm (*Phoenix dactylifera* L.) leaves and pollen by comprehensive two-dimensional liquid chromatography of phenolic compounds extracted with different solvents. *Microchem J* 182: 107874. https://doi.org/10.1016/j.microc.2022.107874
2. Ibrahim A, Alghannam A, Eissa A, Firtha F, Kaszab T, et al. 2021. Preliminary study for inspecting moisture content, dry matter content, and firmness parameters of two date cultivars using an NIR hyperspectral imaging system. *Front Bioeng Biotechnol* 9: 720630. https://doi.org/10.3389/fbioe.2021.720630
3. Food and Agriculture Organization of the United Nations-Statistic Division. [https://www.fao.org/statistics/en/] [Accessed August 11, 2023]
4. Shabani F, Kumar L, Taylor S. 2014. Suitable regions for date palm cultivation in Iran are predicted to increase substantially under future climate change scenarios. *J Agric Sci* 152(4): 543-557. https://doi.org/10.1017/S0021859613000816
5. Al-Shahib W, Marshall RJ. 2003. The fruit of the date palm: its possible use as the best food for the future?. *Int J Food Sci Nutr* 54(4): 247-259. https://doi.org/10.1080/09637480120091982

6. Chandrasekaran M, Bahkali AH. 2013. Valorization of date palm (*Phoenix dactylifera*) fruit processing by-products and wastes using bioprocess technology–review. *Saudi J Biol Sci* 20(2): 105-120. https://doi.org/10.1016/j.sjbs.2012.12.004
7. Ghnimi S, Umer S, Karim A, Kamal-Eldin A. 2017. Date fruit (*Phoenix dactylifera* L.): an underutilized food seeking industrial valorization. *NFS J* 6: 1-10. https://doi.org/10.1016/j.nfs.2016.12.001
8. El-Far AH, Oyinloye BE, Sepehrimanesh M, Allah MAG, Abu-Reidah I, et al. 2019. Date palm (*Phoenix dactylifera*): novel findings and future directions for food and drug discovery. *Curr Drug Discov Technol* 16(1): 2-10. https://doi.org/10.2174/1570163815666180320111937
9. Hasan F, Nazir A, Sobti B, Tariq H, Karim R, et al. 2022. Dehydration of date fruit (*Pheonix dactylifera* L.) for the production of natural sweet powder. *NFS J* 27: 13-20. https://doi.org/10.1016/j.nfs.2022.02.002
10. Hamad I, AbdElgawad H, Al Jaouni S, Zinta G, Asard H, et al. 2015. Metabolic analysis of various date palm fruit (*Phoenix dactylifera* L.) cultivars from Saudi Arabia to assess their nutritional quality. *Molecules* 20(8): 13620-13641. https://doi.org/10.3390/molecules200813620
11. Parvin S, Easmin D, Sheikh A, Biswas M, Sharma SCD, et al. 2015. Nutritional analysis of date fruits (*Phoenix dactylifera* L.) in perspective of Bangladesh. *Am J Life Sci* 3(4): 274-278. http://doi.org/10.11648/j.ajls.20150304.14
12. Ma C, Dunshea FR, Suleria HAR. 2019. LC-ESI-QTOF/MS characterization of phenolic compounds in palm fruits (jelly and fishtail palm) and their potential antioxidant activities. *Antioxidants* 8(10): 483. https://doi.org/10.3390/antiox8100483
13. Abbasi Bastami Y, Bakhshi D, Torahi A, Pourghayoumi M, Khalifezadeh Koureh O. 2022. Biochemical and physicochemical properties of some date palm (*Phoenix dactylifera*) fruit cultivars. *J Hortic Postharvest Res* 5(3): 197-206. https://doi.org/10.22077/jhpr.2022.4809.1247
14. Gharibzahedi SMT, Jafari SM. 2017. The importance of minerals in human nutrition: bioavailability, food fortification, processing effects and nanoencapsulation. *Trends Food Sci Technol* 62: 119-132. https://doi.org/10.1016/j.tifs.2017.02.017
15. Mohamed RM, Fageer AS, Eltayeb MM, Ahmed IAM. 2014. Chemical composition, antioxidant capacity, and mineral extractability of Sudanese date palm (*Phoenix dactylifera* L.) fruits. *Food Sci Nutr* 2(5): 478-489. https://doi.org/10.1002/fsn3.123
16. Assirey EAR. 2015. Nutritional composition of fruit of 10 date palm (*Phoenix dactylifera* L.) cultivars grown in Saudi Arabia. *J Taibah Univ Sci* 9(1): 75-79. https://doi.org/10.1016/j.jtusci.2014.07.002
17. Kuras MJ, Zielińska-Pisklak M, Duszyńska J, Jabłońska J. 2020. Determination of the elemental composition and antioxidant properties of dates (*Phoenix dactyliferia*) originated from different regions. *J Food Sci Technol* 57: 2828-2839. https://doi.org/10.1007/s13197-020-04314-8
18. Hatami A, Jahromi AA, Ejraei A, Mohammadi-Jahromi AH, Khankahdani HH. 2023. Study of biochemical traits and mineral elements in date palm fruits under preharvest foliar application of organic fertilizers and micronutrients. *Int J Hortic Sci Technol* 10(2): 125-140. https://doi.org/10.22059/ijhst.2022.334068.517
19. Alonso-Salces RM, Herrero C, Barranco A, López-Márquez DM, Berrueta LA, et al. 2006. Polyphenolic compositions of Basque natural ciders: a chemometric study. *Food Chem* 97(3): 438-446. https://doi.org/10.1016/j.foodchem.2005.05.022
20. Lachenmeier DW. 2007. Rapid quality control of spirit drinks and beer using multivariate data analysis of Fourier transform infrared spectra. *Food Chem* 101(2): 825-832. https://doi.org/10.1016/j.foodchem.2005.12.032
21. Abbas F, Foroogh B, Liong M, Azhar M. 2008. Multivariate statistical analysis of antioxidants in dates (*Phoenix dactylifera*). *Int Food Res J* 15(2): 193-200.
22. Hazra SK, Sarkar T, Salauddin M, Sheikh HI, Pati S, et al. 2020. Characterization of phytochemicals, minerals and *in vitro* medicinal activities of bael (*Aegle marmelos* L.) pulp and differently dried edible leathers. *Heliyon* 6(10): e05382. https://doi.org/10.1016/j.heliyon.2020.e05382
23. Farokhzadeh S, Hassani HS, Zinati Z, Rajaei M. 2022. Evaluation of triticale lines compared to wheat cultivars in terms of agronomic traits using supervised learning methods and multivariate statistics. *Philipp Agric Sci* 105(4): 369-389.
24. Noutfia Y, Ropelewska E. 2023. Innovative models built based on image textures using traditional machine learning algorithms for distinguishing different varieties of moroccan date palm fruit (*Phoenix dactylifera* L.). *Agriculture* 13(1): 26. https://doi.org/10.3390/agriculture13010026
25. Mohammed M, Munir M, Aljabr A. 2022. Prediction of date fruit quality attributes during cold storage based on their electrical properties using artificial neural networks models. *Foods* 11(11): 1666. https://doi.org/10.3390/foods11111666
26. Gros-Balthazard M, Newton C, Ivorra S, Pierre M-H, Pintaud J-C, et al. 2016. The domestication syndrome in *Phoenix dactylifera* seeds: toward the identification of wild date palm populations. *PLoS One* 11(3): e0152394. https://doi.org/10.1371/journal.pone.0152394
27. Woodman A. 1941. Food Analysis. MacGraw-Hill Book Co. Inc., New York & London.
28. Mallah N, Sahito H, Kousar T, Kubar W, Jatoi F, et al. 2017. Varietal analyze of chemical composition moisture, ash and sugar of date palm fruits. *J Adv Bot Zool* 5(1): 1-5. https://doi.org/10.5281/zenodo.999942
29. Chapman H, Pratt P. 1962. Methods of analysis for soils, plants and waters. *Soil Sci Soc Am J* 93(1): 68. https://doi.org/10.2136/sssaj1963.03615995002700010004x
30. Heckman M. 1971. Collaborative study of copper in feeds by atomic absorption spectrophotometry. *J Assoc Off Anal Chem* 54(3): 666-668.
31. Khan M, Sarwar A, Wahab M, Haleem R. 2008. Physico-chemical characterization of date varieties using multivariate analysis. *J Sci Food Agric* 88(6): 1051-1059. https://doi.org/10.1002/jsfa.3187
32. Rambabu K, Bharath G, Hai A, Banat F, Hasan SW, et al. 2020. Nutritional quality and physico-chemical characteristics of selected date fruit varieties of the United Arab Emirates. *Processes* 8(3): 256. https://doi.org/10.3390/pr8030256
33. Farokhzadeh S, Shahsavand-Hassani H, Mohammadi-Nejad G. 2013. Evaluation of genetic diversity of primary tritipyrum, triticale and bread wheat genotypes. *Agric Knowledge* 5(9): 93-112.
34. Swarup S, Cargill E, Crosby K, Flagel L, Kniskern J, et al. 2021. Genetic diversity is indispensable for plant breeding to improve crops. *Crop Sci* 61(2): 839-852. https://doi.org/10.1002/csc2.20377
35. Silva-Pérez V, De Faveri J, Molero G, Deery DM, Condon AG, et al. 2020. Genetic variation for photosynthetic capacity and efficiency in spring wheat. *J Exp Bot* 71(7): 2299-2311. https://doi.org/10.1093/jxb/erz439
36. Govindaraj M, Vetriventhan M, Srinivasan M. 2015. Importance of genetic diversity assessment in crop plants and its recent advances: an overview of its analytical perspectives. *Genet Res Int* 2015: 431487. https://doi.org/10.1155/2015/431487
37. Al-Farsi M, Alasalvar C, Al-Abid M, Al-Shoaily K, Al-Amry M, et al. 2007. Compositional and functional characteristics of dates, syrups, and their by-products. *Food Chem* 104(3): 943-947. https://doi.org/10.1016/j.foodchem.2006.12.051
38. Alghamdi AA, Awadelkarem AM, Hossain A, Ibrahim NA, Fawzi M, et al. 2018. Nutritional assessment of different date fruits (*Phoenix dactylifera* L.) varieties cultivated in Hail province, Saudi Arabia. *Biosci Biotechnol Res Commun* 11(2). http://dx.doi.org/10.21786/bbrc/11.2/11
39. Zarbakhsh S, Rastegar S. 2018. Assessment of physicochemical properties and bioactive compound of date fruit (*Phoenix dactylifera*) in two cultivars,"Piarom" and "Zahedi". *Iranian Food Sci Technol Res J* 14(1): 177-186. https://doi.org/10.22067/ifstrj.v14i1.60214
40. Aljaloud S, Colleran HL, Ibrahim SA. 2020. Nutritional value of date fruits and potential use in nutritional bars for athletes. *Food Nutr Sci* 11(06): 463. https://doi.org/10.4236/fns.2020.116034

41. Wood J, Grusak M. 2007. Nutritional Value of Chickpea. In Yadav SS (ed) Chickpea Breeding and Management. Wallingford, UK.

42. Shankar AH, Prasad AS. 1998. Zinc and immune function: the biological basis of altered resistance to infection. *Am J Clin Nutr* 68(2): 447S-463S. https://doi.org/10.1093/ajcn/68.2.447s

43. Maret W, Sandstead HH. 2006. Zinc requirements and the risks and benefits of zinc supplementation. *J Trace Elem Med Biol* 20(1): 3-18. https://doi.org/10.1016/j.jtemb.2006.01.006

44. Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. National Academies Press, Washington, DC. [https://nap.nationalacademies.org/catalog/10925/dietary-reference-intakes-for-water-potassium-sodium-chloride-and-sulfate] [Accessed August 11, 2023]

45. Leterme P, Buldgen A, Estrada F, Londoño AM. 2006. Mineral content of tropical fruits and unconventional foods of the Andes and the rain forest of Colombia. *Food Chem* 95(4): 644-652. https://doi.org/10.1016/j.foodchem.2005.02.003

46. Uba A, Abdullahi M, Yusuf A, Ibrahim Z, Lawal M, et al. 2015. Mineral profile, proximate and amino acid composition of three dates varieties (*Phoenix dactylifera* L.). *Der Pharma Chemica* 7(5): 48-53.

47. Emsley J. 2011. Nature's Building Blocks: An AZ Guide to the Elements. Oxford University Press.

48. Nadeem M, Qureshi T, Ugulu I, Riaz M, An Q, et al. 2019. Mineral, vitamin and phenolic contents and sugar profiles of some prominent date palm (*Phoenix dactylifera*) varieties of Pakistan. *Pak J Bot* 51(1): 171-178. https://doi.org/10.30848/PJB2019-1(14)

49. Sadhra SS, Wheatley AD, Cross HJ. 2007. Dietary exposure to copper in the European Union and its assessment for EU regulatory risk assessment. *Sci Total Environ* 374(2-3): 223-234. https://doi.org/10.1016/j.scitotenv.2006.12.041

50. WHO. 1998. World Health Organisation. Copper Sustains Life.

51. Cabrera C, Lloris F, Giménez R, Olalla M, López MC. 2003. Mineral content in legumes and nuts: contribution to the Spanish dietary intake. *Sci Total Environ* 308(1-3): 1-14. https://doi.org/10.1016/s0048-9697(02)00611-3

52. Youn JH, McDonough AA. 2009. Recent advances in understanding integrative control of potassium homeostasis, *Annu Rev Physiol* 71: 381-401. https://doi.org/10.1146/annurev.physiol.010908.163241

53. Perveen K, Bokahri NA. 2020. Comparative analysis of chemical, mineral and *in-vitro* antibacterial activity of different varieties of date fruits from Saudi Arabia. *Saudi J Biol Sci* 27(7): 1886-1891. https://doi.org/10.1016/j.sjbs.2019.11.029

54. Tandoğan B, Ulusu N. 2005. Importance of Calcium. *Turk J Med Sci* 35(4): 197-201.

55. Medeiros D. 2006. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. The National Academies Press, Washington, DC.

56. Biesalski H, Grimm P. 2004. Pocket Atlas of Nutrition. Thieme Publications.

57. Ismail B, Haffar I, Baalbaki R, Mechref Y, Henry J. 2006. Physico-chemical characteristics and total quality of five date varieties grown in the United Arab Emirates. *Int J Food Sci Technol* 41(18): 919-926. https://doi.org/10.1111/j.1365-2621.2005.01143.x

58. Elleuch M, Besbes S, Roiseux O, Blecker C, Deroanne C, et al. 2008. Date flesh: chemical composition and characteristics of dietary fiber. *Food Chem* 111(3): 676-682. https://doi.org/10.1016/j.foodchem.2008.04.036

59. Desheva G, Kyosev B, Sabeva M, Deshev M. 2021. Genetic variation of gliadins and some quality characteristics in spelt wheat. *Bulg J Agric Sci* 27(3): 541-554.

60. Gawali A, Wagh R, Sonawane C. 2016. Genetic variability in growth and seed traits of *Jatropha curcas* L. germplasm for genetic tree improvement. *Forest Res* 5(171): 2.

61. Dragov R, Uhr Z, Dimitrov E. 2022. Genetic variability, heritability and genetic advance for important quantitative traits of durum wheat: part I. *Bulg J Agric Sci* 28(4): 691-698.

62. Laurentin H. 2009. Data analysis for molecular characterization of plant genetic resources. *Genet Resour Crop Evol* 56: 277-292. https://doi.org/10.1007/s10722-008-9397-8

63. Ebrahimi F. 2022. Allelic variation, population structure and genetic diversity in different genotypes of date palm (*Phoenix dactylifera* L.) using ISSR marker. *Agric Biotechnol J* 14(1): 135-154. https://doi.org/10.22103/jab.2022.18768.1368

64. Razic S, Dogo S, Latinka S, Popovic A. 2005. Inorganic analysis of herbal drugs, part I: metal determination in herbal drugs originating from medicinal plants of the family Lamiacae. *J Serb Chem Soc* 70(11): 1347-1355. http://dx.doi.org/10.2298/JSC0511347R

65. Marzouk H, Kassem H. 2011. Improving fruit quality, nutritional value and yield of Zaghloul dates by the application of organic and/or mineral fertilizers. *Sci Hortic* 127(3): 249-254. https://doi.org/10.1016/j.scienta.2010.10.005

66. Ali N, Hussain I, Ali S, Khan NU, Hussain I. 2021. Multivariate analysis for various quantitative traits in wheat advanced lines. *Saudi J Biol Sci* 28(1): 347-352. http://dx.doi.org/10.1016/j.sjbs.2020.10.011

67. Sarkar T, Salauddin M, Hazra SK, Chakraborty R. 2020. The impact of raw and differently dried pineapple (*Ananas comosus*) fortification on the vitamins, organic acid and carotene profile of dairy rasgulla (sweetened cheese ball). *Heliyon* 6(10): e05233. https://doi.org/10.1016/j.heliyon.2020.e05233

68. Ahmad R, Ali HM, Lisek A, Mosa WF, Ercisli S, et al. 2023. Correlation among some phenological and biochemical traits in date palm (*Phoenix dactylifera* L.) germplasm. *Front Plant Sci* 14: 1014. https://doi.org/10.3389%2Ffpls.2023.1118069