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Article

Characterisation of Physicochemical and Functional Properties of Three Date Fruit Varieties

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Abstract: Date fruit (*Phoenix dactylifera* L.) is a nutrient-dense fruit, known particularly for rich dietary fibre and natural sugars, making it a rapid dietary energy source during moments of hunger or after fasting. This study aimed to characterise the physicochemical and functional properties of three date fruit varieties (Medjool, Maktoom, and Barhee) in Tamale, Ghana. Fruit samples of the three date varieties were purchased from the market, sorted, cleaned, dried and milled into powder, and the physicochemical (pH, total soluble solids, colour, proximate, dietary energy) and functional properties (water and oil absorption capacity, bulk density, swelling capacity and swelling index) were determined using standard procedures. The results showed the fruit varieties differed significantly in pH, colour attributes, total soluble solids, protein, crude fibre, and functional traits. The pH analysis indicates that Medjool dates exhibit milder acidity, which may affect their taste and shelf stability. The Medjool dates had higher lightness (L^*), redness (a^*), yellowness (b^*), chroma (C^*) and hue than the rest, indicating a more vibrant and visually appealing colour. Additionally, Medjool dates are lighter in colour, with richer red and yellow hues, making them visually appealing. The Medjool dates had the highest total soluble solids (11.40 °Brix), followed by Maktoom (11.20 °Brix) and Barhee (10.65 °Brix). Maktoom dates had the highest fibre content (1.98%), whereas Medjool dates had the highest protein content (3.43%). The Maktoom variety had the highest water absorption capacity (338%), swelling capacity (2.80 g/g) and swelling index (2.63 mL/mL), but the poorest oil absorption capacity (182%). The Medjool variety had better oil absorption (236%) and density (0.54 g/mL and 0.65 g/mL), but lower swelling capacity (2.36 g/g) than the others. The findings indicate distinct properties of each date variety that can be leveraged to develop healthy, consumer-preferred food products, thereby enhancing food diversification and contributing to food and nutrition security.

Keywords: date characteristics; food ingredients; food diversification and processing; industrial and home application potential; nutrition security

1. Introduction

Date fruit (*Phoenix dactylifera* L.) is a highly nutritious fruit in the Arecaceae family, consumed globally but more so in the arid and semi-arid regions [1]. It is a staple food in many cultures, known for its rich flavour, chewy texture, and high nutritional value [2]. The fruit is rich in natural sugars, including glucose, fructose, and sucrose, which provide a quick source of energy [3]. It also contains dietary fibre, vitamins (A, B6, and K), minerals (including potassium, magnesium, and copper), and antioxidants [3]. The fruit's dense natural monosaccharide and disaccharide sugars lend credence to its wide usage during fasting periods, especially among Muslims in the

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period of Ramadan. Additionally, date fruit is valued in traditional medicine for its health benefits, including antioxidant and anti-inflammatory properties that help reduce oxidative stress and inflammation [4].

While date fruits' nutritional and sensorial benefits are relished almost everywhere, date palms are mainly grown in the arid and semi-arid zones [5], not only for food and income but also to sustainably help to reduce desertification and its accompanying adverse effects [6]. Thus, non-cultivating nations, such as Ghana, rely on imports to meet the needs of resident consumers.

However, fresh date fruit has a relatively short shelf life due to a relatively high moisture content of about 23–25% [7]. To overcome this limitation and extend the availability of date fruit, it can be processed into various forms, including date fruit powder [8]. Date fruit powder is made by drying date fruit and grinding it into a fine powder. This powder can then be used as a natural sweetener and flavouring agent in a variety of food products. In countries like Ghana, the fruit is typically consumed fresh. Converting the fruit into powder may not only stabilise it for longer periods but also broaden and diversify its consumption. Before the fruit can be turned into powder, drying is required. For fruits rich in sugars and other heat-sensitive compounds such as dates, drying at relatively lower temperatures is important for retaining product quality. Drying methods such as microwave drying, one of the most common in society, are used for their high energy efficiency, minimal case-hardening effect and improved product quality [9].

Date fruit powder is a versatile ingredient widely used in baking, confectionery, and beverages. It serves as a natural sweetener and flavour enhancer in bread, cakes, cookies, candies, chocolates, and energy bars, as well as in smoothies, shakes, and hot drinks owing to its natural sugar density [4,10,11]. Date fruit powder has garnered increasing attention as a functional food ingredient due to its rich nutritional profile and versatile culinary applications [4]. However, despite the growing interest in the fruit's powder, scientific literature regarding its physicochemical and functional properties, particularly across different date varieties, is limited. Studies available largely focused on nutritional and sugar profiles, with reported variations among date varieties such as Barhi, Khulas/Khlass, Mejhoul, Monaif, Rozaiz, Soukari/Sukkari, Soulag and Soughi [12,13]. These studies did not cover other important attributes like colour and functional properties. This limited understanding hinders the optimal utilisation of date fruit powder in the food industry.

Additionally, geographical origin and date variety introduce variability in the powder's composition and properties [14], more so when trans-geographical transportation of the fruit is involved. For example, dates from different regions may have distinct sugar profiles, which could affect the sensorial and physico-functional properties of the date powder. This variability highlights the need for careful selection of date varieties to ensure consistent physicochemical and functional properties in date fruit powder [15].

Furthermore, the physicochemical and functional properties of date fruit powder are pivotal in determining its performance across various food applications [16]. These properties include moisture, ash, protein, fat, carbohydrate, pH, colour, and total soluble solids. Additionally, the functional properties of date fruit powder, such as water and oil absorption capacity, emulsifying properties, and foaming capacity [17], swelling capacity, swelling index and bulk density, are crucial determinants of its functionality in food products.

This study focuses on three specific date varieties available in Ghana: Barhee, Medjool, and Maktoom. Each variety was selected for its unique characteristics and regional popularity. Barhee dates are noted for their soft texture and caramel-like flavour, often consumed fresh due to their high moisture content and rich taste [7]. However, only proximate, mineral, biochemical composition and sugar profile of Barhee/Barhi have been reported [12]. Medjool dates, recognised for their large size, chewy texture, and natural sweetness, are highly valued in both raw and processed forms and are considered a premium variety [18]. The sugar and amino acid profiles of Medjool dates have been reported [13]. On the other hand, Maktoom dates are distinguished by their firm texture and balanced sweetness, making them a popular choice for cooking and baking [18]. While a few studies have reported on the nutritional composition and sugar profile of some of these date varieties in other parts of the world, there is limited information on their physicochemical and functional attributes, particularly from a Ghanaian perspective, limiting their use as potential food ingredients at home and in the food industry. Analysing these three varieties enables a comprehensive examination of date fruit powder, covering a broad spectrum of quality attributes. This approach aims to provide valuable insights into the physicochemical and functional properties of Barhee, Medjool, and Maktoom date powders, thereby assessing their suitability for diverse food applications. This study, therefore, aimed to evaluate the physicochemical and functional properties of date fruit powder from three varieties (Medjool, Barhee, and Maktoom).

2. Materials and Methods

2.1. Samples Source and Preparation

Three date varieties (Figure 1), namely, Medjool, Barhee, and Maktoom, were used for this study. Samples (about 2 kg each) of these varieties were purchased from three main suppliers in the Tamale Central Market in the Northern Region of Ghana. The samples from the three suppliers served as independent replicates. The dates were sorted to remove bad fruit, then thoroughly washed with clean water to remove any adhering dust or dirt. The dates were pitted manually to remove the seeds. The fruits were then microwave-dried at 37 °C for 20 min (Midea 34L, Beijiao, China) (the temperature and time selected based on pre-trials) and cooled for 5 min. The dried fruits were ground with a laboratory-scale grinder (Siver Crest SC-1589, Neckarsulm, Germany) to obtain a fine powder. The powder was sieved through a 100-mesh sieve (150 μm openings) to ensure a consistent texture and particle-size distribution for determining the functional properties. The prepared date fruit powder was stored in airtight containers at room temperature (25 °C) until further analysis.



Barhee Date Fruit Medjool Date Fruit Maktoom Date Fruit

Figure 1. Date fruit varieties used for the study.

2.2. Colour

The colour properties of the samples were determined using a Chroma meter (Konica Minolta CR 410, Tokyo, Japan). The Chroma meter was calibrated before the measurements were taken, using a standard white plate. The colour (lightness, redness, yellowness, chroma, and hue) was measured thrice for each sample.

2.3. pH

The pH of each date fruit powder was measured twice using a digital pH meter (Mettler Toledo AG, Greifensee, Switzerland), as described by Ofoedu et al. [19].

2.4. Total Soluble Solids

Total Soluble Solids (TSS) were determined using a refractometer (ATC, Hangzhou, China). About 5 g of date powder was dissolved in 50 mL of distilled water, and the resulting solution was filtered to remove insoluble particles. The refractometer was calibrated according to the manufacturer's specifications. A few drops of the filtered liquid extract were then placed on the refractometer's prism, and the cover was closed. The TSS was measured (twice for each sample) directly as a percentage of soluble solids (°Brix) using the refractometer.

2.5. Proximate Analysis

The proximate composition of the date samples was determined as outlined by AOAC [20]. The moisture content was determined using the hot-air oven (Memmert UF110, Büchenbach, Germany) method. Samples (3 g) were dried at a temperature of 105 °C for 3 h, and the ratio of the difference in weight of the samples before and after drying to the weight of the samples before drying, expressed as a percentage, represented the moisture content.

Crude fat content of date fruit powdered samples was determined using a Soxhlet extractor (FOSS ST 225 Soxtec^{TM}, Höganäs, Sweden) and petroleum ether as a solvent. Approximately 5 g of sample (non-defatted) was placed in a thimble with filter paper and inserted into extraction tubes. A volume of 240 mL of Petroleum ether was added to the extractor, and cold water was circulated through the condenser to facilitate solvent condensation. The extraction process ran for 6 h, followed by evaporation of the ether and cessation of extraction after 3–5 siphoning cycles. The residual fat in the Petri dish was transferred to a desiccator to remove moisture, and the final

weight was recorded. The fat content was estimated as the weight of fat divided by the weight of the sample, expressed as a percentage.

The crude protein content of the samples was determined using the Kjeldahl method. Protein content was calculated by multiplying the total nitrogen content (%) by 6.25 [20].

Crude fibre determination was done using 2 g of sample. First, the sample was boiled with 200 mL of 1.25% sulfuric acid for 30 min, filtered, and the residue was washed. The residue was then boiled with 200 mL of 1.25% sodium hydroxide for 30 min, filtered, washed, and dried at 130 °C for 2 h before weighing. This residue was then ashed at 550 °C for 3 h. The weight difference before and after ashing is used to calculate the crude fibre content as a percentage of the starting material.

Ash content was determined using a muffle furnace (Carbolite Gero, CWF 1200, Hope, UK). Five grams of the sample were weighed into a pre-weighed crucible and placed in the furnace at 550 °C until fully ashed. The crucibles were then cooled in a desiccator and reweighed. The ash content was calculated by expressing the weight of ash as a percentage of the original sample weight. Carbohydrate content was determined by subtracting the sum of moisture, fat, protein, fibre, and ash content from hundred.

These proximate components were measured twice for each sample. Dietary energy was calculated by multiplying the fat, protein and carbohydrate values of the samples by 4, 9 and 4, respectively, and the outcomes summed up [21].

2.6. Functional Properties

2.6.1. Swelling Capacity and Swelling Index

The swelling capacity (SC) and swelling index were determined as described by Korese & Achaglinkame [21] with slight modifications. Five grams (5 g) of each powdered sample was weighed into a measuring cylinder, and the volume occupied by the sample was recorded as the initial volume. Fifty millilitres (50 mL) of distilled water were added to the sample, and the mixture was left undisturbed for 30 min. The water was gently pipetted from the wet sample, and the new volume and weight of the sample were read. The SC was calculated as the ratio of the weight of the wet sample to the weight (5 g) of the powdered sample, while the SI was estimated as the ratio of the volume of the wet sample to the volume of the powdered sample. The SC and SI were measured twice for each sample.

2.6.2. Water Absorption Capacity

The water absorption capacity (WAC) was determined using the procedure of Sourya et al. [22]. Briefly, 10 mL of distilled water was added to 2 g of each of the powdered samples in a 15-mL falcon tube and allowed undisturbed for an hour. The mixture was then centrifuged (Rotofix 32 A, Tuttlingen, Germany) at 2000 rpm, 30 °C, for 30 min. The weight of the sediment was then measured after gently decanting the supernatant. The WAC was calculated as the ratio of the weight of the sample after water absorption (weight of sediment) to the weight of the sample before water absorption (2 g), expressed as a percentage. The procedure was followed twice for repeated measurements of the WAC for each sample.

2.6.3. Oil Absorption Capacity

Oil absorption capacity (OAC) was measured using the method of Schopf & Scherf [23]. About 10 mL of soybean oil was added to 1 g of date powder in a 15-mL falcon tube and allowed to stand for 30 min. The mixture was then centrifuged at 3000 rpm for 10 min at 30 °C (Rotofix 32 A, Tuttlingen, Germany), and the supernatant was gently decanted. The OAC was estimated using the ratio of the weight of the sample after oil absorption to the weight of the sample before oil absorption, expressed as a percentage. The measurements were taken in duplicate for each sample.

2.6.4. Bulk Density

The untapped and tapped bulk densities of the powdered samples were determined as outlined by Korese & Achaglinkame [21]. Briefly, 50 g of the sample was placed in a 150 mL graduated measuring cylinder, and the initial (untapped) volume was recorded. The cylinder, together with the sample, was tapped gently till there was no change in volume, and the new (tapped) volume was taken. The ratio of the mass (50 g) of the sample to the untapped volume represented the untapped bulk density, while the ratio of the mass of the sample to the tapped volume denoted the tapped bulk density. These measurements were repeated twice for each sample.

2.7. Statistical Analysis

The data generated from the study were statistically analysed using one-way analysis of variance in XLSTAT 2019 (Addinsoft, Paris, France) at a 5% level of significance. The means were separated using the Tukey post hoc test. Principal component analysis was done to dimensionally summarise and visualise the data.

3. Results

3.1. pH, Colour and Total Soluble Solids

3.1.1. pH

The three date varieties differed significantly ($p = 0.013$) in their pH (Figure 2). The Medjool variety had the highest pH at 4.41, followed by the Barhee variety (4.38), while the Maktoom variety recorded the lowest pH of 4.21. The Medjool and Barhee varieties were not statistically different from each other, but both differed from the Maktoom variety by margins of 0.20 and 0.17, respectively.

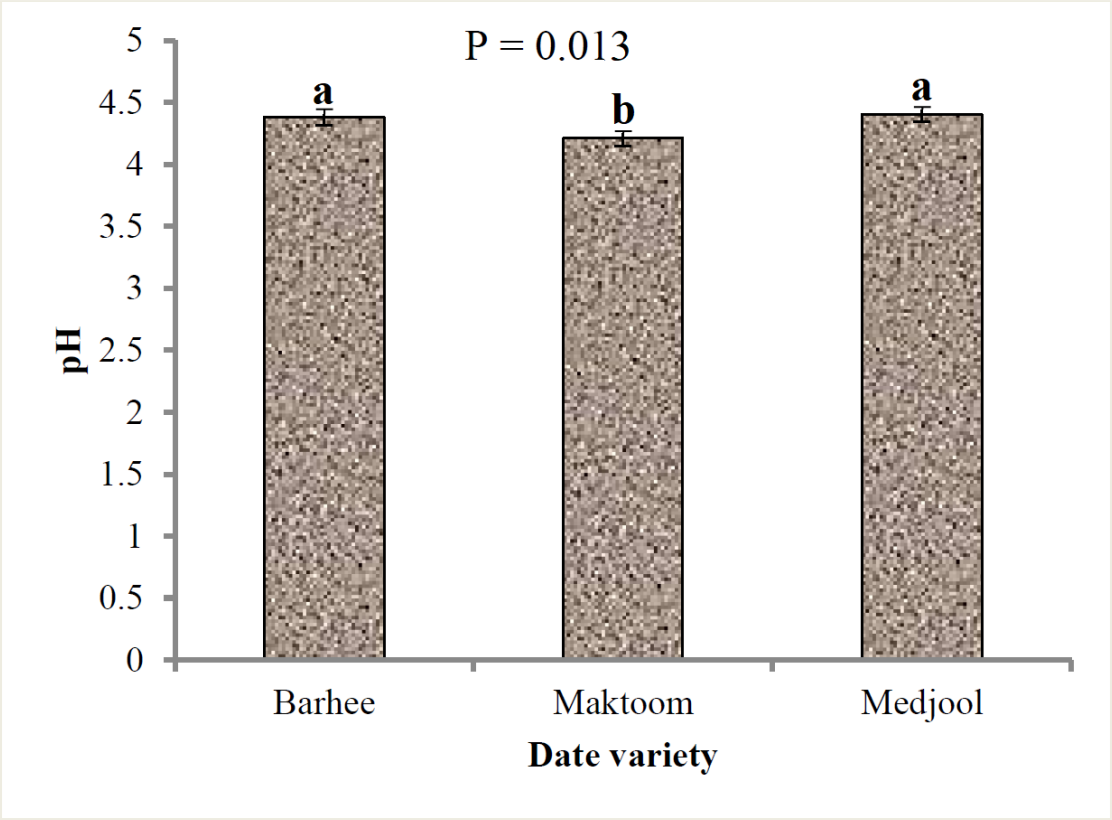


Figure 2. pH of three date fruit varieties. Bars (mean ± standard deviation, n = 3) bearing different alphabets are significantly different at $p \leq 0.05$.

3.1.2. Colour Attribute of Date Fruits

The colour analysis of date fruit powders showed considerable ($p < 0.05$) differences among the varieties (Table 1). The Medjool variety had a higher L* (lightness/darkness) value compared to the Maktoom and Barhee varieties. While the L* value for the Medjool was almost mid-way the L* scale of 0 to 100, the values for the other two varieties were somewhat closer to the zeroth mark (darkness). Whereas the Medjool and Barhee varieties differed significantly in their L* values, the Maktoom was not significantly different from the two. For a* (redness), there was also a considerable difference among the varieties, where the Medjool dates had a statistically higher value than both Barhee and Maktoom dates. The b* (yellowness), C* (chroma or colour intensity) values followed a statistical trend similar to that of the a* values. The hue values statistically trended as that of the L* values. The Medjool variety had comparatively the highest values in all the colour properties measured, with the other two somehow alternating positions.

Table 1. Colour attributes of three different date fruit varieties.

Date Variety	L*	a*	b*	C*	Hue (°)
Medjool	50.99 ± 5.29 [a]	7.46 ± 1.05 [a]	11.38 ± 2.08 [a]	13.61 ± 2.30 [a]	56.64 ± 1.31 [a]
Maktoom	41.01 ± 0.69 [a,b]	3.27 ± 0.11 [b]	4.45 ± 0.51 [b]	6.52 ± 1.32 [b]	53.55 ± 2.69 [a,b]
Barhee	39.83 ± 4.47 [b]	4.23 ± 1.51 [b]	4.78 ± 1.77 [b]	6.38 ± 2.30 [b]	48.58 ± 3.11 [b]
p-values	0.027	0.007	0.003	0.007	0.020

Values (mean ± standard deviation, n = 3) with different superscripts in the same column are significantly different at $p \leq 0.05$. L* denotes lightness/darkness; a* denotes redness (+a*)/greenness (−a*); b* denotes yellowness (+b*)/blueness (−b*) and; C* denotes chroma or colour intensity.

3.2. Total Soluble Solids

The date varieties differed ($p = 0.018$) in their total soluble solids (TSS) (Figure 3). Medjool (11.40) had the highest total soluble solids (TSS), followed by Maktoom (11.20) and Barhee (10.65). The values for Medjool and Maktoom showed no significant differences; however, the value for Barhee differed from the values for the other two.

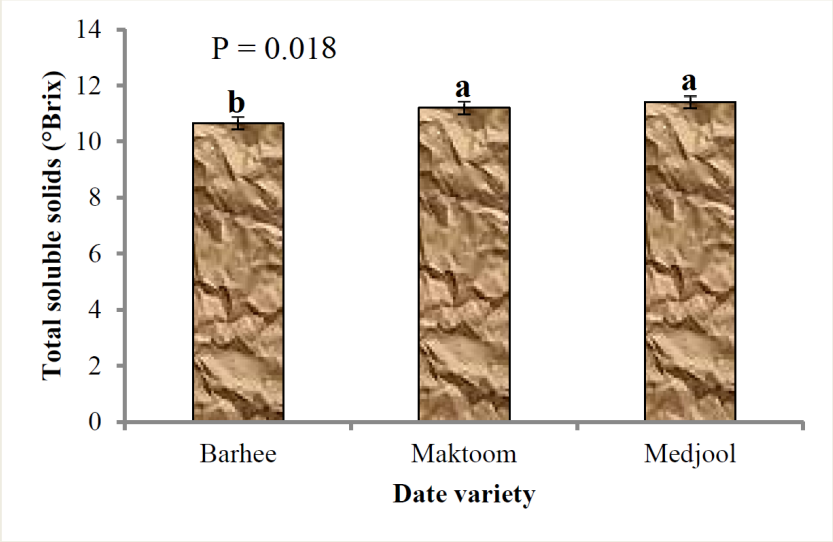


Figure 3. Total Soluble Solids of Date Fruits. Bars (mean ± standard deviation, n = 3) bearing different alphabets are significantly different at $p \leq 0.05$.

3.3. Proximate Composition

The findings revealed significant ($p = 0.011$) differences among the varieties only in fibre and protein contents (Table 2). The varieties did not vary statistically in moisture, fat, ash, and carbohydrate content. The moisture content of the date fruits was relatively low, below 10% and showed no marked difference. The date varieties also showed no difference in fat content, ranging from 0.21% in Medjool to 0.26% in Maktoom. The date varieties varied significantly ($p = 0.011$) in fibre content, with Maktoom recording the highest value (1.98%), followed by Barhee (1.89%) and Medjool (1.48%). The fibre value for Medjool was considerably lower than those of Maktoom and Barhee, which showed no statistical difference between each other. Similarly, the ash content did not differ across the varieties, even though the value for Maktoom was numerically the highest and that of Medjool the lowest. Contrastingly, the varieties showed significant differences in protein content, with Medjool recording the highest value (3.43%) and being statistically different from Barhee (2.90%) and Maktoom (2.71%). No significant difference was observed among the varieties for carbohydrate content and dietary energy.

Table 2. Proximate composition of powders of the three date varieties.

Date Variety	Moisture (%)	Fat (%)	Fibre (%)	Ash (%)	Protein (%)	Carbohydrate (%)	Dietary Energy (kCal)
Medjool	8.60 ± 0.04	0.21 ± 0.08	1.48 ± 0.08 [b]	2.32 ± 0.04	3.43 ± 0.03 [a]	83.98 ± 0.28	351.47 ± 0.29
Maktoom	9.79 ± 2.19	0.26 ± 0.06	1.98 ± 0.09 [a]	2.80 ± 0.21	2.71 ± 0.16 [b]	82.47 ± 1.98	343.00 ± .800
Barhee	8.83 ± 1.16	0.24 ± 0.13	1.89 ± 0.01 [a]	2.57 ± 0.01	2.90 ± 0.04 [b]	83.57 ± 0.97	348.02 ± 5.19
p-values	0.708	0.867	0.011	0.070	0.011	0.549	0.534

Values (mean ± standard deviation, n = 3) with different superscripts in the same column are significantly different ($p \leq 0.05$), while values without superscript letters show no difference ($p > 0.05$).

3.4. Functional Properties

The date varieties varied significantly in all the functional attributes measured, except for swelling capacity (Table 3). Maktoom recorded the highest WAC (337.68), which was 1.38 and 1.46 times the values for Medjool and Barhee, respectively. No significant difference existed between the WAC values of Medjool and Barhee. The date varieties all differed in their ability to absorb oil, with values for Medjool and Barhee being 1.30 and 1.24 times higher than that of Maktoom. Medjool recorded the highest untapped and tapped densities, while Barhee recorded the lowest of these attributes, although it was not significantly different from Maktoom. Though the varieties did not considerably differ in swelling capacity, they did so in swelling index, with Maktoom registering the highest values in both parameters.

Table 3. Functional properties of powders of the three date varieties.

Date Variety	WAC (% g/g)	OAC (% g/g)	Untapped D. (g/mL)	Tapped D. (g/mL)	Swelling C. (g/g)	Swelling I. (mL/mL)
Medjool	245 ± 2 ^{b}	236 ± 11 ^{a}	0.54 ± 0.02 ^{a}	0.65 ± 0.03 ^{a}	2.36 ± 0.37	1.63 ± 0.18 ^{b}
Maktoom	338 ± 5 ^{a}	182 ± 3 ^{c}	0.42 ± 0.00 ^{b}	0.46 ± 0.00 ^{b}	2.80 ± 0.03	2.63 ± 0.18 ^{a}
Barhee	232 ± 4 ^{b}	226 ± 6 ^{b}	0.35 ± 0.03 ^{b}	0.45 ± 0.04 ^{b}	2.74 ± 0.00	1.50 ± 0.00 ^{b}
p-values	<0.001	0.004	0.005	0.011	0.240	0.008

Values (mean ± standard deviation, n = 3) with different superscripts in the same column are significantly different ($p \leq 0.05$), while values without superscript letters show no difference ($p > 0.05$). WAC = Water absorption capacity, OAC = Oil absorption capacity, D. = Density, C. = Capacity, I. = Index.

3.5. Principal Component Analysis

Figure 4 shows that the physicochemical and functional properties of the dates were reliably summarised into two-dimensional components, which explained 100% of the variability observed in the data. The biplot shows the associations among the measured attributes and the contribution of each date fruit to the attributes. Attributes closer to each other are more strongly positively correlated than those far apart, whereas those directly opposite each other are negatively related. Attributes close to a particular date variety are strongly associated with that variety, indicating more contribution from that variety. Thus, Medjool was more strongly associated with most of the attributes compared to the other varieties, further explaining the observations in the bootstrap ellipse plot and results presented above.

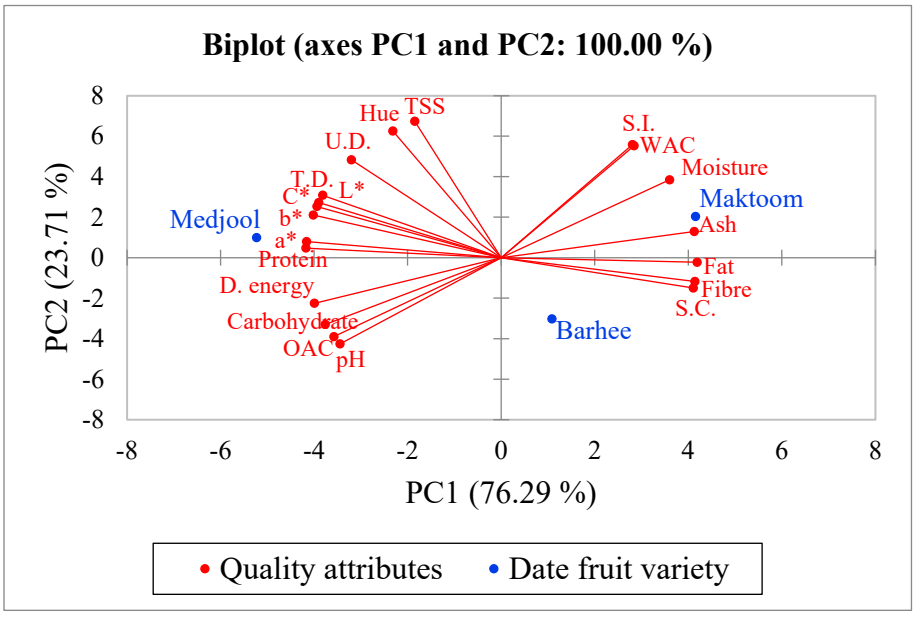


Figure 4. Biplot of the measured attributes in PCA. S.C. = Swelling capacity; S.I. = Swelling index; WAC = Water absorption capacity; OAC = Oil absorption capacity; U.D. = Untapped density; T.D. = Tapped density; TSS = Total soluble solids.

4. Discussion

The Medjool dates recording the highest pH (4.41) indicates a slightly less acidic environment, which may contribute to a milder acidic taste. The lowest pH value (4.21) recorded for Maktoom suggests a more acidic

flavour and potentially enhanced shelf stability due to its inhibitory effect on microbial growth [24]. Barhee dates, with a pH of 4.38, fall between the two, offering a balanced acidity. The values recorded in this study are lower than the pH range of 5.0 to 6.5 reported elsewhere for some date fruits [25]. Rahmawati et al. [26] reported that acidic conditions are beneficial for prolonging the stability and safety of food products by reducing spoilage risks. Hence, Maktoom dates might be particularly advantageous in formulations requiring extended shelf stability. Atasoy et al. [27] suggest that intermediate pH levels can effectively maintain both sensory qualities and microbial stability, positioning the Barhee variety as a versatile option for applications where both flavour and shelf life are critical. Understanding these pH characteristics allows food manufacturers to tailor their products more precisely to achieve desired flavour profiles and ensure optimal shelf life.

The colour (Table 1) analysis of date fruit powders showed that the Medjool dates were lighter, with a richer red and yellow hue compared to Maktoom and Barhee. These colour differences suggest that Medjool dates may have a more desirable appearance, which could positively impact their market acceptance and consumer preference. The colour attributes of Medjool in this study were higher than those reported by a study in Spain [18]. A lighter fruit colour is often associated with enhanced quality and freshness. Furthermore, Medjool dates had a more intense red hue compared to Maktoom and Barhee. This pronounced red tone enhances the visual appeal of Medjool dates. This finding is consistent with Petikirige et al. [28], who posited that a stronger red hue in dried fruits contributes to a more attractive and flavourful perception. The Medjool dates (11.38) also had a more pronounced yellow hue than Maktoom (4.45) and Barhee (4.78). This richer yellow tint contributes to a warmer and potentially more inviting colour profile. Recent research by Sulistyawati et al. [29] indicates that a more intense yellow colour in dried fruits is associated with higher ripeness and sweetness, potentially enhancing consumer preference. The colour intensity (C*) of the Medjool variety was more pronounced than that of Maktoom and Barhee. This greater saturation results in a more vivid and striking appearance, which can positively impact consumer choice. Toscani et al. [30] noted that higher colour saturation is often perceived as an indicator of superior quality. Overall, the hue angle indicates that Medjool dates (56.64°) had a hue angle closer to yellow, whereas Maktoom (53.55°) and Barhee (48.58°) were nearer to red, buttressing the observations made for a* and b*. Steiner & Florack [31] suggest that variations in hue can influence consumer perceptions of fruit quality, with warmer hues generally being more favourable.

The TSS (Figure 3) indicates the concentration of soluble substances in the date fruit powders. The results suggest that Medjool and Maktoom dates had a greater concentration of soluble solids, implying greater sweetness and flavour intensity than the Barhee dates. A recent study by El-Beltagi et al. [32] supports that higher TSS content is associated with increased sweetness and improved taste quality in dried fruits.

The moisture content of the date fruits was relatively low (below 10%), suggesting low susceptibility to microbial growth and spoilage. Handoyo & Sarofa [33] highlight that moisture content is a critical factor in determining the shelf life and stability of date-based products. For the food processing industry, managing moisture levels is crucial to maintaining product quality and extending shelf life. Moreover, the fat content was relatively low across all varieties, aligning with typical fat levels in dates and confirming their suitability for low-fat food products. According to Aljaloud et al. [3], date fruits are generally low in fat, which supports their use in formulations aimed at reducing dietary fat intake. Therefore, the low-fat content of these date varieties is advantageous for creating health-conscious food products. The relatively higher fibre content in Maktoom and Barhee dates could enhance the dietary fibre benefits of products made from them. Nitzke et al. [34] emphasised that higher fibre content can improve digestive health and regulate blood sugar levels. Consequently, for health-centred food products, Maktoom and Barhee dates offer a valuable option for boosting fibre content. The results show no differences in ash content among the varieties, reflecting stable mineral profiles [35]. This consistency is beneficial for the food industry in maintaining reliable mineral content across different date varieties. The protein content of the date varieties was all within the 1.7% to 4.7% range for most date fruits [36]. The findings, however, suggest that Medjool dates could provide greater protein content compared to the other two. Al-Karmadi & Okoh (2024) [1] support this observation by noting that date fruits are a good source of protein, which varies from one variety to the other. For product formulations targeting higher protein content, Medjool dates could be particularly beneficial. The carbohydrate and energy values are consistent with the findings of Hasan et al. [37] that identify dates as a high-energy food source. For the food industry, this stability in carbohydrate content across the date varieties ensures that date-based products consistently provide high energy levels. The high carbohydrate content of the fruits reflects high sugar levels, perhaps explaining their particular consumption during fasting periods.

Higher WAC denotes higher water imbibition and retention by hydrophilic molecules. High WAC has been reported to enhance the texture and mouthfeel of food products, particularly in bakery applications [38]. This indicates Maktoom's ability to retain more water than the other two, which is advantageous in food processing

where moisture retention is critical. While high WAC causes expansion in volume or bulkiness for economic gains, it can also result in nutrient thinning and reduced viscosity.

The higher OAC in Medjool suggests more oil and flavour retention and better mouthfeel [39], making it suitable for products requiring high oil absorption, such as fried foods. Additionally, the variation in OAC among the samples reflects their potential utility across different food applications.

Furthermore, the Medjool variety recording the highest untapped and tapped densities suggests better packing characteristics, which could be beneficial in formulations requiring compact storage or dense products. Conversely, the lower densities in Maktoom and Barhee indicate lighter, more porous and more voluminous materials, potentially suitable for products that prioritise bulk and lightness.

Moreover, the swelling capacity results showed the Maktoom variety had a superior ability to expand upon hydration, very useful for battery products and snacks. Conversely, Medjool and Barhee had slightly lower swelling capacities but still exhibited notable expansion, making them suitable for products that require moderate swelling. The swelling index further supports this, with Maktoom showing the highest value, indicating its pronounced ability to increase in volume when rehydrated. This is consistent with findings from Siddiqui et al. [40].

5. Conclusions

The study revealed significant differences in physicochemical and functional properties across the date fruit varieties, except for moisture, fat, ash, carbohydrate and dietary energy contents.

Medjool and Maktoom dates had higher concentrations of soluble solids than the Barhee dates, suggesting more intense sweetness and flavour than the Barhee dates. Medjool dates, with a relatively higher protein content and more appealing colour attributes, may contribute more to the protein content and visual appeal of food products than the other varieties if used as a food ingredient. The powdered forms of the dates showed moisture content below 10%, signalling a likely longer shelf life. Maktoom dates, characterised by lower pH, are better suited for acidic food formulations or products that demand longer shelf life. Maktoom and Barhee dates had relatively higher fibre content, potentially offering benefits for health-focused products that prioritise dietary fibre. The varieties also had high and comparable carbohydrate content, a sign of a good source of primary dietary energy. The date varieties also showed varied functional and powder properties. The Maktoom variety had the highest water absorption capacity, swelling capacity and swelling index, but the poorest oil absorption capacity. The Medjool variety, on the other hand, had better oil absorption and density, but lower swelling capacity than the others.

These variations in the measured quality attributes among the date fruits potentially offer a broad spectrum of industrial and home-based food applications. This then highlights the need for targeted selection of date varieties in food product development, allowing manufacturers to optimise nutritional content, shelf life, and visual appeal based on specific product requirements. Further research could focus on incorporating date fruit powders into staple foods and how that affects the nutritional and sensory attributes of those staples.

Author Contributions

N.S.M: Conceptualisation, methodology, investigation, writing—original draft; M.A.A: Conceptualisation, methodology, supervision, writing—original draft, writing—reviewing & editing; E.A.A.: Conceptualisation, methodology, supervision, writing—reviewing & editing. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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