INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
24–0328/2025/33:330302
http://www.fspublishers.org

Full Length Article

Pomological, Nutritional and Biochemical Characteristics of Native Dates (*Phoenix dactylifera*) cv. Mejhoul Sampled at Different Climatic Areas in Morocco

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Received 24 July 2024; Accepted 07 November 2024; Published online 24 December 2024

Editor: Muhammad Farooq

Abstract

This study aimed at studying the pomological, nutritional, and biochemical characteristics of Mejhoul dates collected at four different areas in Morocco. Analytical results showed that the maximum length and width of samples reached up to 42.01 ± 3.89 mm, and 21.55 ± 1.79 mm, respectively. Date maximum weights reached up 17.37 ± 2.22 g. Water content and ash of analysed Mejhoul fruits ranged from 19.65 to 30.41%, and from 2 to 2.53%, respectively. Mejhoul samples were characterized with lower lipid content ranging from 0.03 ± 0.02 to 1.42 ± 0.11 g/100 g DW and protein content varying from 3.09 ± 0.12 to 4.25 ± 0.05 g/100 g DW. Total and reducing sugars ranged from 77.19 ± 0.98 to 80.77 ± 0.12 g/100 g DW and from 31.27 ± 0.72 to 36.01 ± 0.40 g/100 g DW, respectively. The phytochemical analysis showed that total phenolic content ranged from 252.40 ± 3.06 to 488.35 ± 2.64 mg GA/100 g DW, flavonoids between 102.00 ± 0.73 and 297.51 ± 2.76 mg RE/100 g DW, condensed tannins from 34.66 ± 0.15 to 66.93 ± 0.80 mg/100 g DW and anthocyanins from 7.74 ± 0.29 to 14.13 ± 0.32 mg/100 g DW. The antioxidant activity ranged from 84.56 and 131.07 μmol TE/100 g DW using FRAP test and the IC50 values varied from 0.011 and 0.016 mg/mL for DPPH test. These findings highlight the effect of geographical location and pedoclimatic conditions on the morphology, phytochemical profiles and biochemical properties of Mejhoul dates. It can be concluded that the Mejhoul variety is of great importance from a nutritional point of view and influenced by environmental conditions.

Keywords: Mejhoul; *Phoenix dactylifera*; Nutritional value; Phytochemicals; Antioxidant activity

Introduction

Date fruits have been consumed by humans since prehistoric times as a source of nutritious energy. Their high sugar concentration acts as a natural preservative, reducing the risk of bacterial contamination. Archaeological evidence, including date seeds found in sites from Lebanon to Mozambique in the Great Rift Valley, underscores their historical significance and illustrates the role of dates in ancient diets (Zaid and Oihabi 2022).

Morocco, situated in the Mediterranean and Northern Africa, is renowned for producing a diverse range of date varieties with varying qualitative and quantitative characteristics. Among these, the Mejhoul variety is notable as a native Moroccan cultivar (Elhoumaizi *et al*. 2006). Mejhoul date palms are primarily located in the southeastern region of the country, particularly in the Tafilalet oasis, which spans approximately 32,500 km². This area includes 30 rural settlements across the Errachidia and Tinghir provinces.

Dates are highly sought after by consumers worldwide

To cite this paper: Goubi A, D Amghar, EDT Bouhlali, W Bouzir, H Elidrissy, A Zinedine, LE Ghadraoui, R Guemmouh (2025). Pomological, nutritional and biochemical characteristics of native dates (*Phoenix dactylifera* L.) cv. Mejhoul sampled at different climatic areas in Morocco. *Intl J Agric Biol* 66:330302. https://doi.org/10.17957/IJAB/15.2278
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due to their nutritional value (Alasalvar *et al.* 2020). They are rich in carbohydrates, lipids, proteins, dietary fiber, essential vitamins, and minerals (Khalid *et al.* 2017). Furthermore, as dried fruits, dates exhibit strong antioxidant properties attributed to their polyphenol content (Alasalvar *et al.* 2020). Notably, thirteen glycosylated flavonoids including luteolin, quercetin, and apigenin as well as various medicinal procyanidins, have been identified throughout the maturation phases of date fruits (Maqsood *et al.* 2020), enhancing their pharmacological potential (Baliga *et al.* 2011). Consequently, date extracts have been shown to offer numerous health benefits, such as antioxidant, anti-diabetic, anti-inflammatory, and antimutagenic properties (Khallouki *et al.* 2018). For instance, studies have indicated that date extracts may protect against diabetic peripheral neuropathy in diabetic rats induced by streptozotocin (Zangiabadi *et al.* 2011) and enhance the serological activities of paraoxonase and arylesterase in hypercholesterolemic rats (Takaeidi *et al.* 2014). Recently, various studies have investigated the morphological and biochemical characteristics, as well as the antioxidant activity, of lesser-known date varieties with reduced economic value (Taouda *et al.* 2014b; Bouhlali *et al.* 2015; Elhoumaizi *et al.* 2023).

The cultivation of Mejhoul dates significantly contributes to Morocco's socioeconomic landscape. In 2020, exports reached 3,288 tons, valued at approximately 5.6 million US dollars. In response to this demand, Morocco has initiated ambitious production plans through the Green Generation Plan, aiming to produce 70,000 tons of Mejhoul dates by 2028 (Zaid and Oihabi 2022). The Mejhoul date is a local Moroccan product, recognized for its rarity and high economic value, primarily cultivated in the Tafilalet Valley (Errachidia). It is especially popular during celebrations, such as weddings and commands a relatively high price compared to other hybrid varieties. Currently, the average price for one kilogram of Mejhoul dates in Morocco is around 150 MAD (15.24 US dollars). As part of the Generation Green strategy (2020–2030), Morocco plans to plant 5 million palm trees and produce 300,000 tons of dates by 2030.

Therefore, the present research study aims to investigate the morphometric parameters (length, width and weight), biochemical composition (water, ash, sugar, lipid, and protein), phytochemicals, and antioxidant activity of extracts from Mejhoul dates, considering the harvesting region. Additionally, the study will address the factors influencing these characteristics.

Materials and Methods

Samples collection

Mejhoul date samples (Fig. 1) were collected during the *Tmar* ripening stage in October 2023 from four distinct geographic and climatic regions: Rissani, Zagora, Tata and Figuig (Table 1; Fig. 2). Approximately two kilograms of each sample was collected in a 60 × 10 x 1 factorial design

Table 1: Climatological data of the production areas of the studied *Mejhoul* dates

Sampling area	Rissani	Zagora	Tata	Figuig
Altitude (m)	759	724	688	900
Latitude	31.17'18.8556"N	30°19’’’50’ N	29°44',784 N.	32°06’32’’N
Longitude	4°16'30.9174"W	5°50’’17’W	7°58',176 W	1°13’42’’W

Fig. 1: Example of studied Mejhoul samples with different morphometric parameters

Fig. 2: Geographical location of the four studied regions in Morocco

(dates x trees x plot) with trees selected randomly. Immediately following collection, the morphometric parameters of fruits were recorded. The samples were then transported to the laboratory in cardboard boxes and stored at 4°C for further analysis.

Pomological characterization

A total of sixty fruit samples (n = 60) were collected from the studied sites for the measurement of the entire date's weight. An analytical balance (AXIS) was employed to

measure the weight of the pulp and seed. Additionally, digital calipers (Delixi-DWKC-2012) were used to measure the fruit's length (mm) and breadth (mm). The quality ratios were calculated using the formulas outlined by Outghouliast *et al.* (2019):

$$\text{P/D ratio (\%)} = \frac{\text{Flesh weight}}{\text{Date weight}} \times 100$$

Physico-chemical characterization

Moisture content was measured using the oven drying method at 105°C until a constant weight was achieved, in accordance with AOAC method (AOAC 1970) Following this, the ash content of the date samples was determined by heating them in a muffle oven at 550°C for 8 h.

Proteins, sugars and lipid contents

The protein content of the studied samples was calculated by multiplying the total nitrogen content, determined using the Kjeldahl method, by a factor of 6.25 (Cunniff and Washington 1997). Total sugar content was assessed using the spectrophotometric method described by DuBois *et al.* (1956). In this procedure, 1.0 mL of a 5% phenol solution was added to 0.5 mL of the aqueous extract, followed by the addition of 5.0 mL of concentrated sulfuric acid. The absorbance of the resulting mixture was measured at 490 nm, with the sugar content reported as milligrams of glucose equivalent per 100 mg of jujube extract.

To determine the reducing sugars, the dinitrosalicylic acid (DNS) method was employed. This involved mixing 1 mL of the sugar solution from each sample with 1 mL of DNS in a test tube, which was then boiled for 5 minutes. The absorbance of the solution was measured at a wavelength of 540 nm. The standard range for this assay was established using a combination of glucose and fructose in various volumetric proportions (Chafi *et al.* 2015).

Lipid content in each sample was isolated using a Soxhlet apparatus with chloroform as the solvent over a period of 8 h. Following extraction, the solvent was removed using a rotary evaporator set at 40°C, and the lipid content was quantified according to the methodology reported by Bouhlali *et al.* (2017).

Phenolic compound extraction

Phenolic extract was prepared according to the method described by Bouhlali *et al.* (2017). In summary, 30 g of date powder was mixed with 150 mL of a methanol-water solution (4:1, v/v) and incubated in an orbital shaker at 35°C for 12 h. After incubation, the mixture was filtered, and the filtrate was concentrated using a rotary evaporator set at 40°C and reduced pressure until the solvent was completely evaporated. The resulting crude extracts were stored in dark glass vials at 20°C to protect them from light and maintain their stability.

Total phenolic compound evaluation

Phenolic compound content of dates was determined according to the internationally standardized ISO method (ISO 14502-1, 2005). A volume of 100 μL of the extract was mixed with 500 μL of a 1/10 diluted Folin-Ciocalteu reagent in water. Subsequently, 400 μL of sodium carbonate solution (7.5% w/v) was added to the mixture. It was then allowed to settle at room temperature for 60 min. Absorbance was measured at a wavelength of 765 nm. A calibration curve was established using gallic acid and all phenolic components were reported as gallic acid equivalents in mg per 100 g of dry weight (DW).

Flavonoid content: Flavonoid content was determined using the method outlined by Kim *et al.* (2003) First, 1 mL of date extract was mixed with 4 mL of distilled water. Next, 0.3 mL of a 5% sodium nitrite solution and 0.3 mL of a 10% aluminum chloride solution were added to the mixture. After incubation, 5 min at room temperature, 2 mL of sodium hydroxide (1 M) was added to the mixture, and the final volume was adjusted to 10 mL with distilled water. The resulting mixture was thoroughly vortexed, and the absorbance was measured at 510 nm. Measurement results were calibrated against a standard curve generated from a catechin solution. Total flavonoid content was reported as milligrams of Rutin equivalents (RE) per 100 g of dry weight (DW).

Condensed tannin content: The concentration of condensed tannins was determined in dates methanolic extracts of using a method previously described by Ribéreau-Gayon and Stonestreet (1965). In this procedure, 1 mL of the 50-fold diluted extract was mixed with 0.5 mL of distilled water and 1.5 mL of 12 N hydrochloric acid in two separate test tubes. One of the test tubes was placed in a water bath set to 100°C for 30 min, while the other was kept at room temperature. The reaction was terminated by adding 0.25 mL of 95% ethanol. Absorbance was then measured at 550 nm using a spectrophotometer. The concentration of total condensed tannins was calculated by assessing the difference in optical density before and after heating, in accordance with the following correlation:

$$\text{Total condensed tannins g/L} = 19,33 \times (\text{D0 (hydrolysis)} - \text{D0 (control)})$$

Anthocyanin content: date extracts anthocyanin content was measured using the method described by Ribéreau-Gayon and Stonestreet (1965). Initially, 0.5 mL of the extract was mixed with 0.5 mL of ethanol containing 0.1% hydrochloric acid (HCl), followed by the addition of 10 mL of 2% hydrochloric acid. In the first test tube, 2.5 mL of this mixture was combined with 1 mL of distilled water and the optical density was measured at 550 nm (OD1). In the second test tube, 2.5 mL of the mixture was combined with 0.5 mL of distilled water and 0.5 mL of sodium bisulfite ($NaHSO_3$) and the optical density at 550 nm (OD2) was measured. The determination of the anthocyanin content in dates was based on the correlation established from these measurements.

$$Anthocyanin\ content\ \left(\frac{mg}{L}\right) = (OD1) - (OD2)$$

Antioxidant activity evaluation

DPPH radical scavenging activity: The DPPH test was conducted following the method outlined by Blois (1958), with slight modifications. The reaction mixture consisted of 100 μL of date extracts at varying concentrations and 1.9 mL of a 0.3 m*M* methanolic DPPH solution. The mixture was incubated at room temperature for 20 min, after which the absorbance was measured at 517 nm. The IC_{50} values, representing the concentration required for 50% inhibition, was calculated by plotting the scavenging activity against the sample concentration.

Ferric reducing antioxidant power assay: The FRAP analysis was conducted according to the protocol described by Al-Najada and Mohamed (2014) with slight modifications. This analysis focuses on the reduction of a ferric 2,4,6-tripyridyl-s-triazine complex (Fe^{3+}-TPTZ) to its colored form, ferrous (Fe^{2+}-TPTZ), in the presence of antioxidants. To prepare the FRAP reagent, a mixture was created consisting of 25 mL of acetate buffer (pH 3.6, 0.3 M), 2.5 mL of 2,4,6-tris-(2-pyridyl)-s-triazine (10 m*M*) and 2.5 mL of ferric chloride (20 m*M*). Subsequently, 280 μL of the FRAP solution was combined with 20 μL of the extract, and the mixture was incubated in the dark at room temperature for 30 min. The absorbance was then measured at 593 nm using a UV-Visible spectrophotometer. To quantify the results, a calibration curve was generated using Trolox, with the final results expressed in μmol TE per 100 g of dry weight (DW).

Climatological studies of the regions: To study the climatic position of the four regions studied (Rissani, Zagora, Tata and Figuig) we used a mathematical modelling of the minimum (m) and maximum (M) temperatures converged with the rainfall (P). This is the Emberger model with its versions (Table 2).

Statistical analysis

The collected data were subjected to statistical analysis using SPSS software (version 12). A comparison of means was conducted using ANOVA, with a significance level set at 5%. In this study, Principal Component Analysis (PCA) was employed as a multivariate statistical tool analysis to represent the variability of the parameters across different regions (Boussakouran *et al.* 2019).

Results

Morphological characterization of Mejhoul dates

Fig. 3a–b presents measurements of the various studied samples. The data indicate that dates from the Zagora region exhibit higher values for several parameters, including length, width, and pulp thickness. Specifically, the

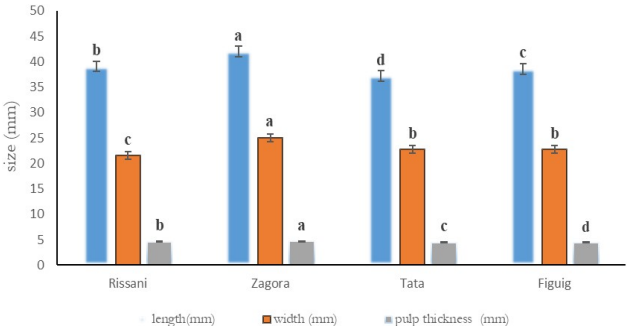

Fig. 3a: Graphical representation of *Mejhoul* date parameters measurement of studied regions (Note: a ≠ b ≠ c ≠ d)

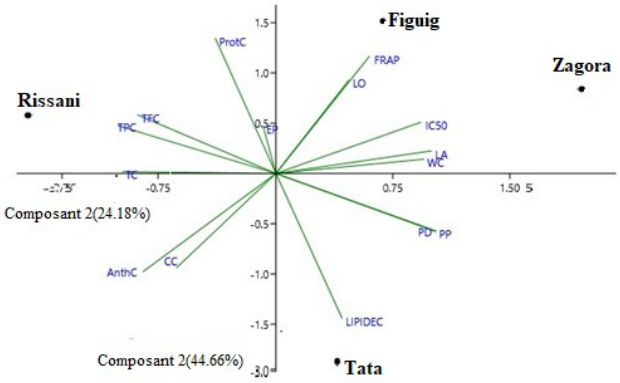

Fig. 3b: Dimensional analysis of individuals (localities) and variables (characteristics) of Mejhoul dates

Note: 1: PP: Pulp weight, Flav: flavonoid content; Tan: condensed tannin content; Ant: anthocyanin content; Prot: protein content; Ash: ash content; Lip: lipid content; WC% water content; IC 50(DPPH): antioxidant activity; FRAP: FRAP Test Weight D: Date Weight; Weight N: Kernel Weight; Ratio (P/D): Pulp to Date Weight; Ratio (N/D): Kernel to Date Weight Ratio

measurements are as follows: length 42.01 ± 3.89 mm; width 25.04 ± 1.80 mm; and pulp thickness 4.65 ± 0.23 mm. Conversely, dates from the Tata region show lower measurements for length and width, recording values of 37.17 ± 3.92 mm and 22.74 ± 2.84 mm, respectively. Additionally, dates from Figuig demonstrate reduced weight for both the date and pulp, with values of 15.36 ± 3.26 g and 14.20 ± 3.10 g, respectively.

In terms of weight, dates from the studied regions exhibited significantly higher values for both the total weight and pulp weight, as well as the weight ratio of pulp to dates (P/D). Specifically, these measurements were recorded as follows: total weight 17.37 ± 2.23 g; pulp weight 16.36 ± 2.22 g; and pulp-to-date weight ratio 94.09%. These values are detailed in below Table 2.

Protein content: Significant differences were observed in the protein content of Mejhoul date samples from various regions (Table 4) (F = 59.91, F' = 4.06 and $P = 7.97*10^{-06}$). The dates from Figuig exhibited the highest protein content, measuring 4.25 ± 0.05 g/100 g DW. In contrast, the dates sourced from Tata showed the lowest protein content at 3.09 ± 0.12 g/100 g DW.

Table 2: Emberger's bioclimatic Quotient formulas

Formulas	Reference	Climatological parameters
Q2 = 200∗P/ (M2-m2)	(Emberger 1942)	P: Annual rainfall in mm/m^2/year
Q2= 3.43P∗/ (M-m)	(Stewart 1968)	M: Maximum temperature of the hottest month in K, m: Minimum temperature of the coldest month in K
Q2= 2000P/ (M+m+546.4) ∗ (M-m)	(Mokhtari *et al.* 2013)	P: Annual rainfall in mm/m^2/year M: Maximum temperature of the hottest month in ℃, m: Minimum temperature of the coldest month in ℃

Table 3: Date weight, pulp weight and date weight pulp, ratio weight

	Rissani	Zagora	Tata	Figuig
Weight of date (g)	12.03 ± 2.11	17.37 ± 2.22	17.13 ± 2.82	15.35 ± 3.26
Weight of pulp (g)	11.15 ± 2.02	16.35 ± 2.21	15.98 ± 2.79	14.19 ± 3.09
Ratio of (P/D)	92.63% ± 3.60	94.09% ± 0.011	93.15% ± 0.01	92.32% ± 0.01

Table 4: Nutritional value (sugar, protein, lipid and ash (g/100 g dry weight) and water content (%) of Mejhoul dates from the different regions studied

Origin	Rissani	Zagora	Tata	Figuig
Reducing sugars	33.45 ± 0.75	36.01 ± 0.40	32.25 ± 0.39	31.27 ± 0.72
Total sugars	77.19 ± 0.98	71.75 ± 0.65	80.77 ± 0.12	72.19 ± 0.55
Protein	4.19 ± 0.17	3.56 ± 0.12	3.09 ± 0.12	4.25 ± 0.05
Lipid	0.03 ± 0.02	0.60 ± 0.11	1.42 ± 0.11	0.46 ± 0.60
Ash	2.53 ± 0.28	2.38 ± 0.26	2.24 ± 0.06	2 ± 0.13
Water content (%)	19.65 ± 0.05	28.18 ± 0.05	26.91 ± 0.04	30.41 ± 0.29

Table 5: Antioxidant activity, phenolic content, flavonoid content, condensed tannin content and anthocyanin content of Mejhoul deferent region

Region	Rissani	Zagora	Tata	Figuig
TPC (mg GA/ 100 g DW)	488.35 ± 2.64	252.40 ± 3.06	255.60 ± 1.35	309.04 ± 1.27
Flavonoids (mg RE/ 100 g DW)	297.51 ± 2.76	154.69 ± 1.27	102.00 ± 0.73	128.63 ± 1.50
Condensed tannins (mg / 100 g DW)	66.93 ± 0.80	34.66 ± 0.15	53.07 ± 0.42	58.09 ± 0.71
Anthocyanins (mg / 100 g DW)	14.13 ± 0.32	7.74 ± 0.29	13.37 ± 0.15	8.28 ± 0.31
IC_{50} (mg/ml)	0.013 ± 0.001	0.023 ± 0.001	0.016 ± 0.003	0.011 ± 0.008
FRAP (μmol TE/100g DW)	85.48 ± 3.70	110.31 ± 4.42	84.56 ± 3.52	131.07 ± 1.34

Total and reducing sugars: The total carbohydrate content (Table 4) of date fruit samples, at the '*Tamr*' stage ranged from 71.75 to 80.77 g/100 g DW, Presents a significant difference (F = 129.68; F' = 4.06 and P = 4.022 *10^{-07}). Among the samples, those from Tata exhibited the highest dry matter content, while the dates from Zagora had the lowest. The reducing sugar content varied across the studied dates, with Mejhoul from Figuig showing 31.27% and Mejhoul from Zagora exhibiting 36.01% with significant variation (F = 3.95; F' = 4.06 and P = 5.43*10^{-05}).

Lipid content: Studied dates lipid content revealed notable differences (F = 110.515; F' = 4.06 and P = 0.003). The dates from the Rissani region contained lipids in the skin, measured at 0.03 ± 0.02 g/100 g DW. In contrast, the dates from Tata exhibited a higher lipid content of 1.42 ± 0.11 g/100 g DW (Table 4).

Ash content: The results regarding the ash content of the studied dates revealed not significant variation (F = 3.58; F' = 4.06 and P = 0.066). The ash content of Mejhoul samples from the Figuig region was measured at 2.00 ± 0.13 g/100 g DM, whereas the ash content of dates from Rissani was higher, at 2.53 ± 0.28 g/100 g DM (Table 4).

Water content: Water content of analyzed dates ranged from 30.41% to 26.91% (Table 4). Notably, the dates from Figuig displayed the highest moisture content, while those from Tata were driest. It is important to note that higher water content can accelerate spoilage during storage.

Phenolic compound: Phenolic content of the studied dates varied significantly (F = 7471.45, F' = 4.066 and P = 3.987), ranging from 252.40 ± 3.06 to 488.35 ± 2.64 mg GAE/100 g DW (Table 4). The highest phenolic content was recorded in dates from Rissani, at 488.35 ± 2.64 mg GAE/100 g DW, followed by dates from Figuig (309.04 ± 1.27 mg GAE/100 g DW), Tata (255.60 ± 1.35 mg GAE/100 g DW) and Zagora (252.40 ± 3.06 mg GAE/100 g DW) (Table 5).

Flavonoid content: Flavonoid contents of dates from the various studied regions indicate a significant difference in flavonoid levels (F = 7583.20, F' = 4.06 and P = 3.75). The highest flavonoid content was found in dates from the Rissani region, measuring 297.51 ± 2.76 mg RE/100 g MS. This was followed by dates from Zagora (154.69 ± 1.27 mg RE/100 g DW), Figuig (128.63 ± 1.50 mg RE/100 g DW), and Tata (102.00 ± 0.73 mg RE/100 g DW) (Table 5).

Condensed tannins: Condensed tannins analysis in Mejhoul dates from different regions revealed significant differences in content (F = 1639.99, F' = 4.06, $P = 1.7*10^{-11}$). Dates from Rissani region exhibited the highest condensed tannin content, measuring approximately 66.93 ± 0.80 mg/100 g DW. This was followed by dates from Figuig (58.09 ± 0.71 mg/100 g DW), Tata (53.07 ± 0.42 mg/100 g DW) and Zagora, which had the lowest content at 34.66 ± 0.15 mg/100 g DW (Table 5).

Anthocyanin content: Anthocyanin content of Mejhoul samples, varied based on the sampling area (F = 426.97; F' = 4.06 and $P = 3.64*10^{-09}$) (Table 5). The highest anthocyanin content was found in dates from Rissani, measuring 14.13 ± 0.32 mg/100 g DW. This was followed by dates from Tata (13.37 ± 0.15 mg/100 g DW), Figuig (8.28 ± 0.31 mg/100 g DW), and Zagora (7.74 ± 0.29 mg/100 g DW), all expressed in cyanidin 3-glucoside equivalents.

Antioxidant activity: DPPH assay for of antioxidant activity the Mejhoul variety across the four studied regions are summarized in Table 5. A not significant difference among the samples was observed (F = 3.95, F' = 4.06 and $P = 0.05$). Overall, DPPH activity ranged from 0.011 ± 0.008 mg/mL to 0.023 ± 0.001 mg/mL across the regions investigated. The highest antioxidant radical scavenging activity was noted in Mejhoul dates from Zagora, while the lowest activity was recorded in dates from Figuig (0.011 ± 0.008 mg/mL).

The results of the FRAP test indicated that the dates possess considerable reducing power, with significant variation depending on the studied region (F = 125.24, F' = 4.06, $P = 4.61*10^{-11}$). Antioxidant activity ranged from 131.07 ± 1.34 to 84.56 ± 3.52 μmol TE/100 g DW. Maximum FRAP activity was observed in Mejhoul dates from Figuig, followed by those from Zagora, Rissani and Tata.

Dimensional analysis

The figure below shows that the analyzed parameters contribute in both parts of the two components of the analysis. The two dates of Mejhoul planted in Figuig and Zagora contribute in the positive parts of the two components and are strongly correlated with the antioxidant activity experienced in FRAP and IC50. The date of Mejhoul planted in Tata contributes in the positive part of component 1 and the negative part of component 2, it is strongly characterized by high lipid contents. The date of Mejhoul planted in Rissani contributes in the negative part of axis 1 and the positive part of axis 2 and it is strongly characterized (correlated) with high contents in phenolic compounds and essentially in flavonoids.

Bioclimatic study of studied Mejhoul production areas

Mean analysis (m Q) done by the ANOVA test shows that the difference is significant between the studied areas (F = 13.17 > F' = 4.066, $P = 1.8 * 10^{-3}$). This means that the morphometric variability (Table 3) and biochemical (Table 6) is linked to the variability of the Embrothermic coefficients (Q). This parameter shows that the physiology of the plant varies according to Mejhoul planting area. The Fig. 4 Emberger climatogram illustrates areas production distribution dates Mejhoul where we note that Rissani zone is located in a Saharan vegetation stage with a cool winter. While the other three zones are located in a mild vegetation stage in a gradient of 4, 5 and 6 respectively for Figuig, Zagora and Tata. Fig. 5 illustrates the effect of minimum temperature on the growth of Mejhoul date fruits.

From this figure, we observe that the size of the fruits increases with the increase in minimum temperature (m), until it stabilizes.

Discussion

Our findings regarding Mejhoul dates width and length measurements align with those documented by Outghouliast *et al.* (2019). However, Chafi *et al.* (2015) reported lower measurements why compared to our findings. The pulp content, expressed as a percentage of weight (pulp weight/date weight), ranged from 92% to 94% in analyzed dates. These results corroborate the findings of Taouda *et al.* (2014a) who reported a value of 93% for Mejhoul dates from Figuig oasis, as well as those of Outghouliast *et al.* (2019) who studied Mejhoul dates from eight regions in Morocco, with percentages ranging from 91% to 94%. In contrast, Chafi *et al.* (2015) indicated that the pulp weight to date weight ratio was approximately 95% for Mejhoul dates from the Figuig oasis.

Regarding date pulp thickness, measurements are ranged from 4.43 ± 0.31 to 4.65 ± 0.23 mm, suggesting that dates from Zagora exhibit a comparatively higher pulp thickness than those from other Morocco regions, with a ratio of approximately 94% (Table 3).

Mejhoul samples sugar content is significantly higher than that reported by Sayah (2010) who found total sugar values of 65% for the *Deglet Baida* variety and 50% for the *Deglet Nour* variety. These differences in total sugar content can be attributed to several factors, including genotypic and climatic variations between date cultivars. Additionally, varieties with a semi-soft consistency tend to have higher total sugar content than dry dates. Generally, results reported by various authors suggest that dates total sugar content is around 60% to 80% of the pulp (Munier 1973; Sayah 2010). Conversely, Siboukeur (1997) reported a reducing sugar content of approximately 62.41%, which is lower than our findings. Furthermore, Sawaya *et al.* (1983) noted reduced sugar content in certain date varieties from Saudi Arabia. Reducing sugars, primarily glucose and fructose, result from the degradation of sucrose bonds by invertase during the ripening stages of dates. It has been reported that invert sugar (fructose) prevents sugar crystallization (Alais *et al.* 1997). The texture of soft and

Table 6: Climatological parameters of the date production sites studied

Region	*Rissani*	*Zagora*	*Tata*	*Figuig*
Rainfall (mm)	15	5.2	12.275	10.97
m (°C)	2.9	5	6	4
M (°C)	38.3	42	40	39
Q Emberger	2.05	0.59	1.56	1.46
Q Stewart	1.45	0.48	1.24	1.07
Q Mokhtari	1.44	0.37	1.22	1.06
Moyenne (m_O)	1.65	0.48	1.34	1.197

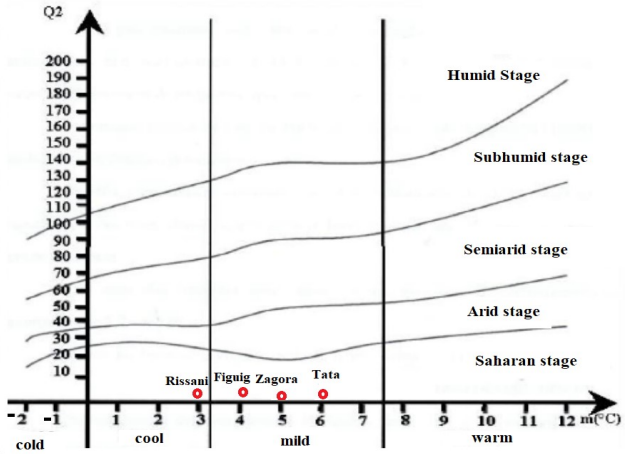

Fig. 4: Location of production zones for the dates studied on the Embreger diagram

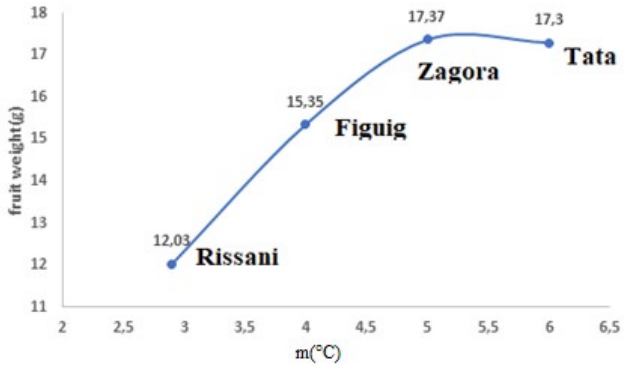

Fig. 5: Evolution of the weight of dates as a function of the minimum temperature m

semi-soft dates, coupled with their high sweetening power, likely contributes to the sweet taste of these dates. According to Cheftel (1980) reducing sugars promote browning, which may enhance enzymatic dates browning.

Regarding protein content, our findings are consistent with those of Elhoumaizi *et al.* (2023), who reported similar protein contents of 3.12 g/100 g DW and 3.33 g/100 g DW for Jordanian and Palestinian dates, respectively. In contrast, Hasnaoui *et al.* (2011) noted that Mejhoul protein content dates ranged from 2.1 to 2.7 g/100 g DW.

Concerning ash content, our findings are lower than those obtained in other studies by Elhoumaizi *et al.* (2023), which reported ash content values of 3.03 to 3.24 g/100 g in dates from Jordan, Palestine, USA and Saudi Arabia. However, Bouhlali *et al.* (2015) reported similar results to ours, with ash content around 2.30 g/100 g. Ash content variation among the studied dates depends on several factors, including soil type, irrigation methods, water quality, fertilizer nature, and product geographical origin (Al-Hooti *et al.* 1997). Additionally, some authors have indicated that temperature and sunlight influence the dates mineral concentration (Woolf and Ferguson 2000).

Regarding lipid content, our findings align with those reported by Bouhlali *et al.* (2015), who found a lipid content of 0.318 g/100 g DW in Moroccan dates. These findings also correspond with those of Al-Farsi *et al.* (2005), who reported lipid contents ranging from 0.52 to 1.41 g/100 g DW in dates from Oman.

With respect to water content and moisture, it is important to highlight that dry dates with lower water content may be less favored by consumers (Golsan and Fooladi 2006). According to marketing and quality control standards for dates (Cee-onu ddp-08 2020), the moisture content of Moroccan dates across all varieties must exceed the recommended national marketing limit of approximately 30%, which aligns with international standards. Studies have shown that changes in dates moisture content are influenced by relative humidity (Dowson and Aten 1963). Moreover, dates moisture content can fluctuate based on various factors, including irrigation methods and fertilizer types. For instance, studies conducted in Aswan (Egypt), demonstrated that irrigation during the final ripening stage increased date fruits moisture content (Elhoumaizi *et al.* 2023). According to FAO and IFAD (2008), effective management of irrigation frequency is essential to reduce crop moisture. Additionally, potassium-based fertilizers have been shown to enhance dates water content (Soliman *et al.* 2018) found that crops treated with 400 g of K_2O produced dates with higher water content.

Regarding phenolic content, our findings align with those reported by Bouhlali *et al.* (2015). In contrast, Taouda *et al.* (2014b) reported significantly lower phenolic values, specifically 2.6 mg/100 g DW, for Moroccan dates from the Figuig region. Total polyphenols biosynthesis in dates appears to be influenced by various factors, including genetic variation among varieties, harvesting season, soil and climatic conditions, types of fertilizers used, storage conditions, and exposure to sunlight. This multifaceted aspect has been extensively emphasized in previous studies (Kallithraka *et al.* 2005).

Compared to other fruits, Mejhoul dates exhibited higher phenolic content than raisins (194 mg EC/100 g), but lower than plums (551 mg EC/100 g) and similar to apricots (333 mg EC/100 g) and figs (256 mg EC/100 g), as noted by Vinson *et al.* (2005).

Studied Mejhoul dates flavonoid content appears to exceed those reported in previous investigations, which documented flavonoid content ranging from 0.098 to 0.72

μg EQ/100 g (Hasnaoui *et al.* 2012a), 0.04 mg QE/100 g DW (Taouda *et al.* 2014b) and 77.73 mg/100 g DW (Bouhlali *et al.* 2015). Our findings indicate notably higher flavonoid content in the Moroccan Mejhoul dates compared to other fruit types. For instance, raisins exhibit a flavonoid content of 30.9 mg/L, apricots 31.9 mg EQ/100 g water, and plums and figs have 46.6 mg EQ/100 g and 79.9 mg EQ/100 g water, respectively (Tikent *et al.* 2023).

These observed variations in polyphenol and flavonoid content among studied dates appear to be influenced by several factors, including geographical origin, soil composition, degree of ripeness, variety and environmental conditions (particularly light and temperature) during fruit ripening (Bano *et al.* 2022).

In terms of tannin content, our findings are consistent with those of Bouhlali *et al.* (2015), who obtained a condensed tannin content of approximately 64.29 mg EC/100 g DW in the Mejhoul variety from Errachidia. Conversely, the anthocyanin content values observed in the studied dates surpass those reported by Al-Farsi *et al.* (2005), who documented values ranging from 0.24 to 1.52 mg/100 g DW in Omani varieties. Anthocyanins are highly sensitive to heat during food processing (Markakis 1982; Mutha *et al.* 2021). Research indicates that drying dates during processing leads to the complete anthocyanins degradation, facilitated by both enzymatic and non-enzymatic browning reactions (Wrolstad 2004). Additionally, factors such as light exposure, storage conditions, and temperature contribute to anthocyanin degradation (Al-Farsi *et al.* 2005).

Regarding antioxidant activity, our findings align with those of Taouda *et al.* (2014b), who reported DPPH values of 0.026 mg/mL, and those of Bano *et al.* (2022), who studied Algerian varieties at different ripening stages, yielding values ranging from 3.36 to 14 μg/mL. However, other studies have reported higher DPPH values than those obtained in the present study (Hasnaoui *et al.* 2012b; Bouhlali *et al.* 2015). Dates contain numerous phytochemicals crucial for antioxidant formation post-oxidative stress, and oxidative stress decreases as dates mature (Bano *et al.* 2022). The observed antioxidant activity is significantly influenced by various factors, including soil types, pedoclimatic conditions, ecological factors, agricultural practices and fertilizers used types (Amira *et al.* 2012). These findings differ from those reported by Bouhlali *et al.* (2015), who recorded an antioxidant value of approximately 469.03 μmol TE/100 g DW in the Mejhoul variety. Other studies reported higher antioxidant activity values ranging between 579.07 and 851.06 μmol TE/100 g DW compared to our results (Bano *et al.* 2022). According to several reports, FRAP activity during the ripening stages of all date varieties, as well as, the activity of specific antioxidant enzymes, is significantly influenced by climatic variations, ecological factors unique to each region, particularly temperature, water stress, and mineral nutrients (Shoukat *et al.* 2022). These findings are consistent with those of Souli *et al.* (2018) who found that changes in FRAP activity depend on a range of factors.

Multivariate analysis

Principal component analysis (PCA) of the biological parameters of dates from the different studied regions reveals distinct characteristics. Mejhoul dates from both the Zagora and Figuig regions exhibit large sizes, characterized by notably high measurements in parameters such as length, width, pulp weight, and pulp-to-date weight ratio. These dates display elevated protein content alongside low lipid content. Additionally, dates from these regions demonstrate slightly elevated levels of polyphenols, flavonoids, and condensed tannins, while exhibiting low levels of anthocyanins and ash content (Fig. 3a–b).

In contrast, dates from Tata region are of medium size but possess high lipid content and low protein content. Their chemical composition indicates low levels of polyphenols, flavonoids, and condensed tannins, with very low antioxidant activity (FRAP). However, they are relatively rich in anthocyanins and ash content.

Lastly, dates originating from the Rissani region are characterized by their small size, very low lipid content and relatively high protein content. These dates boast high levels of polyphenols, flavonoids, condensed tannins and anthocyanins, alongside elevated ash content. Despite these attributes, they exhibit very low antioxidant activity (FRAP).

Climatological analysis

Temperature plays a very important role in plant growth. Thus, it is noted that the minimum temperature of Rissani (2.9°C) results in a small fruit size (Table 3; Fig. 5) since low temperatures inhibit the enzymatic activity involved in the growth of the plant and the fruit (12.03 g). This is also reproduced in Figuig (15.35 g). On the other hand, the minima of Zagora (5°C) and Tata (6°C) induce good growth of the fruits (17.3 and 17.37 g respectively).

Conclusion

The present research study revealed significant variances in Mejhoul dates biological properties from the various evaluated regions. Dates from Zagora and Figuig regions are notably larger in size and contain more water than those from Tata and Rissani. Additionally, dates from Rissani, Zagora and Figuig exhibit higher quantities of proteins, phenolic compounds, flavonoids, and condensed tannins content, which contribute to substantial antioxidant activity and enhance preservation quality. These findings indicate that dates from these three areas possess excellent quality attributes.

Despite their smaller size, Rissani dates are rich in qualitative attributes, featuring high protein content along with abundant polyphenols, flavonoids, and condensed

tannins. In contrast, samples from Tata are characterized by high lipid content, along with significant amounts of anthocyanins and ash. The assessment of Mejhoul dates from various localities, considering both their biochemical and morphological components, highlights the inherent heterogeneity of the fruit. This heterogeneity encompasses their pomological features, chemical composition, and antioxidant activity. These data support the notion that the morphological and phytochemical characteristics of Mejhoul variety are heavily influenced by geographical location. Ultimately, these findings contribute to a better understanding of factors affecting the attributes of this recognized date variety. The minimum temperatures (m) are responsible for the metabolic and morphological modulations of the dates studied. It can finally be concluded from this study that *Zagora* region is the most suitable for producing dates of the Mejhoul variety in Morocco.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for profit sectors.

Authors' Contributions

Conceptualization: L.E. and R.G.; Methodology: A.G. and D.A.; Validation: E.T.B and A.Z.; Investigation: A.G. and D.A; Resources: A.G., H.E. and W.B; Writing—original draft preparation: A.G.; Writing—review and editing: A.Z., L.E. and R.G.; Supervision: L.E. and R.G. All authors read and approved the final manuscript.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

Data Availability

The data will be available on a fair request to the corresponding author.

Ethics Approval

Not applicable to this paper

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