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Physiochemical Variability of Hmira Date Cultivar (Phoenix Dactylifera L.) From Saoura Region (Algeria) Across Ripening Stages

Ali Boulanouar[1], Larbi Benlarbi[2], Zineb Hamani[3]
[1,2,3]Laboratory Development of Biological Resources and Food Security, TAHRI Mohamed University of Bechar, ALGERIA,
boulanouar.ali@univ-bechar.dz[1], benlarbi.larbi@univ-bechar.dz[2], hamani.zineb@univ-bechar.dz[3]
[1]https://orcid.org/0000-0002-2464-2337, [2]https://orcid.org/0000-0003-2729-6289and
[3]https://orcid.org/0000-0002-8791-0968

Abstract
The Saoura region is situated in southwestern Algeria, encompassing key oases such as Igli, Béni Abbès, El Ouata, and Kerzaz, it is notable for its high density of date palms (Phoenix dactylifera L.). This study focuses on Hmira, a locally cultivated date variety, aiming to characterize its physicochemical properties across five distinct ripening stages: Loulou, Khalal, Bser, Routab and Tmar and to enhance the scientific understanding of its biochemical maturation, which remains underexplored despite the fruit's nutritional, economic, and cultural importance.
Fruit samples were harvested from the Igli palm groves and subjected to morphological and physicochemical analyses. Lipid content was consistently low across all developmental stages: Loulou (0.98%), Khalal (0.20%), Bser (0.44%), Routab (0,44%) and Tmar (0.50%). In contrast, total sugar content increased markedly from early to late stages: Loulou (6.8%), Khalal (40.0%), Bser (68.0%), Routab (71%) and Tmar (77.6%). The pH remained slightly acidic (5.0-6.0), while titratable acidity exhibited a gradual rise: Loulou (0.19%), Khalal (0.25%), Bser (0.28%), and Tmar (0.30%). Water content was highest during early maturation and declined significantly in later stages: Loulou (66.0%), Khalal (74.33%), Bser (54.66%), Routab (31%)and Tmar (18.33%).
The ripening index, calculated as the ratio of water content to total sugars, was determined to be 4.23, indicating that Hmira is a dry date variety. These findings contribute to a better understanding of the biochemical dynamics during fruit development and support the valorization of this locally adapted yet scientifically undercharacterized cultivar.
Keywords: *Southwestern Algeria, physicochemical properties, Phoenix dactylifera L., ripening stages.*

1. INTRODUCTION

1.1 Importance of date palm (Phoenix dactylifera L.)

The date palm (Phoenix dactylifera L.) constitutes the cornerstone of agricultural systems in Saharan oases, where it plays a vital role as a primary source of food, income, and cultural heritage for populations in arid and semi-arid regions. In Algeria, its cultivation is predominantly concentrated in the northern fringe of the Sahara, where agro-climatic conditions are characterized by high temperatures and minimal rainfall are particularly well-suited to its development (Benmeddour, 2016). In the Saoura region, for instance, the date palm dominates the local vegetation, a distribution strongly governed by environmental factors such as temperature, with optimal growth occurring around 30 °C, and annual precipitation rarely exceeding 100 mm. This ecological adaptation underpins the species' strategic role in sustaining agricultural livelihoods and combating desertification in fragile ecosystems.

a. Dates fruits of palms

The fruit of the date palm, commonly referred to as the date, is a berry containing a single pit. Structurally, the date comprises a fleshy mesocarp enclosed by a thin epicarp, while the seed is encased in a parchment-like endocarp. The stone is typically elongated and may vary in size; it can be smooth or exhibit lateral protuberances in the form of ridges or fins, with a distinctive ventral furrow. The embryo is positioned dorsally, and the seed's texture is hard and horny. The external color of the date varies depending on the cultivar and stage of ripeness, ranging from pale yellow or translucent amber to various shades of brown, red, or black.

b. Date Fruit Development and Ripening

Following pollination and fertilization, the growth of the date fruit exhibits a sigmoidal pattern and is conventionally divided into five distinct developmental stages, known by their Arabic names, these stages are primarily distinguished by changes in color, texture, aroma, and flavor (Haider et al., 2013).

c. Date Classification

Dates are commonly classified into three categories based on their texture, which is largely determined by the moisture content of the pulp. The stability of a date fruit depends on the ratio of total sugars to water content. These sugar-to-water ratios—also referred to as quality or firmness indices, are reliable indicators of fruit stability and preservation potential (Munier, 1963; Bouabidi, 1996).

The classification is as follows:

Soft dates: These have a firmness index "r" below 2. They pass through the 'Routab' stage and remain soft even at the 'Tmar' stage. They are typically rich in reducing sugars. (Dowson & Aten, 1963).

Semi-soft dates: These have a firmness index between 2 and 3.5. Although they also pass through the 'Routab' stage, they tend to be slightly drier at the 'Tmar' stage. Their sugar content is primarily composed of reducing sugars (Bouabidi et al., 1996; Munier, 1973). Notable cultivars include Deglet Nour, Kenta, Tazerzeit, and Khalt Feggous.

Dry dates: These exhibit a firmness index above 3.5 and typically do not pass through the 'Routab' stage. They are mostly characterized by a high saccharose content.

A firmness index of r = 2 is considered optimal for fruit stability and long-term storage capacity (Munier, 1963).

d. Date Palm Cultivars

Date palm (Phoenix dactylifera L.) cultivars are highly diverse, with only a limited number possessing significant commercial value. Cultivars differ in terms of flavor, texture, shape, color, weight, and size (Djerbi, 1994; Buelguedj, 2001). In Algeria alone, more than 940 distinct date palm cultivars have been identified (Hannachi et al., 1998).

The main cultivated varieties include:

Deglet Nour: Widely recognized as the premier commercial cultivar, Deglet Nour is a semi-soft date renowned for its distinctive appearance, smooth texture, and rich flavor. At full maturity, the fruit exhibits an amber-brown color with a smooth, slightly wrinkled and glossy epicarp. The mesocarp has a fine texture that is mildly fibrous (Boudrar et al., 1997; Kendri, 1999).

Common cultivars: These varieties have lower commercial value compared to Deglet Nour. The most prevalent among them are Ghars, Degla Beïda, and Mech Degla (Kendri, 1999; Masmoudi, 2000). According to Buelguedj (2001), a large proportion of these common cultivars have soft consistency. Together, Ghars, Degla Beïda, and Mech Degla account for approximately 53% of the national production.

In total, around 200 cultivars are actively grown and marketed in Algeria, showing considerable diversity in fruit quality (particularly in terms of consistency) and market preference.

1.2 Specific Objectives of Your Study

In addition to their nutritional, economic, and cultural significance, dates (Phoenix dactylifera L.) represent a unique fruit that is consumed across various stages of ripening. In certain regions, such as the Gulf countries, Iran and Egypt, early ripening stages like the balah 'Bsir stage' are preferred for consumption. In contrast, populations in the Maghreb region tend to favor more advanced stages, such as Routab and fully ripened Tmar dates. This raises important questions regarding the variation in nutritional composition throughout the ripening process.

This study aims to:

To characterize the main ripening stages of date fruits (Phoenix dactylifera L.) based on morphological and physicochemical parameters.

To analyze the variation in moisture content, sugar composition, and other key biochemical constituents (e.g., proteins, tannins, organic acids) during fruit maturation.

To determine the stage at which the fruit reaches its peak nutritional quality in terms of energy value, sugar concentration, and digestibility.

To assess the suitability of each ripening stage for consumption, storage, and processing based on its physicochemical stability.

To compare the biochemical profiles of selected date cultivars at each ripening stage and evaluate the influence of varietal differences.

To provide scientific insights that can guide consumer preferences, industrial applications, and optimal harvest timing.

2. MATERIALS AND METHODS

The present section provides a detailed account of the experimental materials and procedures employed to assess the physical and chemical characteristics of Hmira dates at different ripening stages. The methodology encompasses a thorough investigation of two primary components: the sampling and collection process conducted at the study site in the Igli region (southwestern Algeria), and the subsequent laboratory analyses. These analyses covered a range of physicochemical parameters such as weight, dimensions, color, moisture content, pH, titratable acidity, fat content, ash, and total sugars. Additionally, sensory attributes including texture and visual appearance were noted when applicable. The study also integrated statistical tools to interpret the collected data, ensuring a robust evaluation of the quality and nutritional potential of the Hmira date cultivar across its developmental stages.

2.1 Study Area Description

The Saoura is a desert region located in the southwest of Algeria, forming the western boundary of the Grand Erg Occidental. It lies approximately 1,200 kilometers from the capital, Algiers, extending to the Algerian-Moroccan border. The region derives its name from the Saoura Valley, which is formed by the confluence of two rivers, the Oued Guir and the Oued Zouzfana. This confluence occurs in the Igli palm grove, from which a succession of palm groves extends along the river, including Beni Abbes, El Ouata, Kerzaz, Ouled Khedier, and Gsabi .

2.1.1 Geomorphological Overview

a. Watercourses

The Saoura region originates at the Igli oasis, located at the foot of the Grand Erg Occidental dunes. It is formed by the confluence of two Ouadis: the Oued Zouzfana, a desert stream with rare floods from the Ksour Mountains (between Figuig and Beni Ounif), and the Oued Guir, a more regularly flowing river that drains the Eastern High Atlas north of Boudenib and Bouanane (Chavillon, 1964).

b. Relief

Over 80% of the region lies between 420 and 580 meters above sea level, with an average altitude of 535.5 m, indicating a generally flat topography characterized by low-relief features (Chavillon, 1964).

c. Dune Geomorphology

The Grand Erg Occidental is the region's largest and most continuous sand accumulation. It consists of dune chains (40–100 m high) shaped by dominant southwest winds. The northern erg contains structured dunes (Gassi or Fedj), while the south features larger dunes. Depressions are lined with calcareous crusts and tufa. The mobile dunes are barren, apart from sparse vegetation used by nomadic herders (Conrad, 1969).

Geologically, the Saoura Valley extends from Igli to Foum Khneg (south of Kerzaz), bordered by the Grand Erg Occidental to the east and the Hamada of Guir to the west. The region's bedrock comprises Paleozoic formations (Cambrian to Visean). Quaternary deposits dominate the surface—hamadas, terraces, crusts, dunes, recent alluvium, sebkhas, and slope deposits (Paryen, 1952). The Cambro-Ordovician, Mio-Pliocene, and Quaternary layers constitute the main aquifers, with shallow wells mostly tapping Mio-Pliocene and Quaternary waters.

d. Pedological Overview

The soils in most Saoura oases are sandy (70–80% sand or silica) and have the following characteristics:

- Light and low in resistance;
- Quick to warm up;
- Highly permeable and prone to drying;
- Poor in nutrients;
- Generally acidic.

These conditions favor soil fauna (worms, larvae, insects) and support drought-adapted vegetation (Margulis, 1963).

2.1.2 Climatology

Climate is a key factor influencing ecosystems. Rainfall and temperature directly affect plant growth and animal development.

e. Rainfall

Saharan rainfall is irregular and can occur in any season without predictable patterns (Boulanouar, 2010). Emberger (1930) describes the Saharan climate as one with erratic, non-annual precipitation. Rainfall sources vary seasonally: summer rains result from monsoonal lows; winter rains from polar fronts; and transitional-season rains from Sudan-Saharan depressions crossing the desert (Dubief, 1963).

f. Temperature

The analysis of maximum (M) and minimum (m) temperatures has biological significance, as it reflects thermal variation

The lowest recorded temperature occurs in January (5.2 °C), while the highest is observed in July (42.84 °C) (Emberger, 1930).

2.2 Selection of Date Cultivar

Given the wide diversity of date palm cultivars in Algeria, the variety used in this study is Hmira, sourced from the Igli palm grove in the Beni Abbes province. The fruits were collected at different stages of ripening (Figure 01).

The selection of this cultivar is based on the following criteria:

- It is a common and widely consumed variety in the region;
- It is commercially distributed throughout the area;
- It is locally abundant and easy to preserve due to its low moisture content.

2.3 Study Site

All samples are collected from the Igli palm grove (Beni Abbes province), using date palms of the Hmira variety. The palm grove is locally called IFLAN.

Table 1: Sampling dates and geolocation of the Iflane palm grove

Stages	Characteristics	Harvesting period	Palm grove geolocation	Palm grove altitude
Loulou	young green fruit	mid-April, 2019	30°26'44.22" N 02°16'36.76"W	498m
Khalal	rapid growth phase	mid-May, 2019		
Bsir	dates yellowing	mid-July, 2019		
Routab	partially ripe stage	mid-August, 2019		
Tmar	fully ripe stage	mid-October, 2019		

2.4 Date Fruit Sampling Method

a. Sampling Type

Stratified random sampling.

b. Stratification Criteria

Sampling is stratified based on the four main developmental stages of date fruit maturation: Loulou, Khalal, Bser, Routab and Tmar (Figure 01).

c. Study Site

All samples are collected from the Igli palm grove (Beni Abbes province), using date palms of the Hmira variety. The palm grove is locally called IFLAN.

d. Palm Selection

Ten healthy, productive female palms of the Hmira variety are selected at random from different sections of the grove to ensure representativeness.

e. Bunch Selection

Samples are chosen from the third bunch from the top, facing south, to minimize variability due to sunlight or position.

6. Fruit Sampling from Bunches:

Dates are sampled evenly from the inner, middle, and outer spikelets of the selected bunch, ensuring morphological diversity within the bunch.

f. Sample Size

50 fruits per developmental stage

10 fruits from each of 5 different palms

Each group of 50 fruits is divided into 3 subsamples (replicates) for biochemical analysis

g. Harvest and Preservation Conditions

Fruits are hand-harvested in the early morning, placed in sterile paper bags, transported in a cooled container at 4 °C, and stored at -04 °C in the laboratory until analysis.

2.5 Physicochemical quality

a. morphological characterization of dates

The following analyses were conducted on a sample of 10 dates to calculate average values (Antame and Tama, 1997):
Color was assessed visually;
Consistency was evaluated by calculating the r index;
Dimensions were measured using a caliper, and the following ratio was calculated:

- **Length/width ratio = Date length (cm) / Date width (cm)**

The weight was determined using an analytical balance and the following indices were determined:

- **Pulp/date ratio = Weight of pulp / Weight of whole date (g);**
- **Stone/date ratio = Weight of stone (g) / Weight of whole date (g);**
- **Pulp/stone ratio = Weight of pulp (g) / Weight of stone (g).**

b. Water Content

Water content was determined using a 1 g aliquot of ground sample, which was spread in a glass capsule and dried in an oven at 103 ± 2°C until a constant weight was achieved.

c. Ash Content (NF V05-113, 1972)

The ground date pulp is incinerated at 550°C in a muffle furnace until a whitish ash of constant weight is obtained.

Procedure:

Weigh 2 g of ground date pulp into porcelain crucibles.
Place the crucibles in a muffle furnace preheated to 550 ± 15°C, and maintain for 5 hours, until a light gray or whitish ash is formed. Remove the crucibles from the furnace, cool them in a desiccator, and then weigh them.

d. Total Sugar Content (Dubois Method, 1956)

Principle:

The Dubois method is used to determine total sugars through a colorimetric reaction involving phenol and concentrated sulfuric acid. In the presence of these reagents, sugars produce a creamy yellow coloration, the intensity of which is directly proportional to the sugar concentration. Optical density is measured at 492 nm.

Procedure:

Sample Preparation:
Weigh 1 g of dried, ground date pulp.
Mix with 300 ml of distilled water and 3 g of calcium carbonate ($CaCO_3$).
Heat the mixture to boiling for 30 minutes, stirring continuously.
After cooling, dilute to 1 liter with distilled water.
Add an appropriate amount of lead acetate to the cooled mixture.
First Filtration:
This step aims to remove proteins by precipitation with lead acetate.
A small amount of potassium oxalate is then added to assist in removing excess lead.
Second Filtration:
The purpose of this step is to eliminate the excess lead precipitated by potassium oxalate.

1. Weigh 1 g of dried, ground date pulp;
2. Add to 300 ml of distilled water and 3 g of calcium carbonate ($CaCO_3$);
3. Heat the mixture to boiling for 30 minutes, stirring continuously;
4. Allow to cool, then dilute to 1 liter with distilled water;
5. Add an appropriate amount of lead acetate to precipitate proteins;
6. First filtration: remove the precipitated proteins;
7. Add a small quantity of potassium oxalate to eliminate excess lead;
8. Second filtration: remove the resulting precipitate. The clear filtrate is used for sugar analysis;
9. Establishing the Calibration Curve. To quantify the total sugar content, a standard curve is established using glucose solutions of known concentrations.

e. r Index:

Dates are classified into three categories dates soft, semi-soft, and dry based on the "r" index:

$$\text{r index} = \frac{\text{total sugar content}}{\text{moisture content}}$$

- Soft dates $r < 2$
- Semi-soft dates $2 < r < 3.5$
- Dry dates $r > 3.5$

f. Fat Content (NF EN ISO 734-1, 2000)

Principle:

Fats are organic compounds that can be extracted from fruit samples using non-polar organic solvents in a Soxhlet extraction apparatus.

Procedure:

1. Dry a 500 ml round-bottom flask in an oven at 100°C for 1 hour;
2. After cooling in a desiccator, weigh the empty flask with a precision of ±0.001 g;
3. Weigh 25 g of the dried, ground sample and place it into an extraction cartridge;
4. Insert the cartridge into the Soxhlet apparatus;
5. Pour 200 ml of petroleum ether into the flask and an additional 50 ml into the extractor;
6. Heat the system and perform extraction for hours, or until the fat content is completely extracted;
7. Remove the solvent by rotary evaporation;
8. Dry the flask at 70–80°C, then cool in a desiccator and weigh it to ±0.001 g;
9. Repeat the drying and weighing process until a constant weight is obtained.

The fat content is then calculated based on the weight difference before and after extraction.

g. Protein Determination

Proteins are quantified using the Kjeldahl method. The organic matter in the test sample is mineralized by the action of hot concentrated sulfuric acid in the presence of a catalyst. Organic nitrogen is converted into ammoniacal nitrogen, which is then distilled after alkalization with sodium hydroxide, and quantified via titration with sulfuric acid (after absorption in boric acid) in the presence of a color indicator.

In a digestion flask, 1 g of dates was mixed with a pinch of catalyst (copper and potassium sulfate) and 15 ml of pure sulfuric acid. The sample was then gradually heated: first a cold digestion for 15 minutes until white sulfur trioxide fumes appeared, followed by strong heating for 5 hours. When the solution became clear, it was cooled and diluted to 100 ml with distilled water.

Distillation was carried out using a semi-automatic distiller, adding 20 ml of 35% sodium hydroxide to the flask and using 25% boric acid in a 250 ml flask. The released ammonia was captured in the boric acid solution containing a color indicator (a mixture of methylene blue and methyl red). The excess ammonia was titrated with 0.05 N sulfuric acid using an automatic titrator (Boulkour, 2012).

2.9Statistical Analysis

To ensure the accuracy and reliability of the experimental results, all physicochemical analyses were conducted with an adequate number of replications for each parameter across the different ripening stages. The collected data were subjected to statistical treatment using one-way Analysis of Variance (ANOVA), a widely used method in biostatistics to determine whether there are statistically significant differences between the means of three or more independent groups. In this study, ANOVA enabled the comparison of key variables such as moisture content, pH, titratable acidity, sugar content, and fruit dimensions across the Loulou, Khalal, Bser, and Tmar stages. By minimizing variability within groups and maximizing differences between groups, this method enhanced the precision of the findings and contributed to more credible conclusions. Statistical significance was determined at the 5% probability level ($p < 0.05$), and when significant differences were detected, post-hoc tests were applied to identify the specific stages responsible for the observed variations.

3. RESULTS

2.10 Morphological Characteristics

The morphological characteristics of date fruits are summarized below, based on the mean values from ten replicates (Figure 01).

a. Color

Differences in date fruit color are attributed to variations in genetic makeup and biochemical composition.

Color is a critical and objective indicator of fruit quality, as it changes progressively with maturation and can signal freshness or spoilage to consumers (Romain, 2006). It also reflects underlying physiological and metabolic transitions occurring during ripening (Abdel Moneim et al., 2012).

Based on our observations, the fruit color at different ripening stages is as follows:
Loulou: the fruit is entirely covered by the perianth and presents a yellowish-green appearance.
Khalal: this stage is marked by a vivid green coloration.
Bser: the fruit begins to transition from green to pale yellow, reflecting early ripening.
Routab: during this stage, both color and consistency evolve. The upper part of the fruit retains the yellow tones of the Bser stage, while the lower part begins to darken and soften, showing early signs of the Tmar stage.
Tmar: this final ripening phase is characterized by a uniform brown coloration, which darkens further as sugars accumulate and moisture content decreases.

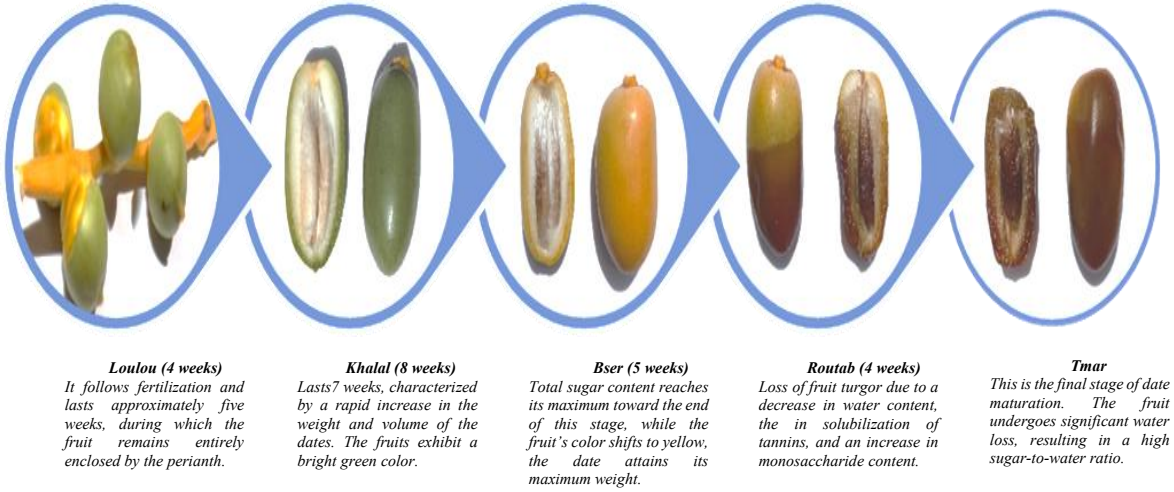

Figure 01. Morphological characteristics of the different fruit development stages of Hmira date variety

b. Consistency

Based on their moisture content and texture, dates can be classified into three main categories:
-Soft dates have a high moisture content and a very tender consistency, typically with a pulp-to-seed ratio less than 2.
-Semi-soft dates maintain a softer texture than dry types but have a slightly reduced moisture level, with a pulp-to-seed ratio between 2 and 3.5.
-Dry dates are naturally dehydrated and have a firm texture, with a ratio exceeding 3.5 (Munier, 1973). This classification remains relevant today, as moisture content continues to be a key criterion in postharvest handling and storage of date fruits (Al-Yahyai & Al-Khanjari, 2008).

c. Dimensions

Morphometric analysis was conducted to evaluate the physical characteristics of Hmira dates (Figure 02) , focusing primarily on fruit length and diameter. These parameters are crucial indicators of commercial value, influencing both consumer preference and market grading standards (El Hadrami & Al-Khayri, 2012).

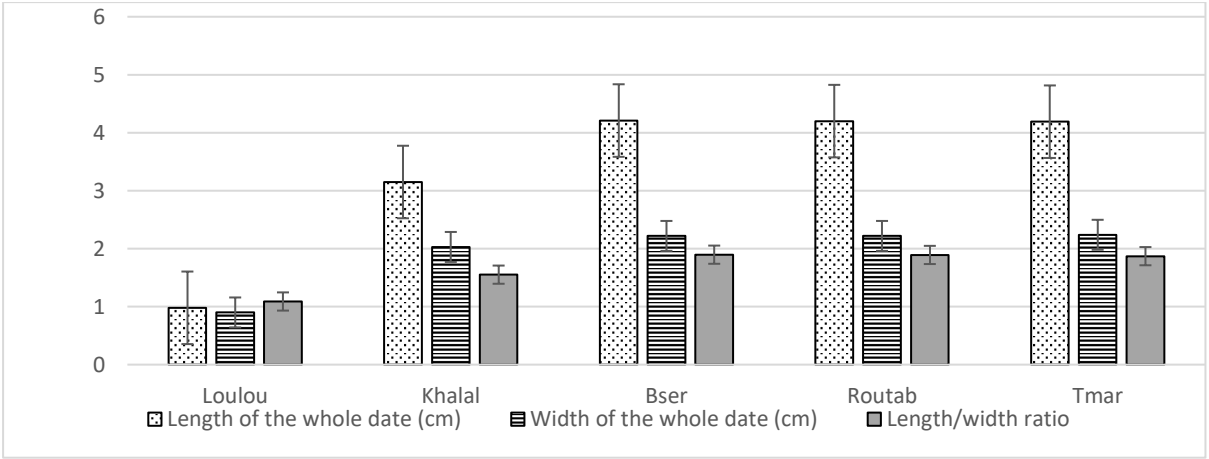

Figure 02. Evolution of Fruit Length During Maturation Stages of Hmira Dates

d. Weight

The weight characteristics of the dates are summarized in (Figure 03) below, based on the average of ten replicates. The parameters measured include whole fruit weight, pulp weight, and pit weight, along with derived ratios such as pulp-to-date, pit-to-date, and pulp-to-pit. These morphometric indicators are essential for assessing the fruit's physical composition and market value. In particular, the pulp-to-pit ratio serves as a key determinant of consumer appeal and processing suitability (Selim et al., 2020).

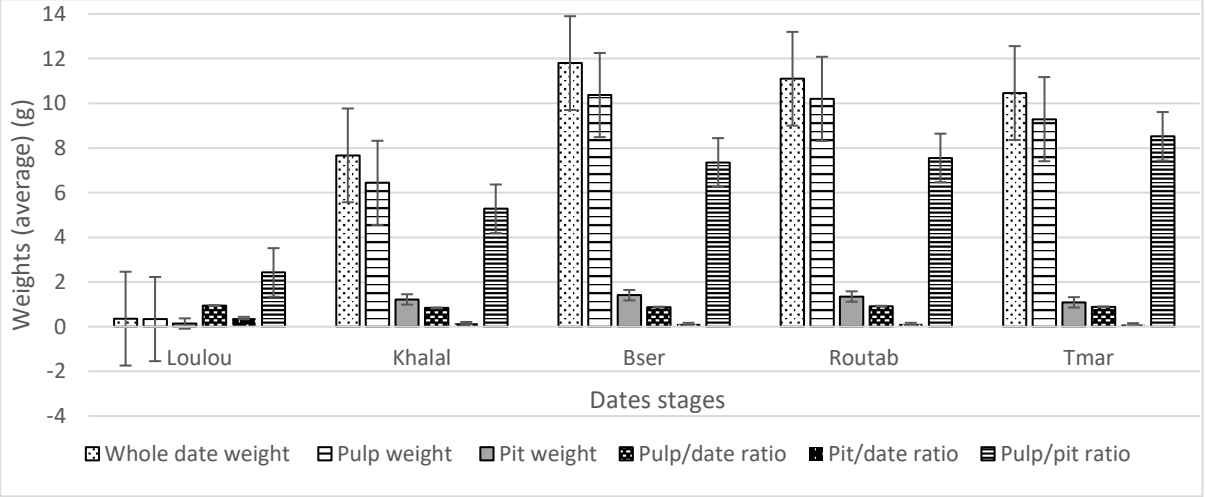

Figure 03. Variation in Fruit Weight Across Ripening Stages of Hmira Dates

2.11 Physicochemical Characteristics

a. Moisture Content:

Water is one of the essential components of the fruit. It plays a fundamental role in the quality of dates and significantly affects their preservation (Bensalah and Hellali, 2003).

It is noted that the moisture content varies considerably during ripening. It gradually increases from the end of the Khalal stage to the middle of the Bser stage, where softening has already begun. However, this same moisture content decreases rapidly during the Routab and Tmar stages (Figure 04).

Moisture content is a key parameter for determining and managing harvesting, storage, and preservation operations in a rational way (Meligi and Sourial, 1982)

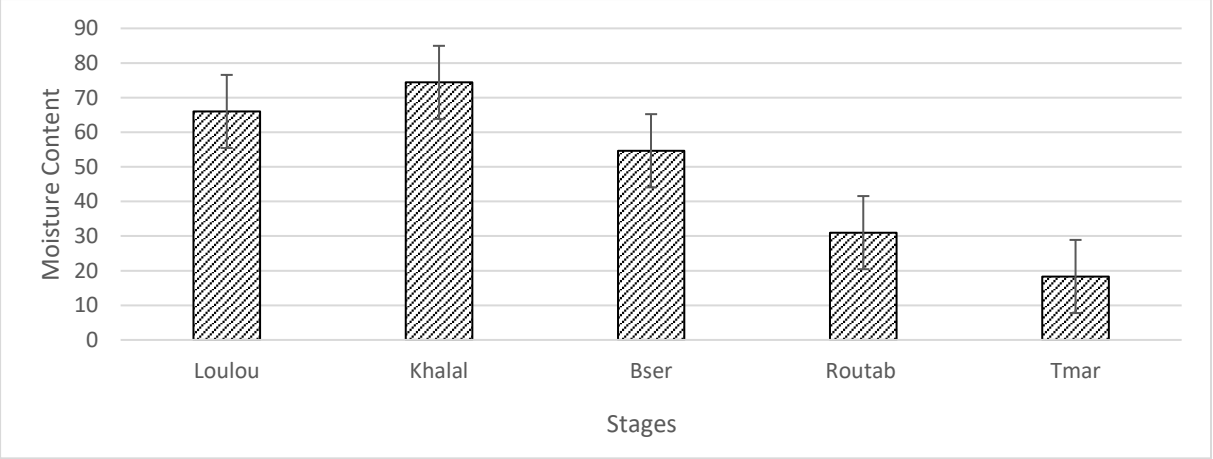

Figure 04. Moisture Content Variation at Different Stages of Ripening for of Hmira Dates

The results obtained in this study reveal moisture contents ranging from 18.33% to 74.33% (Figure 04), depending on the stage of ripening.

Among the various stages, Khalal recorded the highest moisture level at 74.33%, followed by Loulou at 66%. The Bser stage exhibited a reduced moisture content of 54.66%. At the final ripening stage, Tmar, the moisture level dropped significantly to 18.33%. This value is slightly below that reported by Makhloufi (2012) (21.90%) and closely aligns with the findings of Gourchala (2015) (18%).

Such variation in moisture content is largely influenced by multiple environmental and agronomic factors, including:

- Frequency and volume of irrigation;
- Agricultural practices and climatic conditions;
- Post-harvest storage conditions;
- Phytosanitary status of the palm tree;
- Timing and method of harvesting.

At the Tmar stage, the recorded moisture value (18.33%) aligns with the standards for good physical quality according to the Algerian national norm.

Previous studies support these findings. Hussein and Hussein (1983) emphasized the importance of irrigation practices during the Bser stage and the impact of relative humidity during harvest and storage. Similarly, Guerin et al. (1978) highlighted that relative humidity is a critical factor for maintaining product stability. According to Djerbi (1994), ambient humidity plays a determining role in the final texture of the fruit, whereby dates ripened in humid conditions tend to become soft, while those exposed to drier air develop a firmer consistency. Recent findings further confirm that environmental parameters such as irrigation frequency and air humidity substantially affect the moisture profile and textural quality of date fruits during ripening (Al-Harrasi et al., 2022).

b. Ash Content

The ash content of dates, which reflects their mineral composition, has been the subject of numerous studies. Several authors, including Matallah (1970), Munier (1973), Abdel Moneim et al. (1983), and Siboukeur (1997), have reported average values around 2%. In a study on Sudanese cultivars, Khatab et al. (1983) observed ash levels as high as 2.84%. Similarly, Sawaya (1983) noted that certain Saudi and Iraqi varieties may exhibit elevated ash content, ranging between 2% and 4%.

In the present study, ash content varied significantly across the ripening stages of the dates under investigation (Figure 05). The Loulou stage showed the highest value at 7%, followed by Khalal (4%), Bser (2%), Routab (1.5%) and Tmar (1.5%). These results suggest that early-stage consumption (particularly at Loulou) could offer a richer intake of essential minerals.

Furthermore, the ash content recorded at the Tmar stage (1.5%) closely aligns with findings from Boulerbage and Benbellal (2017), who reported values of 1.69% for Hmira and 1.5% for Feggous cultivars. This trend is consistent with recent reports emphasizing that mineral concentration in dates tends to decrease progressively as ripening advances, likely due to dilution effects and metabolic changes (Al-Zoreky & Al-Taher, 2021).

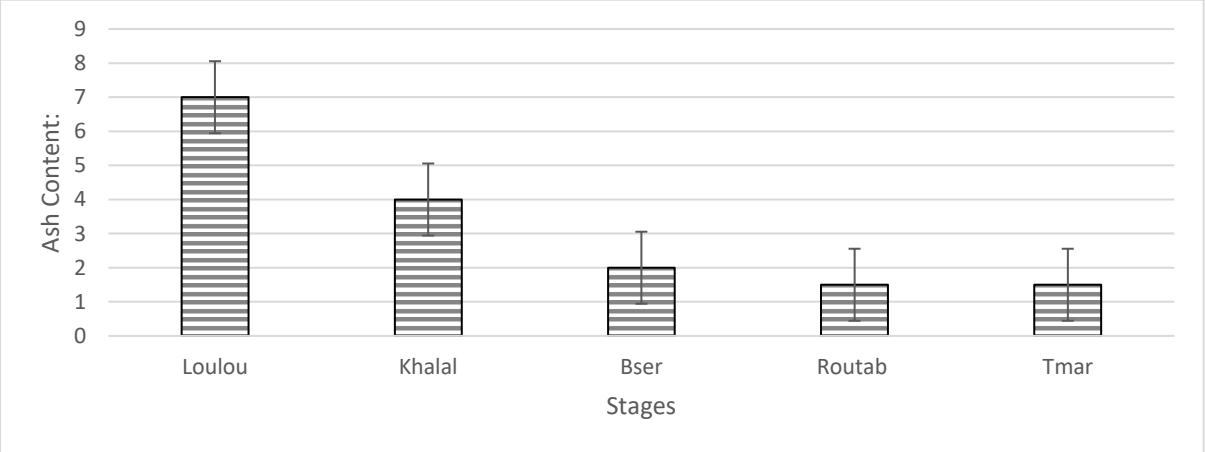

Figure 05. Ash Content Reduction Across the Ripening Stages of Hmira Dates

Our results indicate lower ash values compared to those previously reported for several North African date varieties. For instance, Hasnaoui et al. (2010) documented ash contents ranging from 3.46 ± 0.01% in the pulp of Tadmamt to 2.15 ± 0.05% in Taâbdount, both Moroccan cultivars. Similarly, Abdelmoneim et al. (2012) observed values between 2.53% for Gondeila and 3.20% for Black Gau among Sudanese varieties.

Comparable variation was reported by Acourene et al. (2001), who analyzed several Algerian cultivars from the Zibans region. Their study revealed ash contents ranging from 3.7% in Bent-Merague to as low as 1.1% in Laoun-Bouarrous, underscoring significant inter-cultivar variability. These discrepancies are frequently attributed to environmental factors, particularly soil salinity, which is notably high in the Zibans region and can influence mineral uptake by date palms.

More recently, studies have confirmed that soil composition, water quality, and climatic stress play crucial roles in modulating ash content in date fruits, emphasizing the importance of local agro-ecological conditions in determining mineral accumulation patterns (Ahmed et al., 2021).

c. pH

pH is one of the key parameters that determines the preservation potential of food. It represents a major barrier that microbial flora must overcome to proliferate (Giddey, 1982; Gatel, 1982; Brissonet et al., 1994). A pH range between 3 and 6 is particularly favorable for the development of yeasts and molds. These microorganisms can cause spoilage, especially affecting the organoleptic quality of the product (Bourgeois et al., 1988).

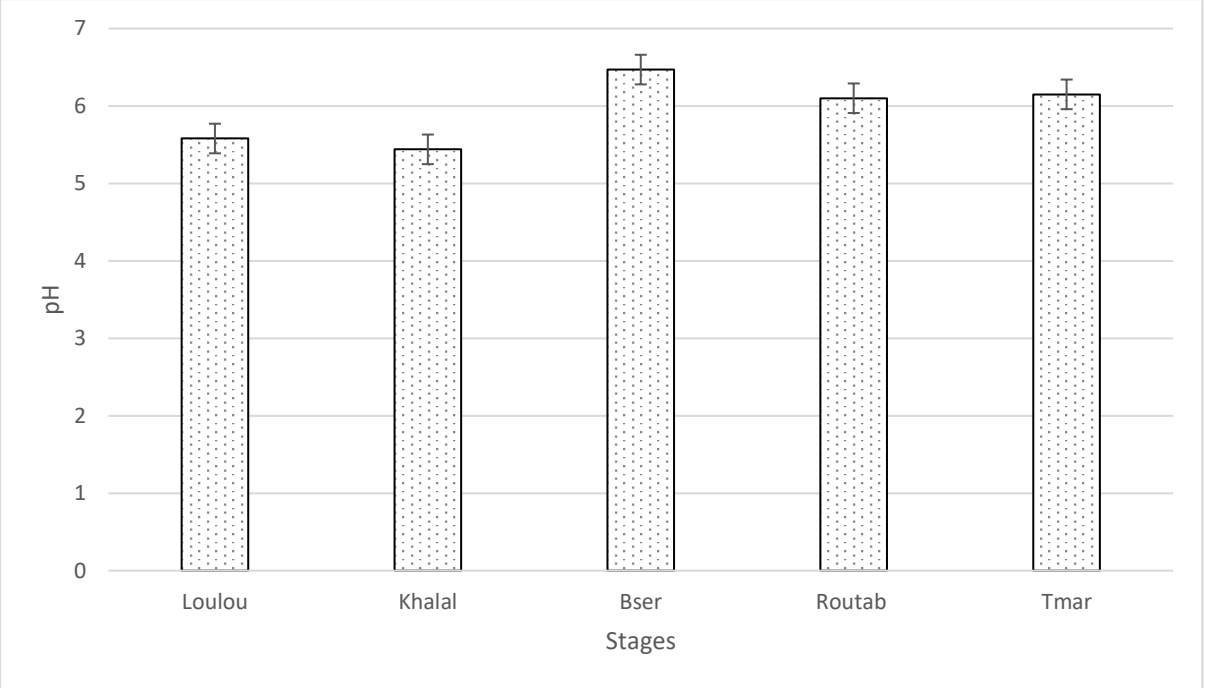

Figure 06. pH Fluctuation During Ripening of of Hmira Dates

The pH values observed during the different ripening stages of the studied dates range from 5.44 to 6.47. Specifically, the recorded values were: Loulou (5.58), Khalal (5.44), Bser (6.47), Routab (6.01) and Tmar approximately 6.15 (Figure 06). According to quality standards, the pH recorded at the Tmar stage reflects good physical characteristics.

These findings are consistent with the pH range reported for some Algerian date cultivars by Benmeddour (2016), which varied between 5.15 and 6.81. However, our values are slightly higher than those documented for Tunisian varieties by Besbes et al. (2009), who found pH values ranging from 5.63 to 5.79. Similarly, Djoudi (2013) reported values close to ours in several Algerian varieties: Bayh El Ghoul (6.4), Hamrayat El Gaid (6.3), and D'guel Melk Lahcene (6.2).

This variation in pH levels may result from multiple factors including harvest time, storage conditions, and environmental influences, which are known to affect the chemical composition of the fruit.

d. Titratable Acidity

Titratable acidity, reflecting the concentration of organic acids, is a key parameter influencing both microbial stability and sensory characteristics of dates. Organic acids are essential intermediates in metabolic pathways and play a pivotal role in the ripening and senescence of fruits (Al-Farsi et al., 2005). They also modulate taste and contribute to the organoleptic profile (Jadhav, 1997; Siebert, 1995, cited in Djoudi, 2013).

The composition and concentration of these acids are affected by several variables such as cultivar, growth conditions, season, geographical origin, soil type, and exposure to sunlight (Ahmed et al., 1995).

In the present study, titratable acidity increased progressively during ripening (Figure 07), from 0.19% at the Loulou stage to 0.3% at the Tmar stage. The final acidity value is consistent with those reported by Acourene et al. (1997) for Algerian dates, which ranged from 0.1% to 0.3%. Our findings also slightly exceed the values found in Egyptian varieties such as Siwi and Amhat, which were between 0.1% and 0.22% (Khalil et al., 2002; Youssef et al., 1992).

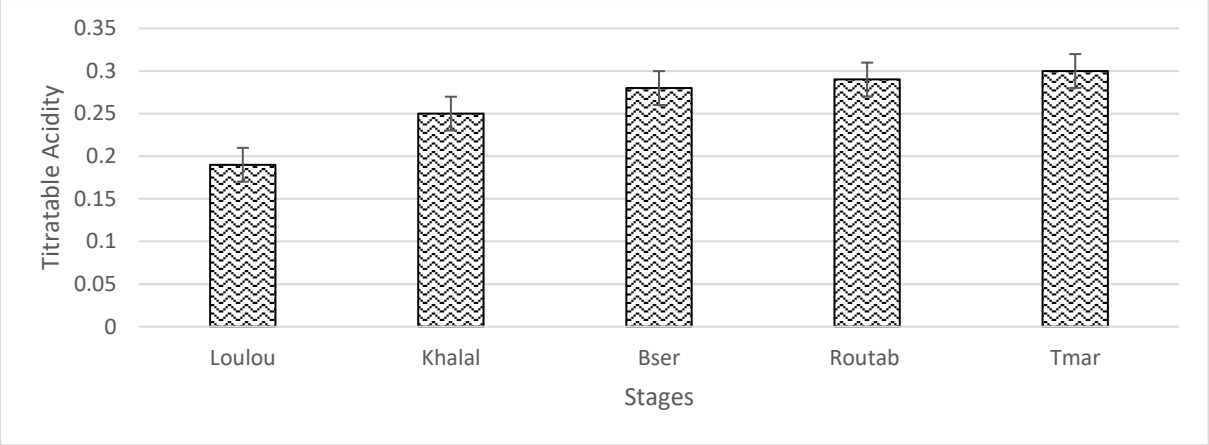

Figure 07. Changes in Titratable Acidity Throughout Fruit Development of Hmira Dates

e. Total Sugar Content

Sugars are the primary contributors to sweetness in dates, and their proportion in fruit is markedly higher than that of other constituents. They occur mainly as sucrose and reducing sugars (Amellal, 2008). Sugars play an essential role nutritionally by providing energy, sensorially by improving texture and color, and technologically by acting as a preservative through water activity reduction (Romain et al., 2006,)

According to our sugar analysis (Figure 08), total sugar content increases from about 6.8% at the early stages to 77.6% at the Tmar stage. This high value at Tmar aligns with typical patterns observed in ripening dates. Most literature reports sugar contents in the range of 60% to 80% at advanced maturity. For example, Sawaya et al. (1982) and Lambiotte (1983) found similar levels, as did Favier (1993) and Makhloufi (2012), confirming a consistent ripening-dependent sugar accumulation trend.

More recent compositional analysis across ten cultivars showed very high sugar concentrations between 71.2% and 81.6% in ripe dates, reinforcing our findings (Assirey et al., 2015)

The variability in sugar content across studies is also attributed to cultivar differences, growing climate, and ripening progression points well documented by Munier (1973), Nixon et al. (1978), and Sawaya et al. (1983). Finally, total sugar content surpassing 70% is widely accepted as an indicator of good quality in dates.

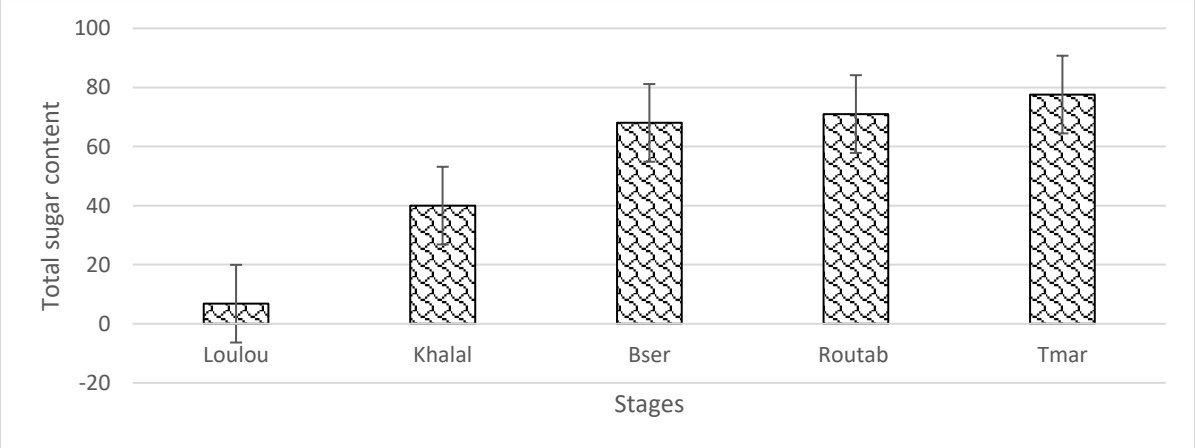

Figure 08. Total Sugar Content Accumulation During Ripening of Hmira Dates

f. r - Index:

The ratio of total sugar content to moisture content gives the r index (sugar content/moisture content), which ranged between 0.1 and 4.23 (Figure 09). Our results for the four developmental stages are as follows: Loulou 0.1, Khalal 0.54, Bser 1.24, Routab 2.29 and Tmar = 4.23.

According to the r index, dates are classified into three texture-based categories:

Soft dates $r < 2$

Semi-soft dates $2 < r < 3.5$

Dry dates $r > 3.5$

Based on the classification standards, the Tmar stage of Hmira dates harvested from Igli region, with an r

value of 4.23, is therefore categorized as dry dates (stored Hmira).

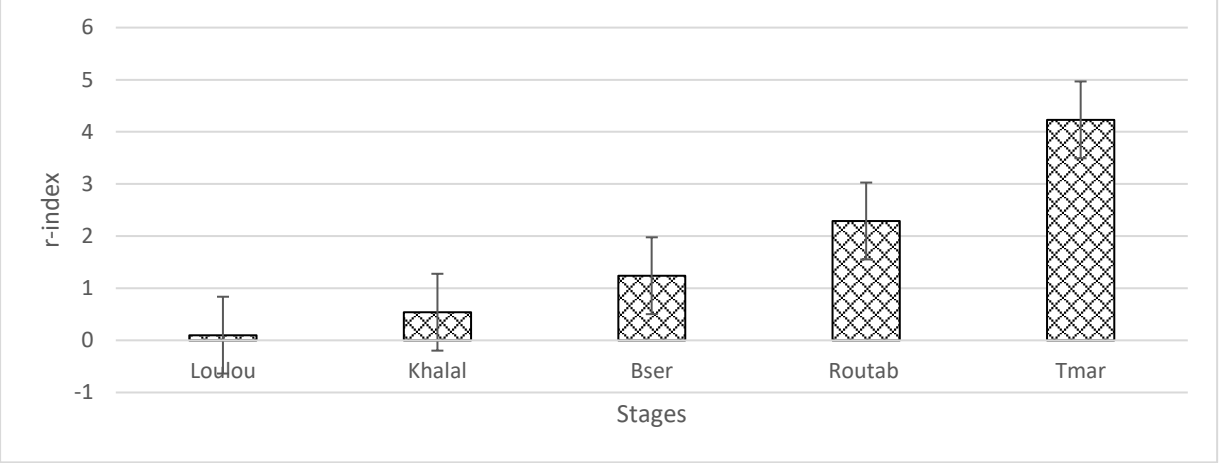

Figure 09. Evolution of the "r" Index (Total Sugars / Moisture) Across Repining Stages of Hmira Dates

g. Fat Content

The lipid content results for Hmira dates are presented in Figure 10.

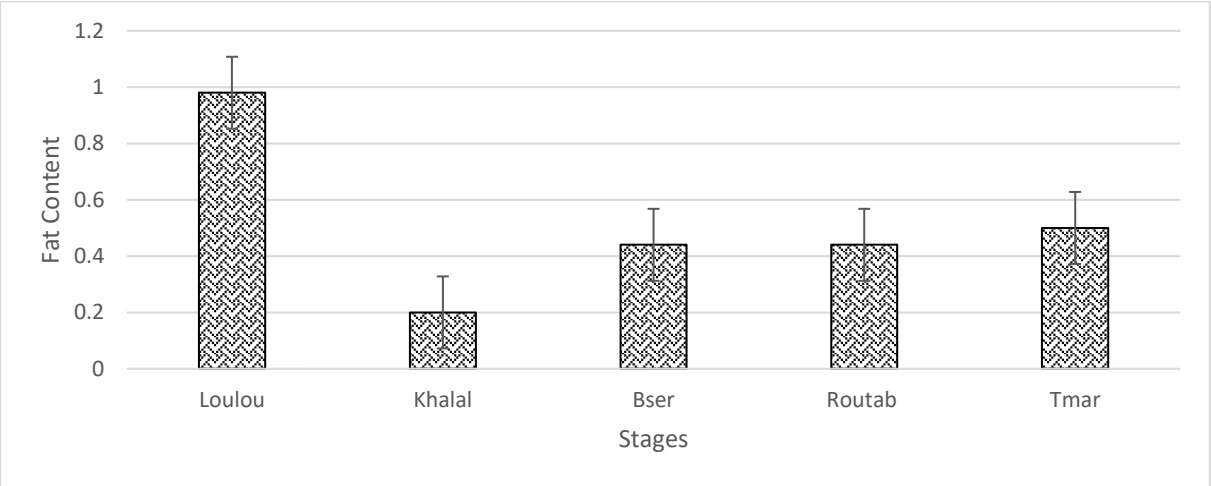

Figure 10. Fat Content Variation Across Hmira Dates Maturation

The fat content of Hmira dates during ripening ranged from 0.2% to 0.98% (Figure 10). At the Tmar stage, the fat level was approximately 0.5%, which aligns with previous findings reported for Emirati date cultivars, ranging between 0.2% and 0.5% (Al-Hooti et al., 1998; Al-Farsi et al., 2007).

According to Matallah (1970), the lipid content in dates is generally low and does not exceed 1.5%. Several studies have confirmed these observations, including Sawaya et al. (1982) who reported fat contents between 0.5% and 0.9% in various date varieties. Similarly, Youssef et al. (1982) (cited in Amellal, 2007) recorded values ranging from 0.3% to 0.5%, while Belitz et al. (2009) emphasized that the lipid fraction in dates rarely surpasses 0.5% of the total composition.

More recent studies support these values. For example, Habib and Ibrahim (2009) analyzed several date cultivars from the Arabian Peninsula and reported fat contents between 0.2% and 0.7%, while Al-Harrasi et al. (2014) noted that fat content in Omani dates typically falls below 1%, reinforcing the low-lipid profile of dates in general.

Interestingly, the highest fat content was recorded at the Loulou stage. This may be explained by the presence of the developing pit, which remains closely adhered to the mesocarp and is difficult to separate at this early stage. Consequently, this physical fusion may lead to an overestimation of fat content during the analytical process, as the pit contributes lipids not solely attributable to the edible pulp (Kader, 2006; Al-Farsi et al., 2005).

h. Protein Content

The protein content obtained for the Hmira cultivar in this study was 2.07%, placing it within the average range reported in the literature for various date palm cultivars. Al-Hooti et al. (1997) reported protein levels between 1.5% and 2.5% for five date varieties from the United Arab Emirates. Similarly, Al-Farsi and Lee

(2008) observed a range of 1.2% to 2.8% among several Omani cultivars. In Sudanese dates, Fadoul et al. (2012) recorded protein contents from 1.55% to 2.20%, while Mohamed et al. (2016) reported values between 1.32% and 2.45% for Saudi Arabian varieties.

Additional studies confirm these findings. For instance, Habib and Ibrahim (2009) analyzed the nutritional composition of various date seeds and found protein levels ranging from 1.7% to 2.2%. Al-Shahib and Marshall (2003) also noted that the protein content of edible date fruit could reach up to 2.5%, depending on the variety and stage of ripening.

Therefore, the protein value of 2.07% recorded for Hmira (Figure 11) supports its nutritional quality, placing it within the expected norms and confirming its relevance in local diets. These results underline the potential of Hmira dates with other cultivars to significantly contribute to the dietary protein intake of populations in oasis and arid zones, particularly where alternative protein sources may be limited (Baliga et al., 2011; El Hadrami & Al-Khayri, 2012; Ghnimi et al., 2017).

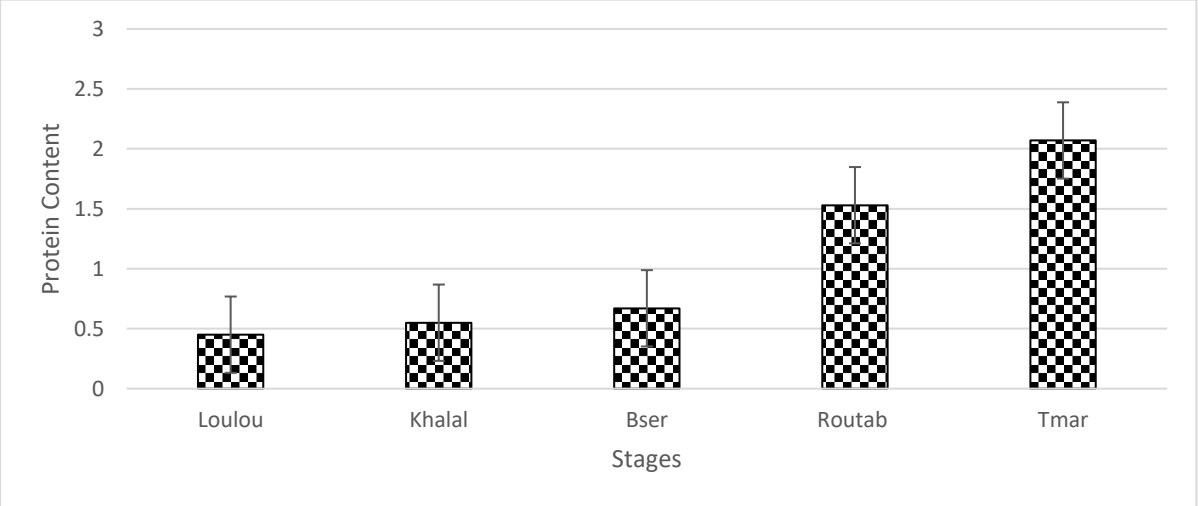

Figure 11. Protein Content Variation Across Ripening Stages of Hmira Dates

2.12 Evolution of Physicochemical Composition During the Different Stages of Fruit ripening

Following pollination in early spring, flower buds emerge, and the pedicels of the date bunch start to elongate. At the Loulou stage, the pedicel length reaches an average of 9.89 cm, and the fruit exhibits a green coloration, attributed to a high concentration of chlorophyll pigments (El Hadrami & Al Khayri, 2012). During this phase, photosynthetic activity facilitates the accumulation of primary metabolites such as sugars, proteins, and lipids, which progressively increase as the fruit matures. These biochemical constituents generally reach maximum levels at the Bser stage in our study, sugars peaked at 77.6%, fat at 0.98%, and ash at 7%.

This trend is consistent with earlier findings by Rygg (1946) and corroborated by recent studies highlighting a clear increase in sugar content and decrease in moisture during fruit ripening (Al-Farsi & Lee, 2008; Ghnimi et al., 2017). The final stage, Tmar, is characterized by a high sugar concentration and significant water loss, leading to textural softening and sweetness enhancement (Baliga et al., 2011).

According to Rygg (1946), several physiological and chemical transformations take place throughout fruit development:

a. Size:

At stage I (Loulou), the fruit is roughly the size of a pea. It then undergoes rapid cell expansion and elongation during stage II (Khalal), eventually reaching its full size. This phenomenon is linked to the mobilization of photoassimilates and the activation of growth regulators such as auxins and gibberellins (Reynolds & D'Antuono, 2021).

b. Weight:

The initial fruit weight is typically less than 1 gram, but it increases significantly by the end of stage II (Khalal) or early stage III (Bser). Subsequently, a decline in turgor and water content occurs, resulting in weight stabilization or a slight reduction during stage V (Tmar). This dynamic is well documented in several cultivars across arid regions (Al-Hooti et al., 1997; Habib & Ibrahim, 2009).

c. Sugar and Tannin Content:

As the fruit enters stage II (Khalal), starch is enzymatically converted into simple sugars, notably glucose

and fructose, with total sugar content peaking at stage III (Bser). However, sugar evolution follows a non-linear pattern, influenced by enzymatic activities and varietal differences (Ghnimi et al., 2017; Mohamed et al., 2016). Meanwhile, tannins, responsible for the astringent taste of immature dates, begin to polymerize and become insoluble at the end of stage III (Bser) or the beginning of stage IV (Routab), leading to reduced astringency and a sweeter taste profile (Al-Shahib & Marshall, 2003).

d. Color:

At fruit set, the date is whitish to light green, progressively turning a deeper green throughout stage II (Khalal) due to chlorophyll retention. As the fruit transitions to stage III (Bser), it begins to show varietal-dependent color changes shifting toward yellow, red, or brown. This color evolution initiates at the apex and gradually spreads downward, eventually homogenizing across the entire fruit surface (Cavell, 1947; Turrell, 1940; Bakkaye, 2006). Recent studies have attributed these changes to the degradation of chlorophyll and the biosynthesis of carotenoids and anthocyanins, which vary by genotype and environmental conditions (Ahmed et al., 2021; Kchaou et al., 2021).

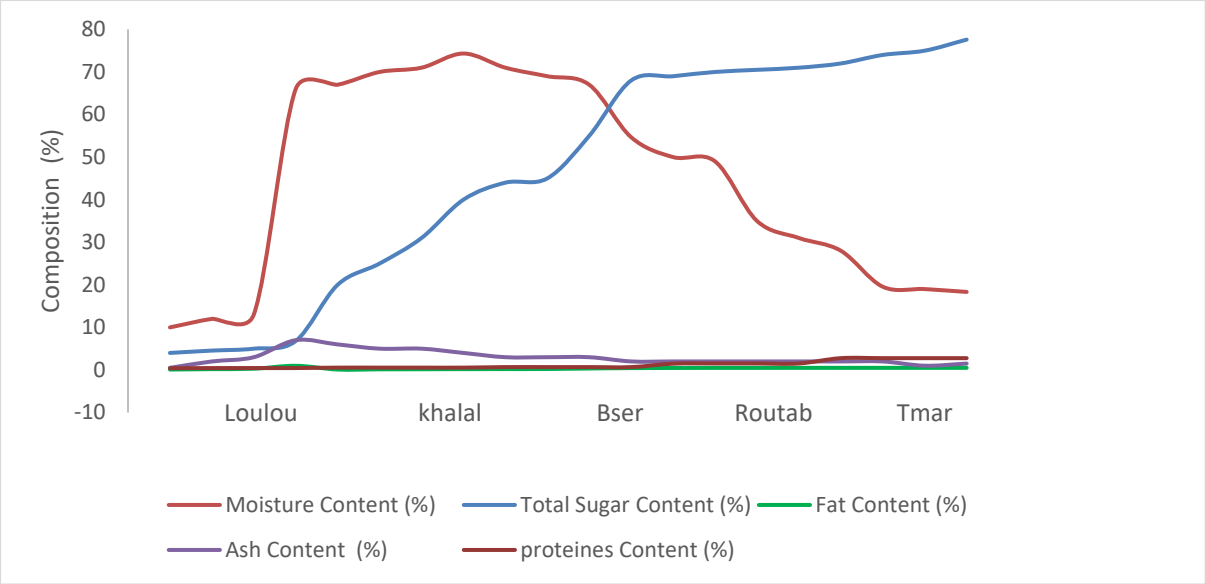

Figure 12. Summary of Physicochemical Composition Across Developmental Stages

3 CONCLUSION

This study aimed to characterize the physicochemical evolution of Hmira dates during five key ripening stages Loulou, Khalal, Bser, Routab and Tmar in the arid region of Igli, southwestern Algeria. The research focused on a set of essential parameters: fruit weight and dimensions, color, moisture content, pH, titratable acidity, protein content and total sugar content.

These physical and chemical assessments are essential not only for ensuring quality control and meeting both national and international classification standards (Al-Farsi et al., 2005; Baliga et al., 2011), but also for determining nutritional value and raising public awareness regarding the health benefits of date consumption, especially during early ripening stages.

The findings demonstrate that:

Morphometric traits showed significant development: fruit weight increased from 0.36 g to 11.8 g, length from 0.98 cm to 4.19 cm, and width from 0.90 cm to 2.24 cm.

Moisture content was highest at the Khalal stage (74.4%) and decreased significantly at the Tmar stage (18.33%), consistent with dehydration processes typical of fruit maturation (Al-Hooti et al., 1997).

pH values ranged from 5.44 to 6.47, with Bser exhibiting the most alkaline conditions yet remained within the acidic domain, as expected in ripening fruits.

Fat content varied from 0.2% to 0.98%, confirming previous findings by Sawaya et al. (1982) and Belitz et al. (2009) on the low lipid concentration in dates.

Titratable acidity increased during ripening, from 0.19% to 0.3%, while ash content decreased from 7% to 1.5%, indicating ongoing metabolic transformations.

Total sugars, a major determinant of flavor and texture, increased substantially. Using the "r index" (total sugar/moisture), the Hmira dates were classified as dry, with values exceeding 3.5 in line with

international standards (FAO, 2020).

Despite constraints related to the limited analytical capacity of local academic laboratories, this study provides a comprehensive overview of the physicochemical dynamics of the Hmira cultivar during maturation.

To strengthen and expand upon the current work, we propose the following recommendations:

Complete the physicochemical profile by analyzing remaining nutritional components, such as dietary fiber, micronutrients, and antioxidant compounds;

Investigate the effect of post-harvest storage on physicochemical stability and nutritional retention;

Incorporate advanced biochemical assays to evaluate protein and vitamin content more precisely;

Extend the study to include other cultivars from the region to enable comparative profiling;

Raise awareness among the local population about the importance of consuming dates, particularly at the Bser and Routab stages, given their elevated sugar, mineral, and hydration levels (El Hadrami & Al Khayri, 2012; Mohamed et al., 2016);

Encourage the promotion of dates, in all stages of ripeness, as a natural alternative to processed foods associated with chronic health conditions such as obesity, diabetes, and certain cancers (Baliga et al., 2011; Guo et al., 2022).

In conclusion, the Hmira date cultivar represents a valuable local resource with promising nutritional potential. Promoting its consumption and valorization through scientific analysis and public education could significantly contribute to food security and public health in arid and semi-arid regions.

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