

A Comparative Study of the Physicochemical and Nutritional Properties of Moroccan Picholine Olives and Related Varieties: A Pathway to Development and Improvement

Oumaima Mrabet^{1a}, Bouchaib Bahlaouan^{1,2b}, Said El Antri^{1c}, & Nadia Boutaleb^{1d*}

¹Laboratory of Biochemistry, Environment and Agri-Food, Hassan II University, Faculty of Science and Technology, Casablanca, Morocco

²Laboratory of Healthcare and Sustainable Development, Higher Institutes of the Nursing Professions and Techniques of Health, Casablanca, Morocco

^aORCID:0009-0003-6582-5994; **Email:** oumaima.mrabet@etu.fstm.ac.ma;

^bORCID:0000-0002-0976-1274; **Email:** b.bahlaouan@ispitcasa.ac.ma;

^cORCID:0000-0003-3534-2476; **Email :** said.elantri@fstm.ac.ma;

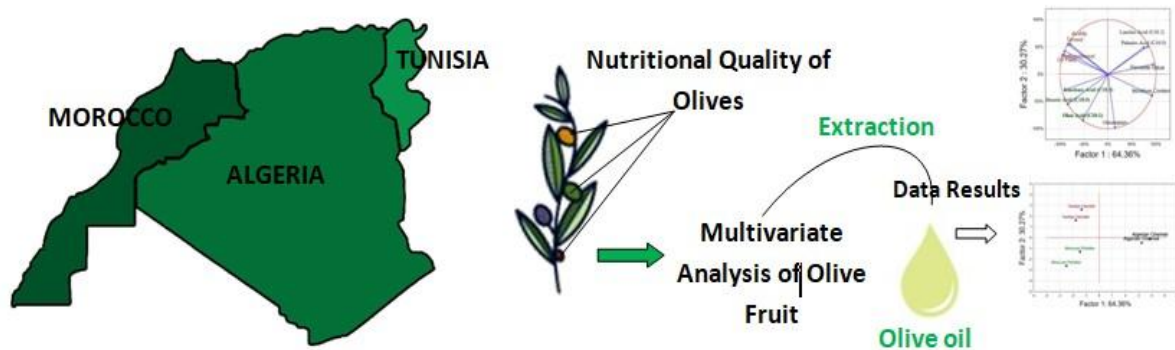
^dORCID:0000-0003-1628-4311; **Email :** nadia.boutaleb@fstm.ac.ma;

***Corresponding author:**

Prof. Nadia Boutaleb; **email address:** nadia.boutaleb@fstm.ac.ma

Graphical Abstract

This research focuses on a comparative study of the nutritional quality of olives in Maghreb countries (Morocco, Algeria, Tunisia). It combines multivariate analysis of olive fruits, olive oil extraction, and data interpretation through advanced statistical tools. The study adopts a regional approach to valorise olives and their derived products, providing valuable insights for improving production processes and enhancing the quality of olive oil.



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Abstract: Understanding the quality of Moroccan Picholine olives is essential for both consumers and producers. This study investigates their physicochemical and nutritional properties, comparing them to neighbouring varieties: Tunisian Chemlali and Algerian Chemlal. Our analysis reveals that Moroccan Picholine olives have a significantly higher oleic acid content (68.47%), associated with cardiovascular health benefits, compared to lower levels in the other varieties. Additionally, they demonstrate superior oleuropein levels (167.81 mg.kg⁻¹), a phenolic compound linked to antioxidant properties, while showing potential for increased hydroxytyrosol content. Quality assessments indicate moderate moisture content (53.66%) and acidity (0.29%), alongside a competitive oil yield (42.32%) and low peroxide value (4.37 meq/kg), suggesting good oil freshness. These findings highlight the nutritional advantages of Moroccan Picholine olives and propose strategies for enhancing cultivation and processing methods to elevate their quality and market position.

Keywords: Moroccan Picholine, Nutritional properties, Market differentiation.

Introduction

The olive tree holds a distinguished position within Mediterranean cultures and territories, to the extent that it is often regarded as the quintessential indicator of the Mediterranean climate zone. Once climatic conditions allow, olive trees are promptly planted and become a prominent feature of the landscape. They define the Mediterranean region in which they thrive. Different olive varieties are valued for their unique characteristics, such as flavour, oil yield, and disease resistance. These attributes influence their suitability for various products, including table olives and olive oil, and play a significant role in their economic impact within the agricultural sector [1].

In Morocco, the olive tree accounts for 65% of the total tree-growing area, covering 1,045,186 ha. Of this, 37% (384,528 ha) is irrigated, while 63% (660,658 ha) is non-irrigated. In terms of production, 65% of olives are used for pressing, 25% for canning, and the remaining 10% is allocated to losses and domestic consumption [2]. Moreover, olive cultivation is a vital socio-economic sector, accounting for up to 5% of the agricultural GDP and 15% of the country's agricultural food exports [3]. It stands out in the Mediterranean olive-growing landscape with its unique varietal profile. Despite having several local varieties, the 'Moroccan Picholine,' locally known as 'Zeitoun' or 'Zeitoun Beldi,' remains the dominant variety [4]. The Ministry of Agriculture's technical services designate this variety as 'Moroccan Picholine' (PM) and estimate that it comprises at least 92% of the olive trees in Moroccan orchards.

Moroccan Picholine olives are celebrated for their distinctive flavour, making them highly sought after in both domestic and international markets. Their unique taste and texture make them ideal for use in table olives as well as in olive oil production [5]. This variety thrives in Morocco's particular climatic and soil conditions, which imparts distinctive physicochemical properties. Attributes such as oil content, acidity, and flavour profile are essential for assessing their quality and determining their suitability for various applications. The nutritional profile, including fatty acid composition and antioxidant content, has implications for health and wellness [6]. Understanding the physicochemical and nutritional properties of Moroccan Picholine in comparison to neighbouring varieties will help producers better position their product in the market based on quality, taste, and health benefits [7]. By evaluating the environmental impact of different olive varieties, such as water use and soil management, it is possible to adopt more sustainable practices. This can help in reducing the environmental footprint of olive cultivation [8].

The physicochemical properties of olive oils and their abundance of bioactive components have a major impact on their nutritional value. Key ingredients that contribute to their health benefits include

fibre, vitamin E, and oleic acid. Oleic acid, a monounsaturated fatty acid, is well-known for its cardio protective properties, as it lowers bad cholesterol and promotes overall heart health [7]. Furthermore, hydroxytyrosol and oleuropein, two phytochemicals found in abundance in olive oils, have anti-inflammatory and antioxidant qualities that can reduce oxidative stress and the risk of developing chronic illnesses. The fibre content of olives adds to their health benefits by fostering satiety and supporting digestive health. Establishing a clear classification system based on these parameters can better highlight the nutritional advantages of olive oils and help consumers make informed choices, ultimately showcasing the potential for particular kinds, such as Moroccan Picholine olives, to stand out in the market [6].

The aim of this study is to comprehensively evaluate and compare Moroccan Picholine olives with selected neighbouring olive varieties across several key dimensions. This includes assessing and contrasting their physicochemical characteristics, such as oil content and acidity, alongside their nutritional profiles, including levels of vitamins, minerals, and antioxidants. The study also seeks to analyse the economic implications and market potential for Moroccan Picholine olives, focusing on production costs, market prices, and consumer preferences. Additionally, the research will explore the agricultural requirements and adaptability of these olives, examining factors such as soil and climate needs, and resistance to diseases and pests. Finally, the study aims to identify and promote sustainable cultivation practices by evaluating resource use efficiency and environmental impact, thereby providing valuable insights for enhancing olive production and market strategies

Materials and Methods

Date and Period of Study

The study was conducted over a period of six months, from november 2022 to june 2023. This timeframe allowed for comprehensive data collection on the physicochemical and nutritional properties of Moroccan Picholine olives, as well as for their comparison with neighbouring varieties, Tunisian Chemlali and Algerian Chemlal. The extended duration was essential to ensure that seasonal variations and environmental factors were adequately accounted for in the analysis

Sample Collection

In this study, the olive varieties selected for comparison include Moroccan Picholine olives, along with several neighbouring varieties, such as Algerian Chemlal and Tunisian Chemlali. Moroccan Picholine olives are celebrated for their unique flavour profile and culinary versatility. Grown predominantly in

the fertile regions of Morocco, these olives are prized not only for their taste but also for their high-quality oil, which is rich in healthy monounsaturated fats. As represented in Figure 1, Moroccan Picholine olives are often harvested at various stages of ripeness, allowing producers to create a range of products, from table olives to premium olive oil. Their firm texture and distinctive green hue make them a popular choice in Mediterranean cuisine, while their nutritional benefits, including antioxidants and healthy fats, contribute to their growing popularity in health-conscious markets.



Figure 1. Moroccan Picholine Olives tree.

Samples were collected from local olive farms in the Fes-Meknes and Gharb regions of Morocco (Figure 2). These locations were selected to reflect the diverse growing conditions and agricultural practices characteristic of the country's olive cultivation. This focus on Moroccan Picholine olives enabled an in-depth analysis of their unique physicochemical and nutritional properties.

Description Sites

The study was conducted in two major olive-growing regions of Morocco: the Fes-Meknes region and the Gharb region.



Figure 2. Geographic regions of high-quality Moroccan Picholine olive production.

Fes-Meknes Region

Located in central Morocco at approximately $34^{\circ} 02' 00''$ N, $5^{\circ} 00' 00''$ W, this region features rolling hills and varied topography, creating diverse microclimates ideal for olive cultivation. With elevations ranging from 400 to 1200 metres above sea level, it benefits from rich soil and ample sunshine, supporting the growth of high-quality Moroccan Picholine olives. Cooler temperatures at higher elevations and warmer, more humid conditions in the valleys further enhance this favourable environment for olive production [7].

Gharb Region

Renowned for its fertile plains, the Gharb region is located in north-western Morocco at approximately $34^{\circ} 15' N$, $6^{\circ} 35' W$. This area benefits from alluvial soil enriched by the Oued Bouregreg river, which provides excellent drainage and nutrient availability for olive cultivation. The Mediterranean climate, characterised by mild, wet winters and hot, dry summers, creates optimal conditions for the growth and ripening of olives. Additionally, the region's flatlands facilitate mechanised farming practices, enhancing productivity and making it ideal for cultivating various olive varieties, including Moroccan Picholine [1].

Physicochemical Properties

Oil Extraction

The oil was extracted using the cold pressing method, which preserves the natural flavours and nutritional properties of the olives. This technique involves mechanically crushing the olives at low temperatures to maintain the integrity of the oil's bioactive compounds. The extraction process utilised a hydraulic press, which efficiently crushes the olives, followed by a decanter centrifuge that separates the oil from the solid and aqueous phases. This combination of equipment ensures the production of high-quality extra virgin olive oil [9].

Oil Yield

Olives are first washed, sorted, and then crushed into a paste. The paste is then subjected to mechanical pressing or cold extraction methods to separate the oil from the solid materials. The yield is calculated based on the weight of the extracted oil relative to the initial weight of the olives [9].

Storage Conditions Prior to Analysis

The oil was stored at a temperature of 15-20°C in dark glass bottles. These conditions were selected to protect the oil from exposure to light and air, ensuring its quality and stability prior to analysis.

Acidity

A sample of olive oil is mixed with a solvent (e.g., ethanol or hexane) and titrated with a sodium hydroxide (NaOH) solution. The acidity is determined by the volume of NaOH required to neutralise the free fatty acids in the oil and is expressed as a percentage of oleic acid [10].

Peroxide Value

A sample of olive oil is reacted with an iodine solution, and the peroxide value is determined by titrating the excess iodine with a sodium thiosulphate solution. This measures the concentration of peroxides, which are indicators of oxidation [10].

Phenolic Compounds

Olive oil is prepared and analysed using HPLC to separate and quantify phenolic compounds, which are important for flavour and antioxidant properties [11].

Fatty Acid Composition

The olive oil sample is trans esterified to convert fatty acids into fatty acid methyl esters (FAMES). These FAMES are then analyzed by gas chromatography to determine the fatty acid profile [9].

Moisture Content

Moisture content is determined by oven-drying for 24 h at 105°C [12].

Nutritional Analysis

Table 1. Methods and references for the analysis of physicochemical and nutritional properties of Moroccan Picholine Olives

Parameter	Method	Reference
Vitamin: A, E, k	Vitamins A and K were determined according to the modified AOAC method. Vitamins E by HPLC	[12-13]
Minerals: Ca, Fe, K, Mg	Utilize Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or Atomic Absorption Spectroscopy (AAS)	[14]
Fatty acid	Analyze using Gas Chromatography (GC) to determine the types and quantities of fatty acids	[15]
Antioxidants	DPPH radical scavenging test	[16]
Fibre content	Analyze using enzymatic-gravimetric methods	[17]

Statistical Methods

To compare the physicochemical and nutritional properties of Moroccan Picholine olives with those of neighbouring varieties (Tunisian Chemlali and Algerian Chemlal), several statistical methods were employed [18]. Descriptive statistics, including means and standard deviations, were calculated for each variable to summarise data distribution and variability. A one-way ANOVA was conducted to assess whether significant differences existed among the means of the three olive varieties for each measured parameter. In cases where significant differences were detected, Tukey's HSD (Honestly Significant Difference) test was utilised to identify specific group differences while controlling for Type I errors. Additionally, Pearson correlation coefficients were calculated to examine relationships between different fatty acid profiles, phenolic compounds, and quality parameters, allowing for insights into potential associations. A significance level of $p < 0.05$ was established for all tests to ensure robust findings. These comprehensive statistical approaches ensure that the comparisons made are reliable and meaningful, providing a solid foundation for interpreting the result.

Results and Discussion

Physicochemical Properties

Table 2. Physicochemical properties of Moroccan Picholine Olives and neighbouring varieties.

Parameters	Unit	Moroccan Picholine*	Tunisian Chemlali [19]	Algerian Chemlal [20]
Moisture content	%	53.66 ± 3.11 ^A	49.30 ± 0.24 ^{AC}	61.05 ± 2.50 ^A
Acidity	%	0.29 ± 0.71 ^{AB}	0.33 ± 0.1 ^B	0.2 ± 0.01 ^D
Oil Yield	%	42.32 ± 2.82 ^A	48.24 ± 0.20 ^C	35 ± 2.00 ^{AB}
Peroxide Value	meq kg ⁻¹	4.37 ± 1.41 ^B	4.5 ± 0.50 ^{AB}	6 ± 1.00 ^A

Mean ± standard deviation. Values sharing same letters differ non-significantly ($P > 0.05$). *This study

Moisture Content

Moroccan Picholine olives have a moisture content of $53.66 \pm 3.11\%$, which is slightly higher than Tunisian Chemlali ($49.30 \pm 0.24\%$) but lower than Algerian Chemlal ($61.05 \pm 2.50\%$). A higher moisture content can enhance the juiciness and flavour of the olives, making them more palatable. However, it also raises concerns about shelf stability and spoilage, particularly in warmer climates. The moderate moisture level in Moroccan Picholine olives suggests they may strike a balance between flavour and preservation, appealing to consumers seeking quality products without sacrificing shelf life. Producers may consider employing appropriate storage and handling techniques to maintain quality [21].

Acidity

The acidity of Moroccan Picholine ($0.29 \pm 0.71\%$) is comparable to that of Tunisian Chemlali ($0.33 \pm 0.1\%$), indicating that both are within acceptable limits for quality olive oil. However, Algerian Chemlal shows lower acidity ($0.2 \pm 0.01\%$), which might appeal more to premium markets seeking superior quality. Acidity is a key determinant of olive quality, with lower levels generally indicating better taste and preservation properties. The acidity levels observed in Moroccan Picholine olives suggest a well-rounded flavour profile that can cater to diverse consumer preferences. This balance may enhance its attractiveness to both local and international markets, where flavour complexity is valued [22].

Oil Yield

With an oil yield of $42.32 \pm 2.82\%$, Moroccan Picholine is slightly lower than Tunisian Chemlali ($48.24 \pm 0.20\%$) but higher than Algerian Chemlal ($35.00 \pm 2.00\%$). This suggests that while Moroccan Picholine performs well, there is still potential to enhance oil extraction techniques to improve yield. The lower yield of Moroccan Picholine olives indicates a need for optimisation in cultivation practices or processing techniques to enhance oil extraction efficiency. Focusing on improving yield could not only benefit producers economically but also position Moroccan Picholine olives more competitively in the market [23].

Peroxide Value

The peroxide value for Moroccan Picholine is 4.37 ± 1.41 meq kg^{-1} , which is similar to Tunisian Chemlali (4.50 ± 0.50) and indicates good oxidative stability. However, Algerian Chemlal has a higher peroxide value (6 ± 1.00), suggesting that Moroccan Picholine may have better freshness and shelf life. A lower peroxide value indicates fresher oil with a reduced risk of rancidity, which is critical for consumer acceptance and product quality. This finding underscores the potential of Moroccan Picholine olives in terms of oil quality, suggesting they could be marketed as a premium product with superior freshness. The ability to maintain low peroxide levels can enhance brand reputation and consumer trust [24].

Fatty Acid

Table 3. Fatty acid composition of Moroccan Picholine Olives compared to Neighbouring varieties.

Fatty acids	Units	Moroccan Picholine Our study*	Tunisian Chemlali [25]	Algerian Chemlal [26]
Oleic acid (C18:1)	%	68.47 ± 10.00^B	62.55 ± 0.02^D	62.39 ± 1.87^A
Linoleic acid (C18:2)	%	12.51 ± 3.72^{AC}	13.49 ± 0.02^B	14.11 ± 1.03^{AD}
Palmitic acid (C16:0)	%	16.24 ± 2.16^C	16.61 ± 0.30^{AB}	16.87 ± 0.30^C
Stearic acid (C18:0)	%	3.01 ± 1.58^A	2.18 ± 0.03^C	1.67 ± 0.61^D
Linolenic acid (C18:3)	%	1.2 ± 0.96^B	0.66 ± 0.02^{AC}	0.20 ± 0.56^{AB}

Legend: Mean $\pm$ standard deviation. Values sharing same letters differ non-significantly ($P > 0.05$).

Oleic Acid (C18:1)

The Moroccan Picholine olives have a significantly higher oleic acid content (68.47%) compared to Tunisian Chemlali (62.55%) and Algerian Chemlal (62.39%). The higher oleic acid content in Moroccan Picholine olives offers significant health benefits, particularly for cardiovascular health. Oleic acid, a monounsaturated fatty acid, helps reduce LDL (bad) cholesterol levels while increasing HDL (good) cholesterol, thereby lowering the risk of atherosclerosis and other heart diseases [27]. Additionally, its anti-inflammatory properties can help mitigate the risk of chronic conditions such as arthritis, diabetes, and certain cancers by reducing inflammatory markers in the body [28]. Research also suggests that diets rich in oleic acid may improve insulin sensitivity, which is crucial for maintaining healthy blood sugar levels. Furthermore, olive oil, known for its culinary versatility, remains stable at higher temperatures, making it a healthier alternative to saturated and trans fats. Overall, the elevated oleic acid levels in Moroccan Picholine olives highlight their potential as a functional food that supports heart health and enhances overall nutritional intake [29].

Linoleic Acid (C18:2)

Moroccan Picholine olives show a lower linoleic acid percentage (12.51%) than both the Tunisian (13.49%) and Algerian (14.11%) varieties.

Palmitic Acid (C16:0)

The levels of palmitic acid in Moroccan Picholine (16.24%) are comparable to those in the other varieties (Tunisian Chemlali at 16.61% and Algerian Chemlal at 16.87%).

Palmitic acid, a saturated fatty acid found in various oils, including olive oil, has a complex role in health that often sparks debate. While saturated fats, including palmitic acid, can raise LDL cholesterol levels, which is linked to increased cardiovascular risk, the overall impact of palmitic acid on health is nuanced [30]. Some studies suggest that the effect of palmitic acid may vary based on its source and the overall dietary context in which it is consumed. In the case of olive oil, which is rich in monounsaturated fats and antioxidants, the presence of palmitic acid is often outweighed by its beneficial components [31]. For instance, the health benefits of olive oil, such as its ability to reduce inflammation and improve heart health, can mitigate some of the potential negative effects associated with palmitic acid. Furthermore, emerging research indicates that the impact of saturated fats on heart health may not be as straightforward as previously thought, suggesting that the focus should be on the overall dietary pattern rather than individual fatty acids. Thus, while palmitic acid is indeed a saturated

fat present in Moroccan Picholine olives, its health implications should be viewed within the broader context of a balanced diet rich in diverse nutrients and healthy fats [32].

Stearic Acid (C18:0)

Moroccan Picholine has a higher stearic acid content (3.01%) compared to Tunisian Chemlali (2.18%) and Algerian Chemlal (1.67%).

Stearic acid is a saturated fatty acid that stands out due to its unique effect on cholesterol levels. Unlike many other saturated fats, which can raise LDL cholesterol (the "bad" cholesterol) [33], stearic acid has been shown to have a neutral effect on blood cholesterol levels. This characteristic makes stearic acid a favourable component in dietary fats [34]. In the context of Moroccan Picholine olives, which contain a higher percentage of stearic acid compared to some other olive varieties, this can be a significant positive aspect. The presence of stearic acid, combined with the high levels of beneficial monounsaturated fats and antioxidants typically found in olive oil, contributes to a heart-healthy profile. This property can be particularly appealing to health-conscious consumers who are wary of saturated fats. By highlighting the favourable fatty acid composition of Moroccan Picholine oil, producers can position it as a heart-healthy choice that provides the richness of olive oil without the potential drawbacks associated with other saturated fats [35].

Linolenic Acid (C18:3)

The Moroccan Picholine has a higher linolenic acid content (1.2%) than both the Tunisian (0.66%) and Algerian (0.20%) varieties.

Alpha-linolenic acid (ALA), a type of omega-3 fatty acid found in Moroccan Picholine olives, plays a significant role in human health due to its numerous potential benefits. ALA is an essential fatty acid that the body cannot synthesise, necessitating its intake through diet. One of its primary advantages is its anti-inflammatory properties, which can help mitigate chronic inflammatory conditions such as arthritis and inflammatory bowel disease by competing with omega-6 fatty acids and balancing the inflammatory response [36]. Furthermore, research indicates that higher intakes of omega-3 fatty acids, including ALA, are associated with a reduced risk of heart disease, as ALA contributes to lowering blood pressure, reducing triglyceride levels, and improving endothelial function [37]. Additionally, omega-3 fatty acids are crucial for brain health, supporting cognitive function and potentially lowering the risk of neurodegenerative diseases [38]. Some studies also suggest that linolenic acid may improve insulin sensitivity, thereby reducing the risk of type 2 diabetes. The presence of ALA in Moroccan Picholine olives not only enhances their nutritional profile but also positions them as an appealing

option for health-conscious consumers seeking to incorporate beneficial omega-3 fatty acids into their diet.

Table 4. Phenolic Compound Content in Moroccan Picholine Olives Compared to Neighbouring Varieties.

Phenolic compounds	Units	Moroccan Picholine Our study*	Tunisian Chemlali [21]	Algerian Chemlal [23]
Oleuropein	mg kg ⁻¹	167.81 ±15.50 ^B	45.50 ± 0.73 ^C	133±0.01 ^D
Hydroxytyrosol	mg kg ⁻¹	58.31 ±10.00 ^{AB}	83.34 ± 5.8 ^{AC}	3 ± 0.08 ^A
Tyrosol	mg kg ⁻¹	31.14 ± 5.24 ^A	56.60 ± 2.7 ^B	3 ± 0.02 ^{AB}

Legend: Mean ± standard deviation. Values sharing same letters differ non-significantly ($P > 0.05$).

Oleuropein Content

The Moroccan Picholine variety demonstrates a remarkably high oleuropein concentration (167.81 mg kg⁻¹) compared to the Tunisian Chemlali (45.50 mg/kg) and the Algerian Chemlal (133 mg kg⁻¹). Oleuropein is well known for its antioxidant and anti-inflammatory properties, which play a crucial role in promoting cardiovascular health and protecting against oxidative stress. The substantial oleuropein content in Moroccan Picholine not only highlights its potential health benefits but also suggests that this variety may be more effective in supporting heart health and preventing chronic diseases than its neighbours. This characteristic could serve as a pivotal selling point for producers, particularly in markets increasingly focused on functional foods [39].

Hydroxytyrosol Levels

With a hydroxytyrosol content of 58.31 mg kg⁻¹, Moroccan Picholine olives are lower than the Tunisian Chemlali (83.34 mg kg⁻¹) but much higher than the Algerian Chemlal (3 mg kg⁻¹). Hydroxytyrosol is recognised for its potent antioxidant effects, including the ability to lower blood pressure and provide neuroprotective benefits. While the Moroccan variety may not lead in hydroxytyrosol content, it still offers significant health advantages, suggesting that it could be marketed effectively to consumers seeking antioxidants. Additionally, strategies to enhance hydroxytyrosol content during cultivation or processing could further increase the appeal of Moroccan Picholine olives [39].

Tyrosol Content

The tyrosol levels in Moroccan Picholine olives (31.14 mg kg^{-1}) position them between the Tunisian Chemlali (56.60 mg kg^{-1}) and the Algerian Chemlal (3 mg kg^{-1}). Tyrosol possesses anti-inflammatory and antioxidant properties, making it another beneficial component for health-conscious consumers. While the Moroccan variety is slightly lower than the Tunisian, it still provides a healthful option. This information can be leveraged to market Moroccan Picholine olives as a wholesome choice, emphasising their comprehensive phytochemical profile [40].

Comparisons between Moroccan Picholine and Neighboring Olive Varieties

Quality Parameters

In terms of quality, Moroccan Picholine has a moisture content of 53.66%, higher than Tunisian Chemlali (49.30%) but lower than Algerian Chemlal (61.05%). This balance may provide a favourable flavour without significantly compromising shelf life. The acidity level of 0.29% is comparable to Tunisian Chemlali (0.33%), indicating a similar flavour profile, while the lower acidity of Algerian Chemlal (0.20%) suggests a potentially sweeter taste. The oil yield of Moroccan Picholine (42.32%) is lower than that of Tunisian Chemlali (48.24%), indicating a need for improvement in oil extraction efficiency, though it is higher than Algerian Chemlal (35%). Lastly, the peroxide value of Moroccan Picholine (4.37 meq kg^{-1}) is similar to that of Tunisian Chemlali (4.5 meq kg^{-1}) but significantly lower than Algerian Chemlal (6 meq kg^{-1}), suggesting better oil freshness and quality.

Fatty Acid Composition

Moroccan Picholine olives exhibit a notably higher oleic acid content (68.47%) compared to Tunisian Chemlali (62.55%) and Algerian Chemlal (62.39%). This higher oleic acid level is beneficial for cardiovascular health, highlighting Moroccan Picholine's potential as a healthier choice. However, it contains lower linoleic acid (12.51%) than both neighboring varieties, which could influence consumer choice based on dietary preferences.

Phenolic Compound Content

The phenolic profile of Moroccan Picholine is impressive, especially its oleuropein content ($167.81 \text{ mg kg}^{-1}$), significantly higher than Tunisian Chemlali (45.50 mg kg^{-1}) and competitive with Algerian Chemlal (133 mg kg^{-1}). Oleuropein is associated with various health benefits, including antioxidant and anti-inflammatory effects. In contrast, hydroxytyrosol (58.31 mg kg^{-1}) is lower than in Tunisian Chemlali (83.34 mg kg^{-1}), suggesting that while Moroccan Picholine excels in oleuropein, it could enhance its hydroxytyrosol levels to boost its overall health benefits.

Interpretation of Results and their Implications

The findings regarding Moroccan Picholine olives reveal a promising profile in terms of fatty acid composition, phenolic compounds, and quality parameters. The high oleic acid content (68.47%) suggests significant cardiovascular benefits, aligning with literature that associates oleic acid with a reduced risk of heart disease Sofi *et al.* [41]. The elevated oleuropein levels (167.81 mg kg⁻¹) highlight the variety's antioxidant potential, reinforcing its appeal as a functional food. However, the relatively lower linoleic acid content and hydroxytyrosol levels indicate areas for improvement that could impact consumer choice, especially among those prioritising balanced fatty acid profiles in their diets.

In comparison to existing literature, Moroccan Picholine's oleic acid levels align well with studies indicating that high oleic acid content in olives enhances nutritional value Cicerale *et al.* [42]. The oleuropein concentration also supports findings from previous studies that emphasise the health benefits of phenolic compounds in olive oils Servili & Montedoro [43]. However, the lower hydroxytyrosol content compared to Tunisian Chemlali suggests that Moroccan Picholine could benefit from enhanced cultivation or processing methods aimed at increasing this compound, as hydroxytyrosol has been associated with various health benefits, including anti-inflammatory effects.

Comparative Analysis of Nutritional and Physicochemical Properties of Moroccan Picholine, Tunisian Chemlali, and Algerian Chemlal Olives.

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was employed to identify patterns in the physicochemical and nutritional properties of Moroccan Picholine olives compared to Tunisian Chemlali and Algerian Chemlal varieties. The PCA results shown in Figure 3a revealed that the first two principal components explained a significant portion of the variance in the dataset, effectively differentiating the olive varieties based on key attributes such as oleic acid content, oleuropein levels, and moisture percentage. Specifically, Moroccan Picholine olives clustered distinctly, indicating their superior nutritional profile, characterised by high oleic acid and oleuropein concentrations. This clustering suggests potential health benefits associated with their consumption, particularly in relation to cardiovascular health. The visualisation of the PCA biplot in Figure 3a further highlighted the contribution of each variable, underscoring the importance of oleic acid and phenolic compounds in distinguishing Moroccan Picholine olives from their neighbours. These findings not only enhance our understanding of the unique qualities of Moroccan Picholine olives but also point to avenues for targeted improvement in cultivation and processing practices.

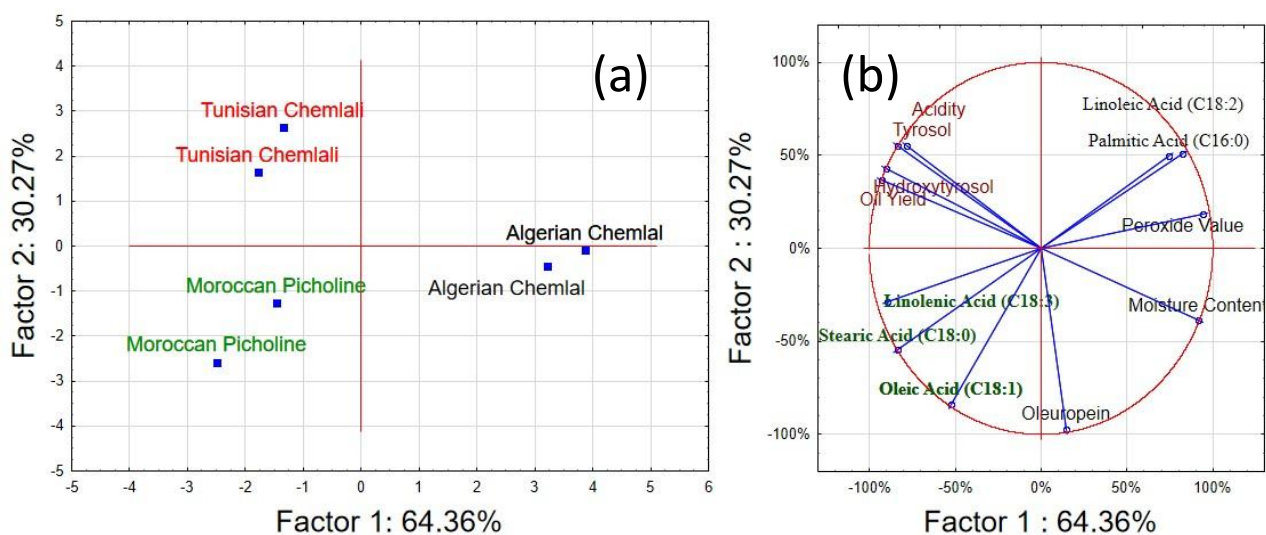


Figure 3. Biplot analysis of nutritional and physicochemical properties of olive varieties (a); correlation circle of key nutritional components in Moroccan Picholine Olives (b).

Based on the provided data, Moroccan Picholine olives consistently exhibit higher oleic acid content, averaging 68.47%, compared to Tunisian Chemlali and Algerian Chemlali, which have lower values of 62.55% and 62.39%, respectively. This elevated oleic acid level suggests greater cardiovascular health benefits associated with Moroccan Picholine. Additionally, the oleuropein content stands out significantly at 167.81 mg kg⁻¹, in contrast to the 45.50 mg kg⁻¹ and 133.00 mg kg⁻¹ found in the neighbouring varieties, indicating superior antioxidant properties. While moisture content is moderate at 53.66%, the oil yield of 42.32% remains competitive, reflecting quality. The lower acidity (0.29%) and peroxide value (4.37 meq kg⁻¹) further emphasise the freshness of Moroccan Picholine olives. Overall, these metrics highlight the unique nutritional profile of Moroccan Picholine, reinforcing its potential for market differentiation and health promotion.

Potential for development and improvement in cultivation or processing

To further capitalize on the strengths of Moroccan Picholine olives, targeted improvements in cultivation and processing practices could enhance both yield and health benefits:

Cultivation Practices

Soil Management: Implementing soil amendments and optimising irrigation could improve the overall health of olive trees, potentially leading to higher oleic and linoleic acid yields. Adopting sustainable agricultural techniques, such as organic farming and integrated pest management, can enhance the health of olive trees and increase yields. Optimising irrigation methods to ensure consistent moisture levels, particularly in arid regions, will improve fruit quality [44].

Varietal Selection: Exploring cross-breeding or selection techniques could introduce traits from neighbouring varieties, such as higher hydroxytyrosol content, without compromising the unique characteristics of Moroccan Picholine.

Processing Enhancements

Invest in modern processing equipment to minimize the time between harvesting and oil extraction, preserving the olives' nutritional properties and freshness. Implement best practices in oil extraction and storage to maintain quality, such as using cold-press methods and minimizing exposure to light and air [45].

Improving Hydroxytyrosol Content

Focus on breeding programmes aimed at increasing hydroxytyrosol levels, which are beneficial for their antioxidant properties. Research into genetic variations could lead to the development of higher-yielding varieties. Educate farmers on harvesting techniques that maximise the retention of phenolic compounds, which can be affected by timing and handling [46].

Collaboration with Farmers and Stakeholders

Foster partnerships with local farmers to share knowledge and resources, ensuring that best practices in cultivation and processing are widely adopted. Collaborate with industry stakeholders, such as researchers and agricultural organisations, to promote research and development initiatives aimed at enhancing olive quality and sustainability [47].

Processing Techniques

Cold Extraction Methods: Utilising advanced extraction methods can enhance oil quality and yield, reducing oxidation and increasing the retention of beneficial compounds. **Timing of Harvest:** Harvesting at the optimal ripeness can maximise oil yield and enhance the phenolic profile, particularly oleuropein and hydroxytyrosol [48].

Enzymatic Treatments: The application of specific enzymes during the oil extraction process can enhance oil yield by breaking down cell walls in the fruit, allowing for better oil release. Exploring enzymatic pre-treatments prior to pressing could lead to significant yield improvements [48].

Varietal Crossbreeding

Research into higher-yield varieties: Ongoing research into crossbreeding Moroccan Picholine with higher-yield varieties presents an opportunity for genetic improvement. By leveraging the genetic traits of other olive cultivars known for their superior oil yield, it may be possible to develop new strains that maintain the unique flavour and quality characteristics of Picholine olives while improving overall productivity [50].

Comparative Analysis of Cultivation Methods

Traditional Versus Modern Farming

In the cultivation of olives, traditional and modern farming practices coexist and evolve across regions. Moroccan Picholine olives are traditionally grown using organic methods with minimal intervention, fostering a deep connection to sustainable agriculture. Recently, however, there has been a gradual shift towards modern techniques, including the implementation of drip irrigation and integrated pest management, which aim to enhance both yields and fruit quality [51]. In Tunisia, Chemlali olives thrive in traditional groves that benefit from a rich heritage of cultivation techniques. The recent adoption of modern practices, such as soil health management and mechanised harvesting, seeks to improve efficiency and increase oil yield [51]. Similarly, Algeria blends traditional and modern approaches, utilising local varieties while incorporating improved agricultural methods like crop rotation and organic fertilisation to boost productivity [50]. This integration of practices across these regions highlights the ongoing evolution of olive cultivation in response to both environmental and market demands.

Conclusion

This study highlights the distinct physicochemical and nutritional properties of Moroccan Picholine olives compared to neighbouring varieties, Tunisian Chemlali and Algerian Chemlal. The results indicate that Moroccan Picholine possesses a significantly higher oleic acid content, which is beneficial for cardiovascular health, alongside impressive levels of oleuropein, a phenolic compound known for its antioxidant properties. However, there is potential for improvement in hydroxytyrosol content and oil yield, which could enhance its marketability and health benefits. Statistical analyses confirmed significant differences among the varieties, providing a robust foundation for the findings. The insights gained from this research underscore the importance of targeted cultivation and processing practices to further enhance the quality and nutritional profile of Moroccan Picholine olives. By focusing on these improvements, producers can position Moroccan Picholine olives as a

premium product in the global olive oil market, emphasising their unique health benefits and flavour characteristics. Future research should explore innovative agricultural techniques and processing methods to maximise the potential of this valuable variety, contributing to the economic development of the olive industry in Morocco.

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Code availability: Not applicable

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