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Presented by:

Mrs.KHAMKHOUM Samira

In front of the Jury committee composed of:

Mrs FARHI Kamilia	Professor	University of Mohamed Khider ,Biskra	**President**
Mrs BOUKHALFA Hassina Hafida	Professor	University of Mohamed Khider ,Biskra	**Supervisor**
Mr. MEHAOUA Mohamed Seghir	Professor	University of Mohamed Khider ,Biskra	**Examiner**
Mr.BEN SALAH Mohamed Kamel	Research Director	Scientificand Technical Research Center for Arid Regions, (CRSTRA) ,Biskra	**Examiner**

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Dedication

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اللَّهُ نُورُ السَّمَاوَاتِ وَالْأَرْضِ ۚ مَثَلُ نُورِهِ كَمِشْكَاةٍ فِيهَا مِصْبَاحٌ ۖ
الْمِصْبَاحُ فِي زُجَاجَةٍ ۖ الزُّجَاجَةُ كَأَنَّهَا كَوْكَبٌ دُرِّيٌّ يُوقَدُ مِنْ شَجَرَةٍ
مُبَارَكَةٍ زَيْتُونَةٍ لَا شَرْقِيَّةٍ وَلَا غَرْبِيَّةٍ يَكَادُ زَيْتُهَا يُضِيءُ وَلَوْ لَمْ تَمْسَسْهُ
نَارٌ ۚ نُورٌ عَلَىٰ نُورٍ ۗ يَهْدِي اللَّهُ لِنُورِهِ مَنْ يَشَاءُ ۚ وَيَضْرِبُ اللَّهُ
الْأَمْثَالَ لِلنَّاسِ ۗ وَاللَّهُ بِكُلِّ شَيْءٍ عَلِيمٌ

Allah is the Light of the heavens and the earth. The Parable of His Light is as if there were a Niche and within it a Lamp: the Lamp enclosed in Glass: the glass as it were a brilliant star: Lit from a blessed Tree, an Olive, neither of the east nor of the west, whose oil is well-nigh luminous, though fire scarce touched it: Light upon Light! Allah doth guide whom He will to His Light: Allah doth set forth Parables for men: and Allah doth know all things

The Light سورة النور – An-Noor: Verse 35

Abbreviations List

AHC: Ascending Hierarchical Classification

ANOVA: Analysis of variances

B. La fayette: Bouchouk La fayette

B. Soumam: Bouchouk Soumam

B.C: **B**efore **C**hrist; Years before the birth of Jesus

BAR: Biskra Agricultural Room

Blanquette G: Blanquette de Guelma

DAS: Directorate of Agricultural Services

ETc: Evapotranspiration

EU: European Union

EVOO: Extra Virgin Olive Oil

FFA: Free Fatty Acid

GC: Gas Chromatography

IOC: International Olive Council

LA: Leaf Area

LL: Leaf Length

LW: Leaf Width

MEVOO: Monovarietal Extra Virgin Olive Oil

MI: Maturity Index

OMW: Olive mill wastewater

PCA: Principal Component Analysis

RDI: Regulated Deficit Irrigation

Rougette .M: Rougette de Mitidja

SDI: Sustained Deficit Irrigation

UPOV: Union for the Protection of New Varieties of Plants

ITDAS: The Technical Institute for the Development of Saharian Agriculture

VOO: Virgin Olive Oil

EC: Electrical conductivity

Figures Liste

Tables List

Summary

Chapter I

Chapter II

Chapter III

General introduction

General introduction

The olive tree (*Olea europaea L.*) stands as a prominent and iconic symbol of the Mediterranean environment, revered for its significant cultural and commercial value (Besnard et al., 2018), as an important indicator of the Mediterranean climate (Moriondo et al., 2013; Vargas & Kadereit, 2001).

Archaeological evidence, such as olive pollen dating back to 7000 BC in Greece(Langgut et al., 2019; Moody, 2000), suggests early human interaction with the olive tree, initially for its wood and later for its fruit and oil (Besnard et al., 2018; Kostelenos & Kiritsakis, 2017; Langgut et al., 2019), however, ancient Greece not only revered this tree as a source of sustenance but also awarded olive wreaths to Olympic victors (Fabbri, 2023), this tree has a storied history, evident in countries like Italy, Greece, Montenegro, Palestine, and even Iran(Baldoni et al., 2006; Barazani et al., 2014; Cherubini et al., 2013; Cicatelli et al., 2013; Erre et al., 2010; Lazović et al., 2016; Maravelakis et al., 2013; Mariotti et al., 2010; Mousavi et al., 2014; Petruccelli et al., 2014; Salimonti et al., 2013).

Researchers have documented both cultivated and wild forms of this ancient tree, which has a potential average lifespan of up to 1000 years (Rhizopoulou, 2007), estimates place the oldest recorded olive tree, "The Tree of Vouves," at 4000 years old (Bombarely et al., 2021; Langgut et al., 2019; Lewington, 2012), illustrating the Mediterranean's deep historical roots of olive cultivation dating back to 4800 B.C (Butzer, 1990; Smith, 2005) and the consumption of olives and olive oil for over 6,000 years(Raja et al., 2021).

The olive tree and its products hold significant importance in various religions. The Quran repeatedly mentions olives, illustrating their significance, for example, Surah Al-An'am, Verse 99, describes the growth and benefits of various fruits, including olives, as signs for those who believe (Marwat et al., 2009). Similarly, Surah An-Nahl, Verse 11, highlights the growth of olives as a sign for thoughtful people (Marwat et al., 2009).

Other verses also mention olives' significance in diet and as a source of blessing (Surah Al-Muminoon, Verse 20; Surah An-Nur, Verse 35; Surah At-Tin, Verses 1–4)(Ghaffar, 2018; Marwat et al., 2009; Sense, n.d.). In Hadith, the Prophet Muhammad (SAW) emphasised the benefits of olive oil for consumption and topical use, he described it as a cure for seventy diseases, including leprosy, and recommended it for health and healing (Tirmidhi, 1775; various narrations by Abu Huraira, Khalid Bin Saad, and Zaid Bin Arqam) (Ghaznavi, 1991; Saheb et al., 2019; Sense, 2022).

Muslims view olives as a divine gift, revered for their sacred and nutritional value. The olive tree is also significant in Christianity, with nearly 200 mentions in the Bible. It symbolizes the "Tree of Life," and its oil represents the "Holy Spirit," or belief in Jesus. Churches used olive oil for lighting lamps and anointing kings, symbolising divine appointment to govern(M. Ali et al., 2024; S. Ali et al., 2024).

The Catholic and Orthodox Churches continue to use olive oil for blessings and rituals, as well as in cooking, particularly in regions abundant with olive trees (Austin, 1985; McDougall, 2022).

The olive tree, known by various names such as Zaitouna in Arabic (Quran), Olivo in Italy, Aceituna in Spain, Eelia in Greece, Jaitun in India, Olive in England, Olivier in French, and Zaitun in Pakistan (Hashmi et al., 2015), is a globally recognized plant with significant symbolic value due to its large distribution in the world (Hashmi et al., 2015). It is botanically named Olea europaea, derived from Latin 'oleum' and Greek 'elaia'(Iqbal et al., 2020; Kaniewski et al., 2012; Rehman et al., 2013).

Botanically, the olive tree belongs to the *Olea europaea L.* group, encompassing six subspecies and has 30–35 species spread across Asia, Africa, Europe and Oceania ((Green, 2002; Medail et al., 2001), it is the primary cultivated species (Cronquist, 1981)and the sole edible species in the genus (Hashmi et al., 2015).

Today, the world celebrates the olive tree's products, particularly olive oil and table olives, for their nutritional and health benefits, even in regions far from traditional cultivation areas, such as Eastern Asia, Australia, and America, there is a growing interest in cultivating olive trees and consuming their valuable products. (Valls-Pedret et al., 2012).

In 2000, the global olive cultivation area was 8,351,778 hectares, producing 15,654,216.91 tons of olives, Algeria contributed 217,112 tons from 168,080 hectares (*FAOSTAT*,2022). By 2022, the global harvested area for olives expanded to 10,948,521 hectares, yielding 21,449,867.5 tons, Algeria also experienced growth, with harvested area and production increasing to 457,609 hectares and 822,973.59 tons, respectively (FAOSTAT, 2022 ; IOC, 2022).

During this time, olive oil production rose from 2,544,588.67 tons in 2000 to 3,098,500 tons in 2022,in Algeria, olive oil production increased from 30,488 tons in 2000 to 91,000 tons in 2022 (IOC, 2022).

Global olive oil consumption nearly doubled from 1990/91 to 2020/21, but a provisional decrease of 4.4% was recorded for the 2020/21 crop year, resulting in a consumption of 3,125,000 tons. By 2022, global consumption further declined to 3,240,000 tons. In Algeria, olive oil consumption was 91,000 tons, with a per capita consumption of 1.8 kg in 2022(IOC, 2022).

About the table olives, According to the International Olive Council (IOC) 2022, the world table olive production reached 3,101,000 tons in the 2021/2022 crop year, with a global consumption of 2,849,000 tons. Algeria contributed significantly to this production, with 306,000 tons, accounting for 10.8% of the world total, placing it fourth among the top table olive-producing countries, following Spain (659,000 tons), Egypt (650,000 tons), and Turkey (450,000 tons). In terms of consumption, Algeria stands second in the world for table olive consumption per capita, after Albania, with an average of 6.8 kilograms per inhabitant per year.

In 2022, the global olive oil market was valued at USD 14.2 billion, with projected growth to USD 14.6 billion and USD 18.4 billion in 2022 and 2023, respectively.The top olive oil importers are the USA (36%), the European Union (EU) (14%), Brazil (8%), Japan (7%), and Canada (5%), accounting for 70% of imports(Europe Olive Oil Market Trends, Size, Industry Report & Forecast, 2023.).

This market growth is due to increased demand for olive oil in food service and retail, as well as interest in trying exotic cuisines where the health benefits of *Olea europaea* fruit oil, especially in the virgin oil segment, stand out.

Producers are continuously striving to meet rising consumer demand by ensuring high-quality oil production amidst global climate change. Recent data shows a 40% increase in the price of extra virgin olive oil (EVOO) in the main producing countries (OLIVE OIL PRICES - April 2023 Update)(IOC, 2023a) and a 26.9% annual change in the EU-27 in the first quarter of 2023 compared to the same period in 2022 (EU27 - Harmonised Index of Consumer Prices - Olive Oil, 2023;IOC, 2023b).

Bioactive compounds in EVOO and table olives make them the main source of fat in the Mediterranean diet. These areas grow olives (*Olea europaea*) (Donat-Vargas et al., 2023), research from many years ago has shown that a Mediterranean diet that includes olive oil lowers the risk of cancer, metabolic disorders, cardiovascular diseases (Jiménez-Sánchez et al., 2022; Sarapis et al., 2020), and immune-inflammatory disorders (Montoya et al., 2021; Scotece et *al*., 2012) .

It has also been shown that olive oil lowers and improves endothelial function in young women with slightly elevated but normal blood pressure (Moreno-Luna et al., 2012). This idea has gotten a lot of attention in recent years, these products may improve health and longevity; a high intake of both virgin and extra-virgin oil in older individuals with high cardiovascular risk was associated with a significantly 50% reduction of deaths and better memory function and cognition(Valls-Pedret et al., 2012) .

Olive tree leaves also, like olive oil and olive fruit, contain therapeutic and nutritious elements. According to recent studies, they are effective in treating coughs due to their hypoglycemic, astringent, hypotensive, diuretic, and antibacterial characteristics (Mikaili et al., 2012). Pharmaceuticals, cosmetics, and medical items increasingly use olive leaves, rich in phenolics(Erbay & Icier, 2010). People have used olive leaves (*Olea europea L.*) in food, herbal drinks, and medicine (Erbay & Icier, 2010). Globally, people grow olive leaves from small mediterranean trees (Roselló-Soto, Barba, et al., 2015; Roselló-Soto, Koubaa, et al., 2015).

Olive leaves contain polyphenols, volatile compounds, phytosterols, fatty acids, carotenoids, chlorophylls, tocopherols, and squalene, making them potential food additives and nutraceuticals for food waste recovery (Roselló-Soto, Koubaa, et al., 2015).

Olive leaves also, rich in provitamin A carotenoids including β-carotene and lutein, may lower the incidence of age-related macular degeneration and improve eyesight(Krinsky et al., 2003). Human breast milk and infant brains are rich in lutein, which helps neuronal growth and cognitive function in the elderly (Johnson, 2014), its health benefits may lead to official intake recommendations (Ranard et al., 2017).

The olive tree is not beneficial only for the human feeding side; the by-product of the olive industry has a large range of other benefits, so let’s move on to the olive by-product world, the use of olive industry by-products for animal feeds contributes to the circular economy of Mediterranean countries.

Polyphenols in these by-products are promising alternatives to synthetic antioxidants, potentially reducing bacterial infections, especially since the EU banned antibiotics as growth promoters in 2006 (Vastolo et al., 2019).

It has been shown in studies that they improve immunity, antimicrobial and antioxidant power, and production performance in pigs and chickens they also make food more stable against oxidation and protect feed components from oxidation(Lipiński et al., 2017; Mahfuz et al., 2021; Starčević et al., 2015).

It has been shown that these natural antioxidants can reduce oxidative stress, boost growth and feed efficiency, and improve the quality and shelf life of meat by lowering lipid peroxidation, raising monounsaturated fatty acid levels, and improving oxidative status (Branciari et al., 2017; De Oliveira et al., 2021; Paiva-Martins et al., 2009; Rey et al., 2021; Skaperda et al., 2019; Tufarelli et al., 2016; Valenzuela-Grijalva et al., 2017).

Olive mill wastewater(OMW) polyphenols also lower genes related to oxidative stress and inflammation, which helps animals stay healthy and prevents cell death (Cappelli et al., 2021; Maranesi et al., 2021; Surai et al., 2019), additionally, olive mill wastewater (OMW) is the biggest waste product from the olive industry, as the world's population grows, olive oil production and consumption rise, reaching about 3 million metric tonnes in 2020/2021 (IOC).

Mediterranean countries, the primary producers, generate about 30 million cubic metres of OMW annually (Al-Qodah et al., 2022; Chiavola et al., 2014; Ioannou-Ttofa et al., 2017; Meksi et al., 2012), so the ueses of those OMW is the solution for the peoples, animals, and plants.

The olive oil industry typically produces 50% OMW, 30% olive pomace, and 20% olive oil, with variations depending on the extraction method (Calabrò et al., 2018). It is characterised by a dark colour, acidic pH, high turbidity, high organic load, and an unpleasant odour (Al-Qodah et al., 2022), legislation in countries like Italy, Spain, Portugal, Jordan, and Greece regulates the use of OMW as a soil amendment in arid and semi-arid regions (Chalkia et al., 2020; Rusan & Malkawi, 2016, 2016), as for the OMW's benefits, it can make the soil better by improving its structure, aggregation, and hydrodynamics, which can lower water loss and erosion (Mellouli et al., 1998; Niaounakis & Halvadakis, 2006; Paredes et al., 1999), it can temporarily impair soil porosity and infiltration (Cox et al., 1997; Mekki et al., 2006).

OMW initially lowers soil pH but improves cation exchange capacity (CEC) and adds organic and mineral matter, enhancing soil fertility (Ayoub et al., 2014; Cox et al., 1997; Di Bene et al., 2013; Ferri et al., 2002; Niaounakis & Halvadakis, 2006; Tardioli et al., 1997).

Generally, OMW treatment can improve water retention and nutrient availability, though concerns about soil pH and heavy metal buildup remain (Al-Budi, 2011; Justino et al., 2012). The carbon-to-nitrogen (C/N) ratio increases after OMW application (Cabrera et al., 1996; Ferri et al., 2002; Mekki et al., 2006), regulated OMW treatment improves crop (wheat case) growth and microbial activity (Khalil et al., 2021).

Due to their benefits, olive trees have become one of the most cultivated in the world; they are approximately limited between 30° and 45° parallels (Therios, 2008), proper olive growing areas have a mean annual temperature of 15–20 °C, with a minimum of 4 °C and a maximum of 40 °C (Brito et al., 2019), and the ideal temperature range for olive vegetative development typically falls between 10 °C and 30 °C. However, the synthesis of carbohydrates happens more efficiently at temperatures ranging from 20 °C to 30 °C (Tombesi & Tombesi, 2007). Olive trees require a period of low temperatures (0–7 °C) in order to undergo flowering bud differentiation (Therios, 2009). On the other hand, temperatures constantly above 16 °C prevent bud differentiation (Tombesi & Tombesi, 2007).

Nevertheless, it is critical to ensure that the temperature does not go below 7 °C because it may do significant harm to trees. In fact, if the temperature drops below 12 °C, it has the potential to be fatal for them, however, olive farming is not suitable at high elevations (>800 m) because of frost and the limited vegetative season in such areas (Therios, 2009).

The olive tree may thrive in poor, dry, calcareous, and gravelly soils; the best conditions for olive tree annual bearing are deep, sandy loam adequately supplied with nitrogen, phosphorus, potassium, and water (Brito et al., 2019; Therios, 2009), while the optimal pH values range between 5.5 and 8.5 (Fernández & Moreno, 2000).

Although in some cases, olive trees can grow with a rainfall of 200 mm per year (Guerrero, 2003), it should be above 400 mm per year, and values of 600 mm per year, 800 mm per year, and 1000 mm per year are considered sufficient, moderate, and good, respectively (Tombesi & Tombesi, 2007).

Still, 500 mm year−1 is the lower limit for commercial olive yields under rainfed conditions (Ponti et al., 2013), the Mediterranean environment, ideal for olive growth, features hot, dry summers and moderate, wet winters (Dichio et al., 2006; Torres-Ruiz et al., 2015), but climate change and increased water demand threaten olive agroecosystems' sustainability (Cramer et al., 2018; Rallo et al., 2016).

The Mediterranean region, accounting for 90% of global olive cultivation, boasts a diverse range of over 1,200 clonally propagated cultivars (FAOSTAT, 2019), and most cultivars grow in traditional agroecosystems, with only a few planted intensively (Ater et al., 2016; G. Bartolini & Cerreti, 2008; Khadari et al., 2008).

Farmers in different parts of the Mediterranean choose varieties that do well in their area, showing off olive diversity on a local and regional level (Besnard et al., 2018; El Bakkali et al., 2019; Khadari et al., 2008, 2019), this means that having a wide range of olive cultivars is important for keeping production going in a variety of climates.

It is also important to know how these cultivars respond to changes, especially drought, in order to keep growing them (Kassout et al., 2022; Khadari et al., 2019). In the past, olive farms in Mediterranean regions were traditionally low-density, having 50–160 trees/ha, using rainfed conditions (Lorite et al., 2018), but in the last decades, new management, especially in the arid regions, has led to high-density (350–700 trees/ha) and super-density (1,200–2,500 trees/ha) irrigated orchards (Fernández-Escobar et al., 2013).

Despite adaptations, water shortages during crucial stages like blooming and fruit development can cause significant economic losses (Díaz-Espejo et al., 2018; Moriana et al., 2003), so to maintain productivity and global food security, sustainable water management is essential (Gucci et al., 2019).

Water stress is considered the most limiting factor for agricultural productivity worldwide (Taiz et al., 2015), it also has negative repercussions on water relations, nutrient uptake, carbon assimilation, canopy dimension, oxidative pathways, phenology, and reproduction processes (Bacelar et al., 2006, 2009; Brito et al., 2018; Concil (IOC), 2019; Farooq et al., 2009; Petridis et al., 2012; Stocker, 2014).

In semi-arid and arid regions, olive trees often experience water stress due to transpiration exceeding root absorption capacity (Boujnah, 1997). A severe water deficit reduces water potential and turgor, affecting stomatal opening (Stoll et al., 2000), chemical signals from roots to leaves influence stomatal sensitivity to soil drying(Blackman & Davies, 1985; Zhang et al., 1987).

These changes result in decreased photosynthesis and slowed enzymatic processes, ultimately hindering plant growth (Büssis & Heineke, 1998; Kasraoui et al., 2004), while some of these plant responses to adverse conditions are connected with defence adaptation strategies. Although the olive tree is a well-adapted species against drought (Bacelar et al., 2006, 2009; Fernandes-Silva et al., 2010; Torres-Ruiz et al., 2013).

In general, water stress has a negative effect on yield, fruit dry mass, and oil accumulation (S. Bartolini et al., 2014; Fernandes-Silva et al., 2010; Greven et al., 2009; Patumi et al., 2002; Servili et al., 2007), while it accelerates fruit maturation (Bartolini et al., 2014; Machado et al., 2013).

When it comes to the composition of phenolics in fruit and olive oil, many reactions might occur, however, there is a consistent pattern of a simultaneous rise in water stress severity(S. Bartolini et al., 2014; Bucelli et al., 2011; Caruso et al., 2014; Greven et al., 2009; Machado et al., 2013; Patumi et al., 2002; Servili et al., 2007), but oils are occasionally characterised as excessively bitter (Servili et al., 2009).

Nevertheless, at a certain threshold, the increase in quality conferred by phenolic compounds is not compensated by the losses in quantity, with deficit irrigation being the better option (Caruso et al., 2014; Servili et al., 2009).

In line with this, a deficit irrigation strategy has been shown to be effective in producing quality extra virgin olive oil by increasing the content of total phenols and sensory quality (García et al., 2017; Gómez Del Campo & García, 2013). Meanwhile, the influence of the influence of the water deficit on qualitative olive oil indexes and fatty acid composition is inconsistent in the literature.

Generally, the minor effects of irrigation were felt in peroxide value, free acidity, and specific absorption coefficients (K232, K270, ΔK) (Caruso et al., 2014; Patumi et al., 2002; Servili et al., 2009).

Regarding the fatty acid profile, while in some studies no significant influence was detected (Greven et al., 2009; Patumi et al., 2002), in other works, the growing season highly determined the responses (Caruso et al., 2014; Servili et al., 2009), making it difficult to establish a pattern.

Although there is no direct effect from a water deficit, the severity and frequency of frosts may increase with reduced soil and air moisture, this may be a critical event for olive quality, as harvests usually occur when early frosts start coming, scientists have already found that frost can hurt olive fruits and the oil that is extracted from them, this can lead to a loss of pigments and phenolic compounds (Brito et al., 2018; Houliston et al., 2007; J. R. Morelló et al., 2006; J.-R. Morelló et al., 2003).

There is general agreement on the positive effects of irrigation, but some studies show contradictory results, for instance, Ramos and Santos (2010) found no production improvement in 'Cordovil' trees with a 60% ETc sustained deficit irrigation (SDI) strategy compared to fully irrigated trees.

Grattan et al. (2006) reported that increased irrigation reduced the physical extraction of oil in 'Arbequina' trees, a finding supported by Gómez-del-Campo (2013), García et al. (2013), and Fernández et al. (2018).

Most authors agree that irrigation levels have a negligible effect on the main physical and chemical parameters of virgin olive oil (VOO) quality (Faci et al., 2002; García-Inza et al., 2014; Gómez-Rico et al., 2009a; Patumi et al., 1999; Stefanoudaki et al., 2009).However, irrigation impacts positive attributes like fruitiness but does not significantly affect negative attributes (García et al., 2017).

Many studies have shown that irrigation doesn't change the VOO fatty acid composition (Patumi et al., 1999; Tovar et al., 2002; Servili et al., 2007; Gómez-Rico et al., 2009; Caruso et al., 2014), but Gómez Del Campo and García (2013) found that more irrigation made the oleic acid/linoleic acid ratio go down, the inconsistency in results could be due to genetic characteristics and orchard-growing conditions (García et al., 2017).

Irrigation differences less affect cultivars with higher oleic acid content like 'Frantoio' and 'Picual' than 'Arbequina' (Rondanini et al., 2014), high temperatures during ripening may also influence fatty acid desaturation with increased irrigation (Caruso et al., 2014).

Most studies report a reduction in VOO phenolic compounds with increased water supply (Berenguer et al., 2006; Caruso et al., 2014; Patumi et al., 2002; Romero et al., 2002).

However, some studies found no effect or an opposite effect (Baccouri et al., 2009; Dabbou et al., 2010, 2015; Tognetti et al., 2007; Zeleke & Ayton, 2014), and rainfall before harvesting can significantly impact VOO phenolic compounds by increasing fruit water content, thus reducing oil extraction and phenolic dissolution (García et al., 2017).

Other significant factors affecting oil quality are fruit load and harvesting date, the impact of water stress increases with crop load (Martín-Vertedor et al., 2011). Dag et al. (2011) noted that late harvest improved 'Barnea' oil quality but reduced 'Souri' oil quality.

Irrigation delays fruit maturation but also affects phenolic content, fatty acid unsaturation, and photosynthetic pigments (Bengana et al., 2013; Gómez-Rico et al., 2008, 2009a; Gutiérrez et al., 1999).

A study by a research group on 'Arbequina' trees showed that less-irrigated trees had lower ripening indexes, contradicting typical findings (Roca & Mínguez-Mosquera, 2001), higher chlorophyll recovery in VOO was caused by lower watering levels, especially in early harvests, this improved the taste and nutritional value of the compounds (Morrone et al., 2018), and irrigation levels inversely correlate with polyunsaturated fatty acid content, except in the second season (Köseoğlu et al., 2016).

Optimising irrigation in olive orchards during sensitive seasons may reduce water deficits and sustain profitable yields in dry and semi-arid situations (Fereres & Soriano, 2007; Fernández et al., 2018).

Research has shown that restricting irrigation on olive cultivars can save water but reduce yield (Caruso et al., 2017a; Gómez Del Campo & García, 2013; Gucci et al., 2019; Lavee et al., 2007; Serman et al., 2021; Servili et al., 2007), and other research indicates that deficit irrigation solutions may sustain successful olive production (Gucci et al., 2019; Lavee et al., 2007). The olive industry has developed many deficit irrigation systems, including sustained deficit irrigation and regulated deficit irrigation (RDI), to achieve commercial goals (Iniesta et al., 2009; Moriana et al., 2003; A. F. Ramos & Santos, 2010).

Throughout the irrigation season, it supplies less water than the crop's evapotranspirative demand, and at sensitive phenological stages, RDI substitutes the ETc demand with reduced irrigation levels, guaranteeing minimal effects on crop yields (Fereres et al., 2012; Moriana et al., 2003).

Thus, RDI is vital in dry places where water shortages require sustainable water management methods; previous studies (Fernández-Escobar et al., 2013; Gómez-del-Campo, 2013b; Gucci et al., 2019) have shown that modest balances affect water savings, yield, and oil quality in olive trees, particularly from fruit drop to oil synthesis, moreover, applying tactics during critical seasons may greatly affect olive tree growth and production, ultimately affecting oil quality (García et al., 2020; Gucci et al., 2019).

Mediterranean areas may see a 40% drop in annual precipitation by the end of the century (Zittis et al., 2019), competing economic sectors may make agricultural water less available (Cramer et al., 2018), and farms with little water may see less olive tree growth and yield (Palese et al., 2010; Rallo et al., 2016).

It should be noticed that controlled irrigation strategies help olive plants grow in Mediterranean areas with limited water and changing precipitation (Fernández et al., 2001; Rallo et al., 2016), so it should first look into irrigation methods that make better use of water.

Olive orchards use deficit irrigation to reduce water use by taking drought sensitivity into account at each development stage (Dag et al., 2010; Fereres et al., 2012; Gucci et al., 2019; Rapoport et al., 2004), however, a comprehensive understanding of irrigation strategies especially deficit-irrigated and tree physiological responses throughout the growth season is still lacking, measuring plant and soil water status helps evaluate irrigation practices (Fernández et al., 2018), early deficit irrigation studies focused on tree vigour (Chalmers et al., 1981), but it also conserves water and improves fruit quality.

It is possible for olive trees to use less water than they need without losing fruit or oil production (Gómez Del Campo & García, 2013; Gucci et al., 2007; Lavee et al., 2007; Moriana et al., 2003); moderate irrigation limits in fully irrigated trees speed up fruit development, improve the pulp-to-pit ratio, and keep oil yields over 80% (Caruso et al., 2013a; Gómez Del Campo & García, 2013; Gucci et al., 2009).

Over four years, deficit-irrigated applied to-Frantoio olive trees produced 82% more oil and saved 50% of the water (Caruso et al., 2013a). Arbequina reduced irrigation by 70% in July, saving 16% water and yielding 8% less oil than fully irrigated trees (Gómez Del Campo & García, 2013).

The cultivation of olives and the agricultural potential of various olive cultivars under water stress conditions in the arid regions of Algeria, particularly in the Biskra province, present significant research challenges and remain inconclusive. Despite the availability of water resources in these desert areas, olive production is suboptimal compared to the Northern provinces, especially in terms of oil yield. This subpar performance is further exacerbated by a historical lack of planning and limited field studies that address essential factors such as climatic conditions, soil properties, and the suitability of specific olive cultivars. Moreover, existing literature suggests that excessive irrigation can negatively impact both the quality and quantity of olive production.

Given these challenges, this study aims to answer the following key questions: How can the agricultural potential of different olive cultivars be optimized under water stress conditions in the arid regions of Biskra? Can improved management practices, tailored irrigation strategies, and the selection of specific olive varieties enhance productivity and oil yield in these harsh environments?

The primary objective of this research is to develop a robust framework for olive cultivation in arid regions, beginning with an understanding of farmers' practices, preferences, and objectives. The study explores current methods of managing olive groves, including cultivar selection, irrigation strategies, and harvesting techniques. It involves a comprehensive analysis of olive cultivars, all cultivated in a single orchard under uniform agricultural conditions, to assess their morphometric characteristics and productivity.

In addition, the research examines monovarietal olive oil samples to evaluate their physical and chemical properties, aiming to understand how the genetic traits of these cultivars manifest under arid conditions compared to their traditional, more humid environments in the northern regions and other countries such as Spain, Italy, and France.

The research methodology includes an extensive literature review, summarized in the general introduction, highlighting scientific findings from previous studies on the nutritional and agricultural significance of olives. This includes the benefits of olive oil, fruit, leaves, and by-products, as well as their notable resistance to drought and salinity.

Three chapters comprise the doctoral thesis. The first chapter focuses on an investigation with 54 farmers from various municipalities in Biskra to identify and study the characteristics of olive cultivation in this region, illustrating both positive and negative aspects.

In the second chapter of our thesis, I quantified various morphometric and agronomic parameters of olive tree characteristics, focusing on both leaves and pomologic (fruit and stone) characteristics. The study included 13 olive tree varieties from different geographic origins, comprising introduced varieties from Spain, Italy, and France, as well as Algerian varieties.

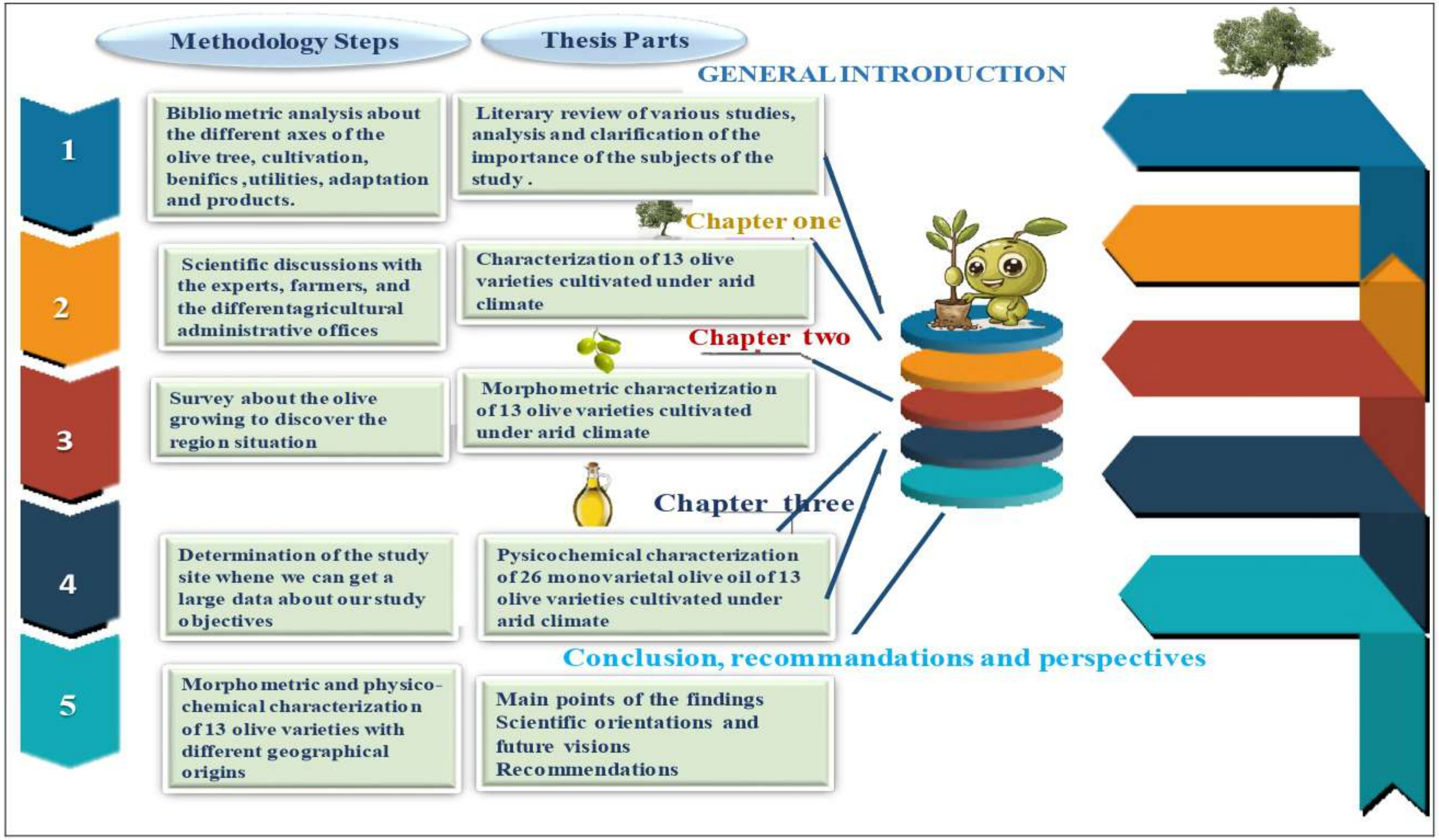
All these varieties are cultivate in the same orchard under the arid climate of Biskra province in Algeria, specifically in the El Outaya region. For leaf measurements, an automated method was developed using macros in ImageJ, an open-access program.

This innovative approach enabled the rapid and easy quantification of leaf surface area, length, and width. For pomologic characteristics, a digital caliper and a digital scale with an accuracy of 0.0001 g were employed to measure these traits accurately.

The third chapter focused on the characterization of 26 monovarietal extra virgin olive oil samples obtained from the same 13 olive varieties studied in the second chapter, with two samples per variety at different maturity indices.

The olive oils were extracted using a mini-hydraulic press through the cold press method. Following extraction, the samples were analyzed for physico-chemical parameters, including acidity, optical density, pigments content (chlorophyll and carotenoids), industrial yield, and fatty acid composition using gas chromatography (GC).

Figure 1 below summarizes the main parts of the thesis and the methodology used in the study.


Methodology Steps

Thesis Parts

GENERAL INTRODUCTION

1

Bibliometric analysis about the different axes of the olive tree, cultivation, benifics ,utilities, adaptation and products.

Literary review of various studies, analysis and clarification of the importance of the subjects of the study .

Chapter one

2

Scientific discussions with the experts, farmers, and the differentagricultural administrative offices

Characterization of 13 olive varieties cultivated under arid climate

Chapter two

3

Survey about the olive growing to discover the region situation

Morphometric characterization of 13 olive varieties cultivated under arid climate

Chapter three

4

Determination of the study site whene we can get a large data about our study objectives

Pysicochemical characterization of 26 monovarietal olive oil of 13 olive varieties cultivated under arid climate

Conclusion, recommandations and perspectives

5

Morphometric and physico-chemical characterization of 13 olive varieties with different geographical origins

Main points of the findings
Scientific orientations and future visions
Recommendations

Figure 1: Graphical abstrat

Chapter I

Olive growing in arid region; case of Biskra Algeria

1 Introduction

Olive groves represent a prominent category of perennial crops globally, covering approximately 25% of the total permanent cultivated area across 63 nations on all continents, totalling 11.6 million hectares. This constitutes slightly over 0.25% of the entire cultivated land area. Notably, 70% of the global olive grove area is designated for rainfed horticulture, with the remaining 30% allocated to irrigation (Vilar & Pereira, 2018).

The consumption of olive tree products, including olive oil, table olives, and olive leaves, has experienced significant growth due to the nutritional, medicinal, economical, and ecological benefits offered by these products (Boronat et al., 2019a, 2019b; Carnevale et al., 2014, 2018; Davis et al., 2017; Diallinas et al., 2018; El-Azem et al., 2019; Violi et al., 2015).

This surge has fuelled the worldwide expansion of olive cultivation, reaching across diverse climatic regions, from the Mediterranean to unconventional olive oil-producing countries such as Argentina (Pardo et al., 2018), Brazil (Antonialli et al., 2018), Chile(Romo-Muñoz et al., 2018), the united kingdom (Martínez et al., 2002), and the arid climate of the southern Algerian desert (Belhacini et al., 2020) .

In Algeria, despite its historical origins, the cultivation of olives has encountered various challenges and undergone significant transformations throughout time. The introduction of olive trees to distant areas characterized by arid and desert climates reflects the impact of historical conquests and population migrations. The discovery of ancient olive presses dating back to the Roman period in remote regions serves as tangible evidence of the olive oil trade between Algeria and Rome during that era (Alloum, 1974). According to Camps-Fabrer (1953) , the region around Ain Zaatout in the village of Ath Ferrah, located in the Biskra province, maintained the longstanding tradition of olive cultivation. This practice was sustained by tapping into subsurface water resources and the presence of ancient olive trees and oil mills that trace their origins back centuries.

Biskra, historically recognized as a vital agricultural hub, employs an oasis agricultural system, creating a microclimate conducive to the growth of olive trees alongside date palms. Olive trees, renowned for their adaptability to harsh environmental conditions such as drought and high temperatures, thrive in this region (Fraga et al., 2020; Mafrica et al., 2021).

Contemporary agricultural systems, facilitated by government initiatives and the implementation of modern irrigation methods, have further propelled olive cultivation in Biskra. Initiatives like the National Agricultural Development Plan (Plan National de

Développement Agricole - PNDA) in the 2000s have opened new avenues for agricultural development in Saharan regions, catalysing a transition from traditional oasis production to a more diverse system (Agoune & Touati, 2023).

The Biskra province stands out as a predominant producer in the southern area of Algeria. The olive cultivation area has significantly expanded in the last decade, reaching 5209 hectares, representing 33% of the overall planted area in the southern region, encompassing a total of 1,238,219 olive trees (DAS, 2021).

While the prospect for olive cultivation in Biskra appears promising, challenges emerge due to the region's arid climate. Testing the adaptability of olive trees to varying climates presents a unique opportunity for study. Maximizing olive yields with minimal input costs remains a crucial consideration. Challenges encompass Phytopathological issues, water deficits, and extreme temperatures (Lionello et al., 2014; Oteros et al., 2014), underscoring the pivotal role of farmers in decision-making. The profitability and sustainability of olive cultivation in new locations hinge not only on farmers' choices regarding olive cultivars (Khadari et al., 2019), agricultural practices, and adaptation strategies(Nastis et al., 2019) but also on the successful implementation of these choices, emphasizing the critical role of farmers in both decision-making and execution.

Our extensive field study in the Biskra region illuminates the intricate processes involved in cultivating olives in an arid environment. The study provides valuable insights specific to Biskra province and serves as a comprehensive reference for regions confronting similar challenges in olive cultivation under arid conditions. By emphasizing the pivotal roles of farmers, education, and sustainable methods, our research establishes a solid foundation for the continual expansion and prosperity of olive cultivation in arid regions, contributing to a sustainable future for this agricultural practice.

2 Background of the researches about the olive cultivation in arid climate

This bibliometric review explores a recent trend of studying olive cultivation in arid climates, focusing on research conducted in the past fifty years. It examines various aspects such as olive groves, olive production in arid zones, difficulties, challenges, and potential solutions. We conducted a comprehensive search of the Scopus database until December 2023, utilizing precise keywords pertaining to olive cultivation and cultural practices. Our aim was to gather valuable information from academic articles, conferences, books, and chapters. In order to gain comprehensive bibliometric data, we utilized VOSviewer (*https://www.vosviewer.com/*) to analyze the interconnections among nations, authors, keywords, and documents, thus providing contextual information for our research focus. This bibliometric review has presented a thorough summary of papers published each year. Since 1999, there has been a surge in research focused on olive cultivation in arid climates for the purpose of wastewater treatment (**Figure2: A**).

The identification of key publications that have significantly contributed to the understanding and progress in the study of olive growing was accomplished by reviewing the 9 most cited or influential papers, representing a comprehensive selection. Analyses of their most productive work identified the most influential authors in the field of Olive growing under arid climate. The authors were grouped together to highlight their areas of expertise and frequent collaborations

The authors' affiliations allowed for the mapping of each country's contribution to the research work. We were able to identify Tunisia, Italy, Spain, France, and Argentina as significant contributors to the study of olive growing (**Figure2: B**). The primary areas of study and emerging patterns in the field were identified through keyword analysis.

Figure2:C shows that certain keywords were commonly linked to olive cultivation, such as arid conditions, irrigation, and various aspects of growing the olive tree (*Olea europaea*). The categorization of documents based on subject area has facilitated the identification of research patterns, international partnerships, and areas experiencing rapid expansion (**Figure2: D**). These findings could provide the basis for future agricultural research, decisions, and agricultural advancements.

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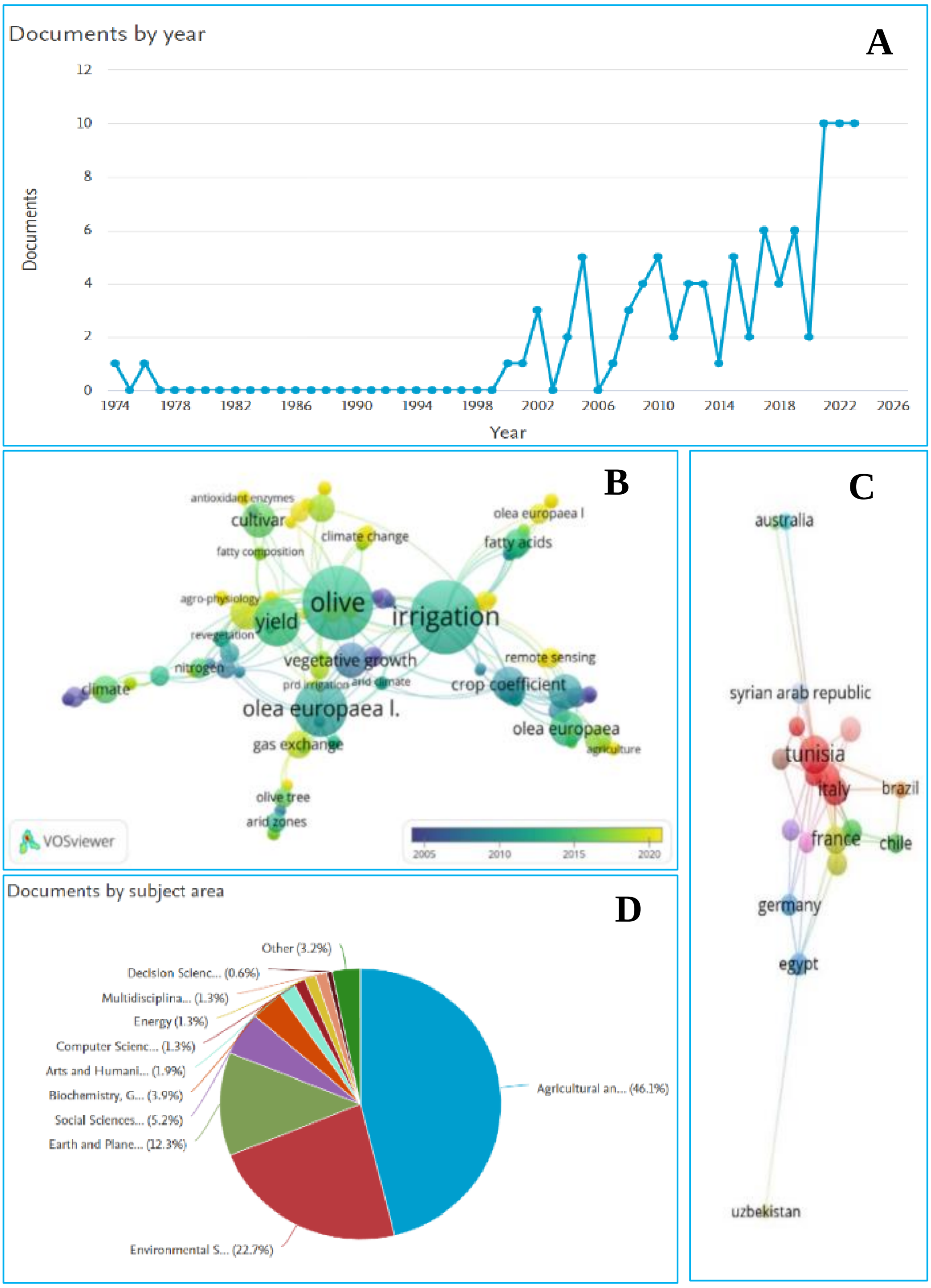


Figure 2: Documents by (**A**) year, (**B**) keywords, (**C**) countries and (**D**) subject area (source: Scopuces

3 Material and methods

3.1 Study area

This study examines olive cultivation in arid regions, specifically in the province of Biskra, located in central and eastern Algeria at the gateway to the Sahara Desert. This province spans an area of 20,986 square kilometres and includes 33 municipalities distributed across 12 districts, as of 2014. The study region has a hot desert climate, as classified by Köppen (1936) (Kottek et al., 2006). It receives less than 150 mm of precipitation yearly and has an average annual evaporation of 2.5 thousand mm. According to Boudibi et al.(2021), the mean temperature varies between 11°C in January and 35°C in July.

The topography of the research region is primarily flat, interspersed with sporadic undulating hills and elevated mountain ranges. The altitude ranges from a minimum of 43 meters in the Oumache region to a maximum of 283 meters in the western section. The area is geologically classified as belonging to the Quaternary epoch, conducive to the replenishment and presence of groundwater (Boudibi, 2021; Sedrati, 2011).

The soils in this region are diverse, impoverished, and shallow. Saline, gypsum, and limestone deposits are found in the southern region. The eastern region contains alluvial soils and fertile clay soils. Conversely, the soils in the northern region exhibit limited development and low fertility. The northwest plain is distinguished by its clay-sodium soils (Khechai, 2001; Masmoudi, 2012; Sedrati, 2011).

The province of Biskra is a prominent producer in the southern region of Algeria. The area dedicated to growing olives has dramatically increased in the past ten years, now covering **4939** hectares, accounting for **33%** of the total cultivated area in the southern region, including **1307800** olive trees (DAS, 2021). The table 1 shows informations on areas, productions and locations of olive growing in the region of Biskra according to the statistics of Biskra Agricultural Room for the season 2020/2021.

Table 1 Distribution of olive growing in the province of Biskra during 2020/2021 (**BAR, 2021**)

Locations	*Area (ha)*	*Total olive trees (tree)*	*Olive fruit production (qx)*	*Olive fruits for oil production (qx)*	*Oil production(hl)*
Eloutaya	1272	325620	15704,3	9826	1657
Mlili	522	161060	3551	1354	224
Ourlal	459	79713	4048	1543	255
Mkhadma	311	93992	3447	1315	217
Oumache	400	116720	5600	2338	404
Elghrous	107	30120	1943	741	122
Branis	142	36930	2400	999	184
Sidi Okba	137	37460	2530,7	1241	225
Chetma	124	42030	2800	1175	202
Mchounech	92	30940	1958	1023	190
El haouch	45	15590	1590	0	0
Zeribet El Oued	126	32940	3150	0	0
Ain naga	88	29810	1847	980	182
El Faidh	133	35160	3112	0	0
El Kantra	101	27060	1841	979	162
Ain Zatout	52	13730	0	1395	243
Djemourah	43	12650	1330	507	84
Tolga	62	16960	1117	426	70
Lioua	266	38815	1992	760	125
Lichana	51	13880	852	325	50
Foughala	32	8940	550	210	35
Bogdj Ben Azzouz	3	1380	95	36	6
M ziraa	111	30000	2713	0	0
Bouchagroun	34	10250	760	290	48
El Hadjeb	111	36250	2844	1085	179
Khangat Sidi Nadji	115	29800	2466	0	0
Total	**4939**	**1307800**	**70241**	**28548**	**4864**

3.2 Sample composition

We selected 54 active farmers to actively participate in our survey. This group was chosen randomly from the list of olive growers provided by the Biskra Agricultural Room for the season 2020/2021. Our survey encompasses fourteen diverse locations, namely: El Hadjeb, Ain Zatout, Ain Naga, Tolga, Sidi Okba, Branis, Oumache, Ourlal, Amlili, Emkhadema, El Outaya, El Kantara, Lioua and Elhouch.

The geographic distribution of these locations is represented by (**Figure 3)** below.

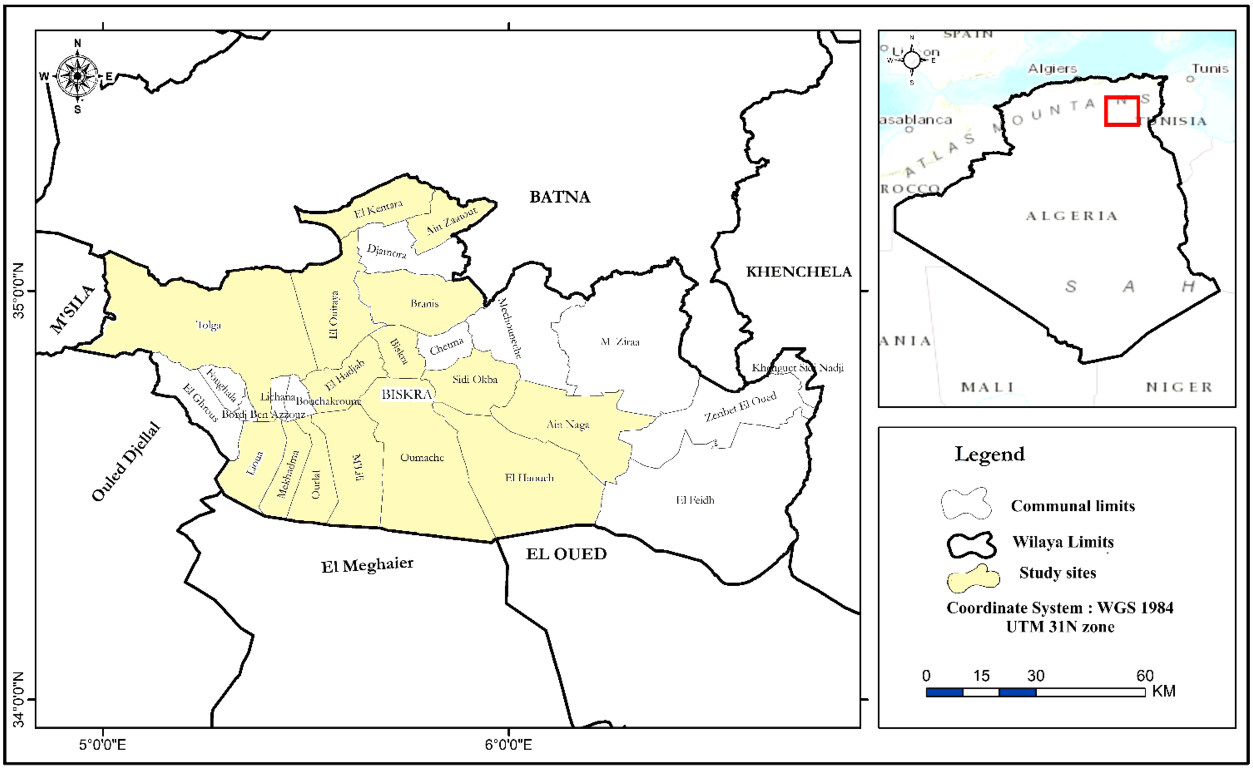


Figure 3 : Study area (**Original 2022)**

We employed a free randomized sampling method to select farmers in the chosen locations, with the number of surveyed farmers in each location reported in **Table 2**.

Table 2 Number of surveyed farmers in selected locations

Locations	Number of surveyed farmers
El Hadjeb	5
Ain Zatout	5
Ain Naga	3
Tolga	3
Sida Okba	3
Branis	2
Oumache	8
Ourlal	3
Amlili	3
Emkhadema	3
El Outaya	9
El Kantara	3
Lioua	2
El Haouch	2
Total	**54**

3.3 Survey steps description

To effectively manage and differentiate questionnaire samples from various locations within our study area, a comprehensive analysis was conducted, considering the size of the study area.

The questionnaire is tailored for farm managers, responsible for both overall management and investment decision-making, aiming to evaluate the methods of olive production in this region. It encompasses various aspects, including farmer profiles, groves identification, plant material used, cultivation practices, and the socio-economic environment.

Data collection occurred from November 2021 to July 2022, adhering strictly to ethical principles. Participants provided consent, and confidentiality was maintained for their personal information. The survey aimed to gather scientific knowledge devoid of personal biases or individual interests.

3.4 Statistical analysis

The collected data underwent processing, coding, and entry for descriptive statistical analysis using Excel 2013 and IBM SPSS (Social Package for Social Sciences) version 27.

4 Results

4.1 Surveyed farmers' profiles

The demographic profile of the surveyed participants **(Table 3**) reveals a predominant male representation, accounting for 92.6% of the sample, while females make up 7.4%. In terms of age distribution, the vast majority of respondents (77.8%) are between the ages of 31 and 50. Notably, the age groups 20-30 years account for 13.0%, 51-60 years for 18.5%, and those over 70 years for 1.9%. The participants' backgrounds are diverse, with 74.1% hailing from cities other than Biskra. It is important to note that these farmers specialize in olive growing in Biskra, our study area. Farmers' educational attainment varies, with 46.3% having completed high school, followed by 29.6% who have completed university. The majority (53.7%) of olive growers have 11-15 years of experience, with 22.2% having received agricultural training. The remaining respondents (77.8%) have not received formal agricultural training**.**

Table 3 Surveyed farmer's characterization

		Percent (%)
Gender	Male	92,6
	Female	7,4
Age	20-30	13
	31-40	27,8
	41-50	31,5
	51-60	18,5
	61-70	7,4
	More than 70	1,9
Original city	Biskra	25,9
	Other city	74,1
Educational level	None	3,7
	Primary school	3,7
	Secondary shcool	16,7
	Hight school	46,3
	University level	29,6
Experience with olive growing	Up to 5	5,6
	6-10	20,4
	11-15	53,7
	16-20	13
	More than 20	7,4
Training in Agriculture	Yes	22,2

4.2 Identification of the Surveyed olive groves

The age distribution of olive trees in the surveyed orchards (**Figure 4; A**) is as follows: 9 trees, accounting for 16.7% of the total, are between 6 and 10 years old. The age group of 11 to 15 years comprises 24.1% of the total, which corresponds to a count of 13 trees. Out of all the trees, 37% of them, which is the majority, fall within the age range of 16 to 20 years. In total, there are 20 trees in this age range. Finally, 22.2% of the olive trees have an age exceeding 20 years, totaling 12 trees.

According to the survey, farms that were classified as larger accounted for 46.3% of the total and had an area of more than 10 hectares. On the other hand, medium-sized farms made up 29.6% of the total and had an area ranging from 6 to 10 hectares. Additionally, there was a presence of small-scale farms, comprising 20.4% of the total, with sizes ranging from 1 to 5.99 hectares. Furthermore, 3.7% of the farms had a size of less than one hectare.

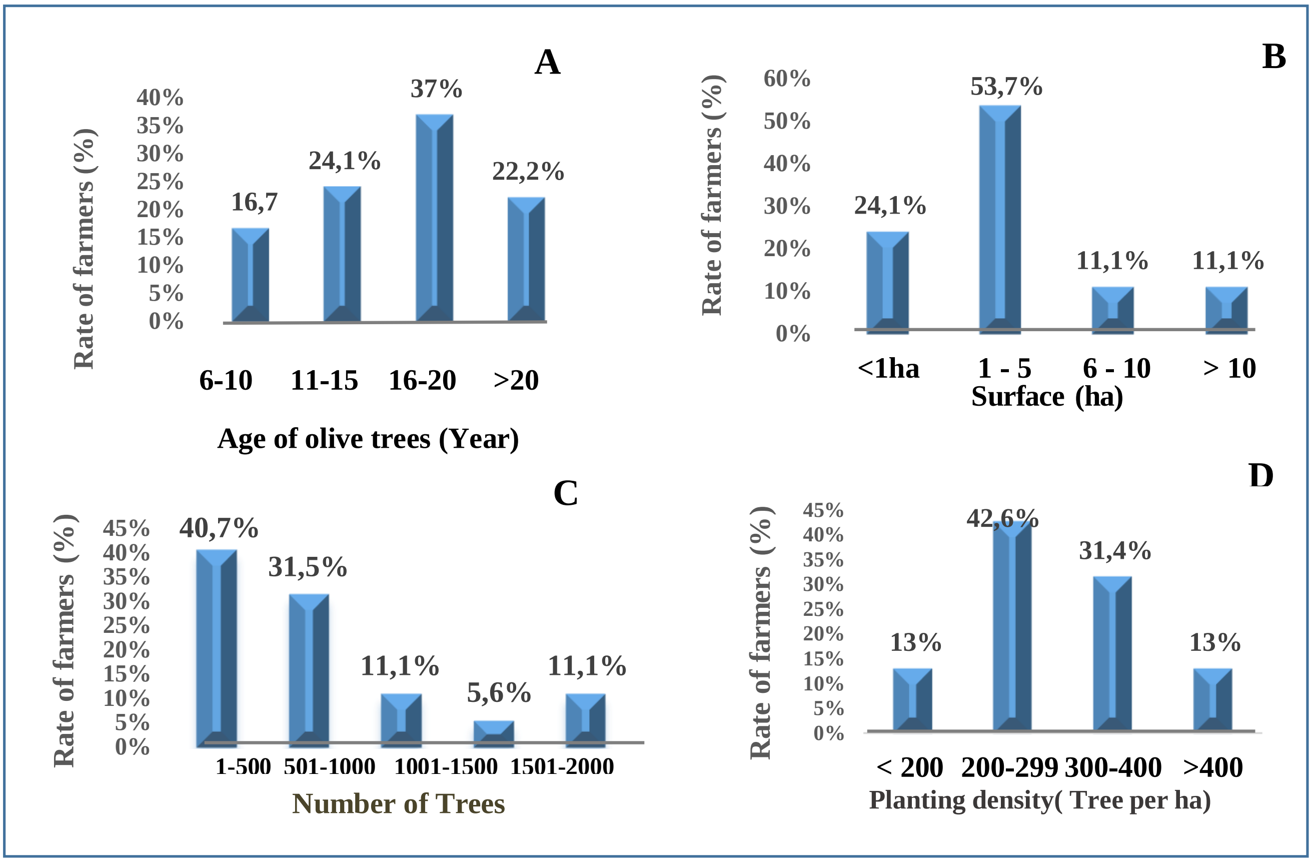


Figure 4 : **a**; Olive tree age, **b**: Olive orchards surface, **c**; Olive tree number, **d**; PLanting density

Regarding the size of olive groves, the findings indicate that most farms had extensive orchards, with 53.7% possessing orchards spanning from 1 to 5.99 hectares.

Additionally, smaller orchards were noted, with 24.1% possessing orchards measuring less than one hectare, and 11.1% possessing orchards ranging from 6 to 10 hectares and exceeding 10 hectares (**Figure 4; B**).

The survey specifically examined the quantity and concentration of vegetation present on the agricultural properties. Among the farms sureyed (**Figure 4;D**); a significant proportion had a substantial quantity of olive trees. Specifically, 40.7% of the farms had between 1 and 500 trees, while 31.5% had between 501 and 1000 trees. The density of olive trees exhibited significant variation.,42.6% exhibited a density ranging from 200 to 299 trees per hectare, while 31.4% fell within the range of 300 to 400 trees per hectare. The lower densities consisted of 13% with less than 200 trees per hectare and 13% with more than 400 trees per hectare (**Figure 4; C**).

The survey revealed that olive groves exhibit variations in their dimensions, tree count, orchard density, and the utilization of either intensive or semi-intensive planting techniques. Farmers commonly employ high density planting techniques to attain optimal crop productivity and enhance the plants' inherent resilience against wind and various plant species. This information is valuable for comprehending the olive cultivation techniques and preferences of the interviewed farmers.

Regarding planting density, the majority of farmers aim to optimize it by reducing the area while increasing the number of trees. This approach allows them to economize on water and irrigation infrastructure costs. These systems are primarily employed for irrigation and commonly utilize the method of immersion irrigation. The close spacing of the trees optimizes efficiency, reducing the time, labor, and water required for watering.

4.2.1 Plant material

The majority of farmers used certified Plants (61.1%) for planting olive trees. A smaller proportion used uncertified plants (22.2%), while a few farmers had planting material of unknown origin (16.7%) (**Figure 5; B**).

4.2.1.1 Olive tree varieties cultivated by the surveyed

In terms of the origin of cultivated olive trees (**Figure 5;B**); (22.2%) of farmers have chosen to cultivate foreign varieties. However, the vast majority (100%) prefer to grow local varieties, indicating a strong inclination toward varieties adapted to the specific conditions of the arid zone.

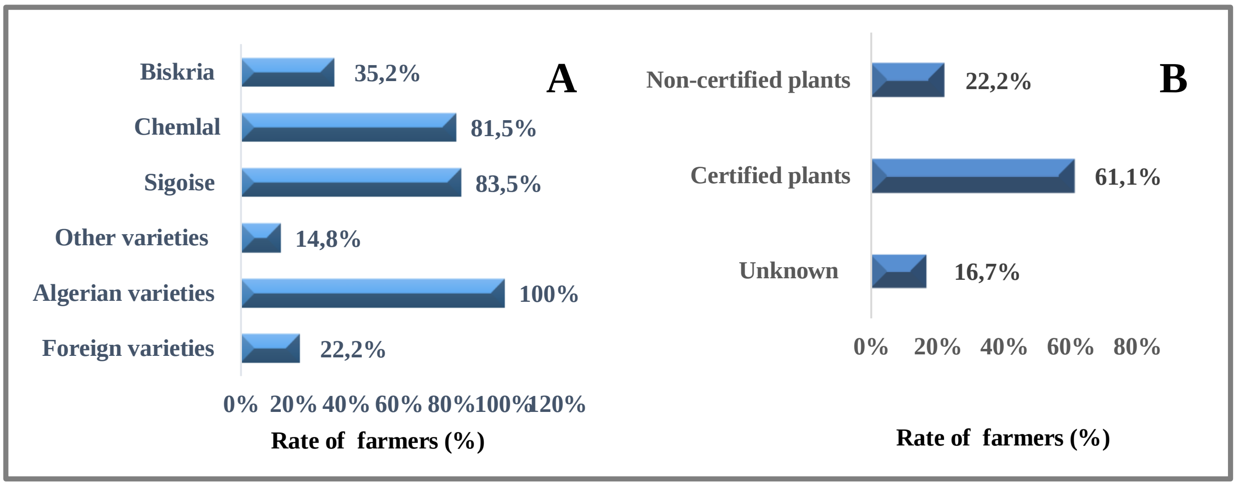


Figure 5 : Plant material characterization
A: Olive varieties information, B: Origin of cultivated olive trees

Specifically, the Chemlal olive variety is widely cultivated, chosen by 81.5% of farmers, the Sigoise olive variety is also popular, with (83.3%) of farmers growing it, suggesting its prevalence in the region. Nearly a third of farmers (35.2%) opted for the Biskria variety, indicating a certain diversification of varieties grown in the region Only 14.8% of farmers chose to cultivate other varieties of olive trees, demonstrating some variability in the choice of varieties within the arid zone of Biskra (**Figure 5; A**).

4.3 Conduct of culture

4.3.1 Cultural treatment practices

The cultural treatment practices observed among the surveyed farmers in Biskra, our study area, demonstrate intriguing patterns. Regarding plant establishment techniques, 46.3% of individuals utilize seedling planting (**Table 4**), indicating a systematic approach to tree management, whereas 53.7% do not conform t established planting guidelines. When it comes to tree pruning (**Table 4**), 70.4% of people choose to engage in training pruning in order to promote better growth, while 29.6% prefer fruiting pruning to improve fruit production.

Regarding fertilization practices (**Table 4**), the majority (88.9%) of individuals opt for both organic and mineral methods to promote sustainable and eco-friendly agriculture, conversely, 11.1% of individuals do not follow this practice. 42.6% of participants utilize phytosanitary treatments to combat diseases and pests, demonstrating their focus on safeguarding crops. Conversely, 57.4% of participants abstain from using these treatments, suggesting a preference for organic or reduced chemical methods. Regarding weed control (**Table 4**); 64.8% of participants engage in the activity of weeding as a means to manage the presence of competing weeds, while 35.2% do not incorporate weeding into their agricultural practices**.**

Table 4 Conduction of the olive groves.

Operation		**Rate of farmers (%)**
Standard tree planting		46.3%
Maintenance Purification of the tree	Training size	70.4%
	Fruiting size	29.6%
Organic fertilization		88.9%
Mineral fertilization		88.9%
Weeding		64.8%
Treatments against diseases and pests		20.37%

4.3.2 Irrigation and drainage

Irrigation is universally necessary for agricultural practices (**Table 5**), with all farmers (100%) actively engaging in irrigation. This is a crucial response to the region's limited water availability.

When analyzing the origins of irrigation water among these farmers (**Table 5**), it is evident that 68.5% rely on boreholes, indicating a significant reliance on groundwater. Additionally, 16.7% use wells, 9.3% obtain water from wadis (rivers), and 5.6% depend on dams.

Regarding irrigation systems (**Figure 6**); 75.9% of farmers choose localized irrigation methods (**Table 5**), such as drip systems, which guarantee accurate water distribution to plants. Meanwhile, 24.1% utilize gravity irrigation systems that make use of the natural movement of water.

The frequency of irrigation practices exhibits heterogeneity (**Table 5**), with 46.3% irrigating every 5 days, 27.8% irrigating every 15 days, and 25.9% employing irregular irrigation practices, possibly influenced by specific crop requirements or the availability of water resources (**Table 5**).

Table 5 Irrigation and drainage practices

		Rate (%)
Irrigation		100%
Source of irrigation water	Dam	5.6%
	Drilling	68.5%
	Well	16.7%
	Wadi	9.3%
Water analysis	Yes	81.48%
	No	18.51%
Irrigation system	Gravity	24.1%
	Localized system	75.9%
Irrigation rate and frequency	Every 5 days	46.3%
	Every 15 days	27.8%
	Irregular irrigation	25.9%
Drainage system application	No	100%

However, in terms of drainage, all surveyed participants do not have drainage systems in place on their farms, indicating a widespread absence of this specific agricultural infrastructure among all respondents (100%).

Figure 6 : Irrigation systems (Original 28-03-2022).

A: Localized irrigation system **B**: Gravity irrigation system

4.4 Socio-economic environment

4.4.1 Production informations

The presented data in Table 6, offers valuable insights into different facets of olive production, such as the destination of the olives, the stage at which they are harvested, the estimated yield, the method of harvesting, and the location of the units where olive oil is extracted.

Table 6 Characterization of Olive production

Settings	Purposes	Rate (%)
Destination of olive production	Table olive	61.1
	Olive oil	20.4
	Oil and table olive	18.5
Harvest fruit stage (Fruit color) for table olive production	Green	80.48
	Black and Green	2 .43
	Depending on the availability of labor	17.07
Harvest fruit stage (Fruit color) for table olive production)	Black	38.09
	Green and Black	19.04
	Depending on the availability of labor	42.85
Estimation of olive yield (kg/ tree)	Less than 20 kg/ tree	50
	More than 20 kg/ tree	33.3
	Uknouwn	16.7
Estimation of olive oil yield (l/ha)	Less than 15L / 1 qx	20.4
	More than 15L / 1 qx	20.4
	Uknown	59.3
Harvesting Methods	Shaking of branches	57.4
	Manual	42.6
	Mechanical	0
Location of olive oil extraction units	Far	60
	Close	40.7

Regarding the distribution of olive production, the largest portion (61.1%) is designated for table olives, while 20.4% is allocated for olive oil and 18.5% is used for a blend of oil and table olives.

When examining the stage at which table olives are harvested, the data indicates that 80.48% are harvested while the fruit is still green, 2.43% when it has turned black, and 17.07% depending on the labor availability.

In table olive production, specifically during the black fruit stage, 38.09% of the olives are harvested when they have turned black, 19.04% are harvested at a different stage, and 42.85% are harvested based on the availability of labor.

The olive yield estimation reveals that 50% of the trees produce less than 20 kg, 33.3% yield more than 20 kg, and 16.7% have an unknown yield.

Similarly, the assessment of olive oil yield indicates that 20.4% yield less than 15 liters per 1 quintal, 20.4% yield more than 15 liters per 1 quintal, and the yield of 59.3% is unknown. Regarding the methods used for harvesting, 57.4% of individuals employ the technique of shaking the branches, 42.6% utilize manual methods, and none make use of mechanical harvesting.

The distribution of olive oil extraction units reveals that 60% are situated at a considerable distance from the source, whereas 40.7% are in close proximity.

4.4.2 Workforce

With regards to the workforce (**Figure 7**), it is worth mentioning that 44.4% of participants depend on permanent workers for their agricultural operations. This substantial proportion indicates a reliable and long-lasting labor force, which contributes to the uninterrupted continuation of agricultural operations. Furthermore, a notable proportion of participants, specifically 42.6%, employ seasonal workers, indicating their ability to adapt to the varying requirements of different seasons.

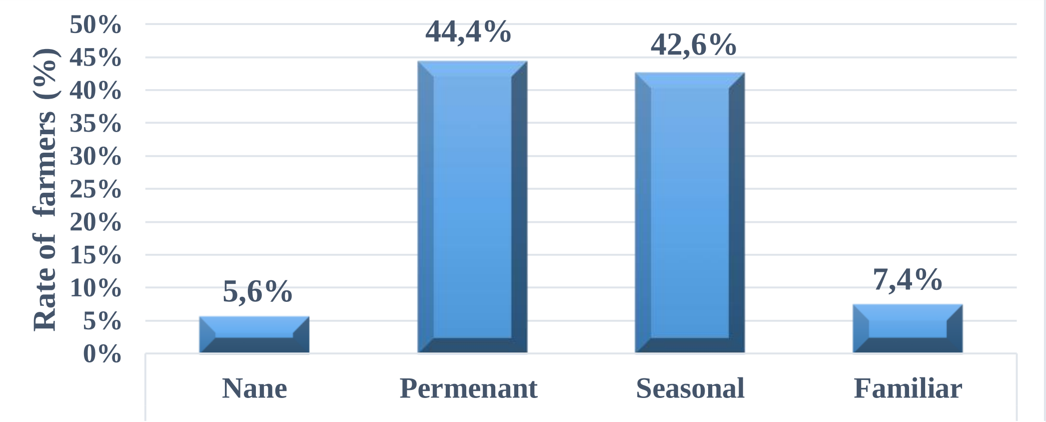


Figure 7 : Workforce types

Seasonal labor is incorporated to ensure flexibility in handling agricultural tasks according to seasonal demands. In addition, 7.4% of participants employ family labor, demonstrating the active engagement of the family in diverse agricultural tasks.

4.4.3 Olive tree products flow

When it comes to the olive products flow (**Figure 8**), a significant 64.8% of farmers primarily grow olives for the local market. This suggests a notable focus on satisfying local demand, which could potentially boost the local economy and fulfill the needs of regional consumers.

Regarding exports, 35.2% of the participants engage in olive production specifically for the purpose of exporting. The simultaneous focus on local and international markets highlights the diversification of the olive production landscape. Curiously, none of the farmers solely cultivate olives for personal use, highlighting the business-focused nature of the olive farming practices among this group of participants. This data offers valuable insights into the composition of the workforce and the strategic market focus of olive producers, reflecting the dynamic socio-economic landscape in the olive cultivation.

Figure 8: Olive trees products destination

5 Discussion

We conducted a field study in the Biskra region to gain insights into the olive farming sector in a desert climate. The study involved administering a questionnaire with a wide range of questions. The survey was conducted with a sample of 54 farmers who exhibited a range of ages. In terms of educational attainment, the majority of the farmers surveyed (46.3%) had completed high school, while 29.6% had completed university-level education.

This illustrates that individuals with a lower educational attainment are less inclined to allocate additional resources towards innovation, which necessitates a higher level of expertise. According to Muhammad-Lawal et al.(2014);there is evidence suggesting that agricultural performance is enhanced by increased levels of education. One possible reason is that effectively utilizing advanced tools requires specialized training and manual analysis to create a product of greater market worth. Moreover, studies conducted by Khaldi (1975) and (Welch, 1971) have substantiated that a greater level of education positively impacts agricultural productivity.

Additionally,(Kafando, 2020)has affirmed that each year of education attained by a farm manager leads to a corresponding increase in farmers' income.

About their original hometowns, they can be divided into two groups: native farmers from Biskra and investors from the northern provenance of the country. This diversity enriches the agricultural culture of the olive farmers.

Natives of the arid environment have a comprehensive understanding of various agricultural methods and techniques, particularly in terms of irrigation and adaptation to the dry desert climate. On the other hand, farmers from the northern regions have extensive knowledge of olive cultivation, pruning techniques, and harvesting.

Therefore, Hernández-Morcillo et al. (2018) and Stutzman et al. (2019), recommend to address the issue of a lack of skills in planning and managing an olive growing system, guidelines, training programs, and possibilities for knowledge exchange between farmers and advisers have been developed. Farmers require ongoing training to deal with the demands of their industry (Hernández-Morcillo et al. (2018); Landini et al.(2017); Stutzman et al.(2019)). A more practical and less theoretical education/training technique has been suggested by (Landini et al., 2017).

Thus, we encourage further research to be carried out to better understand the motivation of advisors to engage in training programs fostering the exchange of ideas between these two groups of farmers and engaging with various agricultural authorities to organize study and training days to promote and develop the olive sector in arid regions.

The majority of orchards surveyed are young, approximately 37% of farmers reported that the ages of their orchards ranged from 16 to 20 years; this means that their orchards were planted in the period from 2000 to 2004. This is primarily due to the National Agricultural Development Plan (PNDA), through this program, olive cultivation areas expanded across the entire Algerian territory by distributing olive trees to most farmers nationwide.

Among these farmers are those from the Biskra region, known for date production and date palm cultivation, as a result of the agricultural nature of our study area, many farmers in this region allocated small spaces to live cultivation. Despite having extensive areas, about 53.7% of farmers stated that their orchards covered an area ranging from 1 to 5 hectares our results are the similar of Ater M., Barbara and H., Kassout . (2016),(Baldini, 1992)with a planting density falling within the intensive planting system; Regarding those kinds of planting density, most farmers focused on the intended planting system to maximize the number of trees in a small area.

This leading to cost savings in irrigation equipment and labor, as well as higher yields per hectare compared to the traditional isolated tree cultivation. Most farmers relied on a density of 200 to 299 trees per hectare (42.5%) as a traditional system planting, followed by a density of 300 to 400 trees per hectare (31.5%), and 13 % by more than 400 trees per hectare. Within these typologies fall olive orchards with intensive plantings characterized by planting densities of 300–1000 trees/ha, (Scaramuzzi, 2007).

As for the third unit of the survey, it included information about the plant materials used. Most farmers used certified plant material. This is essential for successfully cultivation, as it ensures knowledge of the characteristics of the planted variety in terms of quantity and quality of production and adaptation.

Moreover, about the olive varieties, Chemlal and Sigoise are the most commonly used in the region by farmers these are the two most commonly used local varieties in the country (Boukhari, 2014). These two varieties are the most prevalent in the northern part of the country, where they have been extensively planted. Primarily, they were distributed to farmers free of charge by the Technical Institute of Fruit Arboriculture and Vine (Institut Technique de l'Arboriculture Fruitière et de la Vigne “ITAFV”).

The remaining percentage of farmers either owned old orchards purchased from other individuals or relied on planting trees with unknown sources bought from the general market without precise criteria.

Some farmers also mentioned having a local variety specific to the Biskra region, known as 'Biskria' (35.2%). It is essential to verify and genetically and morphologically classify this variety for potential propagation, as it is a successful local variety. Olive cultivars native to dry locations are more adapted to drought circumstances than cultivars from other regions.

For foreign varieties we found just one farm in Ain Naga area that includes an orchard with a high density Arbequina. This variety is considered one of the most adaptabale varieties in arid climates, withe high production yeild (Bacelar et al., 2009; Greven et al., 2009), especially in areas with a more temperate climate.

Michalopoulos et al. (2020), also mentioned that proper pruning techniques that improve within canopy light distribution, foliage aeration, and the development of bearing shoots could help to reduce the "alternate bearing" phenomenon (high/low yield year) and achieve stable yearly crop yield. Furthermore, the same study suggests that shredding pruning wastes rather than burning them enhances soil organic matter, creating a mulching layer as well as improved soil water retention capacity.

Regarding tree pruning, (28%) of farmers engage in the practice of pruning fruits, this practice is essential for achieving improved fruit production. Engaging in this practice is essential for achieving equilibrium in vegetative growth (Baldini, 1992). The growth of fruit production can have a significant impact on light efficiency, which in turn affects the quality of production. This has been demonstrated in studies by Proietti et al. (2011), Reale et al. (2019), and Servili et al. (2013) .

Additionally, the sensitivity of plants to plant diseases is influenced by the balance between vegetative and reproductive activities, which is affected by fruit production. This relationship has been observed by (Viruega et al., 2011),88.9% of farmers primarily use organic fertilizers due to the high cost of mineral fertilizers. Only 11% of farmers utilize mineral fertilizers in their orchards, indicating a widespread scarcity of fertilizer usage. The results of our study are consistent with those of (Therios, 2009) , indicating that this factor plays a critical role in affecting both the quantity and quality of fruit production (Rufat et al., 2014; Sallam et al., 2014).

All the olive orchards in the region are among the crops that are irrigated throughout the year. The only difference that exists is in the source of the water used for irrigation. 68.5 of the farmers' source of water is Drilling, our results are similar to those obtained by Guehiliz (2016) and Guehiliz et al. (2023) about the irrigation sources in Biskra region.

Biskra is a Saharan region where agricultural strategies have resulted in extraordinary agricultural success. Drilling techniques became more common in the 1980s, and their costs fell dramatically, resulting in a phenomenal increase in the number of individual boreholes, which served as the foundation for the development of a new type of Saharan agriculture outside the oases that was intensive and completely market-oriented(Mubarak, 1998).

More than 100,000 hectares of land in the region are irrigated, but the precise number of boreholes in use is unknown. The local branch of the Southern River Basin Agency estimates that there are 17 thousand boreholes in the region, only 8 thousand of which have been sunk with the permission of the necessary authorities.(Daoudi et al., 2017) due to the process of support from the state through loans to farmers, which made drilling wells easier. It is within the reach of most farmers and has contributed to the development of the confiscation of irrigation water in the region, and the rest is between traditional wells and irrigation from the valleys.

The most widely used irrigation system is the local irrigation system, 75.9 percent, and it is widely relied upon in the region because its equipment is available at reasonable prices compared to other systems and does not consume energy.

Large electric, regulating watering periods for olive orchards is necessary and necessary for the success of agriculture. Most farmers irrigate every five days 46.3%, and 27.8% of farmers irrigated every 15 days, which means that irrigation frequencies and periods differ among farmers and are irregular in quantities that are not precisely organized, whether in quantities that is more or less than the trees’ need for water.

However ,a survey of the recent literature shows that deficit irrigation allows to maintain oil yield above 80% of that of fully-irrigated trees while water saving ranges from about 15 to 50% of the volume applied(Caruso et al., 2013a; Gispert et al., 2013a; Gómez-del-Campo, 2013b; Iniesta et al., 2009).

Since olive cultivation is a perennial agriculture and irrigation water is mostly salty, farmers must install a drainage system to avoid the formation of resulting secondary salinity. The accumulation of salts from repeated watering with salty water, will lead in the future to a problem that will harm and perhaps destroy the trees of the olive groves or affect the yield and quality of the product, whether oil or table olives.

Therefore, efficient evaluation of drainage system is essential for sustainable agricultural water management, crop production, soil salinization prevention, and salinized land reclamation(Blann et al., 2009; Khand et al., 2017; Singh, 2019), especially in arid regions with severe water scarcity and intense evapotranspiration.

All farmers mentioned a significant challenge during the harvesting season due to a shortage of labour, which is attributed to the overlap between the region's olive harvest season and the date palm harvesting season, because date palm farming offers a considerably higher daily income compared to olive picking, many young individuals favour engaging in date palm cultivation.

The daily wage for date palm harvesting is approximately twice that of olive picking, creating a substantial income gap that strongly incentivizes young people to choose date palm harvesting over olive picking.

Consequently, working in date palm orchards is increasingly viewed as a practical option for enhancing income and saving time. These factors collectively contribute to the scarcity of available labour for olive harvesting, as the younger workforce is drawn to the financial benefits associated with date palm harvesting, making it a more attractive choice for them.

Olive harvesting is mainly manual methods using hands, long poles, or sticks. However, Hand harvesting accounts for up to 80% of table olive labor input and 60% of production expenditures (Cicek, 2011), Mechanical harvesting is the only solution(Homayouni et al., 2022).

We also noticed a misconception among farmers, 87% of them believe that fully ripe olives with a black and wrinkled appearance have a higher oil content, which is completely untrue. Harvesting olives at this stage deteriorates the quality of the oil and reduces its nutritional value, and as the fruit becomes more ripe the oil content increases, although the quality of the oil deteriorates correspondingly (Salvador et al., 2001; Sönmez et al., 2018).

Moreover, many farmers pick olives and leave them in boxes for two weeks or more, believing that this reduces the water content, a procedure that saves the costs of transportation and pressing. There is a scarcity of oil processing facilities and there are only four processing centers in the entire Biskra region (DSA 2021). It is far from olive groves, as 60% of the farmers surveyed mentioned this problem.

As for the benefit from the harvested olives, 61.1% is directed to the production of table olives, while 20.4% is used to produce olive oil. This is completely consistent with the statistics of the Biskra province (DSA) Agricultural Statistics Directorate. The main reason for the decline in olive oil production is due to the prevailing dietary habits in the region, where olive oil consumption is lower compared to the northern regions of the country.

Many residents of the region consume table olives in large quantities, to the point that every family prepares them at home. In addition, farmers are considering selling olives immediately after harvest, without the cost of turning them into oil, as a quick and cost-effective way to make a profit.

To evaluate tree productivity, we proposed 15 liters of oil per quintal and the same amount in kilograms of olives per tree, based on the age of the orchard obtained from statisticians at the Biskra Agricultural Chamber. Most farmers estimate their production at about 15 liters of oil per quintal and about 20 kilograms of olives per tree. This is normal because most orchards are still in the early stages of production due to their young age.

6 Conclusion

Our comprehensive field study in the Biskra region has provided valuable insights into the multifaceted aspects of olive farming in an arid climate. The findings underscore the pivotal role of education in shaping farmers' attitudes toward innovation and modern agricultural practices. The diversity among farmers, whether native to Biskra or investors from northern regions, presents an opportunity for a rich exchange of agricultural knowledge and practices.

Our recommendations emphasize the need for ongoing training programs, collaborative initiatives, and practical education to bridge skill gaps and foster sustainable agricultural practices. The prevalence of young orchards, the choice of planting systems, and the utilization of local olive varieties highlight the intricate balance between tradition and innovation in olive cultivation.

Moreover, the selection of appropriate olive varieties is paramount for the sustainable development of olive cultivation in the Biskra region, it is crucial to focus on choosing adaptable and productive varieties that can thrive in arid climates. Introducing new varieties from other regions, specifically tailored for arid conditions, could bring about innovation and resilience in the face of climate challenges.

A concerted effort should be made to conduct in-depth research on local olive varieties in the Biskra region, with special attention given to unique varieties such as Biskria. This research should include genetic and morphological classification to ensure a thorough understanding of these local varieties.

Recognizing the inherent advantages of native cultivars in dry regions, especially their ability to acclimate to drought conditions, will inform future decisions on propagation and cultivation practices. This approach aligns with the broader goal of promoting sustainable and climate-resilient olive farming in the desert climate of Biskra.

Agricultural practices such as pruning, fertilization, and irrigation emerged as key determinants of olive production, with a particular emphasis on water-efficient strategies in arid regions. Additionally, addressing misconceptions among farmers, enhancing processing infrastructure, and promoting olive oil consumption are crucial steps toward fostering a thriving olive sector.

The challenges identified, including the scarcity of processing facilities, suboptimal harvesting practices, and regional dietary preferences impacting olive oil consumption, call for a holistic approach involving education, infrastructure development.

In arid regions also emphasizes the importance of multiplying outreach campaigns for producers. Actively supporting scientific research, with a particular focus on combating olive tree diseases, is recommended. Additionally, promoting the establishment of cooperatives and specialized units in quality control, packaging, processing, marketing, and export of olive products is advised.

In essence, our study not only contributes valuable insights to the specific context of Biskra but also serves as a broader reference for regions facing similar challenges in the cultivation of olives in arid environments. The integration of education, collaboration, and sustainable practices emerges as the cornerstone for the continued growth and success of the olive sector in arid climat

Chapter II

Morphometric & Agronomic characterization

1 Introduction

Assessing and describing the range of physical traits shown by crop species is crucial. Olive is a notable species because it has a diverse collection of cultivated varieties and wild plants (G. Bartolini et al., 1998; Rotondi et al., 2003).

The significant diversity of olive cultivars may be readily seen in the morphology of their fruits, leaves, and endocarps in terms of form and size. Thus, doing a morphological study may serve as an effective method for characterizing and distinguishing different cultivars, as well as establishing phenological correlations between them (Al-Ruqaie et al., 2016; N. D. Barranco et al., 2000; Belaj et al., 2016; Ganino et al., 2006).

Recently, there has been significant emphasis on comparing the morphological traits of the primary olive cultivars (Baldoni et al., 2009; Belaj et al., 2012; Bracci et al., 2011). However, much of the focus has been on the molecular genotyping of cultivars to evaluate their genetic diversity (Bagnoli et al., 2009; D'Imperio et al., 2011; Mousavi et al., 2014; Muleo et al., 2016).

Despite many limitations, such as environmental variability, tree age, cultivation practices, and plant phenological stage, this methodology remains the primary method for describing and classifying olive germplasm, the majority of the research conducted by the International Union for the Protection of New Varieties of Plants (UPOV) is centered around morphological descriptors.

These descriptors primarily examine the physical traits of leaves, fruits, and endocarps. Historically, these traits have been extensively used for descriptive reasons to differentiate olive cultivars (Belaj et al., 2002; Malheiro et al., 2015; Santo et al., 2015; Smykalova et al., 2011; Trujillo et al., 2014). Previous studies have shown that many characteristics associated with leaves, fruits, and endocarps are mostly governed by genetics, with little effect from the environment (Fendri et al., 2010).

Although the identification of olive cultivars is widely used, there is currently a lack of a technique to support the ongoing growth of this sector(Belaj et al., 2016). Therefore, using computerized techniques to conduct morphological analysis of olive leaves, fruits, and endocarps is crucial in this area of research to extract maximum information from their numerical data.

Presently, traditional manual methods such as using a screw gauge or caliper, gridded paper, and so on, have been used for the morphological examination of olives (Al-Ruqaie et al., 2016).

The use of image analysis and computerized techniques in plant science and agriculture is on the increase, particularly in the domain of phenomics, numerous tools are available for these specific goals, especially leaf parameters measurements (Fahlgren et al., 2015; Lobet, 2017; Lobet et al., 2013).

Additional software has been developed to measure leaf outlines and extract certain leaf shape characteristics, such as leaf height, leaf area, and leaf breadth (Bakr, 2005; Easlon & Bloom, 2014; Maloof et al., 2013; O'Neal et al., 2002; Yang et al., 2015).

One such program is ImageJ (Abràmoff et al., 2004)]wich is one of the most often used, freely available, scientific applications for analyzing images. The program allows for easy extraction of parameters such as height, breadth, area, and perimeter of the description item.

In this chapter, we examined the physical characteristics and measurements of 13 different types of olives (both Algerian and foreign varieties) in the ITDAS (Institut Technique de développement de l'agriculture saharienne) olive collection in the Biskra region. This analysis was conducted under harsh environmental conditions to identify specific traits that distinguish cultivars with unique agronomic characteristics and high productivity in the Biskra region. The ultimate goal is to distribute these varieties to farmers and enhance the olive industry in Algeria.

Finally, this work also allowed us to find phenotypic descriptors that could identify cultivars presenting intriguing agronomic characteristics and the most productive varieties under the pedo-climatic conditions of the Biskra region at the end of distributing these varieties to the usefulness of farmers and ultimately improve the olive sector in Algeria

2 Material and methods

2.1 Presentation of the study site

The study site is located at the Technical Institute for the Development of Saharian Agriculture (ITDAS) Experimental Station in El Outaya (**Figure 9**), 12 kilometres north of Biskra province in southeastern of Algeria. The orchard's coordinates are 34°93′30.55″ N, 5°65′88.43″ E, positioned along national road number 3, which connects Biskra and Batna, at an elevation of 207 meters, and as Biskra, the study site is characterized by an arid climate, with average annual rainfall rarely exceeding 150 mm and an average of 132 mm over the past 10 years. Annual evaporation is substantial, typically exceeding 2,500 mm, and the average yearly temperature is around 23 °C. The coldest month is January, with an average temperature of 11 °C, while July is the hottest, reaching 35 °C.

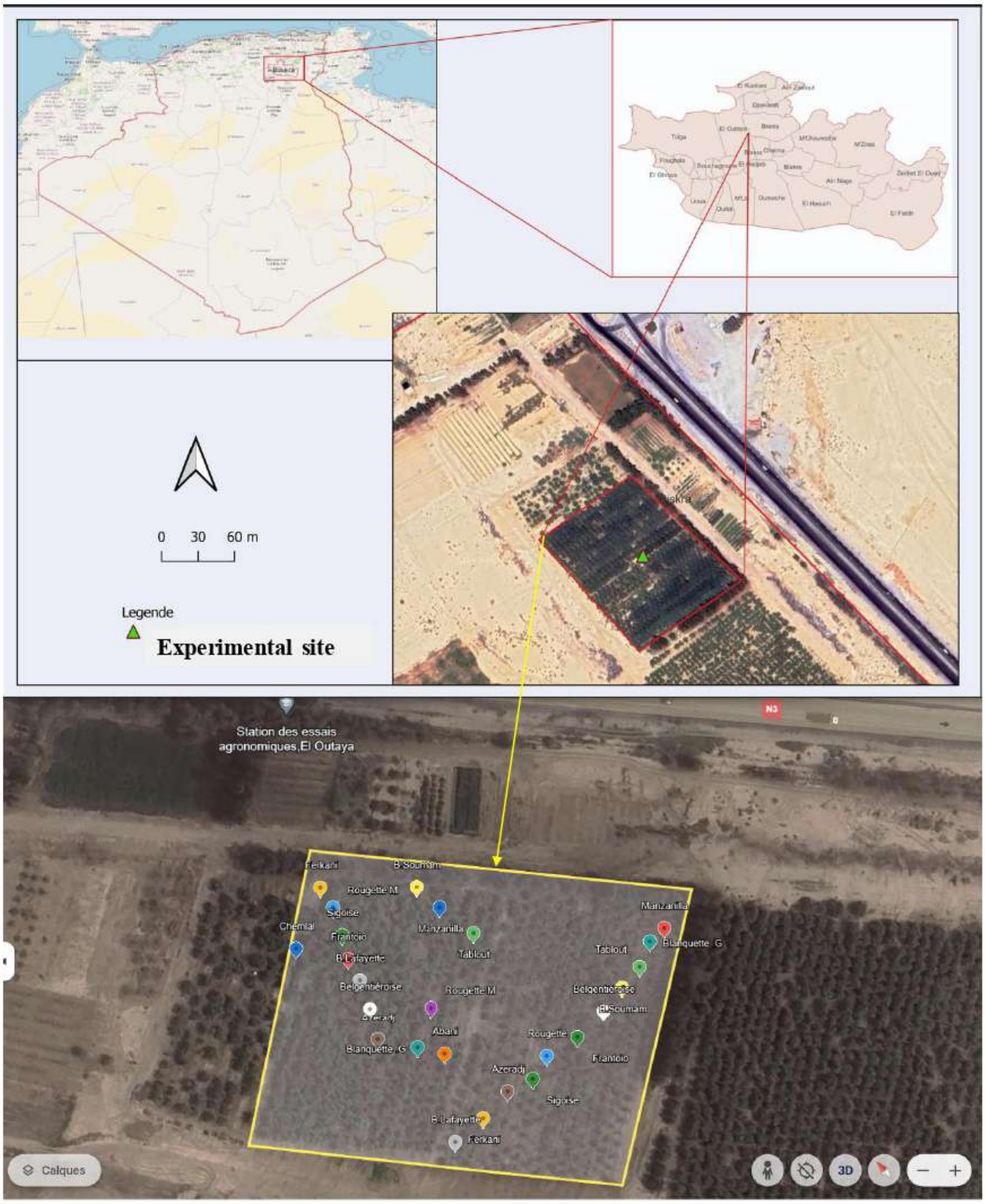


Figure 9: Experimental site with the studied varieties distribution in the olive orchard (Origenal **2024**)

The olive orchard under investigation was established in 2005 and spans about 0,8 hectares (**Figure 9**). It consists of clay-loamy soil with a pH of 8.15 and an electrical conductivity (EC) of 2.71 dS/m. The orchard supports 360 olive plants, planted at a density of 625 plants per hectare. A localized irrigation system is employed, with 18 irrigation sessions conducted annually.

2.2 Material

2.2.1 Vegetable Material

The studied orchard, established 17 years ago, consists of a diverse collection of olive varieties. These include eleven local varieties: Abani, Chemlal, Rougette de Metidja, Blanquette de Guelma, Azeradj, Bouchouk La Fayette, Bouchouk Soumam, Sigoise, Tablout, and Ferkani. Additionally, the orchard includes three foreign varieties: Belgentiéroise, Frontoio, and Manzanilla. (**Table 7**).

Table 7 List of the varieties of the studied collection

No.	**Varieties**	**Production**	**Geographic origin**
1	Abani	Olive oil	Algeria Tebessa
2	Azeradj	Table olives+oil	Algeria (Bedjaia)
3	Chemlal	Olive oil	Algeria (Kabylie)
4	Belgentiéroise	Table olives+oil	France
5	Blanquette de Guelma	Olive oil	Algeria (Guelma)
6	Bouchouk La Fayette	Table olives	Algeria
7	Bouchouk Soumam	Table olives	Algeria (Seddouk in Bejaia)
8	Ferkani	Olive oil	Algeria (khenchla)
9	Frontoio	Olive oil	Italy
10	La Rougette de Metidja	Olive oil	Algeria(Matidja Atlas Blidian)
11	Manzanilla	Table olives+oil	Spain
12	Sigoise	Table olives+oil	Algeria (Sig Mascara)
13	Tabelout	Olive oil	Algeria

2.2.2 Matrial of measurments

For the leaf parameters; an online open access software Image J software,

For the fruit and stone; a digital caliper and a digital scale with an accuracy of 0.0001 g (was used to measure the weight of fruit and stone).

2.3 Methods

2.3.1 Method of samling

In this study eighteen morphological and agronomical traits were used to evaluate phenotypic diversity.

A total of 120 adult leaves and 120 mature fruits per variety were randomly selected and collected over **31 field trips** from **August 2022 to January 2023**. The traits related to the measurements of leaf, fruit, and stone were then evaluated.

We have using the image processing characterization for the olive leaves measurements (part one), and the classical characterization method for the fruits and stone measurements (Part two).

In the characterization of the varieties studied we classified the parameters studied into two categories: qualitative morphological parameters (Fruit shape, stone shape, and leaf shape), quantitative morphometric parameters including; leaf area, leaf length, leaf width, leaf length to width index, fruit weight, fruit diameter, fruit length, fruit length to width index and the same for the olive stone (**Table 8**), and agronomic parameters; pulp weight, pulp/stone ration and the weight of 100 fruits (**Table 9**) .

The qualitative traits were visually examined according to the olive descriptor UPOV (Barranco et al., 2000), and the work presented by Idrissi & Ouazzani (2003) and Cimato & Attilio (2008) served as the basis for the methodology used in our work.

All the studied parameter, type (quantitive or qualitative) are illustrated in the following two tables;

Table 8 Morphpmetric parameters, tools, and IOC standars

Parameter type	Organ	Characters	Measurement/observation tools	IOC Standards
Morphometric parameters	Leaf	srface [2]	ImageJ software	/
		Leaf length [2]		Reduced: < 5 cm
				Average: 5 to 7 cm
				High: > 7 cm
		Leaf width[2]		Reduced: <1 cm
				Average: 1 to 1.5 cm
				High: > 1.5 cm
		Leaf Length/width ratio[2]		Reduced: < 4 cm
				Average: 4 to 6 cm
				High: > 6 cm
		Leaf shape [1]		Elliptical
				Elliptic-lanceolate
				Lanceolate
	Fruit	Fruit weight [2]	Precision scale	Reduced: <2 g
				Average: 2 to 4 g
				High: 4 to 6 g
				Very high: > 6 g
		Fruit length [2]	Numeric Caliper	Reduced: <2 cm
				Average: 2 to 2.5 cm
				High: > 2.5 cm
		Fruit width [2]		Reduced: < 1.5 cm
				Average: 1.5 to 2 cm
				High: > 2 cm
		Fruit Length/width ratio [2]		Reduced: < 1.25 cm
				Medium: 1.25 to 1.45 cm
				High: > 1.45 cm
		Fruit shape [1]		Spherical
				Ovoid

Continuation of the **Table 8;**

	Stone	Stone weight [2]	Precision scale	Lying down
				Reduced: < 0.3 g
				Average: 0.3 to 0.45 g
				High: 0.45 to 0.6 g
				Very high: > 0.6 g
		Stone Length [2]	Numeric Caliper	Reduced: <1.4 cm
				Average: 1.4 to 1.6 cm
				High: > 1.6 cm
		Stone width [2]		Reduced: < 0.65 cm
				Average: 0.65 to 0.85 cm
				High: > 0.85 cm
		Stone Length/width ratio [2]	/	Reduced: < to 1.4
				Average: 1.4 to 1.8
				High: 1.8 to 2.2
				Very high: > 2.2
		Stone shape [1]	/	Spherical
				Ovoid
				Elliptical
				Lengthened

Table 9. Agronomic Parameters

Agronomic parameters	fruit	Weight of 100 Fruits (g) [2]	/	/
		Pulp (g) [2]		/
		Pulp /Stone ratio [2]		/

(1) = Qualitative characteristics

(2) = Quantitative characteristics

2.3.2 Methods of measurements

2.3.2.1 Part 1: Characterization of the olive leaves using image processing by an open Access Software (numeric method)

2.3.2.1.1 Olive leaves samples

In the experimental procedure, we randomly removed leaves from the trees without a predetermined count, focusing solely on the middle part of the tree canopy and the same location on each branch. This location was immediately before the site of the olive fruit attachment on the branch. Only mature and healthy flat leaves were considered.

After collect the olive leaves, we immediately placed them in plastic bags and transported them to the laboratory. We obtained each sample of leaves from a specific olive cultivar and individually placed them in a plastic bag before transporting them to the laboratory.

In the laboratory, we randomly selected 40 (three repetitions) leaves from each sample and carefully positioned them on a high-resolution pixel-equivalent scanner for precise imaging.

The images were captured by a digital scanner (Epson L360) and scaled to 5100 × 7014 pixels. We used the scaled images for box-counting fractal analysis using Image Computing software (Schneider et al., 2012) and stored them in JPEG format for further image treatment.

2.3.2.1.2 ImageJ Software

For the image processing, we have used Imagej, which is the leading free and open-source scientific image analysis software and includes a powerful and accessible scripting language Website; *https://imagej.net/ij/index.html*

2.3.2.1.3 Image capture software

For the screen capture of the different steps of the image treatment, we used FastStoneCapture software: *https://www.faststone.org/FSCaptureDetail.htm*

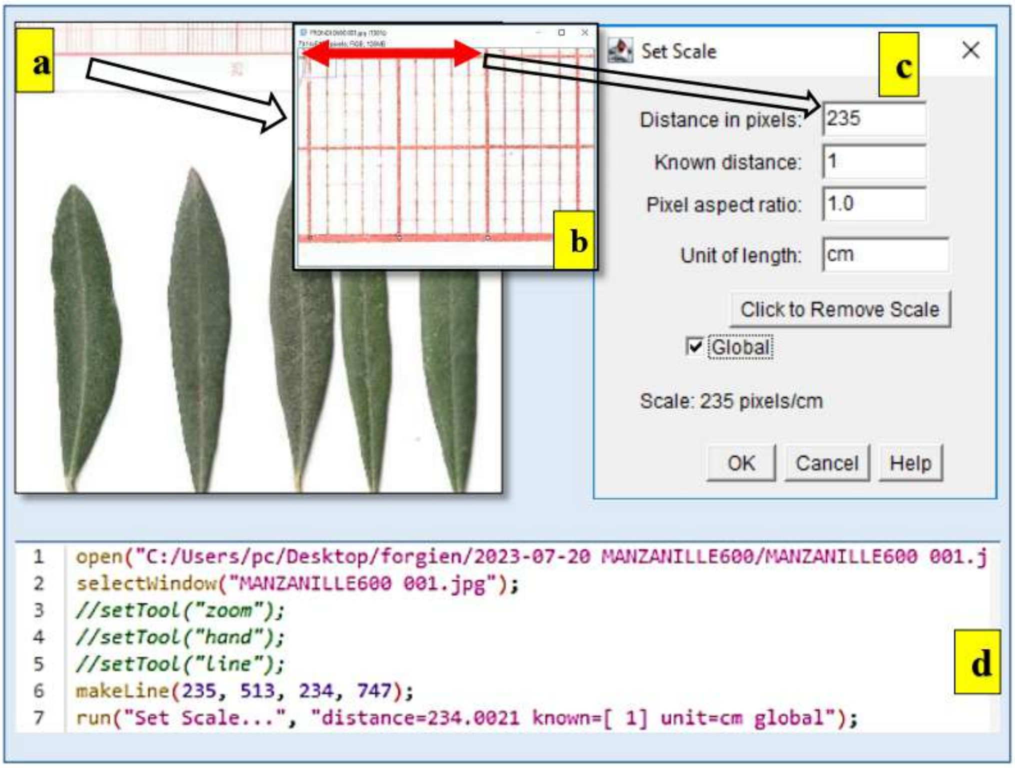
2.3.2.1.4 The created Macro

In order to optimize the image processing workflow, we have created a macro that converts the previously manual procedure into a somewhat automated one. This macro greatly improves productivity by automating repetitive processes and minimizing the risk of human mistake.

The macro streamlines the analysis process by including essential stages such as picture pre-processing, filtering, and feature extraction, enabling users to direct their attention towards more intricate parts of analysis. This not only speeds up the processing time but also guarantees consistent and replicable results, making the whole image processing step more accessible and user-friendly.

2.3.2.1.5 Image processing steps

The **Figure 10**; illustrates the initial step of image processing using the ImageJ software, specifically focusing on setting the scale for accurate measurements. Step (**a**) shows the real scale present in the image, which serves as the reference for calibration. In step (**b**), the distance in pixels is defined by drawing a line along the known scale using the 'Line' tool in ImageJ.



Distance in pixels: 235
Known distance: 1
Pixel aspect ratio: 1.0
Unit of length: cm
☑ Global
Scale: 235 pixels/cm

```
open("C:/Users/pc/Desktop/forgien/2023-07-20 MANZANILLE600/MANZANILLE600 001.j
selectWindow("MANZANILLE600 001.jpg");
//setTool("zoom");
//setTool("hand");
//setTool("line");
makeLine(235, 513, 234, 747);
run("Set Scale...", "distance=234.0021 known=[ 1] unit=cm global");
```

Figure 10 ; First step of the image processing (**Original capture 2023**).

a: real scale , b: defined the pixels distance, **c**: defined the real unit scal basing on the pixels numbers **,** **d**; summurasing all the set scale step by JAVA script language

The software then uses this pixel distance to set the scale. In step (**c**), input the known distance and the corresponding pixel measurement into the 'Set Scale' dialogue box, making sure to set the pixel aspect ratio to 1.0 and specify the unit of length (cm unit). Finally, step (**d**) demonstrates the summarization of the scale setting step through a JavaScript command in ImageJ, confirming the calibration with a scale of 235 pixels per centimeter, this process ensures that subsequent measurements taken from the image are accurate and based on a defined unit of length.

The diagram (**Figure 12)** provides a comprehensive overview of the image processing steps involved in the analysis of olive leaf samples using ImageJ software. The process begins with the **collection and scanning of leaf samples** (labelled '**a**'), the scanned image includes a reference scale to ensure accurate measurements.

Next, we import the scanned image into ImageJ and set the global scale (labelled '**b**'). This step ensures that all measurements are accurate and consistent. The scale setting involves defining the real unit scale based on pixel numbers.

The workflow then branches into two main methods: **the binary method** and **the manual method** (labelled '**d**').

2.3.2.1.5.1 Binary Method

This method utilises a custom macro (LeafBinary.ijm) to process the image. We show the macro steps in detail (labelled '**e**'), illustrating the commands used to enhance contrast, fill holes, and measure the regions of interest (ROIs).

The binary method **(Figure 11)** automates the extraction of leaf parameters such as length, width, and area. We process the images to create a binary map, which in turn generates a distance map for further analysis.

```
run("                    ary.ijm]");
//set
doWar
roiMa
RoiMa
RoiMa
roiMa
roiMa
doWar
roiMa
doWar
roiMa
doWar
roiMa
doWar
roiMa
roiMa
run("
Stri
Stri
saveA                    );
```

Figure 11 : All the image processing steps by JAVA script language **(Original capture 2023)**

2.3.2.1.5.2 Manual Method

In contrast to the binary method, the manual method involves user interaction to select and measure the leaf parameters. We manually process the images to create a distance map and overlay the original image for visual comparison.

Additionally, we used the manual method and the mathematical equation to confirm the binary method's performance, ensuring the accuracy and reliability of the automated measurements.

Finally, we compile the image processing results and calculate the leaf parameter (area) using the specified mathematical equation estabilished by Ahmed & Morsy (1999) .

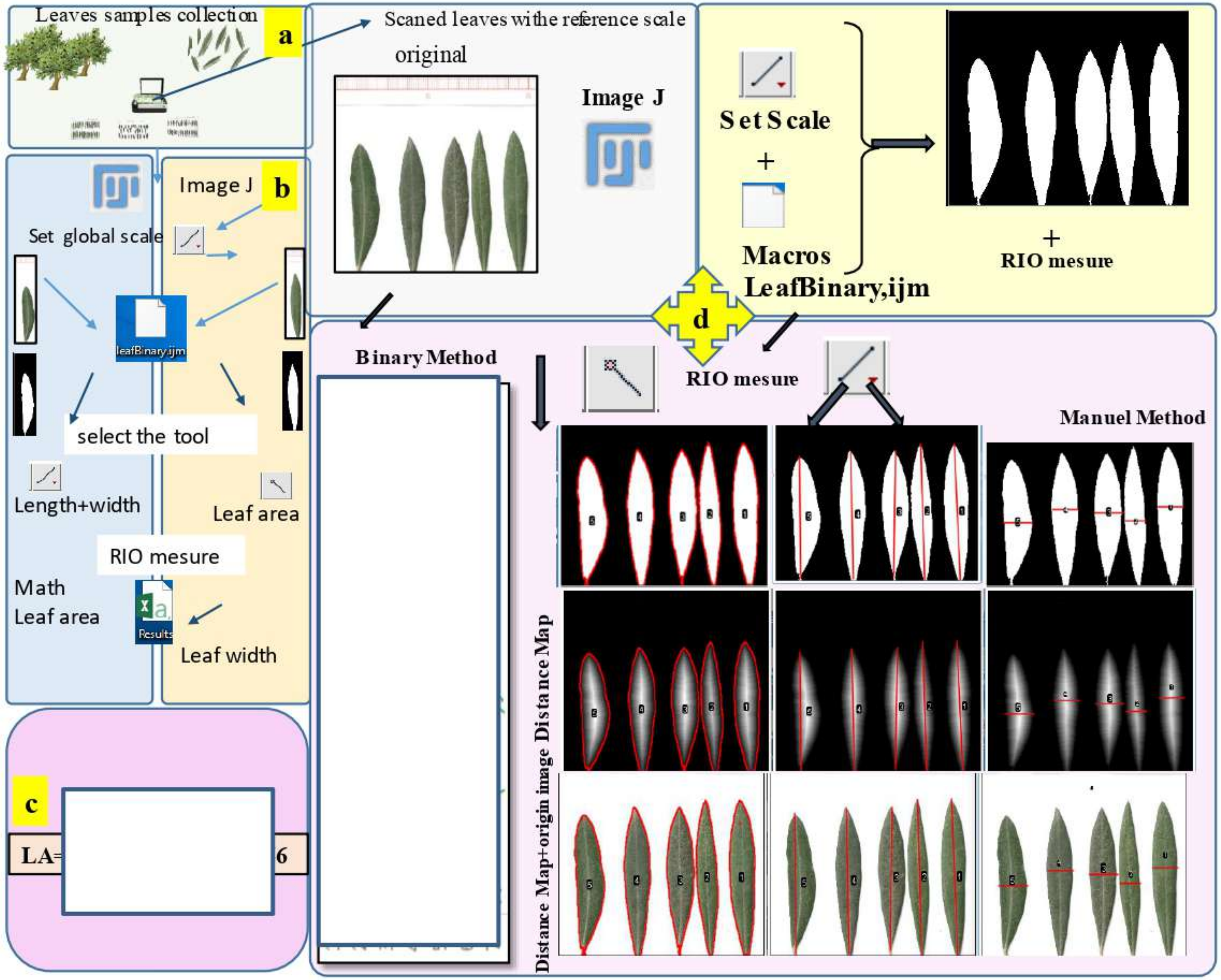
$$\boldsymbol{LA = 0,53(LW * LL) + 1,66} \qquad \textbf{(eq 1)}$$

LA : Leaf Area

LW : Leaf Width

LL : Leaf Lenght

. The diagram **(Figure 12)** effectively illustrates the entire workflow, from the initial collection and scanning of leaf samples to the final computation of leaf metrics using the automated method.



a; Olive leaves samling and scaning

b; Overview of the main stepsof the Image processing

c; Th mathematic equation used in the checking of the performance of the created macros

d ; image traitements for all the studied leaf parameters

e ; Snapshot from image J showing the macro Macro steps details developed to process the slected image automatedly

Figure 12: Diagram of all the steps of the leaf measurement (**Original 2023**)

2.3.2.2 Part 2: Pomologic characterization (manual method)

2.3.2.2.1 Sampling standards

The morphological characterization concerned the quantitative and qualitative descriptors of the fruit and stone described in the methodology of the International Olive Council.

Using three trees per variety, on the southern part of the tree, taken from the middle part of the fruiting branch

These fruits were used, after pulping, to determine the characteristics of the stone (endocarp) (**Figure 13**), samples of the different organs described were collected. The observations covered all members of the varieties studied, observations and measurements were carried out on fruits and stones of each variety studied.

The description of the fruits was carried out on a sample of 120 fruits per variety (three batches of 40 fruits for the repetition).

The **figure 14** illustrates the process of measuring various dimensions and the weight of different olive fruits.

A digital calliper measures the olives's dimensions on the left side, including length and diameter. The calliper displays four examples of olives, each displaying their respective length or diameter measurements on its screen.

Digital scales on the right side measure the weight of the olives, two images depict the scales in use, each with an olive placed on the weighing platform and the corresponding weight displayed on the screen.

Additionally, the right section of the image shows a variety of olive fruits arranged in rows, and some stones, with the different forms and sizes studied. Labels and arrows indicate each stone and olive's length and diameter measurements.

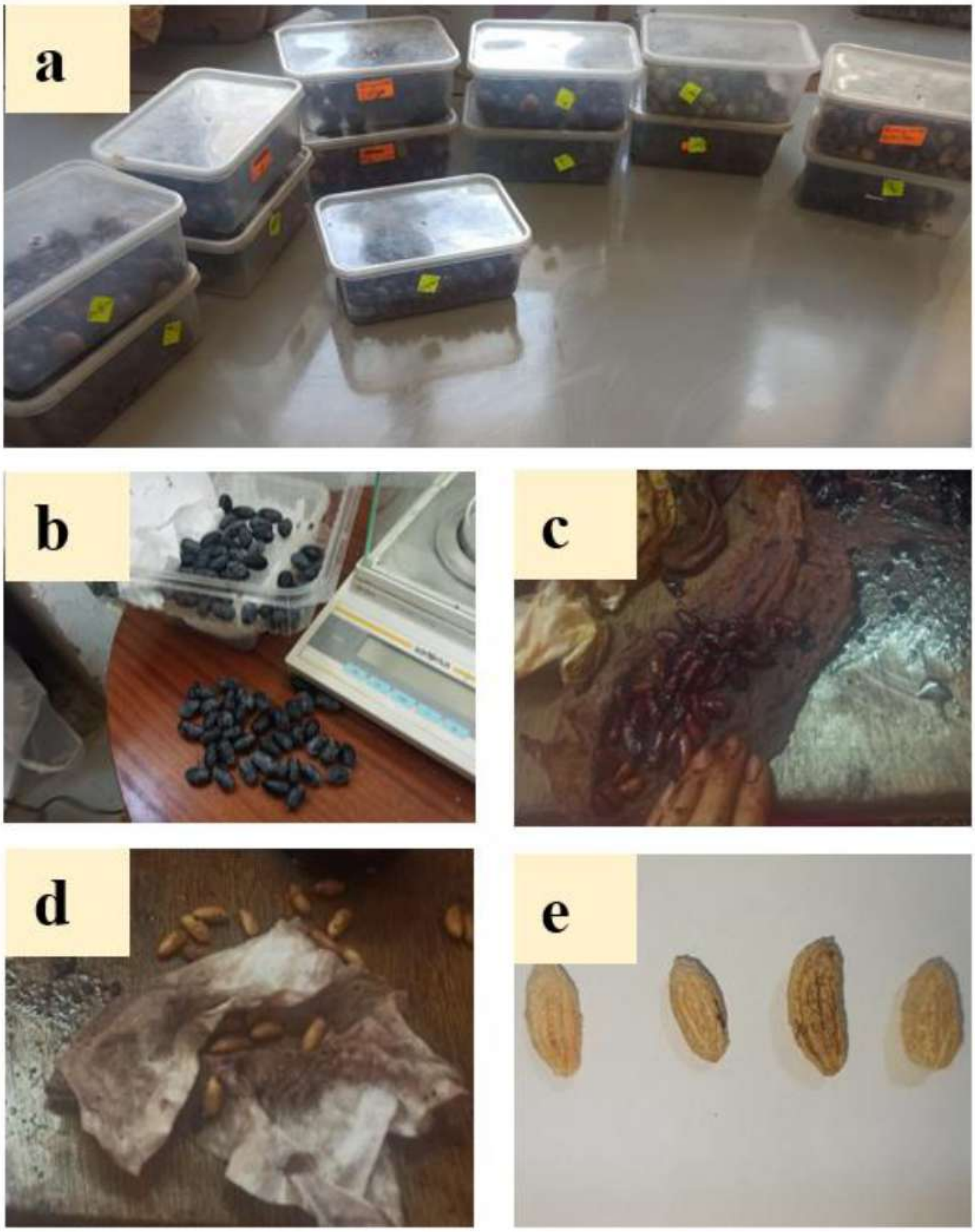


Figure 13 a: Olive fruits batchs, **b**: weithig **c**; moving of the mesocarpe **d**: cleaning of the stones, **e**; stone samples **(Original 2023)**

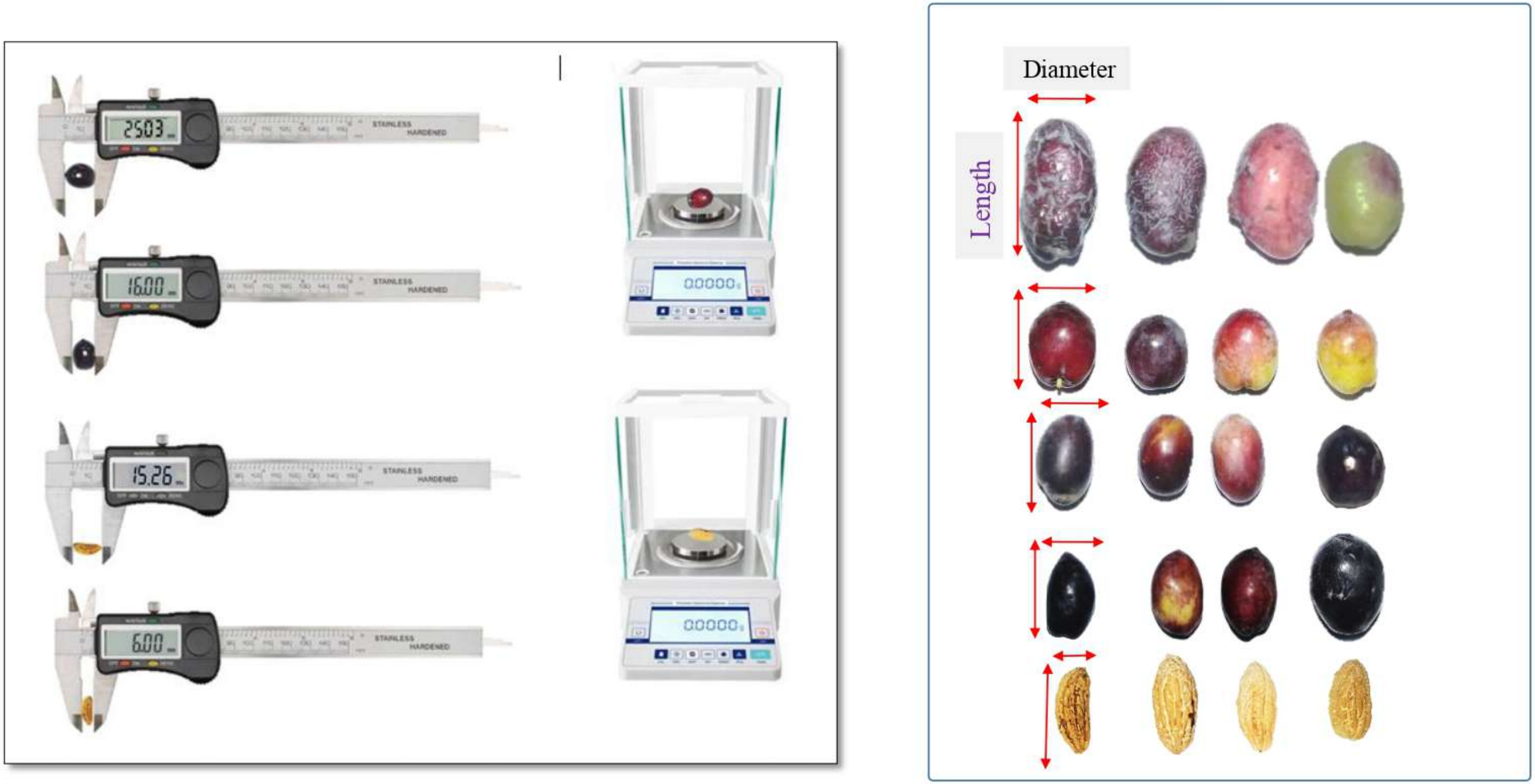


Figure 14: Different studied olive fruit shapes and some stones shapes and the the orientation of the length and the width of each one and their musearments tools **(Original2023)**.

2.4 Statitical analysis

The statistical analysis for the morphological and agronomic characterization of the olive varieties involved a comprehensive examination of both quantitative and qualitative descriptors of the stone, fruit, and leaf. This study adhered to the methodology established by the International Olive Council (IOC) for the primary characterization of olive varieties.

A total of eighteen characters from the fruit, stone, and leaf were analyzed, comprising 15 quantitative and 3 qualitative descriptors, with three replicates in the form of three groups of samples for fruit, stone, and leaf, each containing forty samples.

This resulted in a total of 120 olive fruits, 120 olive stones, and 120 leaves for each olive variety studied, this resulted in a total of 1,560 olive fruits and 1,560 olive stones, with three manual measurements (length, width, weight) for each, amounting to 9,360 manual measurements.

Additionally, 1,560 leaves were measured using the ImageJ software for length, width, and area, resulting in 4,680 measurements. The total number of measurements was 14,040, from which other parameters were derived.

Statistical analyses included Analysis of Variance (ANOVA) to determine significant differences among the varieties and the formation of homogeneous groups at a significance level of alpha = 0.05.

Principal Component Analysis (PCA) and Ascending Hierarchical Classification (AHC) were utilized to identify patterns and relationships within the data, and these analyses were performed using OriginPro 2024 Learning Edition software.

3 Results

The ANOVA test results (leaf, fruit, and stone parameters), illustrated in the following figures, show very highly significant results (alpha = 0.05) with $P < 0.0001$ for all parameters. Means sharing at least one letter are not significantly different according to the Tukey test ($p < 0.05$).

3.1 Image Processing Method performance

Before all the numeric measurements of the leaf parameters, we tested our created ImagaJ software macro based on the mathematical method established by Ahmed and Morsy (1999).

The **figure 15** shows a comparison between the manual and image processing methods for calculating the leaf parametrs of olive leaves.

Box plot comparison between the binary (measured) leaf area (LA Binary) and the estimated leaf area (LA estimated) using the mathematic equation basing on the manual measurments (length and width) (**Figure 14 a**), this box plot shows the distribution of leaf areas calculated using two different methods. The central box represents the interquartile range (IQR) with the median as the line inside the box, and the whiskers extending to the minimum and maximum values within 1.5 IQR from the quartiles. This comparison helps to visually assess if the estimated values align with the binary method values.

In the **Figure 15 b** the Scatter plot showing the correlation between the leaf area calculated by themathematic equation method and the numeric binary method (using ImageJ created macros).

Equation: $y = 0.9207x + 0.0808$

R^2 (coefficient of determination): 0.9603

P-value: < 0.0001

There is a strong linear relationship between the leaf area measurements obtained from the binary method and the numeric method. The high R^2 value (close to 1) indicates that the binary method is very accurate in estimating the leaf area compared to the manual method.

In the **Figure 15 c**, the Scatter plot showing the correlation between leaf length (LL) calculated by the binary method and the manual method.

Equation: $y = 0.9456x + 1.1197$

R^2 (coefficient of determination): 0.9801

P-value: < 0.0001

Similar to **Figure 15 b**, the graph shows a strong linear relationship between the leaf length measurements obtained from the binary method and the manual method. The high R^2 value indicates that the binary method accurately estimates leaf length.

In the **Figure 15 d**, Scatter plot showing the correlation between leaf width (LW) calculated by the binary method and the manual method

Equation: $y = 0.9207x + 0.0798$

R^2 (coefficient of determination): 0.9785

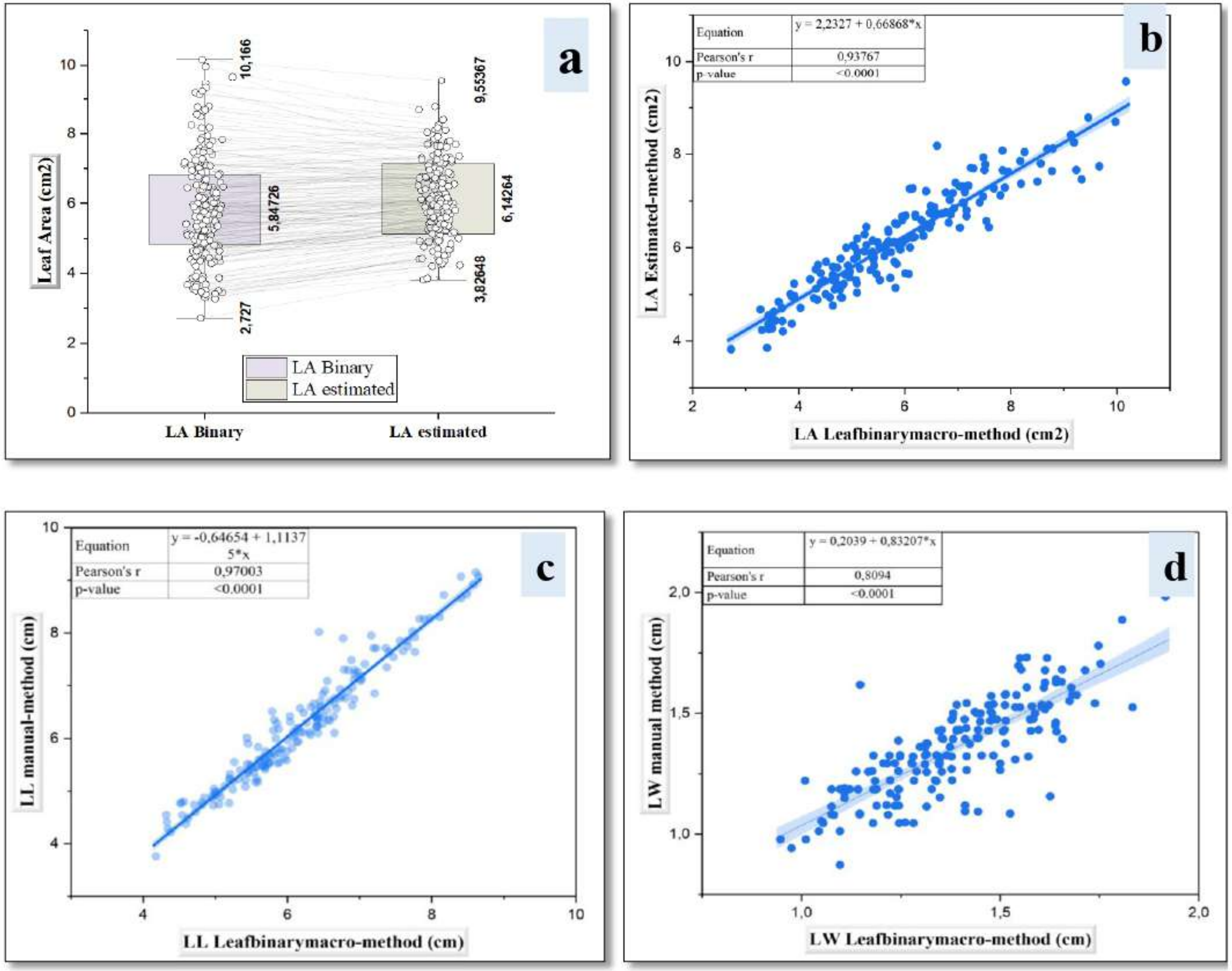
P-value: < 0.0001

There is a strong linear relationship between the leaf width measurements obtained from the binary method and the manual method. The high R^2 value suggests that the binary method is accurate for estimating leaf width as well.

Pearson correlation analysis was used, with a 95% confidence interval, to compare the leaf area (b), length (c), and width (d) calculated manually and by the numeric method (ImageJ created macros).

The numeric method (using ImageJ macros) for calculating leaf area, length, and width shows a strong correlation with the traditional manual (measured) method. The high R^2 values and significant P-values across all panels indicate that the numeric method is reliable and accurate for estimating these parameters in olive leaves.

This comprehensive analysis supports the use of the numeric method as a viable alternative to the traditional method for leaf area measurements, which could potentially save time and effort in similar studies.



a: Comparison between the mathematic and the numeric leaf area *data*, the Correlation analysis (Pearson, confidence interval ¼ 95%) between olive leaf area

b: Comparison between the mathematic and the numeric Correlation analysis between olive leaf area (Pearson, confidence interval 95%)

c: Comparison between the mathematic and the numeric Correlation analysis between olive leaf Length Correlation analysis (Pearson, confidence interval 95%)

d: Comparison between the mathematic and the numeric Correlation analysis between olive leaf width Calculated by manual and the numeric method (our Image j created macros)

Figure 15 : Testing of the performances of our numeric method with the mathematical method established by **Ahmed & Morsy (1999) (Origenal 2023).**

3.1.1 Leaf characterstics

3.1.1.1 Leaf area

Based on the analysis of leaf area among various olive varieties, the results demonstrate a significant range, from the smallest leaf area of 3.81 cm² to the largest leaf area of 8.65 cm². The variety with the smallest leaf area is Ferkani, with a measurement of 3.81 cm², followed closely by Frontoio at 3.87 cm (**Figure 16**).

On the larger end of the spectrum, Azeradj exhibits the largest leaf area, measuring 8.65 cm². This is followed by Sigoise with a leaf area of 8.1 cm².

Chemlal and B. Soumam varieties also show relatively large leaf areas of 7.43 cm² and 7.45 cm², respectively (**Figure16**).

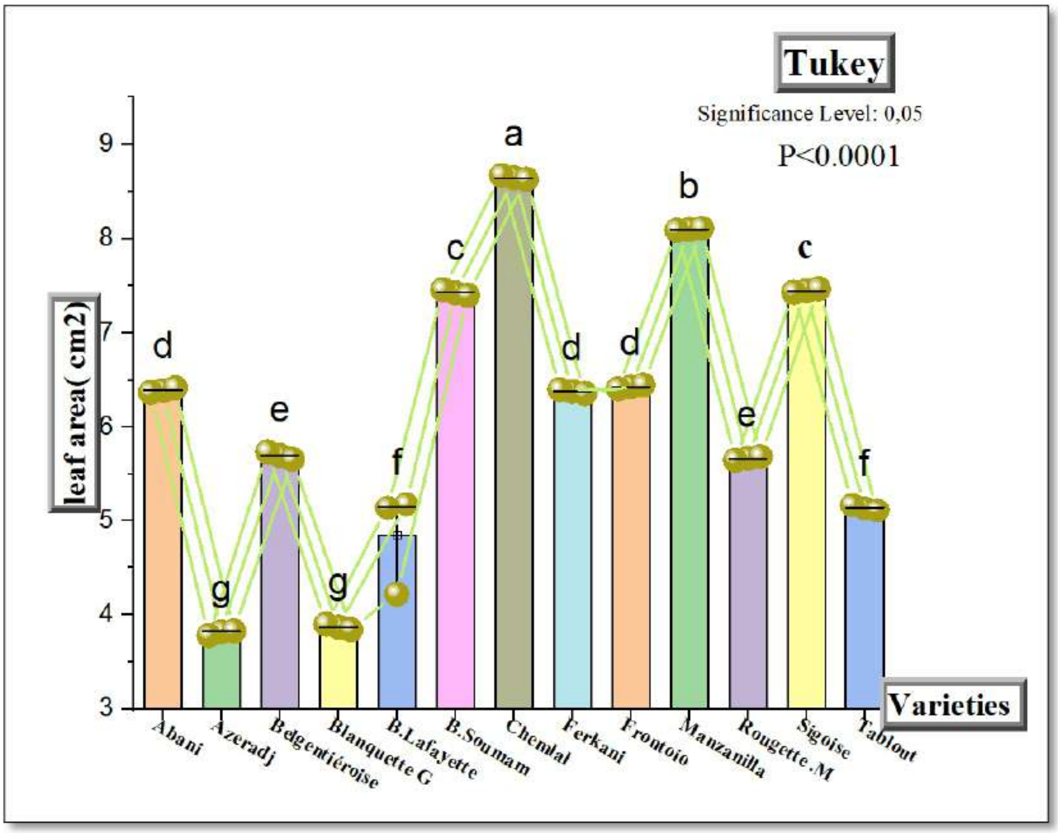


Figure 16: Leaf area averages with the ANOVA Test results

3.1.1.2 Leaf width

The classification of leaf width in various olive varieties, according to the International Olive Council (IOC) norms, is presented in Table 8. The leaf width is categorized into three groups: reduced (< 1 cm), medium (1 to 1.5 cm), and high (> 1.5 cm).

3.1.1.2.1 Medium Leaf Width (1 to 1.5 cm)

Seven olive varieties are classified under the medium leaf width category, with widths ranging from 1 cm to 1.5 cm and they are; Azeradj variety, the Blanquette .G variety, the Belgentiéroise, the B. Lafayette variety , the Tablout variety,the Abani variety , the Manzanilla and Rougette .M varieties (**Figure 17**).

3.1.1.2.2 High Leaf Width (> 1.5 cm)

Six olive varieties exhibit high leaf widths, surpassing the 1.5 cm mark. The B. Soumam variety has a leaf width of 1.53 cm, followed by the Frontoio variety with a width of 1.55 cm, the Ferkani variety measures 1.62 cm, while the Chemlal variety has a leaf width of 1.66 cm. The Sigoise variety has the widest leaf among all the studied varieties, measuring 1.67 cm (**Figure 17**).

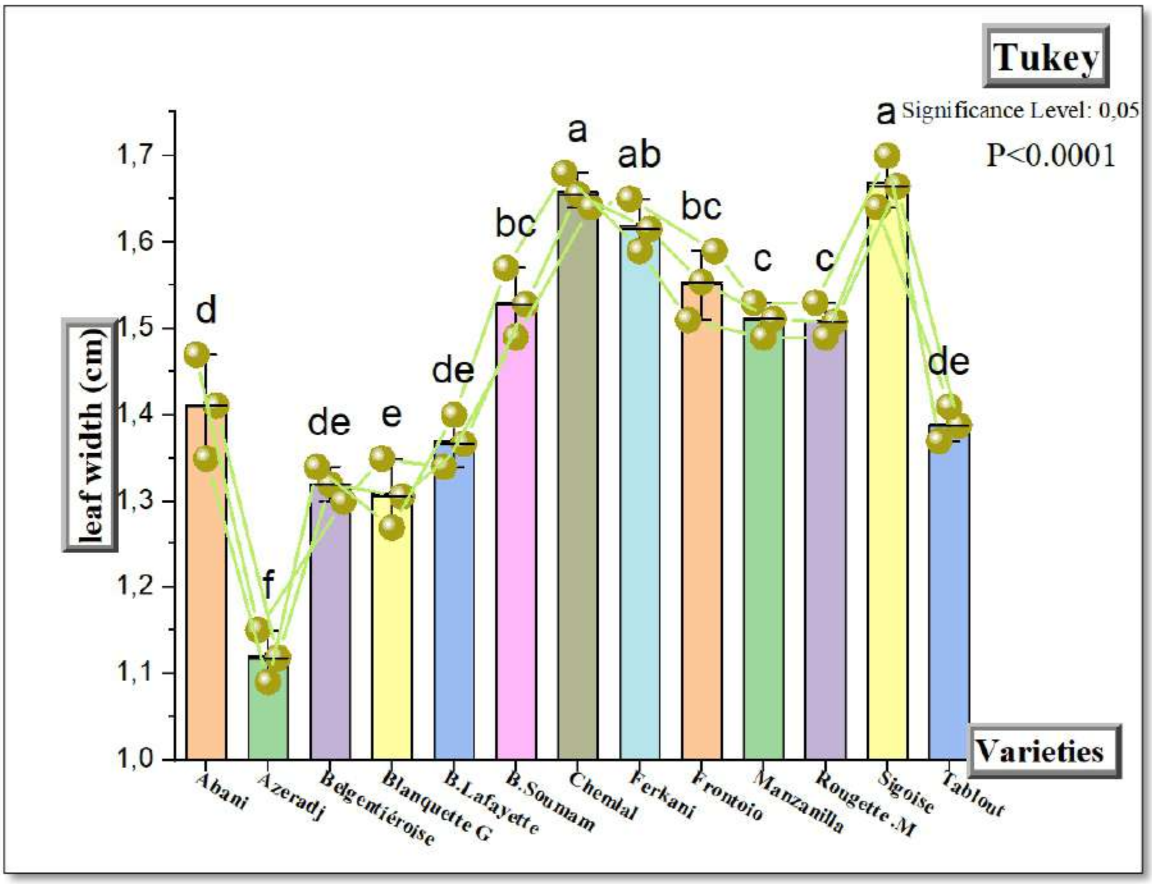


Figure 17: Leaf width averages with the ANOVA Test results

3.1.1.3 Leaf length

The classification of leaf length in various olive varieties, according to the International Olive Council (IOC) norms, is presented in the **Figure 18,** the leaf length is categorized into three groups: reduced (< 5 cm), medium (5 to 7 cm), and high (> 7 cm).

3.1.1.3.1 Reduced Leaf Length (< 5 cm)

One olive variety falls into the reduced leaf length category. The Blanquette.G variety has a leaf length of 4.92 cm, making it the shortest among the studied varieties (**Figure 18**).

3.1.1.3.2 Medium Leaf Length (5 to 7 cm)

Eight olive varieties are classified under the medium leaf length category, with lengths ranging from 5 cm to 7 cm. The Azeradj variety has a leaf length of 5.42 cm , while the Sigoise variety is slightly longer at 7.17 cm (**Figure18)**.

3.1.1.3.3 High Leaf Length (> 7 cm)

Four olive varieties exhibit high leaf lengths, surpassing the 7 cm mark. The Abani variety has the shortest leaf length (7.4 cm), and the Chemlal variety has the longest leaf length among all the studied varieties, measuring 8.63 cm (**Figure 18**).

3.1.1.3.4 Leaf length to width ratio

The classification of leaf length/width ratio in various olive varieties, according to the International Olive Council (IOC) norms, is presented in **Table 8**. The leaf shape is categorized into three groups based on the ratio: elliptical (< 4 cm), elliptical-lanceolate (4 to 6 cm), and lanceolate (> 6 cm).

3.1.1.3.4.1 Elliptical Leaf Shape (< 4 cm)

Three olive varieties fall into the elliptical leaf shape category. The Blanquette. G variety has a leaf length/width ratio of 3.76, making it the shortest in this category. The Rougette .M variety follows closely with a ratio of 3.83, and the Ferkani variety has a ratio of 3.92 (**Figure 19**).

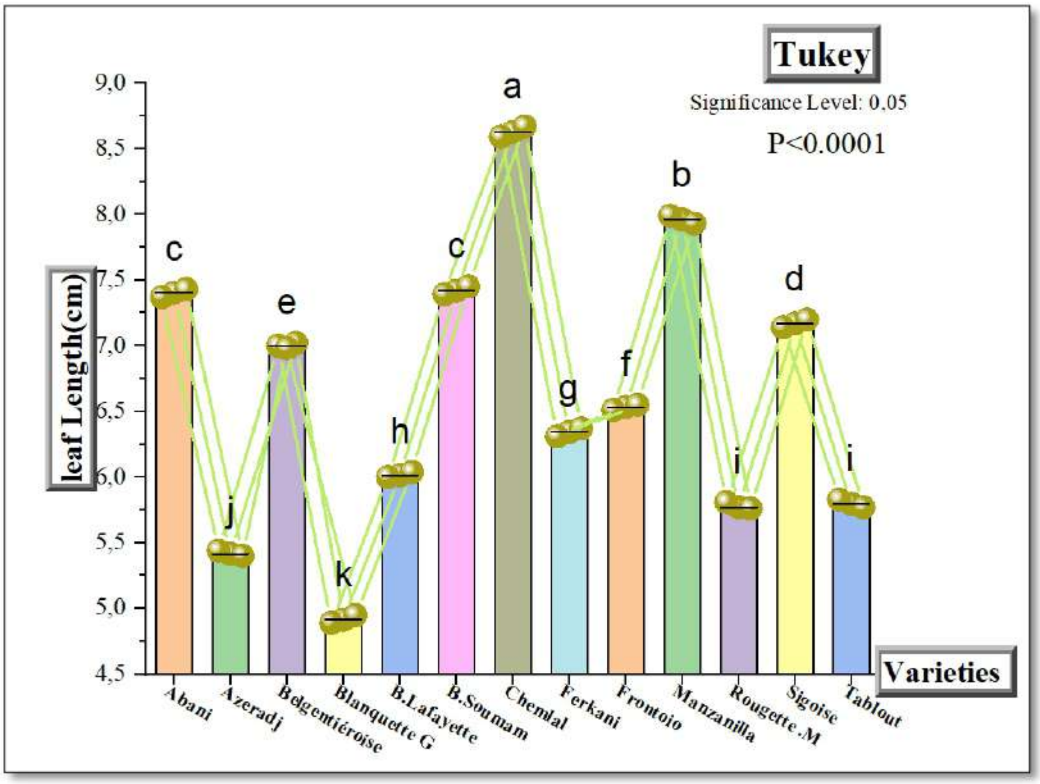


Figure 18: Leaf length averages with the ANOVA Test results.

3.1.1.3.4.2 Elliptical-Lanceolate Leaf Shape (4 to 6 cm)

Ten olive varieties are classified under the elliptical-lanceolate leaf shape category, with ratios ranging from 4 cm to 6 cm are; the Tablout variety, The Frontoio variety, the Sigoise variety; the B. Lafayette variety, the Azeradj variety,the B. Soumam variety, the Chemlal variety, the Abani variety,the Manzanilla and Belgentiéroise varieties (**Figure 19**).

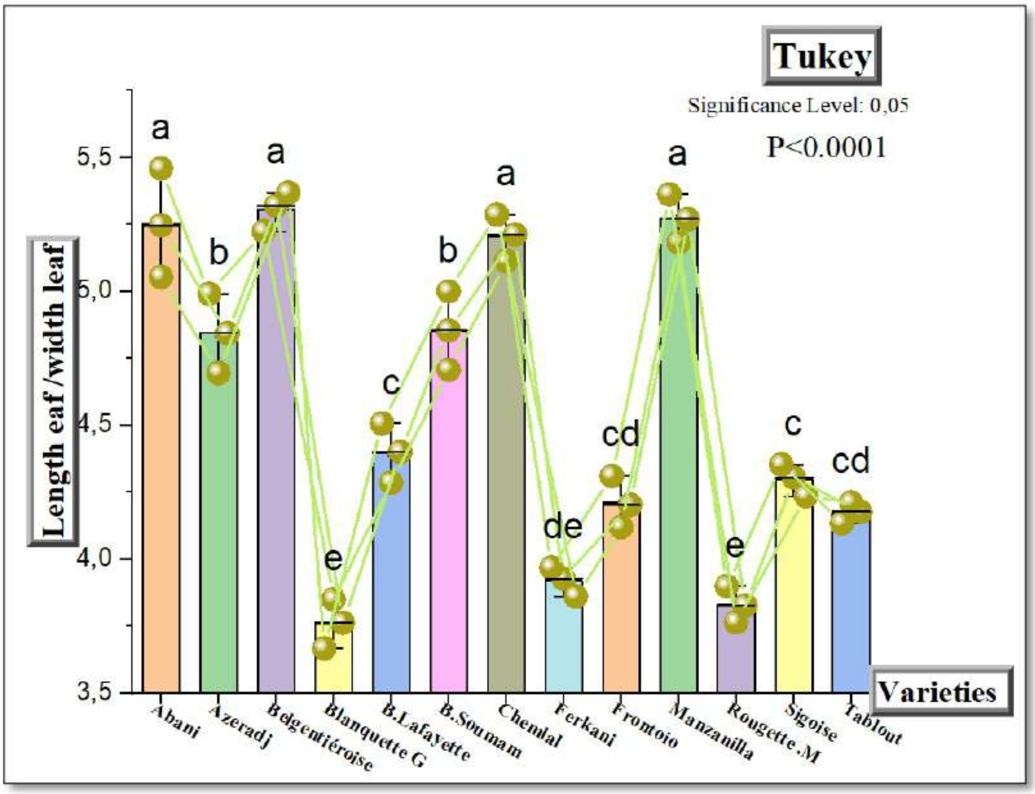


Figure 19 : Leaf length to width ratio with the ANOVA Test results.

3.2 Pomologic characteristics

3.2.1 Fruit characteristics

3.2.1.1 Fruit weight

The classification of fruit weight in various olive varieties, according to the International Olive Council (IOC) norms, is presented in Table 4. The fruit weight is categorized into four groups: reduced (< 2 g), medium (2 to 4 g), high (4 to 6 g), and very high (> 6 g) (**Figure 20**).

3.2.1.1.1 Reduced Fruit Weight (< 2 g)

Only one olive variety falls into the reduced fruit weight category. The Abani variety has a fruit weight of 1.9333 g, placing it in the reduced category.

3.2.1.1.2 Medium Fruit Weight (2 to 4 g)

Eight olive varieties are classified under the medium fruit weight category, with weights ranging from 2 g to 4 g. The Chemlal variety has a fruit weight of 2.2000 g, while Tablout measures slightly more at 2.2100 g.

The Frontoio variety has a fruit weight of 2.4233 g. The Ferkani variety weighs 2.5067 g, and the Rougette .M variety has a fruit weight of 2.7000 g. The Blanquette.G variety, with a fruit weight of 3.2733 g, and the Azeradj variety, at 3.8933 g, round out this category (**Figure 20**).

3.2.1.1.3 High Fruit Weight (4 to 6 g)

Four olive varieties exhibit high fruit weights, ranging from 4 g to 6 g. The Manzanilla variety has a fruit weight of 5.0167 g, followed closely by Sigoise with 5.1700 g.

The B. Lafayette variety weighs 5.5767 g, and the Belgentiéroise variety has a fruit weight of 5.9067 g .

3.2.1.1.4 Very High Fruit Weight (> 6 g)

One olive variety falls into the very high fruit weight category. The B. Soumam variety has a fruit weight of 6.4133 g, making it the heaviest among the studied varieties (**Figure 20**)

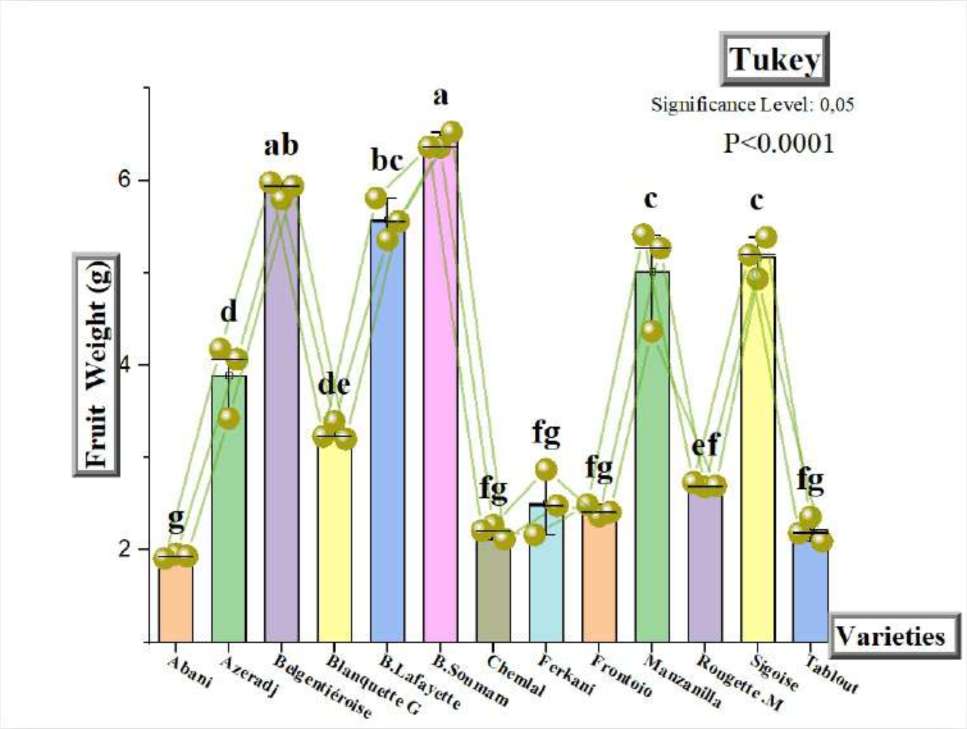


Figure 20: Fruit weight averages with the ANOVA Test results.

3.2.1.2 Fruit diameter

The classification of fruit diameter in various olive varieties, according to the International Olive Council (IOC) norms, is presented in **Table 8**. The fruit diameter is categorized into three groups: reduced (< 1.5 cm), medium (1.5 to 2 cm), and high (> 2 cm).

3.2.1.2.1 Reduced Fruit Diameter (< 1.5 cm)

Four olive varieties fall into the reduced fruit diameter categoryand they are ;Abani variety and it has a fruit diameter of 1.294 cm, making it the smallest in this category, following by Tablout ,Chemlal , Frontoio varieties (**Figure 21**).

3.2.1.2.2 Medium Fruit Diameter (1.5 to 2 cm)

Eight olive varieties are classified under the medium fruit diameter category, with diameters ranging from 1.5 cm to 2 cm and they are; Ferkani, Rougette .M, Azeradj, Belgentiéroise, Blanquette.G, Sigoise, B. Lafayette, Manzanilla (**Figure 21**).

3.2.1.2.3 High Fruit Diameter (> 2 cm)

One olive variety falls into the high fruit diameter category. The B. Soumam variety has the largest fruit diameter among the studied varieties, measuring 2.078 cm (**Figure 21**).

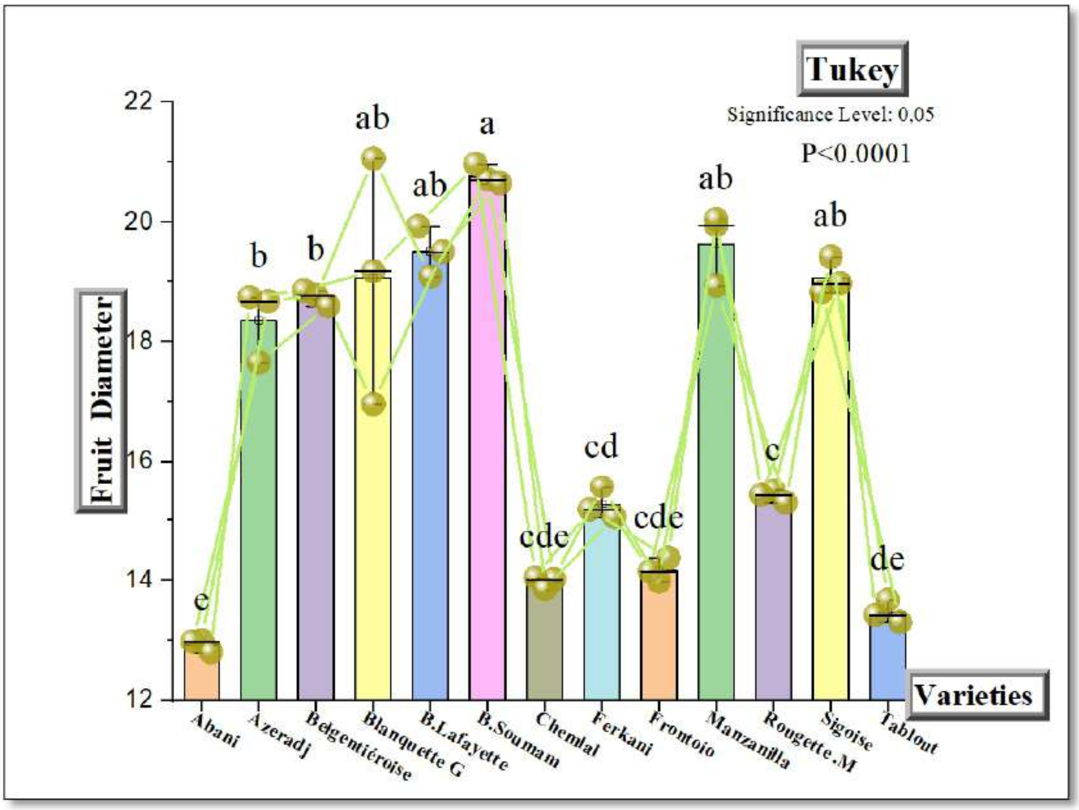


Figure 21: Fruit Diameter avrages with the ANOVA Test results.

3.2.1.3 Fruit length

The classification of fruit length in various olive varieties, according to the International Olive Council (IOC) norms, is presented in **Table 8**. The fruit length is categorized into three groups: reduced (< 2 cm), medium (2 to 2.5 cm), and high (> 2.5 cm).

3.2.1.3.1 Reduced Fruit Length (< 2 cm)

No olive varieties fall into the reduced fruit length category in the provided data (**Figure 22**).

3.2.1.3.2 Medium Fruit Length (2 to 2.5 cm)

Nine olive varieties are classified under the medium fruit length category, with lengths ranging from 2 cm to 2.5 cm.

The Azeradj variety has a fruit length of 2.015 cm. Both the Chemlal and Frontoio varieties measure 2.078 cm.

The Ferkani variety has a fruit length of 2.123 cm, and the Abani variety measures 2.176 cm. The Tablout variety has a fruit length of 2.216 cm, followed by Blanquette.G with 2.226 cm. The Rougette .M variety has a fruit length of 2.257 cm, and the Sigoise variety, at the upper threshold of this category, measures 2.519 cm (**Figure 22**).

3.2.1.3.3 High Fruit Length (> 2.5 cm)

Four olive varieties exhibit high fruit lengths, surpassing the 2.5 cm mark and they are; Manzanilla, B. Soumam, B. La fayette, Belgentiéroise (**Figure 22**).

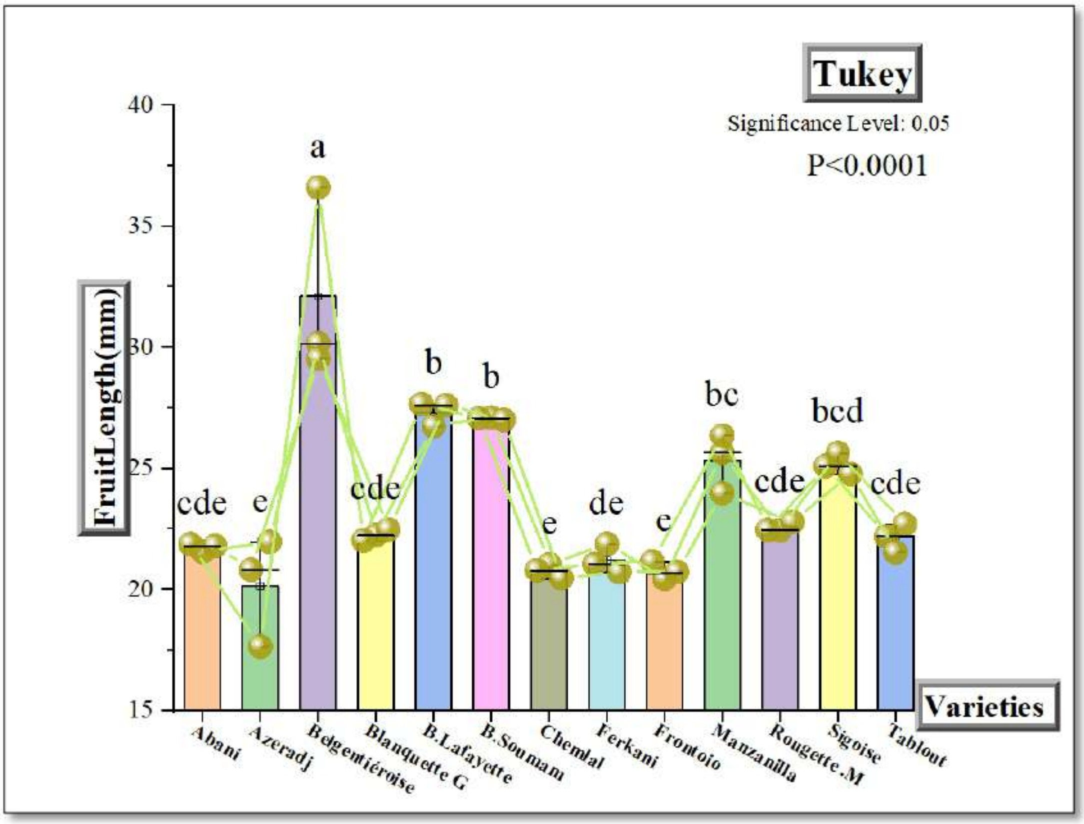


Figure 22: Fruit Length avrages with the ANOVA Test results.

3.2.1.4 Fruit length to diameter ratio

The classification of fruit length/width ratio in various olive varieties, according to the International Olive Council (IOC) norms, is presented in **Table 8**.

The length/width ratio is categorized into three groups: reduced (< 1.25), medium (1.25 to 1.45), and high (> 1.45).

3.2.1.4.1 Reduced Ratio (< 1.25)

Two olive varieties fall into the reduced length/width ratio category. The Azeradj variety has the lowest ratio at 1.10, followed by the Blanquette.G variety with a ratio of 1.18 (**Figure 23**).

3.2.1.4.2 Medium Ratio (1.25 to 1.45)

Six olive varieties are classified under the medium length/width ratio category, with ratios ranging from 1.25 to 1.45.

The Manzanilla variety has a ratio of 1.29, while the B. Soumam variety measures 1.30. The Sigoise variety has a ratio of 1.32, and the Ferkani variety measures 1.39.

The B. Lafayette variety has a ratio of 1.40, and the Frontoio variety follows with a ratio of 1.46 (**Figure 23**).

3.2.1.4.3 High Ratio (> 1.45)

Five olive varieties exhibit high length/width ratios, surpassing the 1.45 value of the Length /width ratio.

The Rougette .M variety has a ratio of 1.47, while the Chemlal variety measures 1.49, following by the Tablout variety has a length/width ratio of 1.64, and the Abani variety measures 1.68.

The Belgentiéroise variety has the highest ratio among all the studied varieties, measuring 1.71 (**Figure 23).**

3.2.1.5 Fruit shape (basing on the length to width ratio)

3.2.1.5.1 Spherical shaped olives (length/width ratio < 1.25)

Constitute 20% of the studied varieties, specifically Azeradj, Blanquette.G, and Manzanilla.

3.2.1.5.2 Ovoid shaped olives (length/width ratio 1.25 to 1.45)

Account for 40% of the varieties, including B. Soumam, Sigoise, Ferkani, B. Lafayette, and Frontoio.

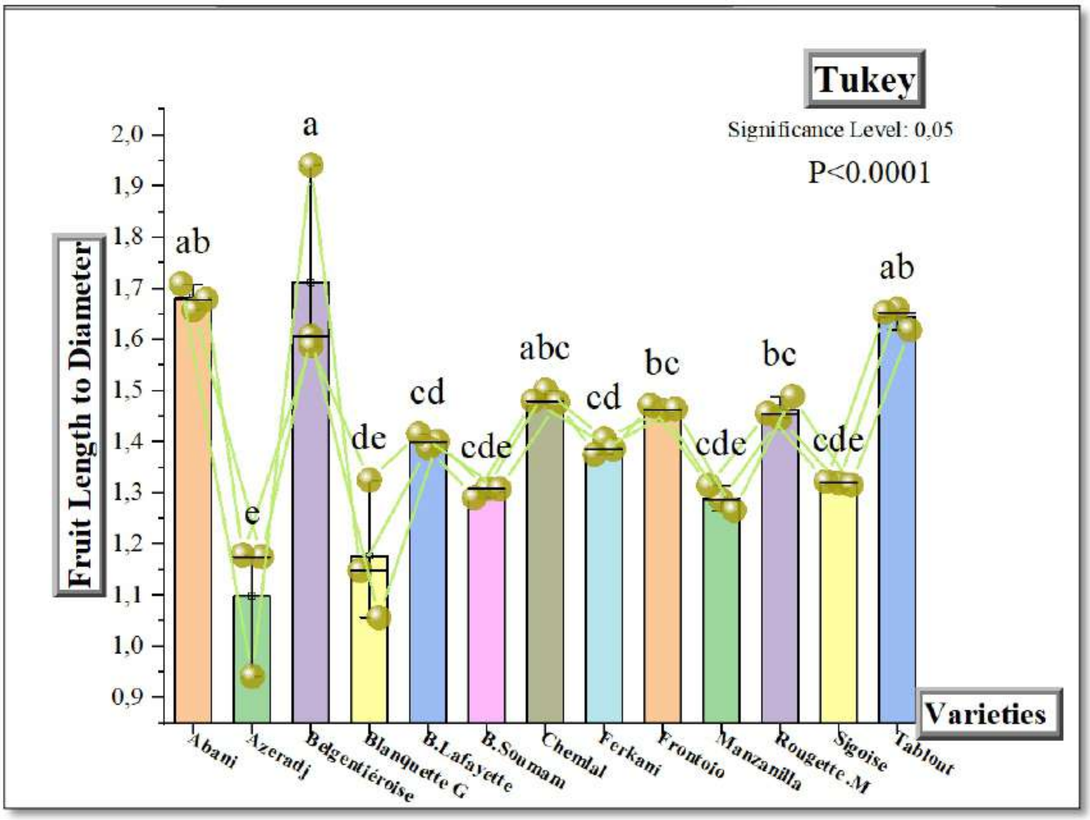


Figure 23: Fruit length to diameter ratio avrages with the ANOVA Test results.

3.2.1.5.3 Elongated shaped olives (length/width ratio > 1.45)

Make up 40% of the varieties, such as Rougette.M, Chemlal, Tablout, Abani, and Belgentiéroise.

3.2.1.6 Pulp Weight

When considering the weight of the pulp, B.Soumam again stood out with the highest pulp weight of 5.7033 g, followed by Belgentiéroise (4.9233 g) and B.Lafayette (4.9133 g). Abani had the lowest pulp weight at 1.6333 g (**Figure 24**).

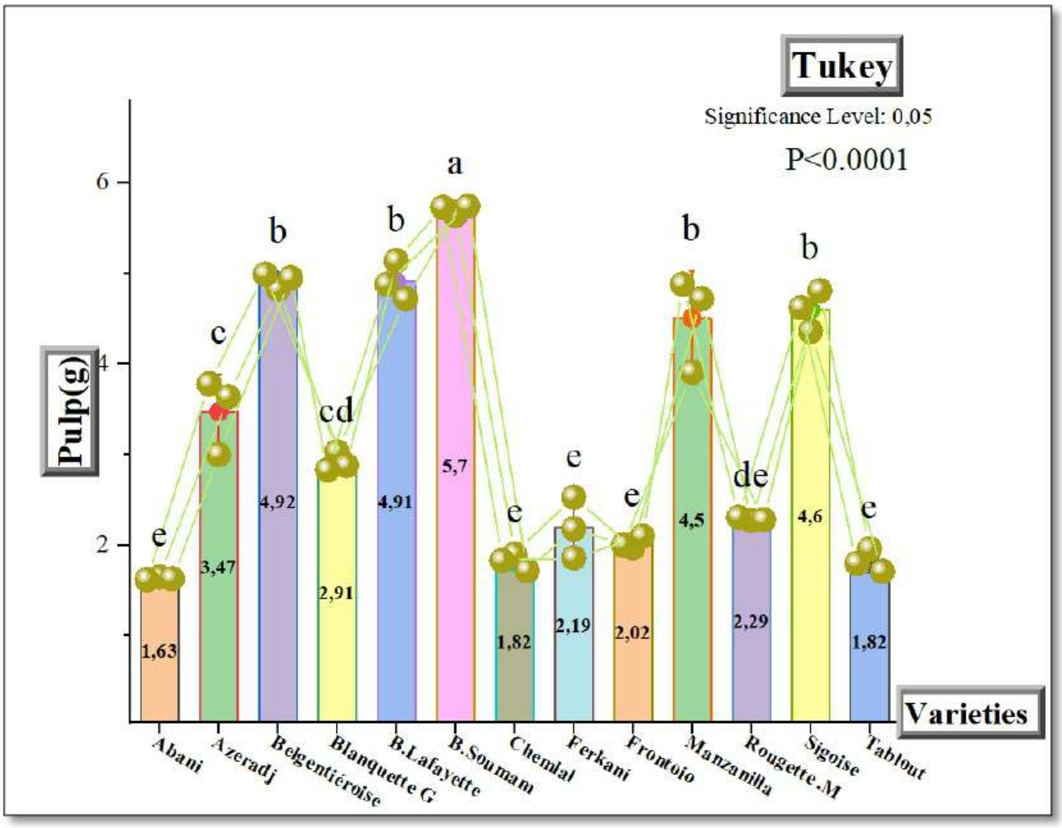


Figure 24: Pulp weight averages with the ANOVA Test results.

3.2.1.7 Pulp stone ratio

The pulp to stone ratios was substantial, varying from a minimum of 4.69 to a maximum of 8.85.

The variety Frontoio exhibited the highest pulp to stone ratio at 8.85, indicating a higher proportion of pulp relative to the stone compared to other varieties.

On the other hand, Azeradj had the lowest ratio at 5.02 (**Figure 25**).

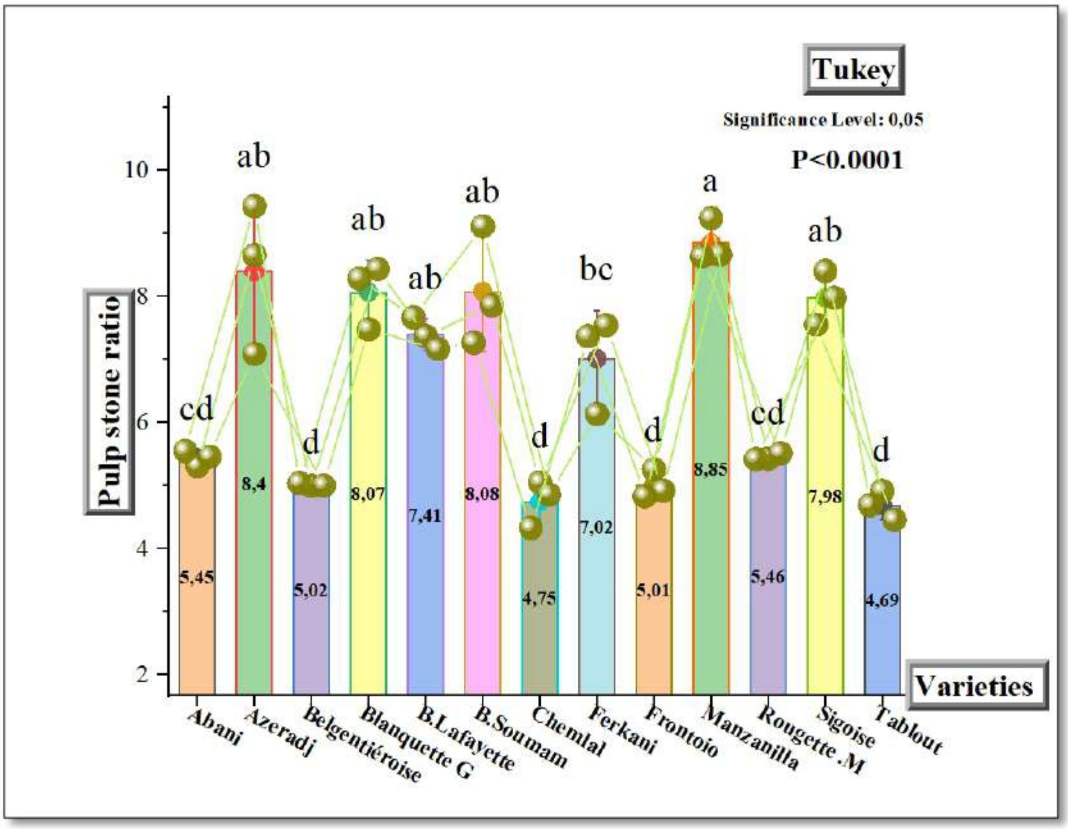


Figure 25: Pulp stone ratio averages with the ANOVA Test results.

3.2.1.8 Weight of 100 Fruits

The weight of 100 fruits also showed significant differences across the varieties. B.Soumam had the highest weight, with 100 fruits weighing 641.60 g, followed by B.La fayette (557.56 g) and Manzanilla (501.59 g).

The variety with the lowest weight for 100 fruits was Abani (193.30 g). The range for the weight of 100 fruits spanned from 193.30 g to 641.60 g (**Figure 26**).

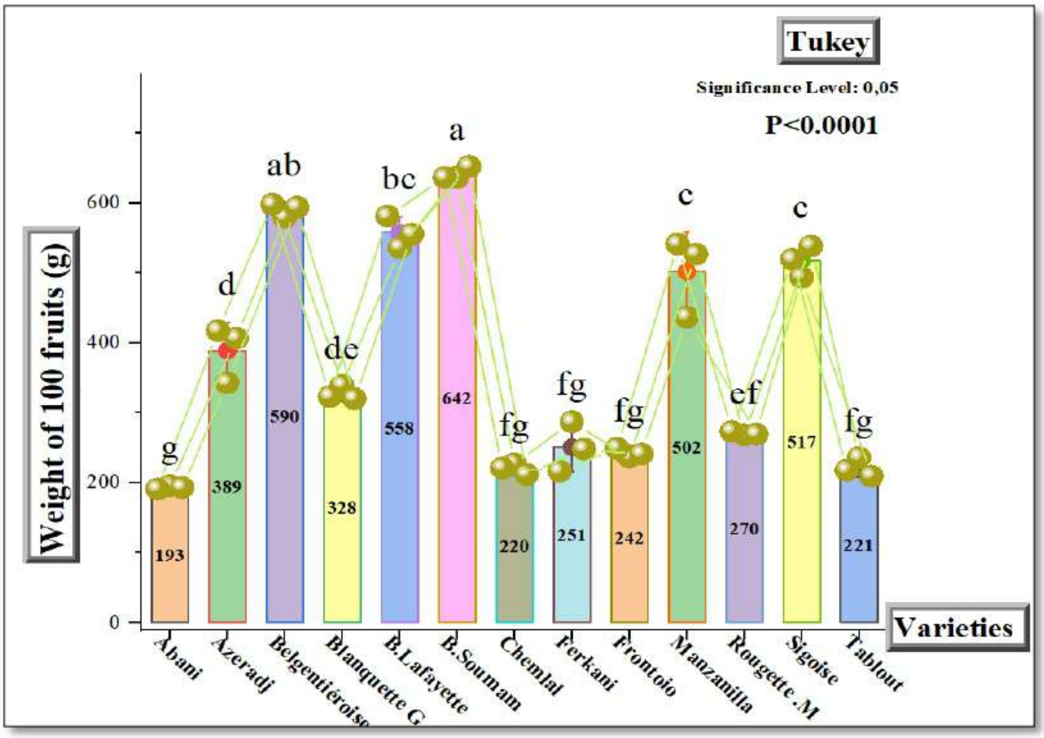


Figure 26 : Weight of 100 fruits averages with the ANOVA Test results.

3.2.2 Stone characteristics

3.2.2.1 Stone weight

The stone weights of the olive cultivars showcases a range of values, indicative of the diversity within the sampled varieties. The lightest stone, weighing 0.3000 g, is observed in the Abani cultivar, while the heaviest stone, weighing 0.9811 g, is found in the Belgentiérois cultivar (**Figure 27**).

The classification of stone weight in various olive varieties according to the International Olive Council (IOC) norms is presented in Table 1. The stone weight is categorized into four groups: reduced (< 0.3 g), medium (0.3 to 0.45 g), high (0.45 to 0.6 g), and very high (> 0.6 g).

3.2.2.1.1 Medium Stone Weight (0.3 to 0.45 g)

Eight olive varieties fall into the medium stone weight category, with weights ranging from 0.3 g to 0.45 g. The Abani variety is on the lower threshold of this category, weighing exactly 0.3 g. Following Abani, Ferkani has a slightly higher stone weight of 0.31 g. The Blanquette G variety has a stone weight of 0.36 g. Chemlal and Tablout varieties have similar stone weights of 0.38 g and 0.38 g, respectively. The Frontoio variety weighs 0.40 g, while the Azeradj variety has a stone weight of 0.4133 g. Lastly, Rougette .M falls just within this category with a stone weight of 0.42 g.

3.2.2.1.2 High Stone Weight (0.45 to 0.6 g)

Two olive varieties are classified under the high stone weight category. The Manzanilla variety has a stone weight of 0.5067g, and the Sigoise variety follows with a stone weight of 0.5767 g.

3.2.2.1.3 Very High Stone Weight (> 0.6 g)

Three olive varieties exhibit very high stone weights, surpassing the 0.6 g mark. The B. Lafayette variety weighs 0.6633 g, and B. Soumam has a stone weight of 0.7133 g. The Belgentiéroise variety has the highest stone weight among all the studied varieties, at 0.9833 g.

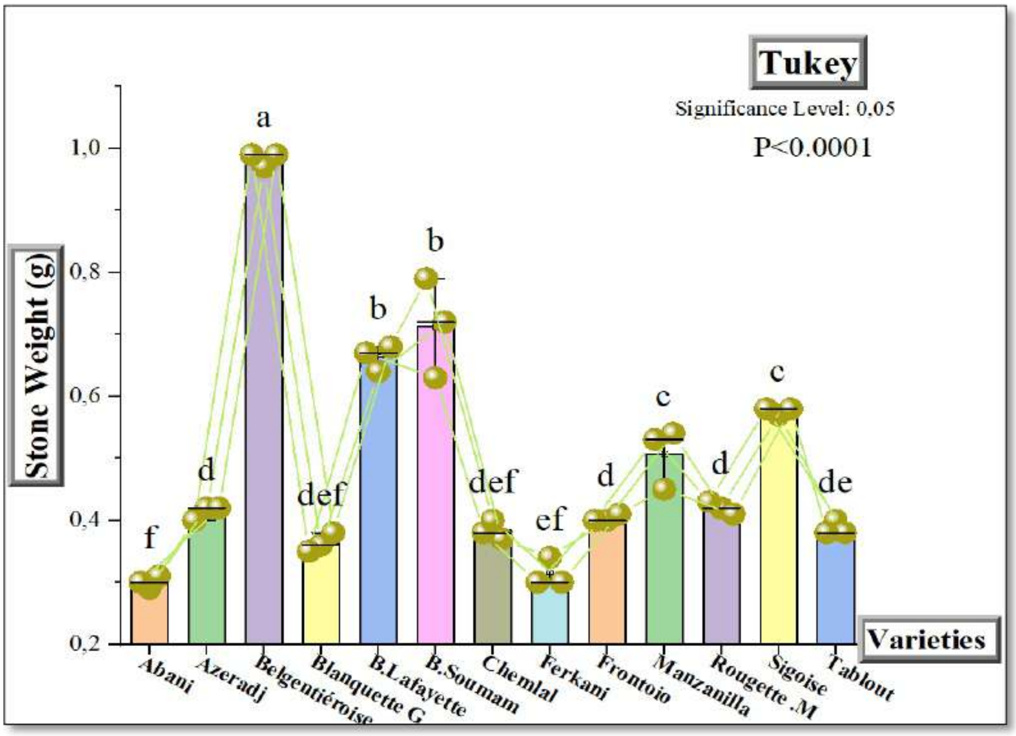


Figure 27: Stone weight averages with the ANOVA Test results

3.2.2.2 Stone diameter

The stone diameters of the olive cultivars reveals a spectrum of sizes, reflective of the diverse genetic makeup and growth conditions of each variety. The smallest stone diameter, measuring 0.57 cm, is observed in the Abani cultivar, while the largest diameter, at 0.97 cm, is found in the B.Soumam cultivar. Other cultivars exhibit intermediate diameters, ranging from 0,61cm for Blanquette G to 0.95 cm for Belgentiéroise (**Figure 28**).

The classification of stone diameter in various olive varieties, according to the International Olive Council (IOC) norms, is presented in **Table 8**. The stone diameter is categorized into three groups: reduced (< 0.65 cm), medium (0.65 to 0.85 cm), and high (> 0.85 cm).

3.2.2.2.1 Reduced Stone Diameter (< 0.65 cm)

Five olive varieties fall into the reduced stone diameter category, with diameters less than 0.65 cm; Abani, Blanquette G, Tablout, Ferkani, Rougette.M.

3.2.2.2.2 Medium Stone Diameter (0.65 to 0.85 cm)

Five olive varieties are classified under the medium stone diameter category and they are ;Chemlal, Frontoio, Azeradj, Sigoise and Manzanilla .

3.2.2.2.3 High Stone Diameter (> 0.85 cm)

Three olive varieties exhibit high stone diameters, surpassing the 0.85 cm value;

B. Lafayette, Belgentiérois, B. Soumam.

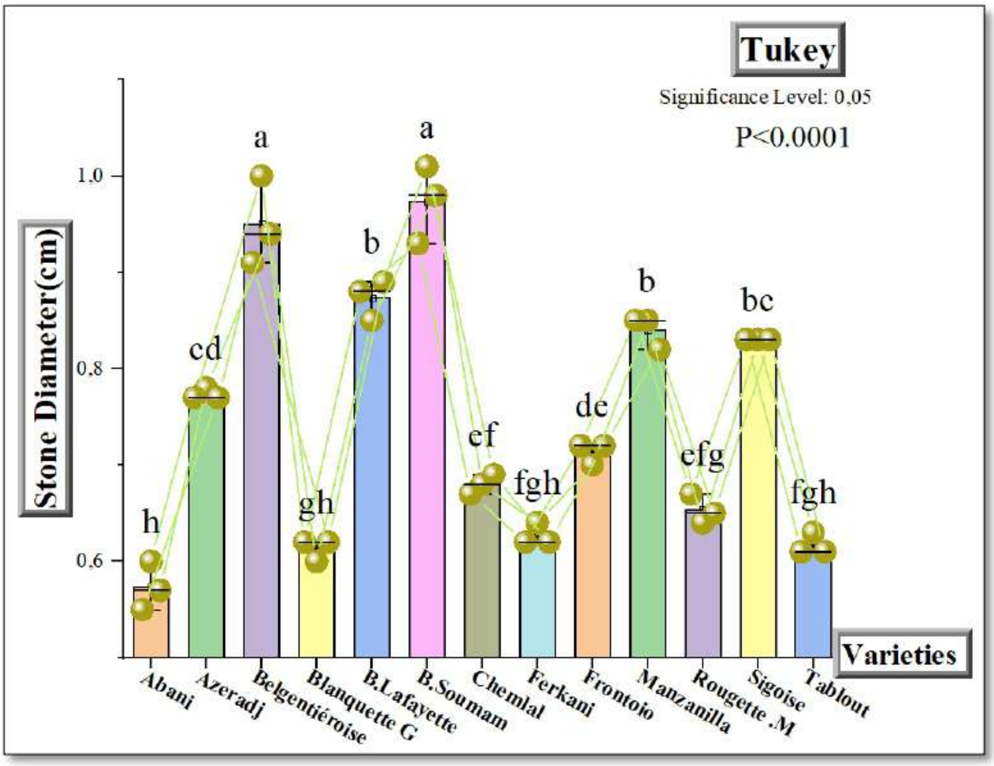


Figure 28: Stone diameter averages with the ANOVA Test results

3.2.2.3 Stone length

The classification of stone length in various olive varieties according to the International Olive Council (IOC) norms is presented in **Table 8**. The stone length is categorized into three groups: reduced (< 1.4 cm), medium (1.4 to 1.6 cm), and high (> 1.6 cm) (**Figure 29**).

3.2.2.3.1 Reduced Stone Length (< 1.4 cm)

Two olive varieties fall into the reduced stone length category, with lengths less than 1.4 cm. The Azeradj variety has the shortest stone length, measuring 1.351 cm. The Blanquette G variety follows closely with a stone length of 1.378 cm.

3.2.2.3.2 Medium Stone Length (1.4 to 1.6 cm)

Seven olive varieties are classified under the medium stone length category, with lengths ranging from 1.4 cm to 1.6 cm; Ferkani, Manzanilla, Chemlal, Rougette .M, Tablout and Abani.

3.2.2.3.3 High Stone Length (> 1.6 cm)

Four olive varieties exhibit high stone lengths, surpassing the 1.6 cm mark; B. Soumam ,Sigoise, B. Lafayette,and Belgentiérois variety wich has the longest stone length among all the studied varieties, at 2.13 cm.

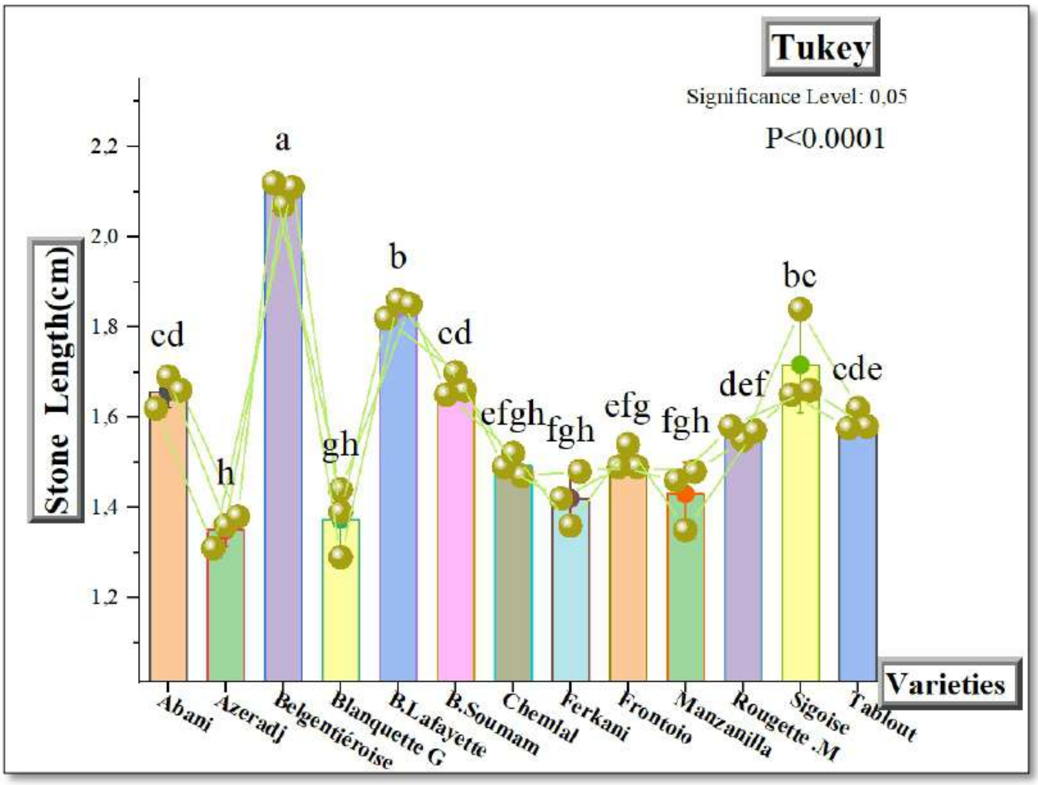


Figure 29: Stone length averages with the ANOVA Test results

3.2.2.4 Stone shape

Basing on the stone length to Diameter index values (**Figure 30**), and the IOC standars (**Table 8**);

3.2.2.4.1 Ovoid shaped stones

Constitute 30.77% of the studied varieties, specifically Manzanilla, B. Soumam, Azeradj, and Sigoise.

3.2.2.4.2 Elliptic shaped stones

Account for 38.46% of the varieties, including Frontoio, B. Lafayette, Chemlal, Belgentiérois, and Blanquette G.

3.2.2.4.3 Elongated shaped stones

Make up 30.77% of the varieties, specifically as Ferkani, Rougette M., Tablout, and Abani.

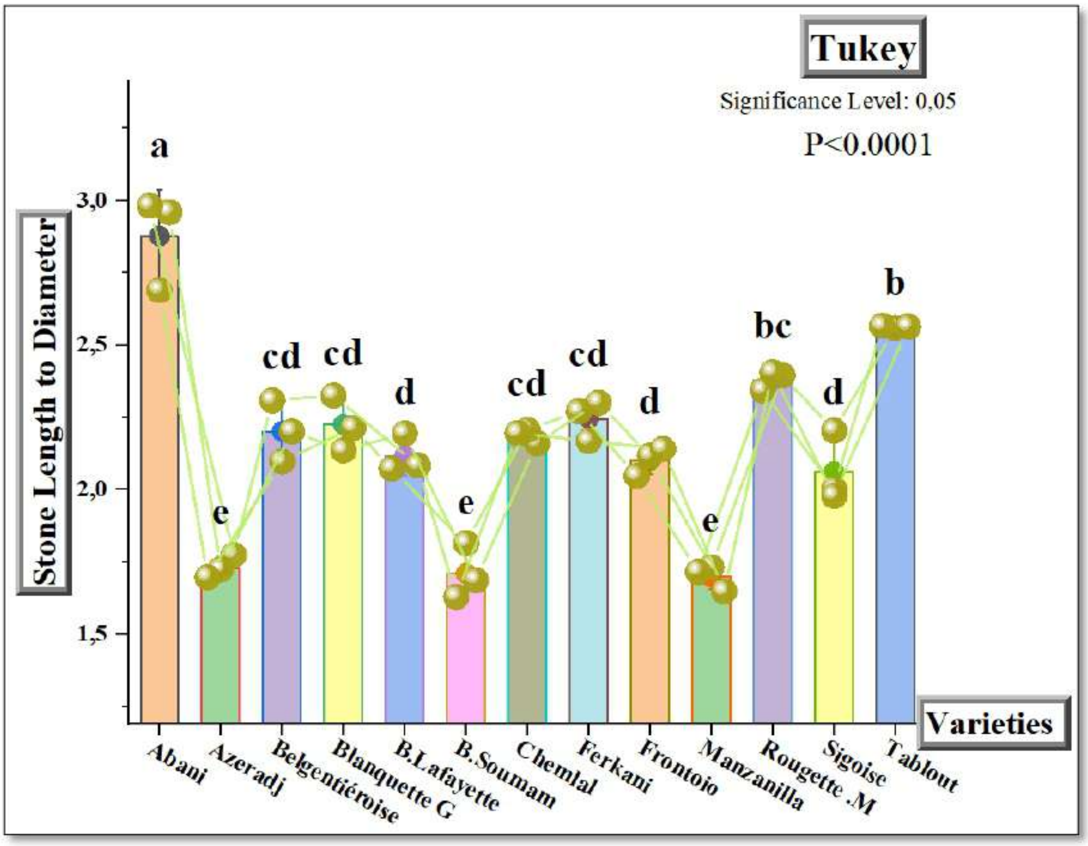


Figure 30: Stone lenght to Diameter ratio averages with the ANOVA Test results

3.3 The principal component analysis statistical test (PCA)

The PCA has been used in the evaluation of olive germplasm (Bandelj et al., 2002; Boukhari et al., 2020; Cantini et al., 1999; Hamlat, 2022; Hannachi et al., 2008; Hosseini-Mazinani et al., 2002; Lazovic et al., 2018; Strikic et al., 2009; Trentacoste & Puertas, 2011; Uylaser et al., 2008; Zaher et al., 2011).

In our study, we applied PCA to the morphometric characterization of olive varieties. The principal idea of PCA is to identify trends of individuals through the condensation of large-dimension data sets into reduced and significant matrices (principal components), while preserving the variation present in the initial data set (Kumar et al., 2014; Messai et al., 2016). By utilizing PCA, we were able to simplify the complex morphometric data of the olive varieties, highlighting the most significant patterns and relationships within the dataset.

This approach facilitated the identification of key morphological traits that differentiate the various olive cultivars, thereby enhancing our understanding of their phenotypic diversity and aiding in the selection and breeding of olives suited to specific arid environmental conditions wich charactirize our study region.

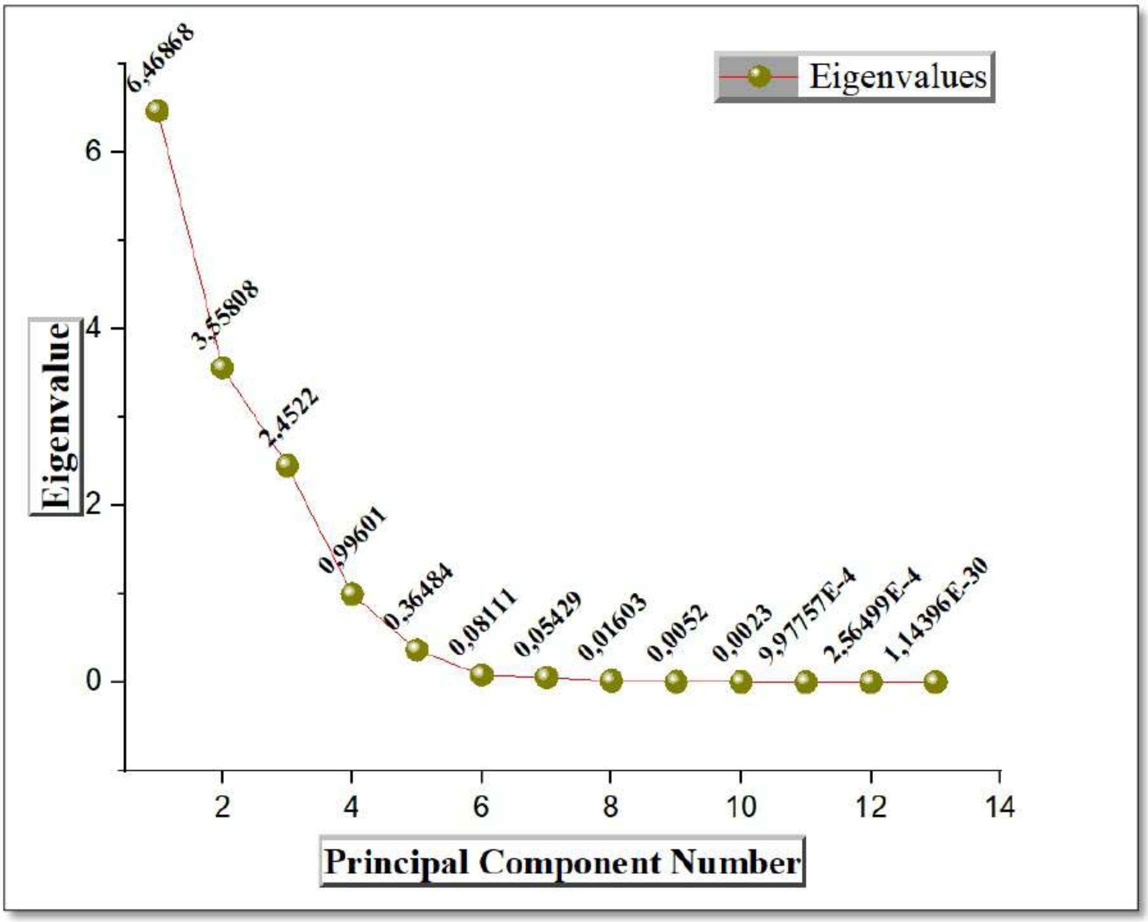


Figure 31: Eigenvalue plot: Value Eigen for the principal components of the variance.

The Eigenvalue plot (**Figure 31**) provides a visual representation of the eigenvalues associated with each principal component (PC), illustrating the contribution of each PC to the total variance in our study results. Key observations from the **Eigenvalue plot** ullustrate in the **Figure 31** are as follows:

3.3.1 Principal Component

3.3.1.1 Principal Component 1 (PC1)

Eigenvalue: 6.48668

Variance Explained: PC1 has the highest eigenvalue, explaining 46.2% of the total variance, which is the largest portion of the variance in the dataset (**Figure 32**).

3.3.1.2 Principal Component 2 (PC2)

Eigenvalue: 3.55808

Variance Explained: PC2 has the second-highest eigenvalue, explaining 25.4% of the total variance, as shown in the Loading plot (**Figure 32**).

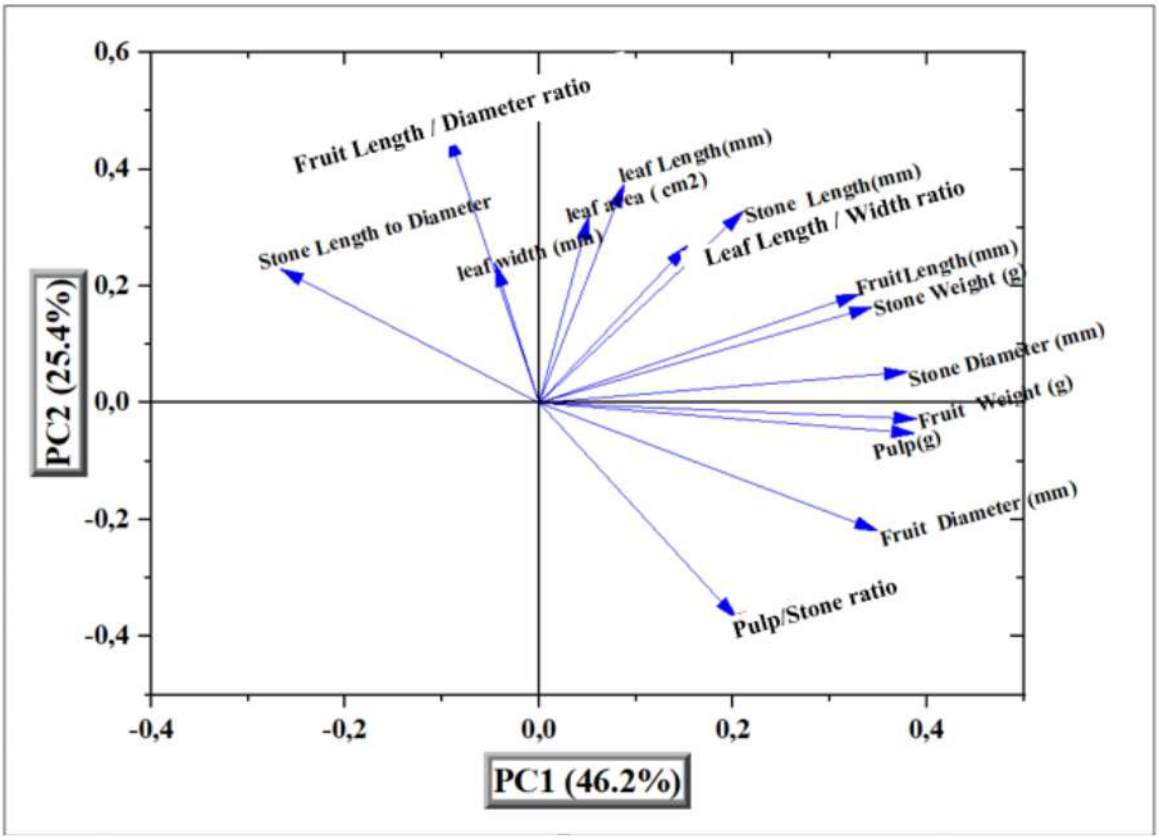


Figure 32: Loading plot of the principal component analysis of the morphological and agronomical parameters: projection of variables.

The PCA Biplot in (**Figure 33**), presents the arrangement of 13 studied olive varieties based on their morphometric and agronomic characteristics, represented as vectors. The attributes included are fruit diameter, fruit weight, fruit length, stone diameter, stone weight, stone length, stone length to diameter ratio, pulp weight, pulp to stone ratio, leaf length, leaf width, leaf area, length to diameter ratio, and length leaf/width leaf ratio (**Figure 33**).

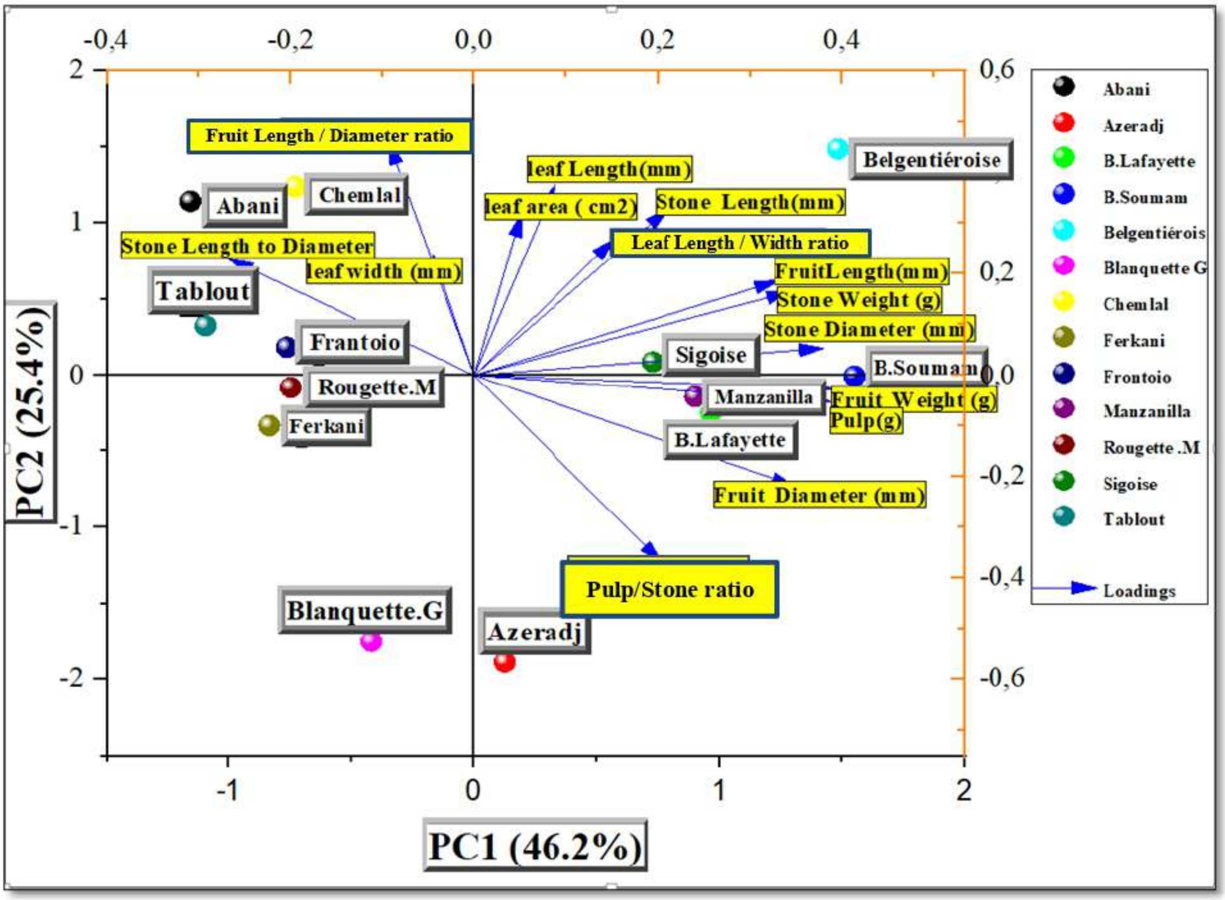


Figure 33: Biplot of the principal component analysis of morpholocical and agronomical.

3.3.2 Principal Component Analysis (PCA) Axes and Their Correlation between Olive Varieties and Morphometric Traits

3.3.2.1 PC1 (Principal Component 1)

3.3.2.1.1 PC1 Positive Correlation

Traits such as fruit diameter, fruit weight, fruit length, stone diameter, stone weight, stone length, and pulp weight show a positive correlation along PC1. Varieties exhibiting high values in these traits align with the positive end of PC1 (**Figure 33**).

3.3.2.1.2 PC1 Negative Correlation

In the biplot, there are no significant traits showing a strong negative correlation along PC1, as most vectors are oriented towards the positive side (**Figure 33**).

3.3.2.2 PC2 (Principal Component 2)

3.3.2.2.1 PC2 Positive Correlation

Traits like length-to-diameter ratio, stone length-to-diameter ratio, leaf width, leaf length, and leaf area show a positive correlation along PC2. Higher values in these traits position varieties towards the positive end of PC2 **(Figure 33).**

3.3.2.3 PC2 Negative Correlation

Varieties like Blanquette.G, positioned towards the negative side of PC2, indicate lower values in the traits positively correlated with PC2.

3.3.3 Correlation between Varieties and Traits

3.3.3.1 PC1 has a high positive correlation

- **Varieties**: B. Soumam, B. Lafayette, Manzanilla, Sigoise
- **Traits**: These varieties are associated with larger fruit and stone dimensions (fruit diameter, fruit weight, fruit length, stone diameter, stone weight, stone length, and pulp weight).

  These morphometric traits exhibit high values, as indicated by their positioning along the positive end of PC1 (**Figure 33**).

3.3.3.2 Moderate positive correlation with PC1 and PC2.

- **Varieties**: Abani, Chemlal, and Tablout.
- **Traits**: These varieties are associated with higher values in leaf traits (leaf length, leaf width, and leaf area), length to diameter ratio, and stone length to diameter ratio. Their positioning in the biplot shows a moderately positive correlation with both PC1 and PC2 (**Figure 33**).

3.3.3.3 PC2 with negative correlation

- **Varieties**: Blanquette.G , Azeradj
- **Traits**: These varieties have unique characteristics that are not strongly aligned with the positive traits of PC1 or PC2. Blanquette.G has lower values for traits that are positively correlated with PC2 (**Figure 33**).

3.3.3.4 Clustered Varieties with Similar Traits

- **Varieties**: Frontoio, Rougette, and Ferkani.

- **Traits**: The clustering of these varieties indicates similar values in a combination of traits. They do not exhibit extreme high or low values in the primary traits identified by PC1 and PC2 (**Figure 33**).

3.3.4 Summary of Key Traits and Varieties Groups

These groupings may be distinguished by their morphological properties, such as leaf and fruit size, stone qualities, and pulp-to-stone ratios.

The first group, situated on the positive sides of both axis 1 (PC1) and axis 2 (PC2), include Belgentiéroise. This variety is closely linked to characteristics like leaf length, leaf area, fruit length, and stone length, suggesting a significant association with higher leaf and fruit sizes.

The second group comprises B. Soumam and Sigoise, located on the positive side of axis 1 and in proximity to the origin of axis 2. These kinds are associated with attributes such as fruit weight, pulp weight, stone diameter, and fruit diameter, indicating an emphasis on fruit size and weight qualities.

The third group, situated on the negative end of axis 1 and the positive end of axis 2, comprises Azeradj and Blanquette G. These types pertain to the pulp-to-stone ratio, highlighting the quantity of pulp in relation to the stone.

The fourth group comprises Frantoio, Rougette M, Ferkani, and Tablout, situated on the negative sides of both axes. This group is defined by characteristics such as the ratio of stone length to diameter and leaf breadth, emphasizing an emphasis on stone and leaf measurements.

3.4 Hierarchical clustering analysis (HCA)

The dendrogram illustrates the hierarchical clustering of various olive varieties based on their morphological characteristics (**Figure 34)**. The y-axis represents the similarity percentage, indicating how closely related the varieties are to each other.

The clustering shows that 'Abani', 'Chemlal', and 'Tablout' form a distinct group with high similarity, as indicated by their close proximity on the dendrogram. 'Ferkani' and 'Rougette de Mitidja' are closely related, and 'Frontoio' joins this cluster. 'Azeradj' and 'Blanquette de Goutta' form another cluster, suggesting a high degree of morphological similarity between them.

The grouping of 'B.Lafayette' and 'Belgentiérois' indicates their close relationship. 'Manzanilla', 'Sigoise', and 'B.Soumam' form the final cluster, with 'B.Soumam' showing the least similarity to the other two.

Images of the olives visually represent each cluster, providing a clear depiction of the morphological traits contributing to their classification (**Figure 34**).

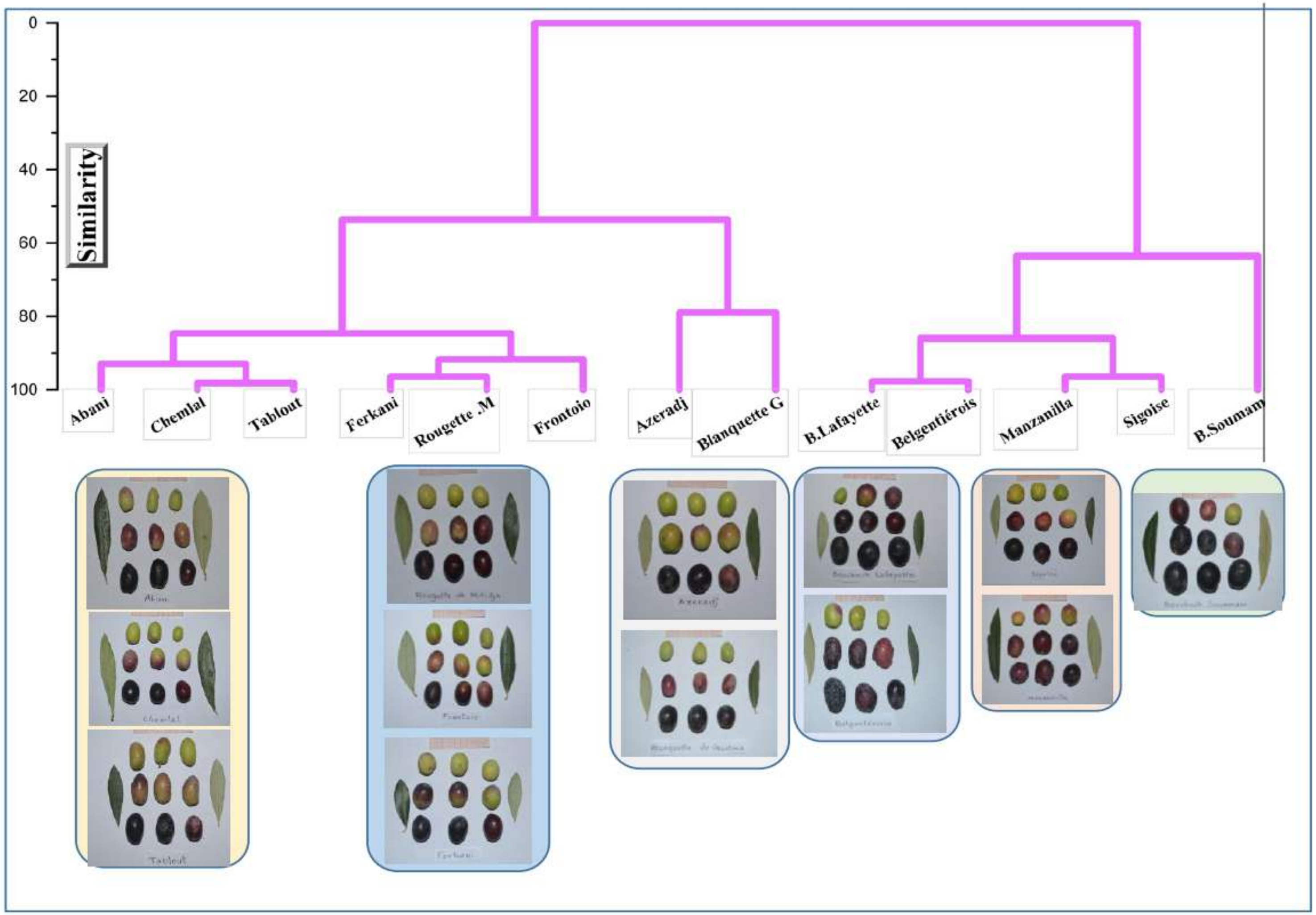


Figure 34: Cluster analysis dendrogram of the morphological and agronomical olive varieties traits (**Origenal 2023**)

4 Discussion

Our finding confirms previous studies in other countries on the importance of measuring morphological and pomological traits (Cantini et al., 1999; Lavee & Wodner, 2004; Lazović et al., 2016; Ozkaya et al., 2006; Taamalli et al., 2006; Trentacoste & Puertas, 2011; Zaher et al., 2011), which successfully classified cultivated olives. Hannachi et al. (2008) found that there was a genetic basis in olive cultivars related to fruit size and probable fruit use.

Fisrt, we begain by leaf parameters, wich are important varietal characters and are used for cultivar identification, they are genetic characters which may differ from cultivar to cultivar under similar soil and environmental conditions (Singh et al., 1999).

Leaf area in our study varies from 3.81 cm^2 to 8.64 cm^2, Mezghani et al. (2015) reported a range from 3.4 cm^2 to 5.3 cm^2, while Sidhoum et al. (2018) found a broader range from 6.59 cm^2 to 9.34 cm^2.

Leaf width in our study ranges from 1.1193 cm to 1.6683 cm, which is lower than the range reported by Sidhoum et al. (2018) from 1.30 cm to 1.83 cm and by Mezghani et al. (2015) from 1.34 cm to 4.20 cm.

Leaf length in our study is shortest at 4.91 cm and longest at 8.62 cm. This is lower than the range reported by Sidhoum et al. (2018) from 6.59 cm to 9.34 cm and higher than the funding obtained by Mezghani et al. (2015) from 3.4 cm to 4.2 cm.

The leaf length to width index in our study spans from 3.7599 to 5.3043. Sidhoum et al. (2018) reported a range from 1.30 to 1.83, which suggests some overlap but also significant differences.

The leaf shape commonly observed in our studied varieties growing under the arid region of Algeria had elliptic-lanceolate and elliptic shapes, the results are in league with the outcomes of (Al-Ruqaie et al., 2016)Al-Ruqaie et al. (2016) who reported similar results in eight olive genotypes grown in Saudi Arabia, and of those results obtained by (Qureshi et al., 2020),who reported similar results in eight olive genotypes collected from Potohar Region (Salt Range) of Pakistan.

Like the leaf traits, fruit and stone related traits are considered very efficient morphological characters in distinguishing among the cultivated olives (Lazovic et al., 2018; Peres et al., 2011; Rotondi et al., 2011). Hannachi et al. (2008) found that there was a genetic basis in olive cultivars related to fruit size and probable fruit use.

Fruit weight in our study is lowest at 1.93 g and highest at 6.42 g. This range is lower than the findings of Sidhoum et al. (2018) in Western Algeria (14 varieties), who reported a range of 2.60 g to 7.41 g, and the range reported by (Mezghani et al., 2015) Mezghani et al. (2015) in the semi-arid region of Tunisia (6 varieties) was from 0.94 g to 7.28 g and of (Khadivi et al., 2022) Khadivi et al. (2022) in the Gilvan area in Zanjan province, Iran (24 varieties), who reported a broader range from 0.97 g to 9.61 g, and of those reported by Sakar et al. (2023) in Mardin (Derik) (8 varieties) found a range from 1.33 g to 7.10 g, respectively, but higher than the range reported by (P. Deiana et al., 2023) Deiana et al. (2023) in North-Central Sardinia, Italy (5 varieties), which was from 2.00 g to 2.33 g. The fruit weight in our study is also lower than that reported by Sevgin & Caner (2019) in the Mardin and Şırnak Provinces (7 varieties), which was from 3.25 to 5.37 g. Other studies, such as those by (Sumrah et al., 2021) Sumrah et al. (2021) in Pakistan (8 varieties), reported a range of 1.52 g to 4.12 g, which is lower than our study.

Fruit diameter in our study ranges from 1,293 cm to 2,078 cm, this is higher than the results obtained by Sevgin & Caner (2019) which ranged from 1,572 cm to 1,885 cm, and lower than the results obtained by Khadivi et al. (2022) in the Gilvan area in Zanjan province, Iran (24 varieties), who reported a broader range from 1,024 cm to 2,371 cm, and Sakar et al. (2023) in Mardin (Derik) (8 varieties) found a range from 1,212 cm to 2,130 cm and by Sidhoum et al. (2018) (from 1,4 cm to 2,15 cm) respectively.

Fruit length spans from 2,015 cm to 3,211 cm in our study. This is lower than the range reported by Khadivi et al. (2022) in the Gilvan area in Zanjan province, Iran (24 varieties), which reported a broader range from 1,304 cm to 3,372 cm and is higher than the range reported by Sakar et al. (2023) from 1,626 cm to 29.74 mm and Sevgin & Caner (2019) from 2,149 cm to 2,416 cm.

The fruit length-to-diameter index in our study is lowest at 1.09 and highest at 1.71. Sidhoum et al. (2018) reported a lower range from 1.10 to 1.49, while Sakar et al. (2023) reported a slightly broader range from 1.20 to 1.96.

The analysis of various olive varieties reveals significant differences across several parameters when compared with other studies, stone weight in our study (in arid region) ranges from 0.30 g to 0.98 g. This range is similar to the findings of Sidhoum et al. (2018); (in Western Algeria) (14 varieties), who reported a range of 0.47 g to 0.96 g, and higher of those of (Sevgin & Caner, 2019) Sevgin & Caner (2019) in Mardin and Şırnak Provinces (Turkey) (7 varieties), who found a range of 0.38 g to 0.72 g.and lower of the results obtained by (Sakar et al., 2023)Sakar et al. (2023) in Mardin (Derik, Turkey) (8 varieties) found a range from 0.44 g to 1.05 g.

Stone diameter in our study varies from 0,577 cm to 0,978 cm, this is similar to the range reported by Sevgin & Caner (2019) from 0.501 cm to 0.940 cm and by Sakar et al. (2023) from 0,686 cm to 0,925 cm However, Sidhoum et al. (2018) found a slightly broader range from 0,68 cm to 0,97 cm.

The shortest stone length in our study is 1,351 cm, while the longest is 2,127 cm, Sakar et al. (2023) reported a similar range from 1,235 cm to 2.336 cm, while Sevgin & Caner (2019) found a range from 1,155 cm to 1,980 cm.

In terms of the stone length-to-diameter ratio, our study spans from 16,99 to 28,78, Sakar et al. (2023) reported a wider range from 15,7 to 30,9 , which is higher than the values found in our study.

The principal limiting factor for pit growth seemed to be the maximum temperatures occurring soon after fruit set, therefore the period in which the rate of cell division is highest in olive fruit (Rapoport et al., 2004) (Rapoport et al., 2004), whereas increased late summer temperatures promoted pit growth. Rapoport et al. (2004), investigating the effect of water stress on fruit development of the Leccino cultivar, observed that early drought conditions constrained pit development but, as water availability was reestablishe

Fruit weight ,pulp weight, pulp/stone ratio and 100 fruits weight are important quality agronomic parameters for the table olive industry fruit and they are important indicator organoleptic characteristics for table olives (IOC. 2014).

The pulp to stone ratio ranges from 4.69 to 8.85, which is higher than the range reported by Sakar et al. (2023) from 1.20 to 1.96 and of the Mezghani et al. (2015) from 5.07 to 8.42, respectively.

The weight of 100 fruits in our study varies from 193.27 g to 641.61 g. This is comparable to the range reported by Sevgin & Caner (2019) from 324.93 g to 537.35 g.

Finally, the pulp weight parameter in our study shows a range from 1.633 g to 5.70 g, which is similar to the range reported by Deiana et al. (2023) from 2.24 to 3.37 g and by (A. C. Ramos et al., 2022) Ramos et al. (2022) from 2.8 to 6.5g

The in-depth study on the characterization of olive cultivars is very important as each cultivar has specific agronomic characteristics, and different production levels at a specific location based on genotypic features (Al Juhaimi et al., 2017; Grati-Kamoun et al., 2006; Youssef et al., 2011), where micro-environmental, ecological, and locally adopted cultivation techniques affect olive varieties productivity (Bignami et al., 1993; Cimato, 1990; Michelakis, 2002), especially the performance of exotic cultivars, which requires investigations regarding their phenological, morphological, and pomological characteristics based on the agronomic performance descriptors (D. Barranco & Rallo, 1985; N. D. Barranco et al., 2000; Cantini et al., 1999; Damigella, 1960; Ouazzani, 2014), and without a doubt; micro-environmental, ecological, and local-adopted cultivation techniques have an impact on productivity and varieties responses (Cimato et al., 1990; Bignami et al., 1994; Michelakis, 2002).

In-depth study on the characterization of olive cultivars is very important, as each cultivar has specific agronomic characteristics and different production levels at a specific location, particularly phenols and oil profiling, which are genotypic features (Grati-Kamoun et al., 2006; Youssef et al., 2011; Al Juhaimi et al., 2017).

To understand how well exotic cultivars do, researchers need to look into their phenological, morphological, and pomological traits using agronomic performance descriptors (Damigella, 1960; Barranco & Rallo, 1985; Cantini et al., 1999; Barranco et al., 2000; Ouazzani, 2014).

5 Conclusion

The differences in fruit weight and pulp-to-stone ratio among the varieties highlight the importance of varietal selection for optimizing yield and quality in arid regions,varieties with higher fruit weights and better pulp-to-stone ratios, such as B. soumam and Belgentiéroise, are particularly promising for cultivation in Biskra, given the potential for higher economic returns.

Additionally, the variability in leaf morphology suggests that certain varieties may be better suited to withstand the harsh climatic conditions, offering resilience and sustained productivity. The agronomic performance of the studied olive varieties is greatly affected by the uniform edaphoclimatic conditions and farming methods, such as irrigation.

The genetic differences between the varieties that come from different places also play a major role. Selecting the appropriate varieties that combine high fruit weight, favourable pulp-to-stone ratios, and suitable leaf morphology can enhance olive production in the arid region of Biskra, Algeria.

Future research should focus on further optimizing irrigation practices and exploring the genetic basis of these agronomic traits to support sustainable olive cultivation in similar arid environments. Irrigation plays a crucial role in the growth and development of olive trees, particularly in arid regions such as Biskra, Algeria.

The consistent and adequate supply of water significantly influences the various agronomic parameters of olive fruits, including fruit weight, size, and overall quality. Despite cultivating all varieties under the same irrigation regime, this study's results highlight the significant influence of irrigation on fruit development.

Fruit enlargement and weight directly correlate with water availability. Adequate irrigation ensures that the trees receive sufficient water for cellular expansion and nutrient transport, leading to larger and heavier fruits.

This is evident in varieties like B. soumam, which exhibited the highest fruit weight of 6.4133 g, and Belgentiérois, with a fruit weight of 5.9067 g, these varieties benefited from consistent irrigation, which supported optimal growth conditions, enhancing fruit development and pulp accumulation.

Moreover, irrigation affects the pulp-to-stone ratio, an essential factor for both table olives and oil production. Consistent water supply enhances pulp formation by promoting the growth of mesocarp tissues, resulting in a higher pulp-to-stone ratio.

Varieties with better water utilization efficiency, facilitated by irrigation, show improved economic value due to the increased edible or processable portion of the fruit.

However, it is also crucial to note that the response to irrigation can vary among different varieties due to their genetic makeup and inherent adaptability to water availability. While some varieties, like Sigoise and Manzanilla, responded positively with increased fruit size and weight under the same irrigation conditions, others may exhibit different growth patterns. In Biskra, irrigation has a profound impact on olive fruit development, significantly improving fruit weight and quality.

Efficient irrigation practices are vital for optimising the yield and economic value of olive varieties in arid regions, ensuring sustainable olive production amidst challenging climatic conditions. Future studies should explore tailored irrigation strategies for different olive varieties to maximise their potential and resilience in arid environments.

Chapter III :

Monovarietal extra Virgin olive oil characterization

1 Introduction

The health benefits of extra virgin olive oil (EVOO) have made it a globally significant agricultural product, especially in the Mediterranean region (Muzammil et al., 2021). EVOO, a staple of the Mediterranean diet, offers numerous health benefits (Jimenez-Lopez et al., 2020), and is derived from fresh, ripe olives, essential in various traditional recipes (Fernández-Lobato et al., 2022), especially monovarietal extra vergin olive oil (MEVOO) is particularly valued for its unique aroma and flavor, with its quality and nutritional characteristics influenced by its chemical composition (Lechhab et al., 2022).

Monovarietal olive oil analysis aids in the identification and classification of different varieties, guaranteeing the oil's provenance and purity and providing advantages to both producers and consumers (Aparicio & Luna, 2002; Kyçyk et al., 2016).

This analysis also supports nutritional research and olive breeding (Uncu & Ozen, 2016; Monasterio et al., 2013; León et al., 2011).

The chemical makeup of MEVOO is influenced by factors such as cultivar, geographical location, and agronomic practices, especially irrigation in arid climates (Ben Hmida et al., 2022), where olive trees are well-adapted to the Mediterranean climate, characterized by limited water resources and variable annual precipitation (Fernandez et al., 2001; Rallo et al., 2016).

Many future projections indicated a decrease in annual precipitation by 10 – 40% in southern Mediterranean areas, coupled with increased water demand from competing sectors (Zittis et al., 2019; Cramer et al., 2018), which led to more research being needed on irrigation practices that optimize water productivity, as low water availability can negatively affect olive growth and production (Palese et al., 2010; Rallo et al., 2016), so we can call this method "Deficit irrigation" wich can reduce water usage while maintaining fruit and oil yields (Gómez del Campo, 2013; Gucci et al., 2007; Lavee et al., 2007; Moriana et al., 2003); moreover, moderate irrigation restrictions can accelerate fruit maturation and maintain oil yield at over 80% of fully irrigated trees, saving about 50% of water (Caruso et al., 2013; Gucci et al., 2009).

Changes in oil quality due to water deficits, including increased phenolic concentrations, have been reported (Caruso et al., 2014, 2017; Gómez del Campo and García, 2013; Gómez-Rico et al., 2007; Servili et al., 2007; Tovar et al., 2001). The rise in phenolic levels is because of better synthesis and maybe also because of hydric stress (Alagna et al., 2012; Artajo et al., 2006; Cirilli et al., 2017), generally, soil water availability during fruit development impacts the sensory profile of oils (Benelli et al., 2015; Berenguer et al., 2006; Servili et al., 2007; Tovar et al., 2002).

The goal of this study was to determine whether there were significant variations in the physic-chemical composition of 26 different monovarietal olive oils sourced from the arid region of Algeria, exactly in the Biskra region, from 13 olive varieties implanted under an arid hot climate at the same orchard with the same density and the same agricultural conduct, and to examine the impact of the hydric stress (deficit irrigation) status on the olive oil quality.

2 Material and methods

2.1 Study site

The study site described in this chapter is the same as the one detailed in Chapter II ; therefore, the site characteristics will not be repeated here (**Figure 35**).

.

Figure 35: Study site with the studied olive cultivars distribution in the orchard

2.2 Studied olive orchard characteristics

2.2.1 Soil Characteristics

- Soil texture: Clay-loamy.
- pH: 8.15.
- EC: 2.71 dS /m or 1.73 g/l.

2.2.2 Water quality

- EC: 6.07 dS/m or 3.88 g/l.
- pH: 7.75.

2.2.3 Distribution of varieties

- Density 625 plants/ha
- Spacing: 04 mx 04 m
- Number of varieties: 13
- Number of plants lengthwise: 24 plants
- Number of plants widthwise: 15 plants
- Total number of plants: 360 plants **(Figure 36)**

2.2.4 Cultivation operations

2.2.4.1 Soil work

Surface plowing was carried out using a cover crop in January.

2.2.4.2 Parcel distribution of varieties

2.2.4.3 Planting Date

The orchard planting was carried out in March 2005.

2.2.5 Irrigation

The irrigation system adopted is the localized system, the number of irrigations of which so far is 18 irrigations per year.

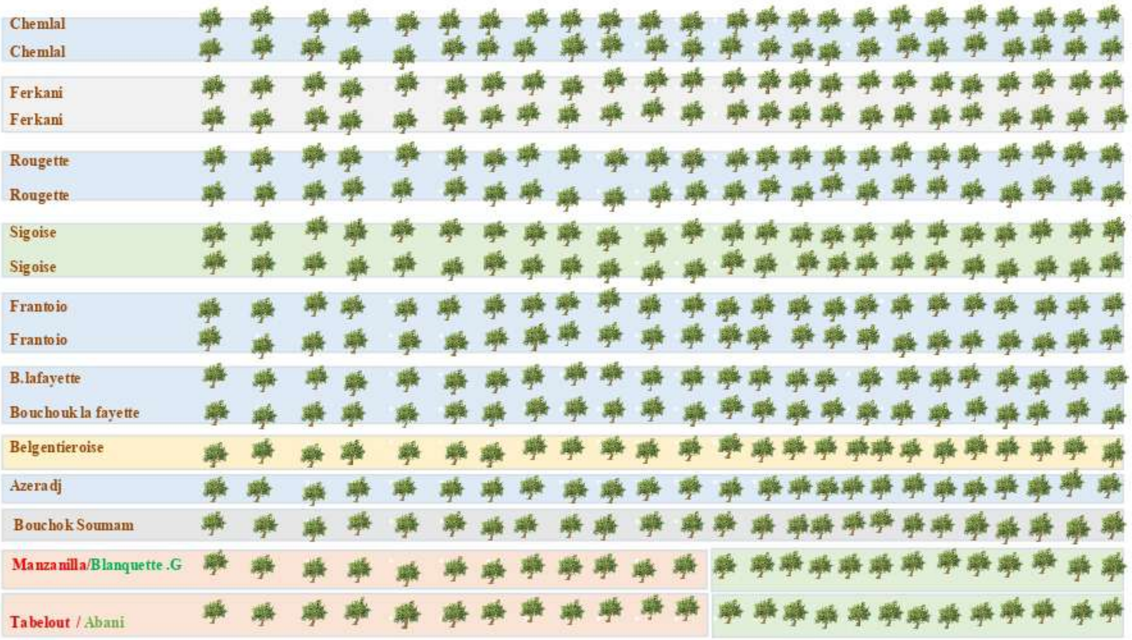


Figure36 : Plot plan for planting (density 4m x 4m) with the variety distribution

2.2.5.1 Irrigation Frequency

The quantity of water provided varies according to the stages of olive tree vegetation, it is indicated in the following table **(Table 10)** . (During the 2021/2022 agricultural season)

Table 11 Irrigation Frequency (During the 2021/2022 agricultural season)

Month Irrigation	**February-mid-October**	**November**	**December**
Irrigation frequencies	Once/ 2 Weeks	Just Once/ Month	No irrigation

2.2.6 Maintenance of manure

First application of nitrogen Urea 46% approximately 500 g per tree at the stage before budburst by ferti -irrigation.

2.2.7 Tree pruning application

During the winter period, fruiting pruning was carried out with the aim of maintaining a correct balance between vegetation and fruiting, and to obtain adequate ventilation and lighting.

2.2.8 Weeding:

Two weeding operations are carried out manually until today.

2.2.9 Phytosanitary protection

During the vegetative cycle of the crop we noticed the appearance of Psylla disease, but it was not treated due to the weak attack of the disease.

2.3 Olive samples harvesting

During the 2021–2022 crop season, olive harvesting took place from September to December. The collection of olive fruit was done manually from individual trees of each variety (Figure 37).

For each sample, 3 kg of olives were randomly selected from each variety, considering two different maturity indices. In total, it was more than 33 visits to the orchard to gather all the olive samples. It is worth noting that, on several occasions, the extraction process failed due to issues such as tearing or bursting of the scourtins.

This necessitated repeating the oil extraction process multiple times. Additionally, significant infestations of the olive fly (Bactrocera oleae) were detected, which also required the collection of new olive samples, further increasing the number of field visits.

The specimens were meticulously put in permeable paper pouches to avoid moisture buildup, maintain the quality, and avoid damaging or breaking the olive epidermis, which may trigger enzymatic activities (Castro-Garcia & Ferguson, 2017; IOC, 2011).

The olives samples were transported using open-mesh plastic crates in order to allow air to circulate and prevent an increase in temperature due to the catabolic activity of enzymes in the olive fruit (Angerosa, 2002; Petrakis, 2006), while being transported to the laboratory.

Hand Hanharvasting of the olive samples **(Original 2022).**

2.4 The Maturity Index (MI)

The maturity level of a certain entity or process is represented by a numerical value (**Table 11**).

The olive maturity index in this study was determined by evaluating the color of the skin and pulp of the olives using the process outlined by the International Olive Oil Council (IOC, 2011).

This technique involves the physical separation of 100 olives, followed by the cutting of their pulp for analysis. The pulp is then numbered and categorized based on its level of maturity (**Figure 38**).

The Maturity Index (MI) values span from zero (representing 100% vivid green skin) to seven (representing 100% purple pulp and black skin).

Table 12: Appearance characteristics and olive categories for the calculation of maturity index (MI) (T simidou et al., 2020)

Appearance	**Categories**	**Number of olives out of 100**
Skin color deep green	Category 0	*n0*
Skin color yellow-green	Category 1	*n1*
Skin color green with reddish spots on < half the fruit surface. Start of color change	Category 2	*n2*
Skin color with > half the fruit surface turning reddish or purple. End of color change	Category 3	*n3*
Skin color black with white flesh	Category 4	*n4*
Skin color black with < half the flesh turning purple	Category 5	*n5*
Skin color black with not all the flesh purple to the stone	Category 6	*n6*
Skin color black with all the flesh purple to the stone	Category 7	*n7*

We determine the MI by applying the following mathematical formula (Uceda & Frias, 1975)(Uceda and Frias, 1975).

$$\boldsymbol{Maturity\ Index\ (MI)} = \frac{(0 \times n0) + (1 \times n1) + (2 \times n2)\ldots\ldots + (7 \times n7)}{100} \qquad \text{(eq2)}$$

Maturity index calculation **(Original 2022).**

The equation (2) represents the calculation of MI, which is the sum of the products of each number (0 to 7) multiplied by their respective coefficients (n0 to n7), all multiplied by 100. The variables n0, n1, n2... n7 represent the quantities of olives in each of the eight categories, ranging from zero (deep green skin color) to seven (black skin color with purple flesh to the stone) (IOC, 2011).

2.5 Extraction of the Monovarietal Extra Virgin Olive Oil (MEVOO) samples following the cold press method

We wanted to be sure that the virgin olive oil (VOO) or extra virgin olive oil (EVOO) we made was of good quality, therefore we used the cold press method to extract it in our study.

Our goal in employing the cold press method was to get an accurate description of the monovarietal olive oil without introducing any variables introduced by the extraction process, like excessive malaxation temperatures, into the data, by limiting our analysis to the specific characteristics of the olive type under study, we were able to draw solid conclusions from our research.

In that where Virgin olive oil is obtained through mechanical pressing alone; this is stated in both the general definition of "virgin oil" in the Codex Alimentarius (Codex Alimentarius Commission, 2017a) and the specific Codex Standard for olive oils (OO) and olive pomace oil (Codex Alimentarius Commission, 2017b).

The oil should remain unchanged regardless of the temperature conditions that are applied. Only filtration, decanting, washing, and centrifugation ought to be performed on the final product. Consequently, thermal treatment of cold-pressed virgin olive oils is not advised. As per the definition provided by the International Olive Council (IOC) (2019a), the cold pressing temperature should not exceed 27°C.

The criteria and categories of commercial products eligible to display optional indications pertaining to the "cold" technology employed are additionally delineated in the olive oil marketing standards legislation of the European Union (EU) (European Union Commission, 2012),

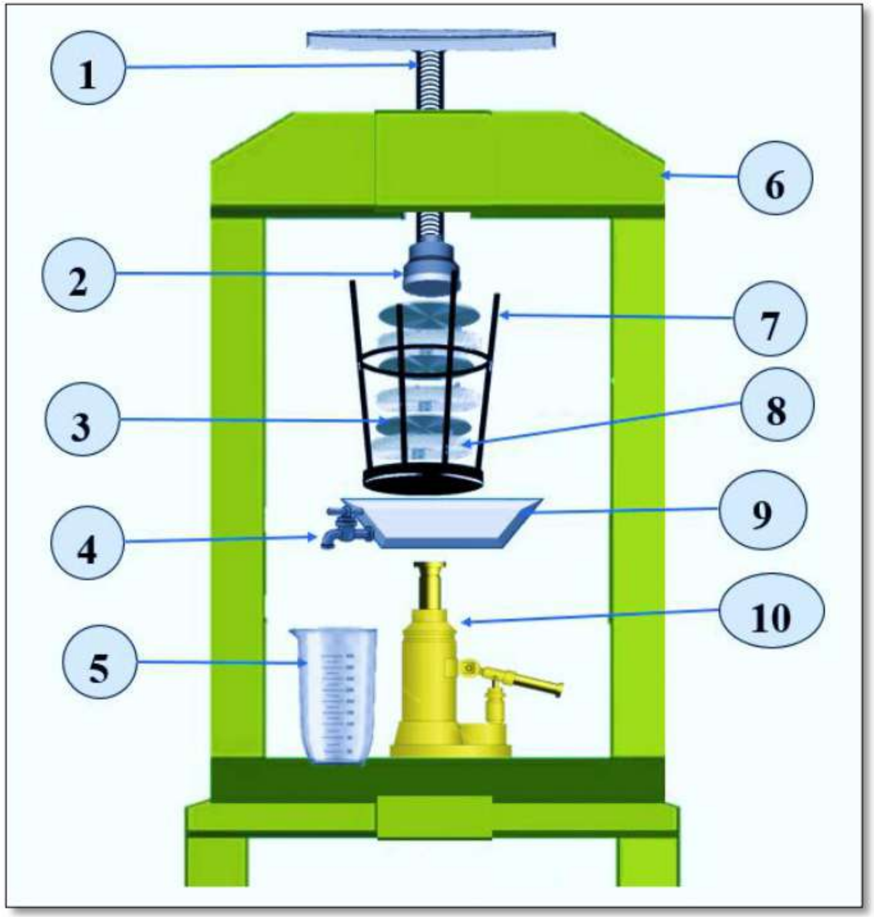
This methodology aligns with this perspective. European Union law restricts edible commercial Virgin Olive Oil (VOO) to only two types : "VOO" and " Extra VOO."

Figure 39 : The different parts of the mini hydraulic press **(Original 2022).**

It should be noted that, to maintain the integrity and accuracy of each olive oil extraction, the materials used in the process are carefully changed before extracting a new sample. This includes replacing the plastic base and scourtins, which may have come into contact with the previous oil.

Additionally, the stones of the crushing step and all the other matreal, are thoroughly cleaned using a solution of sodium bicarbonate and distilled water to ensure the complete removal of any residual olive oil or paste and to avoid contamination between the different monovarietal olive oil samples.

This cleaning procedure guarantees that cross-contamination is prevented, and the quality of the extracted oil remains uncontaminated, ensuring the reliability of the subsequent analyses.



1) **Rotating Steel Arm**: The screw mechanism turns this arm to apply pressure.
2) **The top plate** holds the upper assembly together and provides a surface for applying the pressing force.
3) **A Scourtin** is used to hold the olive paste and allow oil to pass through while retaining solids.
4) **The faucete (outlet valve) :** to control and directs the flow of the extracted liquid, and to Drain the collected liquid in the steel discs container into the Container
5) **Container** : Collects the extracted liquid to put it in a big gradiated funnel (the decontation phase)
6) **The Frame** is the main structure that supports the press and holds all parts together.
7) **Pressing Steel Basket**: This basket holds the remaining parts, ensures their stability, protects the user from potential metal fragments during the pressing process, and ensures even pressing.
8) **Steel Discs** are used to separate the layers of scourtin mats or olive paste, thereby aiding in the pressing process.
9) **A Steel Discs Container**: A Steel Disc Container: designed to prevent any leakage of the extracted liquid and to collect the extracted mixture of oil and vegetative water.
10) **Hydraulic Jack**: Provides the mechanical force necessary to apply pressure to the pressing plates.

Figure 40: Mini hydraulic press part illustraton **(Original 2022 , Designed by Dr.Salim MENACER).**

2.6 The cold press method was used including the following steps

2.6.1 Cleaning

The olives undergo a meticulous cleansing procedure, eliminating any residual debris or contaminants; organic or inorganic impurities, such as leaves or twigs, soil, dust, and stone fragments that could potentially compromise the oil's purity.

In this step as is ullistrated in the **Figure 41**; olives can be washed with water to remove solid contamination (soil mineral or metallic contaminants), that may cause damage to mechanical parts of the machinery or lower the quality of the produced oil (Di Giovacchino et al., 2002).

Olives cleaning **(Original 2023).**

2.6.2 Crushing

The olives were meticulously crushed by hand using two stones (one big stone like a base to put the olives, and the second is the small stone to hit by using the hand to crush the olives), guaranteeing the extraction of a smooth olive paste to facilitate the extraction operation without rupturing the scourtins tissue by the big olive pit parts (**Figure 42**).

Olives crushing **(Original 2023).**

2.6.3 Malaxing

The olive paste was carefully and methodically hand-malaxed for a period of 30 minutes in order to expedite the clumping together of the oil droplets and facilitate the squeezing process.

Additionally, therefore, malaxation time and temperature are critical factors for olive oil quality (Leong et al., 2017) ; this action enhances the disintegration of cellular structures and encourages the clustering of oil droplets. We mix the olive paste in cold weather conditions using a closed bottle of hot water to maintain the temperature of the olive paste at a temperature of 25 to 27 °C to facilitate oil extraction. We measure the temperature degree using a thermometer (**Figure 43**).

After the malaxing operation, the olive paste must be covered with plastic wrap, in order to prevent it from oxidizing.

Olive paste malaxing operation (Original).

2.6.4 Scourtins Preparation

The olive paste was uniformly placed into small scourtin mats, which were made from strong, fabric to effectively separate the oil from the paste.

Utilizing a custom-designed mini-hydraulic press, specifically constructed in the laboratory, was used to apply pressure to the olive paste. Optimal pressure was applied to achieve effective extraction while maintaining the integrity of the oil *(***Figure 44 a).**

a; Scourtins preparation**, b;** Placing of the olive paste in the scourtin **(Original).**

2.6.5 Pressing steps

The pressing of olive paste is a critical step in olive oil extraction. In this phase, we carefully place the olive paste into the scourtins ***(*Figure 44 b)**, ensuring an even distribution across the entire surface of the mat board.

We place two scourtins in their designated positions above the steel disc to initiate the pressing, followed by another steel disc and two additional fully loaded scourtins.

This layering process ensures optimal pressure distribution and extraction efficiency (**Figure 45**).

We gradually apply a pressing force to the scourtins using a hydraulic car jack. We increase the pressure slowly and methodically to ensure thorough extraction without damaging the paste or compromising the oil quality.

We pay attention to the flow of the liquid solution as the pressing continues. We pause the pressing process when we observe the liquid running weakly, indicating the extraction of most of the oil (**Figure 45**).

We carefully remove the scourtins at this point and place a new set of fully loaded scourtins to continue the pressing process. We repeat this cycle until we have pressed all the olive paste.

The extracted liquid, consisting of oil and vegetative water, is first collected in a steel disc container to prevent any leakage. By using the faucet (outlet valve), the flow of the liquid is controlled and directed, allowing it to be smoothly drained from the steel disc container into a larger collection container. From there, the liquid is transferred into a large graduated funnel, where the decantation phase takes place, further refining the separation of the oil from the vegetative water.

Scourtins pressing **(Original).**

2.6.6 Decantation

We meticulously decanted the liquid from the pressing to separate the two distinct phases: olive oil and vegetative water (**Figure 46**).

2.6.7 Olive samples Collection

We carefully collected the olive oil with a pipette to ensure its quality, retrieval of the utmost superior oil (**Figure 46**).

Figure 46 : Decantation **(Original).**

2.6.8 Centrifugation Speed: 3500 rpm)

The collected olive oil samples were subjected to centrifugation at a speed of 3500 revolutions per minute (rpm) to separate the oil from other components, such as water and residual solids. This process allowed for the purification and clarification of the oil by utilizing the differences in density between the oil, water, and solid particles. After centrifugation, the clarified olive oil was carefully extracted and transferred into sterilized glass bottles to ensure preservation. Each bottle was then labelled with the olive variety, the sample number, the maturity index value, and the extraction date. The labelled bottles were subsequently stored in a refrigerator at a temperature below 4°C to maintain the quality of the oil until further analysis (**Figure 47**).

Decotation and Collection and centrifugation of the olive oil samples

(Original).

2.7 The studied parameters

2.7.1 The industrial yield determination

The industrial yield of the extracted oil was determined by dividing the weight of the olive oil extracted from the fresh olive sample by its olive sample weight (Equation 3).

Industrial yield (%) is determined using the following formula, per the International Olympic Committee (IOC, 2011).

$$\textbf{Industrial oil yield } (\%) = \frac{kg\ of\ oil\ obtained}{kg\ of\ olives\ processed} \times \mathbf{100} \quad \mathbf{(3)}$$

2.7.2 Physicochemical analysis

We conducted the physical and chemical analyses of the extracted oil samples in Tunisia at the Olive tree Institute Sfax "EL-ZAITOUNA" (**Figure 46**), which is a public administrative institution under the Ministry of Agriculture, Water Resources, and Fisheries. It is affiliated with the Agricultural Research and Higher Education Institution and is jointly supervised by the Ministry of Higher Education and Scientific Research.

The analyses were performed at the Laboratory of Olive Cultivation Sustainability in Semi-Arid and Arid Regions: Improving Olive Productivity and Product Quality.

The Olive tree Institute Sfax "EL-ZAITOUNA", Tunisia.

The studied physicochemical parameters are; free fatty acids, optical density, and the contents of pigments (chlorophyll content, carotene content), total phenols content and fatty acid composition.

2.7.2.1 Laboratory Material

The materials used in the procedures described include a spectrophotometer, quartz cuvettes, a 10 ml volumetric flask, a precision balance, a beaker, glass cuvettes, a magnetic stirrer, a micropipette, a centrifuge, an Erlenmeyer flask (100 ml), a dispensette, a micro burette, a graduated cylinder, screw-cap test tubes (5 ml capacity) with Polytetrafluoroethylene (PTFE) gasketed caps, and graduated or automatic pipettes (2 ml and 0.2 ml).

The materials for chromatography included a capillary column (50 m length x 0.25 or 0.32 mm internal diameter) coated with cyanopropyl silicone.

2.7.2.2 Studied parameters

The determination of free fatty acid and measuring the optical density of 232 nm and 270 nm (referred to as K232 and K270, respectively), using the analytical methods outlined in Commission Delegated Regulation (EU) (2016).

2.7.2.2.1 Free fatty acid determination (FAA)

The percentage of free fatty acid, relative to oleic acid, was measured by titrating a solution containing 5 grams of oil sample dissolved in 90 milliliters of ethanol with a 0.1 N ethanolic solution of potassium hydroxide. The indicator employed was phenolphthalein.

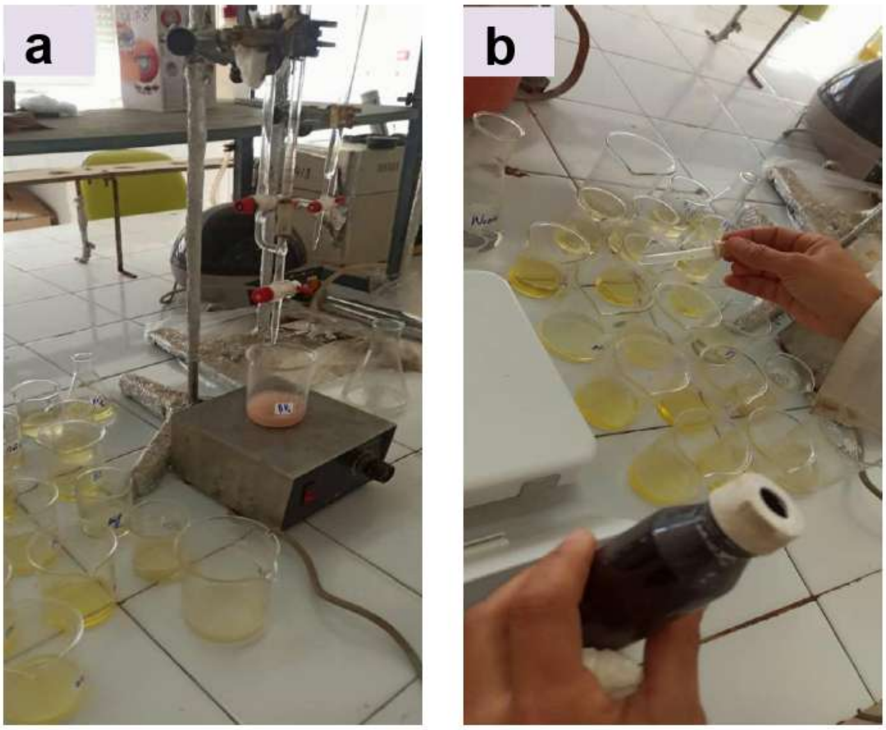


Figure 49: Determination of the free fatty acid by

titrating method **(Original)**

2.7.2.2.2 Optical density

The values of K232 and K270 were determined by measuring the absorbance at 232 nm and 270 nm, respectively, using a UV spectrophotometer (SPECUVIS1; UV-Visible). A 1% solution of olive oil in cyclohexane (1 g/100 ml) was used, with a path length of 1 cm.

Determination of the Optical density using the spectrophotometer **(Original).**

2.7.2.2.3 The contents of pigments

The pigments' quantities were determined using the specific extinction values, following the methodology described by Minguez-Mosquera et al. (1991).

The method involved the dissolution of 75 grams of olive oil in 25 milliliters of cyclohexane. The extinction coefficients employed were ε0 = 613 for pheophytin, the primary constituent of the chlorophyll fraction, and ε0 = 2000 for lutein, the primary constituent of the carotenoid fraction.

The contents of pigments determination using the spectrophotometer

Therefore, the levels of pigments were determined using the following calculations:

$$Chlorophyll\ (ppm)\ =\ \frac{A670-(A630+A710)/2}{0.1086\times W}\quad (4)$$

Where A is the absorbance and W is the spectrophotometer cell thickness (1 cm).

$$Carotenoids\ (ppm)\ =\ \frac{E0\times 7.5}{A470\times 2\times 10{,}000}\quad (5)$$

A470: absorbance of the sample at 470 nm

E0: specific extinction = 2000

2.7.2.2.4 Quantification of total polyphenols content

The total polyphenols content were obtained by performing a twofold extraction of an oil solution in a mixture of methanol and Tween 20 (2% v/w).

An appropriate portion of the extracts was treated with the Folin–Ciocalteu reagent, and the absorbance of the resulting solution at a wavelength of 765 nm was quantified (Singleton & Rossi, 1965).

The values were expressed as milligrams of hydroxytyrosol per kilogram of oil. The quantification of total polyphenols was conducted by converting them into gallic acid equivalents (GAE), employing a calibration curve derived from a recently generated solution of gallic acid.

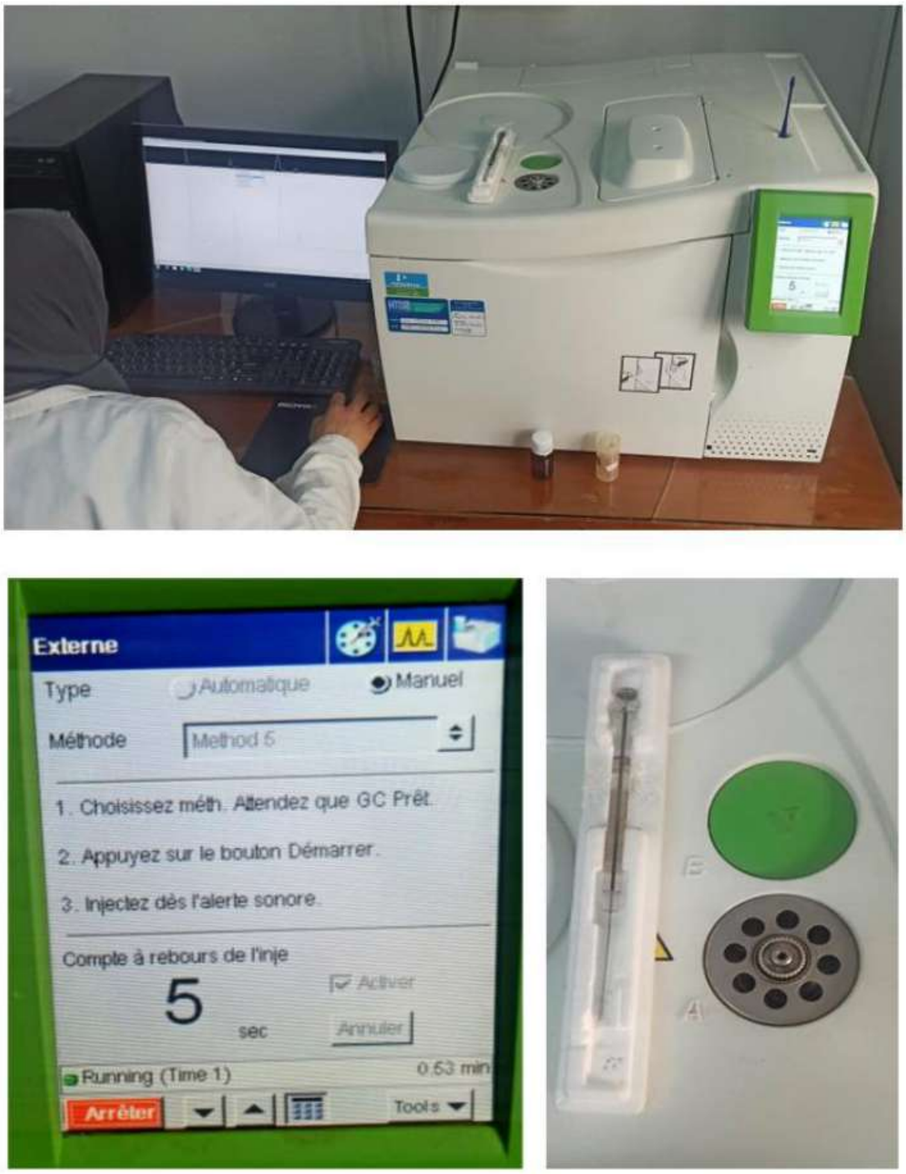
. Total polyphenols content analysis **(Original).**

2.7.2.2.5 Determination of the Composition of fatty acids using gaz chromatography

The conversion of fatty acids to methyl esters was carried out by employing potassium hydroxide in methanol, as specified by the International Olive Council (IOC) (International Olive Council & IOC/T.20/Doc. Nº 24, 2001).

We performed the analysis of these methyl esters using gas chromatography (GC) with a Glarus 580 chromatograph (serial 580S1706501) by PerkinElmer, equipped with a flame ionization detector (FID). SGE Incorporated in Austin, TX, USA, manufactured a BPX70 fused silica capillary column with a length of 50 meters and a film thickness of 0.25 micrometers.

We set the temperature to vary from 160°C to 230°C at a rate of 2°C per minute, and analyzed samples of 0.5 l using hydrogen as the carrier gas. We performed the injection in split mode. We identified the fatty acid methyl esters (FAME) using standard FAMEs from Sigma-Aldrich Co. (St. Louis, MO, USA).


Externe

Type ○ Automatique ● Manuel

Méthode Method 5

1. Choisissez méth. Attendez que GC Prêt.
2. Appuyez sur le bouton Démarrer.
3. Injectez dès l'alerte sonore.

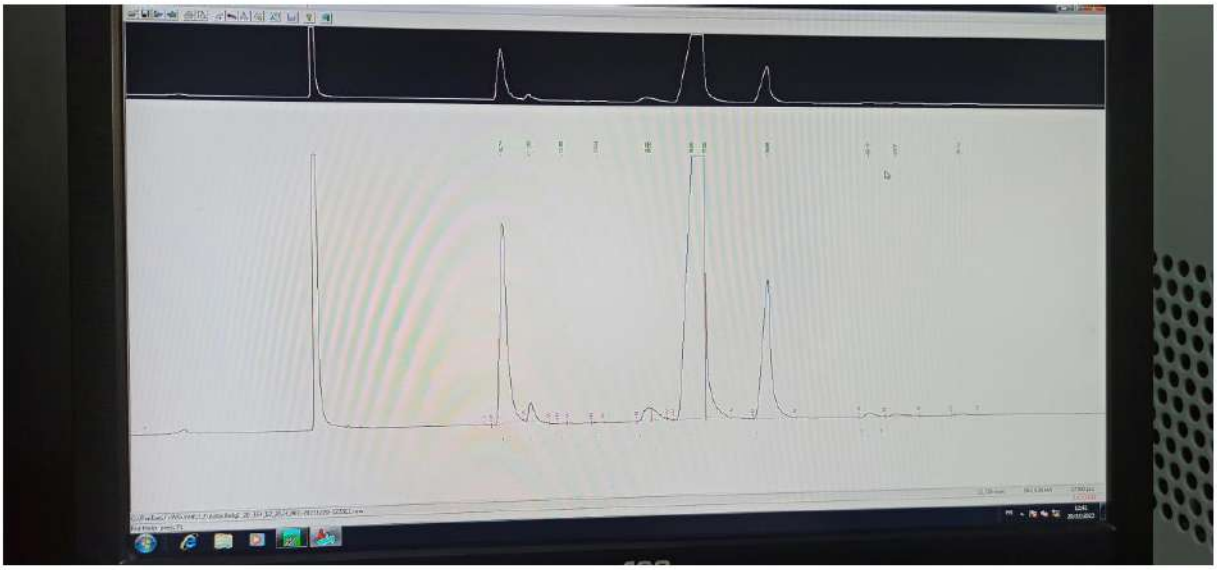
Compte à rebours de l'inje 5 sec

☑ Activer

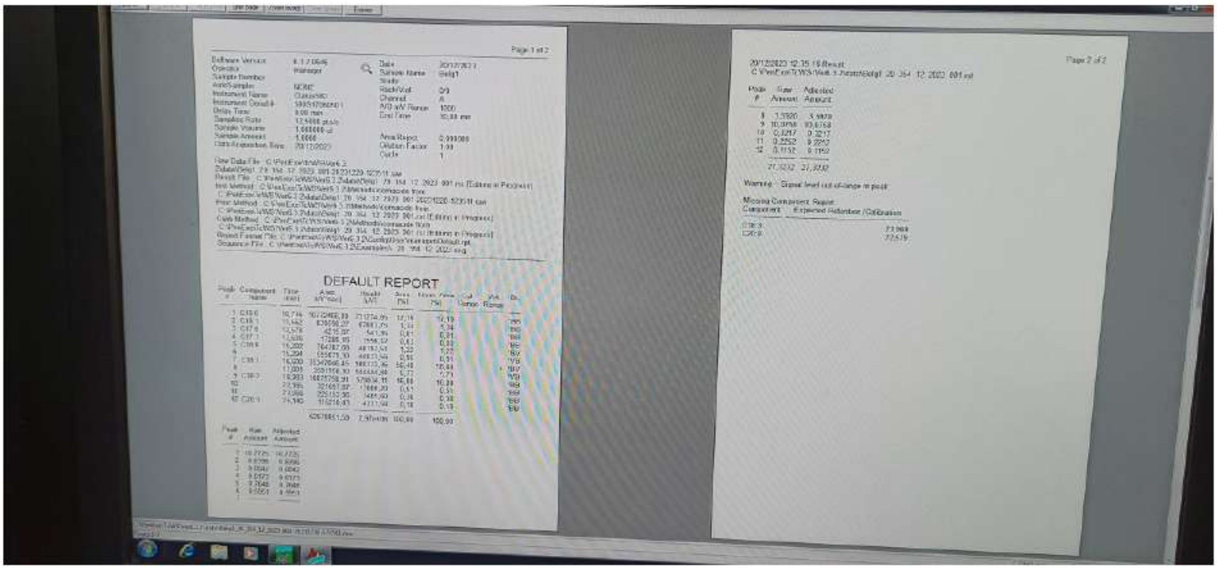
Running (Time 1) 0.53 min

Determination of the fatty acids Composition using gaz chromatography **(Original).**

We determined the fatty acids by comparing the retention durations with reference substances. This study examined ten fatty acids. The following fatty acids were identified: palmitic acid (16:0), palmitoleic acid (16:1n 7), margaric acid (C17:0), margaroleic acid (C17:1n 8), stearic acid (18:0), oleic acid (18:1n 9), linoleic acid (18:2n 6), linolenic acid (18:3n 3), arachidic acid (20:0), and gondoic acid (C20:1n 9). We quantified the acids as a proportion of FAMEs.



GC Chromatograph **(Original).**



Numeric Results of the GC **(Original).**

2.8 Statistical analysis

The data gathered was processed and entered for descriptive statistical analysis using Excel 2013, the statistical analyses conducted in this study involved the use of Analysis of Variance (ANOVA) to identify significant differences among the MEVOO samples and to form homogeneous groups at a significance level of alpha = 0.05. Additionally, Principal Component Analysis (PCA) was employed to identify patterns and relationships within the data. These analyses were performed using OriginPro 2023 and 2024 Learning Edition software.

3 RESULTS

The ANOVA test results (Industrial yieldfruit, The free fatty acid (FFA) content, Optical density,The pigments content, Total polyphenol content and 3.7 Fatty acid composition), illustrated in the following figures,and the table 13, show very highly significant results (alpha = 0.05) with $P < 0.0001$ for all parameters. Means sharing the same letter (s) are not significantly different according to the Tukey test ($p < 0.05$).

3.1 Maturity index

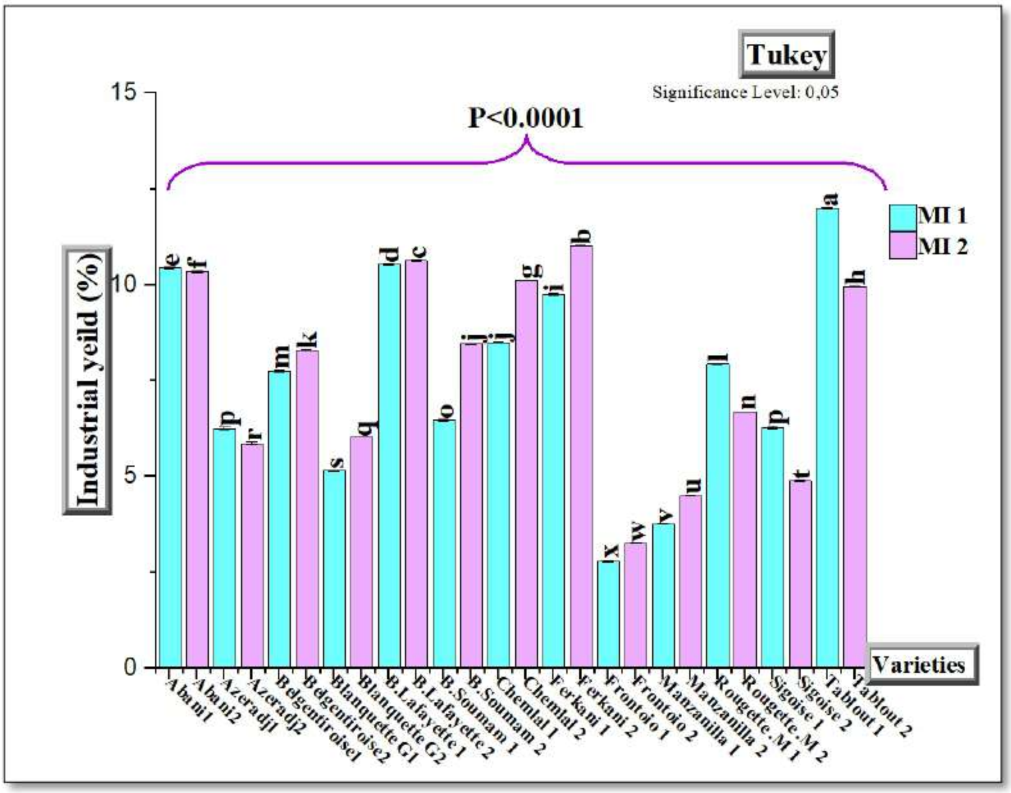
The Tablout 1 variety exhibits the highest maturity index value of 4.43, signifying a more advanced stage of fruit ripeness. On the other hand, the Frontoio 1 variety has the lowest maturity index value, 2.33, indicating less mature olives. This results in a significant range of maturity index values among the samples, ranging from 2.33 to 4.43.

Table 13 Harvesting and extraction dates, and the Maturity index of all the Olives samples.

Varieties	Harvesting date	Extraction date	Maturity Index
Abani 1	06/11/2022	08/11/2022	4,28
Abani 2	21/11/2022	23/11/2022	4,00
Azeradj 1	28/11/2022	29/11/2022	2,33
Azeradj 2	28/11/2022	29/11/2022	4,41
Belgentiéroise 1	23/10/2022	26/10/2022	3,80
Belgentiéroise 2	23/10/2022	25/10/2022	3,15
Blanquette G1	23/10/2022	23/10/2022	2,86
Blanquette G 2	30/10/2022	30/10/2022	4,20
B.Lafayette 1	16/10/2022	17/10/2022	3,16
B.Lafayette 2	31/10/2022	31/10/2022	3,57
B.Soumam 1	08/10/2022	11/10/2022	2,80
B.Soumam 2	08/10/2022	10/10/2022	3,12
Chemlal 1	14/12/2022	15/12/2022	2,80
Chemlal 2	14/12/2022	15/12/2022	2,28
Ferkani 1	20/12/2022	22/12/2022	2,82
Ferkani 2	20/12/2022	22/12/2022	4,43
Frontoio 1	11/12/2022	12/12/2022	3,50
Frontoio 2	11/12/2022	12/12/2022	2,87
Manzanilla 1	16/11/2022	17/11/2022	4,25
Manzanilla 2	27/11/2022	28/11/2022	2,89
Rougette .M 1	17/10/2022	18/10/2022	3,22
Rougette. M 2	22/10/2022	22/10/2022	3,07
Sigoise 1	20/11/2022	21/11/2022	2,72
Sigoise 2	19/12/2022	20/12/2022	4,20
Tablout 1	20/11/2022	24/11/2022	3,59
Tablout 2	20/11/2022	23/11/2022	3,78

3.2 Industrial yield

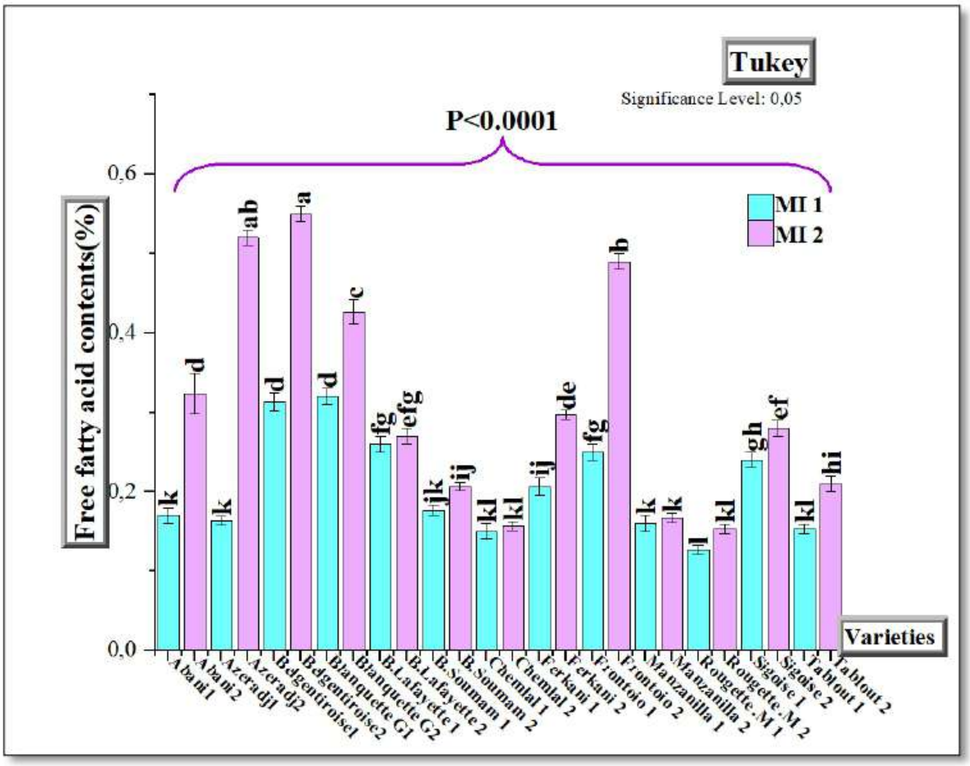
The Tablout 2 variety exhibits the highest industrial yield, with a value of 12, conversely, the Frontoio 1 variety exhibits the lowest industrial yield value, with a value of 2.79 (**Figure 56**).



Industruel yield average with the ANOVA Test results

3.3 The free fatty acid (FFA) content

In the monovarietal olive oil samples (MEVOO) dataset, the highest free fatty acid (FFA) content was observed in the Belgentiéroise 2 MEVOO sample, with a value of 0.55 Conversely, the lowest FFA content was found in the Rougette de Matidja 1 sample, displayed the lowest value at 0.12 (**Figure 57**).



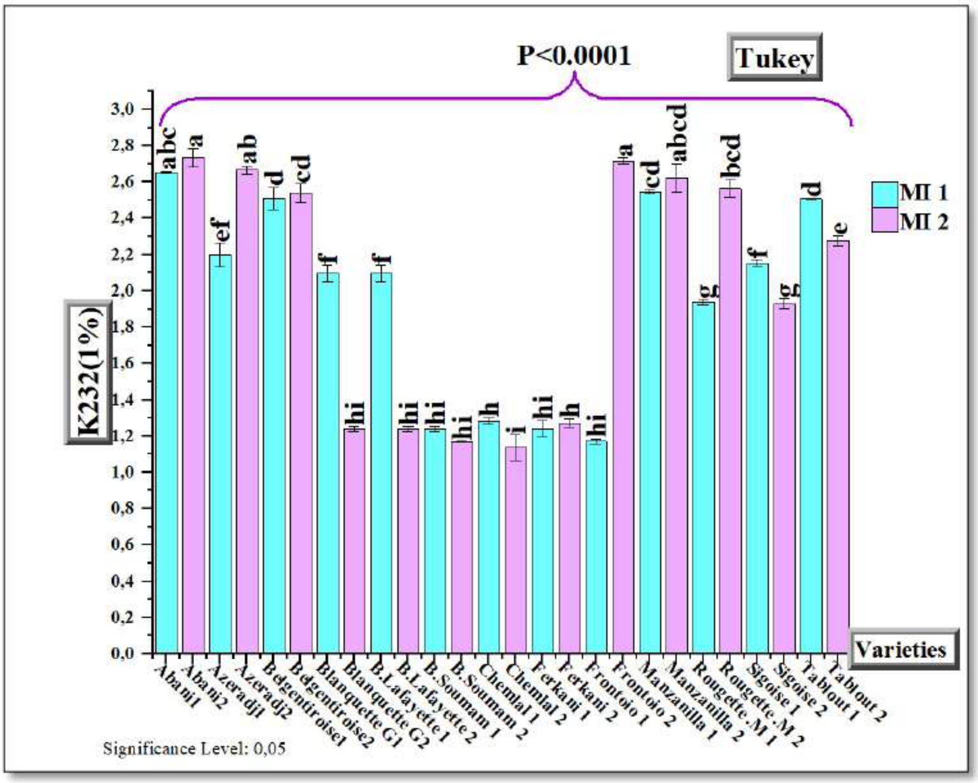
Free fatty acid average with the ANOVA Test results

3.4 Optical density

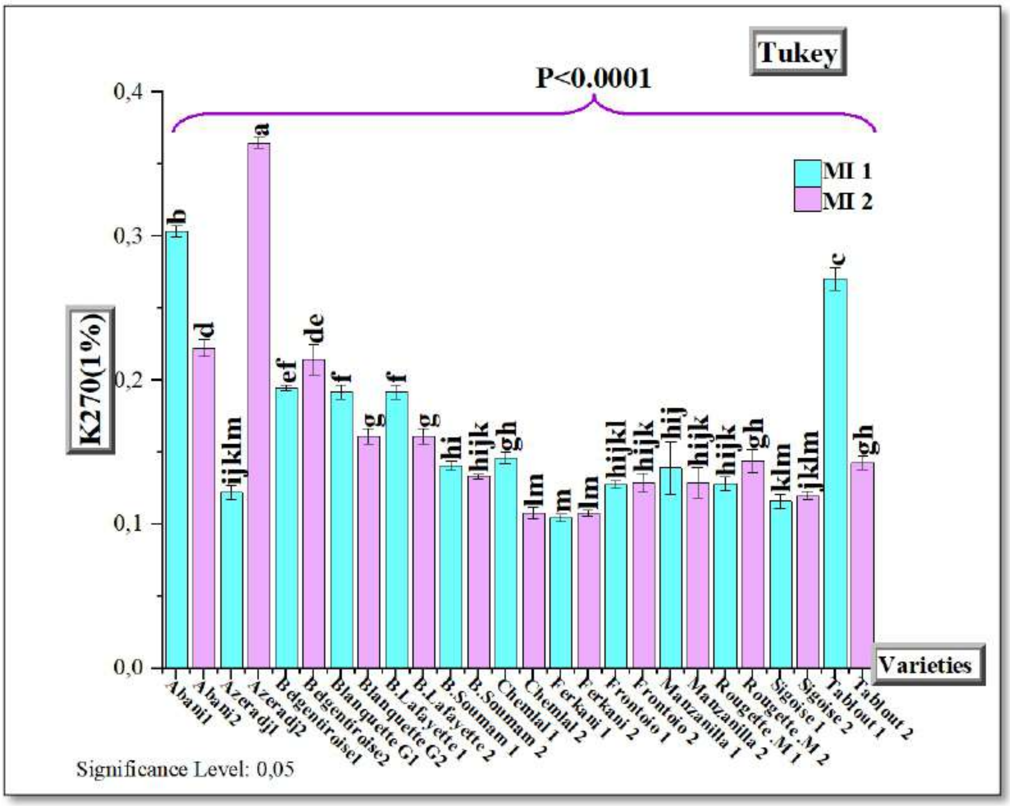
The K232 and K720 values in the studied MEVOO samples display variations across different varieties. The highest K232 value is observed in the Abani 2 MEVOO sample, with a value of 2.71, conversely, the lowest K232 value is found in the Chemlal 2 sample, with a value of 1.14 (**Figure 58**).

Regarding K720 values, the highest value is observed in the Azeradj 2 MEVOO sample, with a value of 0.37.

The range of K720 values among the other MEVOO samples is significant, spanning from 0.1 to 0.3 (**Figure 59**).



Optical density(K232)Valus with the ANOVA Test results



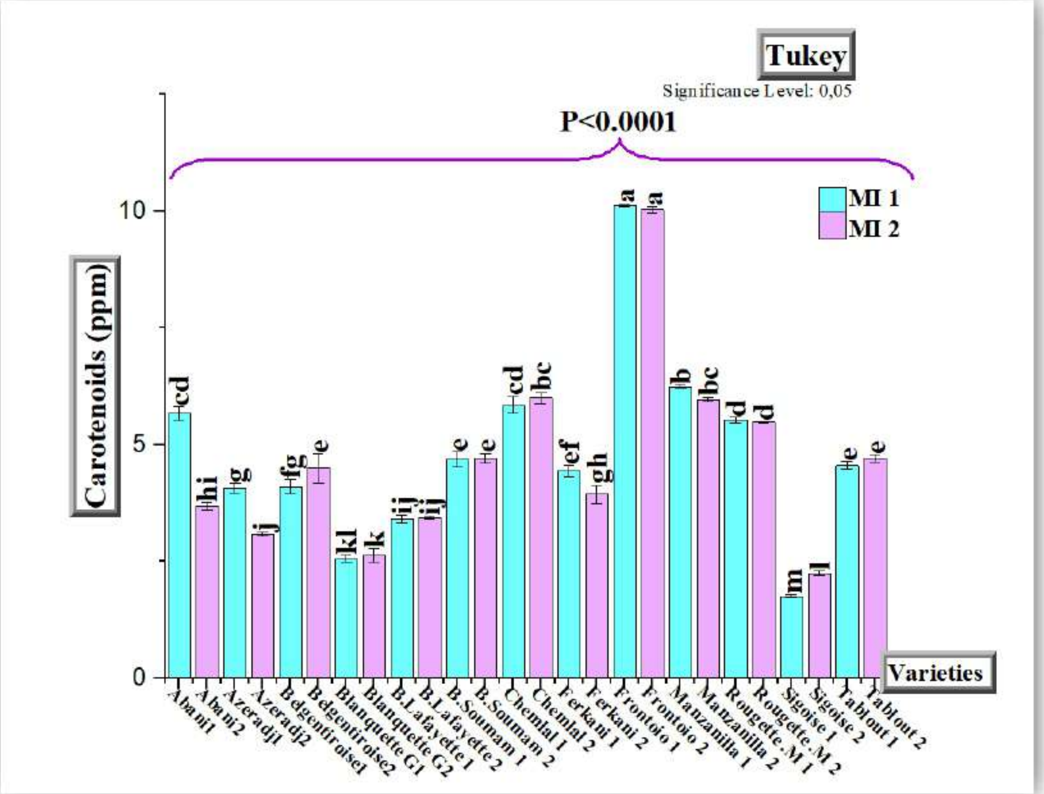
Optical density (K270) Valus with the ANOVA Test results

3.5 The pigments content

The pigment content, including carotenoids and chlorophyll, varies across monovarietal olive oil samples (MEVOO) from different varieties.

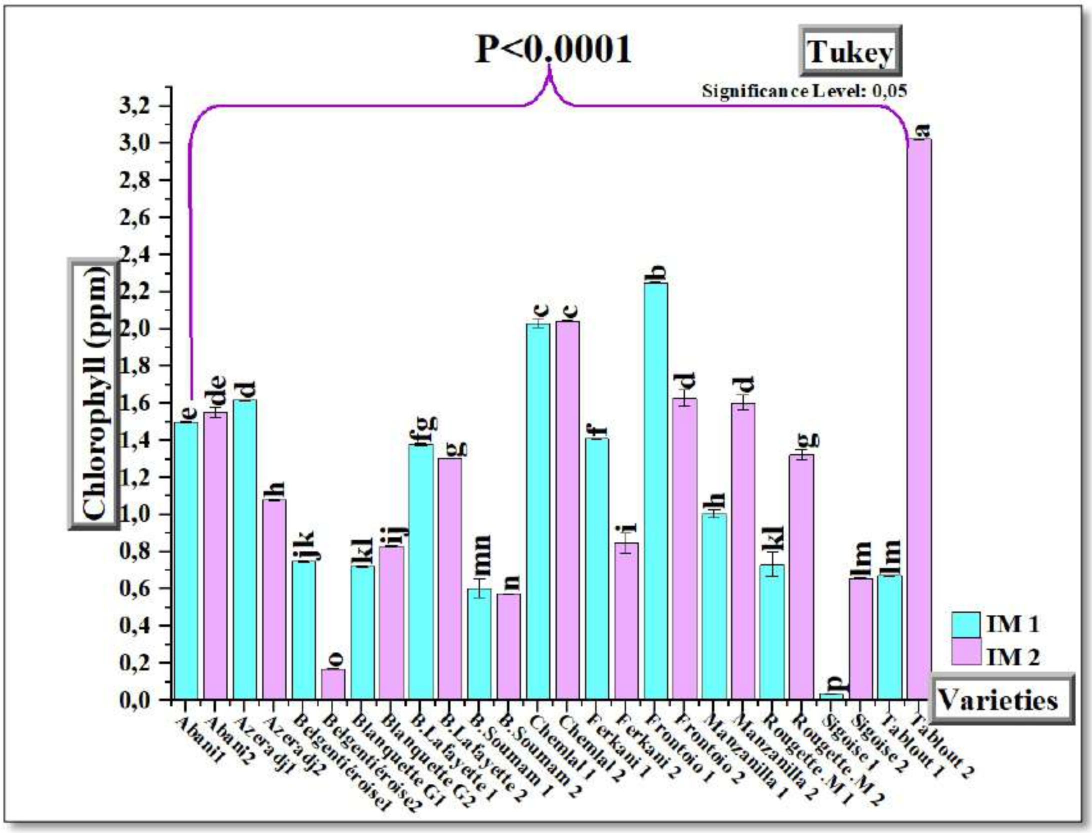
The highest carotene content is observed in the Frontoio 1 and Frontoio 2 samples, both exhibiting values of 10.12 and 10.02 mg/kg, respectively.

Conversely, the lowest carotene content is found in the Sigoise 1 MEVOO sample, with a value of 1.75 mg/kg, this results in a significant range of carotene values among the samples, spanning from 1.75 mg/kg to 10.12 mg/kg and chlorophyll; 3.03 mg/kg to 0,03mg/kg (**Figure 60**).



Carotenoids content valus with the ANOVA Test results

Similarly, the highest chlorophyll content is observed in the Tablout 2 MEVOO sample, with a value of 3.03 mg/kg, while the lowest chlorophyll content is found in the Sigoise 1 MEVOO sample, with a value of 0,03mg/kg. The range of chlorophyll values among the rest of the other MEVOO samples ranging from 0,06mg/kg to 2.25 mg/kg (**Figure 61**).



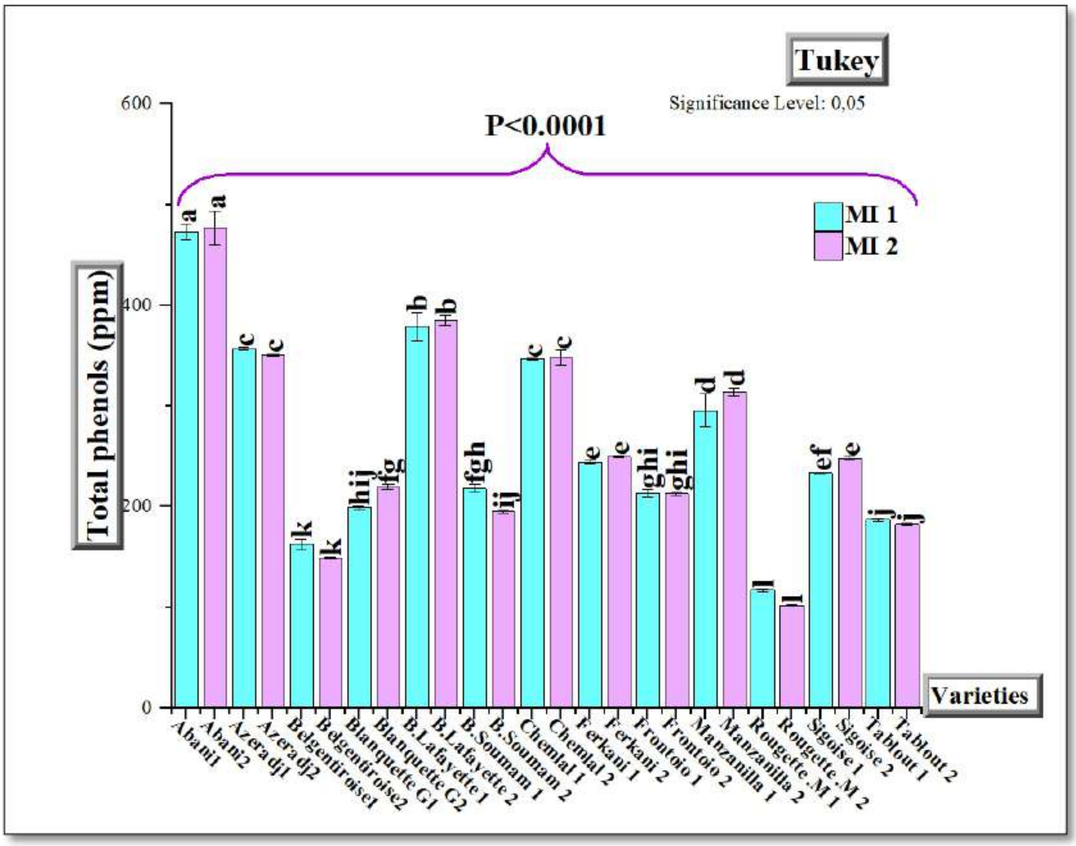
Chlorophyl content Valus with the ANOVA Test results

3.6 Total polyphenol content

The total polyphenol content in the studied MEVOO samples varies significantly across different varieties. Among the samples analyzed, the highest value is observed in the Abani2 MEVOO sample, with a value of 476,91mg/kg, while the lowest total polyphenol content is found in the Rougette.M.2 MEVOO sample, with a value of 101.92 mg/kg.

The Average of the Total polyphenol content according the harvesting month

Month of harvesting	**October**	**November**	**December**
Olive samples	Rougette.M (1+2) Belgentiéroise(1+2) Blanquette.G(1+2) B.Lafayette (1+2) B.Soumam (1+2)	Manzanilla (1+2) Abani (1+2) Azeradj (1+2) Tablout (1+2) Sigoise 2	Chemlal (1+2) Ferkani(1+2) Frantoio (1+2) Sigoise 1
Average of the total polyphenols	**212,57ppm**	**318,88ppm**	**265,95 ppm**



Total phenols average with the ANOVA Test results

3.7 Fatty acid composition of MEVOO samples

The varieties exhibited varying results across different parameters **(Table 14)**.

The palmic acid (C16:0) content ranged from 10.28% in Sigoise 2 to 19.94% in Manzanilla 2.

For Palmitolic acid(C16:1), the values varied from 0.53% in Sigoise 2 to 2.55% in Abani 1 MEVOO sample.

In terms of the Heptadecanoic acid (C17:0) content, the lowest was 0.01% in several varieties, such as Chemlal 2 and Rougette de Matidja 2, while the highest was 0.13% in Bouchouk Lafayette 1.

Similarly, the Heptadecenoic acid (C17:1) ranged from 0.02% in several varieties, like Rougette de Matidja 1, to 0.28% in Bouchouk Lafayette 1.

For the Stearic acid (C18:0), the values varied from 1.31% in Abani 1 to 3.64% in Azeradj 2 MEVOO sample.

Regarding the Oleic acid (C18:1), it ranged from 55.72% in Rougette de Matidja1 to 78.9% in Manzanilla1.

The Linoleic acid (C18:2)content ranged from 4.54% in Manzanilla 1 to 24.33% in Belgéntiroise 2.

The Linolenic acid (C18:3)ranged from 0.11% in Tablout 2 to 1.56% in Begentiéroise 2.

Moving on to Arachidic acid (C20:0), it ranged from 0.02% in Tablout 2 to 0.45% in Chemlal 2.

The Gadoleic acid (C20:1)ranged from 12.57% in Sigoise 2 to 21.56% in Manzanilla 2. SFA values varied from 13.83% in Rougette de Matidja 1 to 20.72% in Manzanilla 1.

Regarding the Saturated Fatty Acid (SFA), it ranged from 13.83% in Rougette de Matidja 1 to 20.36% in Abani 1.

The ΣAG Mono-Unsaturated content varied between 56.41% in Belgéntiroise 2 and 79.05% in Rougette de Matidja 2.

For ΣAG Di-Unsaturated, the values ranged from 5.15% in Rougette de Matidja 2 to 24.33% in Belgéntiroise 2.

The ΣAG Three-Unsaturated content was lowest at 0.32% in Blanquette.G 2 and highest at 1.56% in Belgéntiroise 2.

The ΣUnsaturated Fatty Acid (UFA) content ranged from 71.47% in Abani 1 to 85.96% in Manzanilla 1.

Finally, the UFA/SFA ratio varied between 3.55 in Abani 1 and 6.21 in Manzanilla 1(**Table 14**).

Fatty Acid Composition of Local and Foreign MEVOO Samples, Grouped by ANOVA Results with their following the IOC standars.

Fatty acides MEVOO samples	C16:0	C16:1	C17:0	C17:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	SFA	AGM	AGD	AGT	AGI	UFA/SFA
Abani 1	18,39 bc	2,55 a	0,05 cd	0,16 b	1,79 i	67,57 kl	8,68 pq	0,5 ijk	0,18 efg	0,13 h	20,36 cd	70,12 ij	8,68 pq	0,5 ijk	71,47 i	3,55 m
Abani 2	18,62 c	2,48 a	0,07 de	0,22 cd	1,31 j	60,56 efg	7,93 n	0,5 ijk	0,2 fghi	0,11 cdef	20,13 bc	63,04 def	7,93 n	0,5 ijk	79,3 efgh	3,89 kl
Azeradj 1	16,81 h	0,96 kl	0,1 ab	0,24 ab	3,6 a	65,08 defg	12,27 l	0,63 jk	0,19 a	0,12 cdef	20,6 ef	66,04 ef	12,27 l	0,63 jk	80,07 defgh	4,12 hi
Azeradj 2	15,3 e	0,75 jk	0,11 abc	0,25 b	3,64 a	68,62 hi	10,24 i	0,46 fgh	0,45 efgh	0,18 gh	19,39 bc	69,37 g	10,24 i	0,46 fgh	78,94 fgh	3,83 kl
Belgentiéroise 1	14,03 k	1,14 hij	0,02 ef	0,02 j	2,54 d	60,67 kl	20,11 b	1,12 b	0,13 hijk	0,22 c	16,7 j	61,81 j	20,11 b	1,12 b	83,04 bc	4,97 d
Belgéntiéroise 2	15,08 hi	1,37 fgh	0,02 ef	0,04 ij	2,38 de	55,04 m	24,33 a	1,56 a	0,15 ghij	0,03 i	17,61 i	56,41 l	24,33 a	1,56 a	82,3 cd	4,67 ef
Blanquette .G 1	17,19 e	1,34 fgh	0,01 f	0,03 ij	2,17 efgh	62,13 jk	16,08 f	0,51 ijk	0,36 b	0,18 cdef	19,72 de	63,47 hij	16,08 f	0,51 ijk	80,06 defgh	4,05 ij
Blanquette.G 2	15,93 fg	1,31 gh	0,01 f	0,06 ghi	2,01 h	63,7 ij	16,04 f	0,43 kl	0,3 bc	0,21 c	18,24 gh	65,01 ghi	16,04 f	0,43 kl	81,48 cde	4,46 g
B.Lafayette 1	15,44 h	0,69 ij	0,13 a	0,28 a	2,78 c	62,3 jk	17,7 d	0,32 l	0,25 cde	0,11 h	18,47 g	62,99 ij	17,7 d	0,32 l	81,01 cdefg	4,38 g
B.Lafayette 2	15,92 fg	1,02 l	0,12 ab	0,23 b	3,08 b	58,55 l	19,87 b	0,95 c	0,11 jk	0,15 defgh	19,11 f	59,57 k	19,87 b	0,95 c	80,39 defg	4,20 hi
B.Soumam 1	15,47 gh	1,25 hi	0,04 def	0,15 cde	2,37 de	71,43 bc	8,2 o	0,71 ef	0,18 fghi	0,2 cd	18,02 ghi	72,68 b	8,2 op	0,71 ef	81,59 cde	4,52 fg
B.Soumam 2	16,81 e	1,33 gh	0,09 bc	0,16 cd	2,31 ef	69,1 def	8,89 n	0,89 cd	0,23 def	0,19 cde	19,35 ef	70,43 cdef	8,89 n	0,89 cd	80,21 defg	4,14 hi
Chemlal 1	17,22 e	2,08 b	0,01 f	0,08 gh	1,79 i	67,05 fgh	11,02 k	0,43 kl	0,11 jk	0,21 c	19,12 f	69,13 ef	11,02 k	0,43 kl	80,58 defg	4,21 h
Chemlal 2	17,72 d	2,02 b	0,01 f	0,04 ij	1,47 j	66,62 gh	11,3 k	0,48 ijk	0,19 efgh	0,14 efgh	19,38 ef	68,64 f	11,3 k	0,48 ijk	80,42 defg	4,14 hi
Ferkani 1	16,04 f	1,52 efg	0,02 ef	0,04 ij	2,14 fgh	63,91 ij	15,34 g	0,57 hij	0,28 cd	0,14 efgh	18,46 g	65,43 gh	15,34 g	0,57 hij	81,34 cde	4,40 g
Ferkani 2	15,5 gh	1,74 cde	0,01 f	0,05 hij	2,07 gh	62,65 jk	17,13 e	0,58 ghi	0,16 ghij	0,11 h	17,73 hi	64,39 ghi	17,13 e	0,58 ghi	82,1 cd	4,63 ef
Frontoio 1	14,62 ij	1,7 cde	0,03 ef	0,05 hij	2,76 c	70,31 bcd	9,39 m	0,79 de	0,18 fghi	0,17 cdefg	17,56 i	72,01 bcd	9,39 m	0,79 de	82,19 cd	4,68 e
Frontoio 2	14,57 j	1,88 bc	0,04 def	0,03 ij	2,96 bc	68,76 def	9,67 m	0,93 c	0,04 l	0,12 gh	17,57 i	70,64 bcdef	9,67 m	0,93 c	81,24 cdef	4,62 ef
Rougette. M 1	12,03 a	1,86 cde	0,02 cd	0,09 c	1,76 i	78,9 a	4,54 r	0,66 de	0,04 hijk	0,1 efgh	13,83 k	80,76 a	4,54 r	0,66 de	78,73 gh	3,79 l
Rougette.M 2	12,51 b	2,05 bc	0,01 de	0,02 b	2,19 j	77 a	5,15 s	0,79 fgh	0,13 l	0,14 h	14,83 l	79,05 a	5,15 s	0,79 fgh	77,76 h	3,60 l
Manzanilla 2	18,86 m	1,69 b	0,07 f	0,18 j	1,74 ^{efgh}	56,25 m	19,79 b	1 c	0,12 ijk	0,3 b	20,72 b	57,94 kl	19,79 b	1,00 c	84,99 ab	5,73 c
Manzanilla 2	19,94 m	1,89 bcd	0,05 ef	0,24 fg	1,46 i	55,72 m	19,17 c	0,98 c	0,16 ghij	0,39 a	21,56 a	57,61 kl	19,17 c	0,98 c	85,96 a	6,21 b
Sigoise 1	11,59 n	0,63 l	0,03 ef	0,08 ef	2,84 efg	71,78 b	11,81 h	0,98 c	0,07 l	0,18 b	14,5 m	72,41 b	11,81 h	0,98 m	87,08 a	6,92 a
Sigoise 2	10,28 bc	0,53 l	0,03 ef	0,12 gh	2,27 c	72,18 b	14,26 j	0,11 m	0,02 kl	0,3 cdef	12,57 k	72,71 bc	14,26 j	0,11 c	85,2 ab	5,87 c
Tablout 1	18,57 d	2,43 def	0,04 def	0,14 c	2,1 fgh	67,12 cde	8,45 q	0,69 fgh	0,16 l	0,29 h	20,83 cd	69,55 bcde	8,45 q	0,69 fgh	79,47 efgh	3,96 jk
Tablout 2	17,88 bc	1,6 a	0,04 def	0,18 de	2,14 fgh	69,5 fgh	7,74 no	0,63 efg	0,03 ghij	0,11 b	20,05 b	71,1 ef	7,74 no	0,63 efg	78,69 gh	3,77 l
EVOO	7,5 -20	0,3-3,5	≤0.,30	≤0.,31	0.5 - 5	55-83	3,5-21	≤1,00	≤0,60	≤0,40	/	/	/	/	/	/

Yellow cells in the table indicate non-conformance to IOC fatty acid norms.
Means sharing the same letter (s) are not significantly different

3.8 Principal components Analysis test PCA

PCA is widely regarded as the most frequently employed multivariate technique in metabolomics. It is applicable to various types of multivariate data sets, such as spectra and chromatograms (Cevallos-Cevallos et al., 2009; Mendlein et al., 2013; Messai, Farman, Sarraj-Laabidi, Hammami-Semmar, & Semmar, 2016; Rathore, Bhushan, & Hadpe, 2011; Richards & Holmes, 2015).

The main concept of PCA is to find patterns in people by compressing high-dimensional data sets into smaller and more meaningful matrices called principle components.

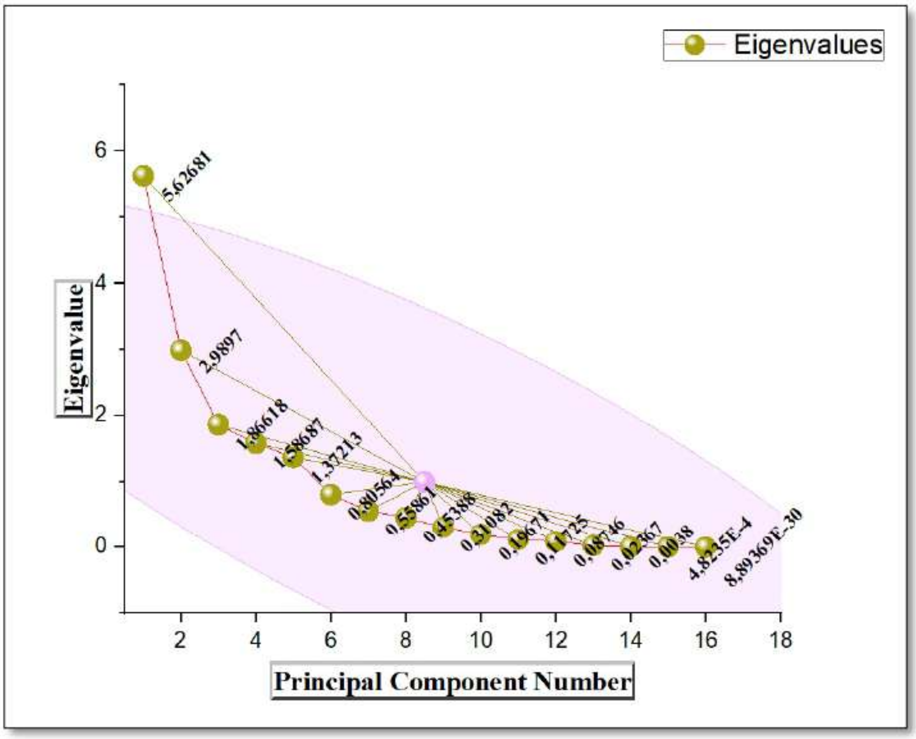
The original data set's variance remains intact after this compression (Kumar et al., 2014; Messai et al., 2016).

We used PCA to assess the quality of 13monovarietal olive oil samples, based on the following parameters: Palmic acid (C16:0), oleic acid (C18:1), saturated fatty acid (SFA), saturated fatty acid content (SFA),AG mono-insaturate, AG di-insaturate, AG three-unsaturated fatty acid content, Unsaturate fatty acid content (UFA),UFA/SFA, Free fatty acid contents (%), total phenols (ppm), carotenoids (ppm), chlorophyll (ppm), K232 (1%), K270 (1%), industrial yield (%), and maturity index.

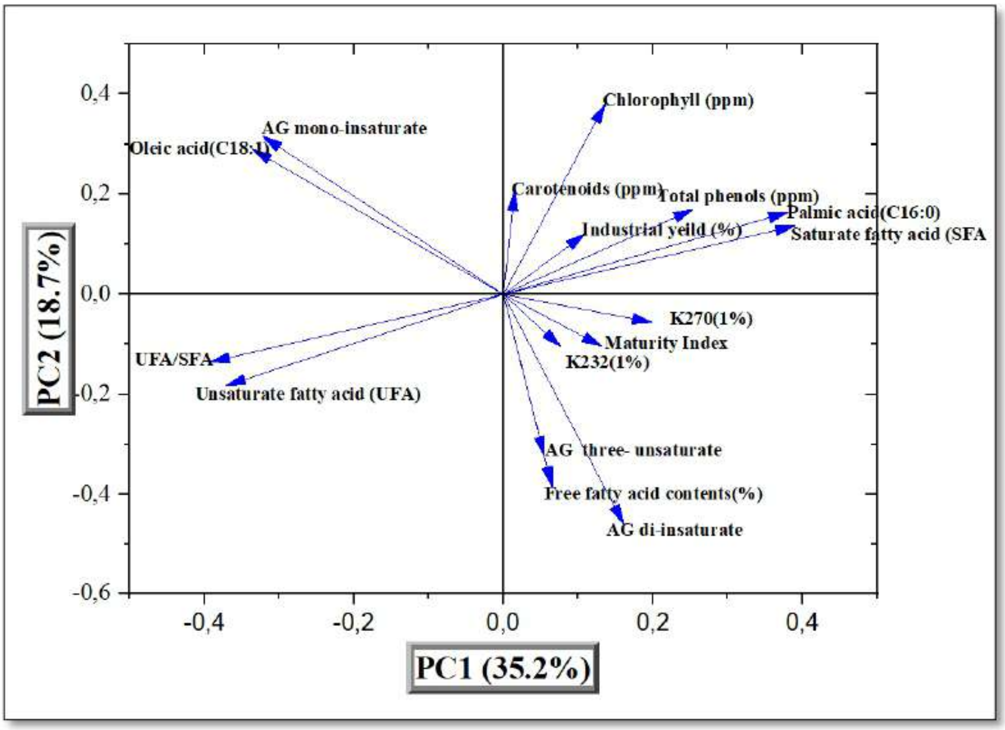
Eigenvalues: The eigenvalues represent the amount of variance explained by each principal component **(Figure 63)**. Higher eigenvalues indicate that the corresponding principal component accounts for a larger portion of the total variance in the data.

The first principal component has an eigenvalue of approximately **5.57**, indicating it explains a substantial portion of the variance.

The second principal component has an eigenvalue of about **2.99**.



Eigenvalue plot: Value Eigen for the principal components of the variance



Loading plot of the principal component analysis of main physicochemical parameters: projection of variables

Figure 64; shows a scatter diagram of 16 parameters. The PCA results indicated that two factors accounted for 53.85% of the total variance (PC1: 35.17%, PC2: 18.68%), reflecting the primary information of the original data

. The first principal component was positively related: maturity index, free fatty acid contents (%), K232 (1%), K270 (1%), C18:1, AGmono-insaturate, AG three-unsaturate, and unsaturate fatty acid (UFA)/SFA. The second principal component included maturity index, industrial yield, free fatty acid contents, carotenoids, K232,K270 ,C16:0,Saturate fatty acid (SFA), AG di-insaturate, and AG three-unsaturated fatty acids.

The variables under study have a significant impact on the distribution of different kinds of our examined MEVOO **(Figure 65)**. The figures show that when the individuals' clouds are projected onto the PCA plane defined by the main components 1 and 2, which account for 18.7% and 35.2% of the total variance, respectively, it suggests the presence of four distinct groups.

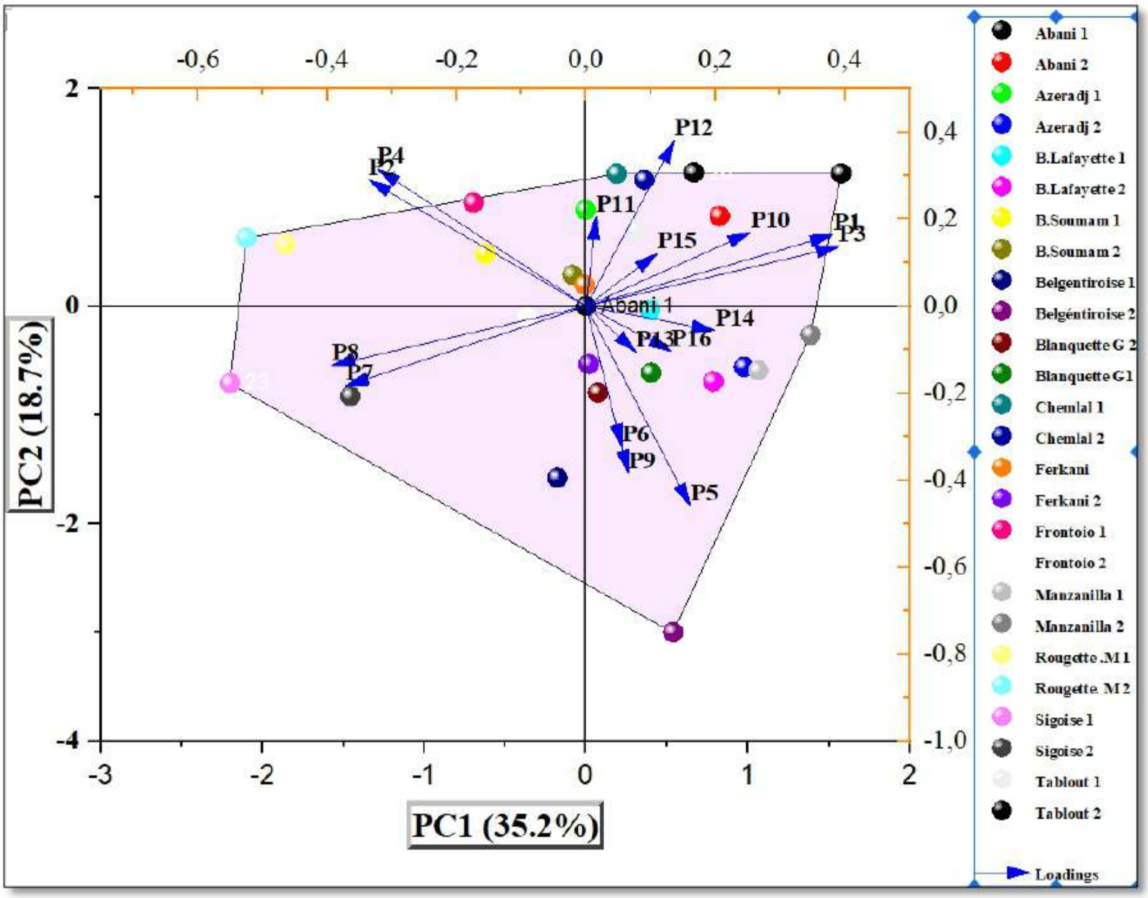
We can differentiate these groups based on their maturity indexes, industrial yields, physicochemical characteristics, and fatty acid composition.

The first group consists of the following olive samples: Frantoio 1, B. Soumam 1, B. Soumam 2, Rougette M1, and Rougette M2. This group is located on axis 1's positive side and axis 2's negative side **(Figure 65)**.

The olive oil samples Abani 1, Abani 2, Tablout 1, Tablout 2, Chemlal 1, Chemlal 2, and Azeradj 1 **(Figure 65)** make up the second group's cloud. This cloud is located on the positive side of axis 1 and towards the positive side of axis 2.

The third group **(Figure65)** consists of the following varieties: Manzanilla 2, Manzanilla 1, B.Lafayette 1, B.Lafayette 2, Blanquette.G1, Blanquette.G2, Azeradj 2, Belgentiéroise 2, and Ferkani 2. This group is located on axis 1's negative side and axis 2's positive side.

The fourth group consisted of the olive samples Sigoise 1, Sigoise 2, Belgentiéroise 1, and Frantoio 2. This group was specifically meant for the negative sides of axes 1 and 2.



Biplot of the principal component analysis of the main physicochemical parameters: projection of variables and varieties classification scores

P1: Palmic acid (C16:0), **P2**: Oleic acid (C18:1), **P3**: Saturate fatty acid (SFA, **P4**: AG mono-insaturate, **P5**: AG di-insaturate, **P6**: AG three- unsaturated, **P7**: Unsaturate fatty acid (UFA), **P8**: UFA/SFA, **P9**: Free fatty acid contents (%), **P10**: Total phenols (ppm), **P11**: Carotenoids (ppm), P12: Chlorophyll (ppm), **P13**: K232 (1%), P14: K270 (1%), **P15**: Industrial yeild (%), **P16**: Maturity Index.

4 Discussion

4.1 Maturity index

According to El Qarnifa et al. (2019), the color of olive fruits indicates their stage of maturation, which is characterized by a series of chemical and physiological changes.

The Sigoise 1 olive sample exhibited a minimum value of 2.28, whereas the Tablout 2 olive oil sample demonstrated a maximum value of 4.43. Our findings are similar to those of Issaad et al. (2024), who studied Algerian olive oil, and those of Touati et al. (2022) who focused on the study of geographical location and cultivar-linked changes in the chemical properties of Algerian olive oils.

In general, the optimal maturity index for a high-quality MEVOO depends on the olive cultivar (Fernández-Poyatos et al., 2021; Kafkaletou et al., 2021; López-Yerena et al., 2021; Yorulmaz et al., 2013).

4.2 Industrial MEVOO Yield

The study examined the production of olive oil and the impact of the cultivars variability, their geographical origin, the maturity index and the irrigation regime strategy used on them. It was found that Frantoio had the lowest output, while Chemlal had the highest yield.

This suggests that there is significant variation among different cultivars even when they are grown in the same geographic and environmental conditions (Al-Ruqaie et al., 2016; Giuffrè et al., 2017).

These results align with the findings of El Yamani et al. (2020) who also noted similar levels of variation in Moroccan olive oil.

Generally, olive trees have the ability to withstand a decrease in water levels without negatively impacting the quantity and quality of their fruit and oil production.

This has been supported by several studies (Gómez del Campo, 2013; Gucci et al., 2007; Lavee et al., 2007; Moriana et al., 2003) in the field of water management.

Research has demonstrated that implementing moderate irrigation limitations can expedite the ripening of fruit, enhance the ratio of pulp to pit, and sustain oil production at levels above 80% of those achieved by fully-irrigated trees (Caruso et al., 2013; Gómez del Campo, 2013; Gucci et al., 2009).

Deficit irrigation of Frantoio variety (Origin Italy) led to oil outputs that were 82% of those from well-irrigated trees over a period of four years. This approach also resulted in a water savings of around 50% (Caruso et al., 2013a).

A different research found that by decreasing irrigation by 70% in a hedgerow olive orchard of Arbequina, 16% of the total irrigation water was conserved while oil output was only reduced by 8% compared to trees that were fully watered (Gómez-del-Campo, 2013a).

Irrigation is essential for enhancing crop output and minimizing production expenses in olive orchards, as several studies have emphasized its advantages compared to relying solely on rainfall for cultivation (Gucci et al., 2009; Lavee et al., 2007; Moriana et al., 2003).

Deficit irrigation is widely recognized as beneficial for improving water use efficiency in arid and semi-arid areas, despite differences in cultivars, soil types, and environmental conditions (Caruso et al., 2013b; Gispert et al., 2013b; Iniesta et al., 2009; Moriana et al., 2003; Rosecrance et al., 2015).

In general an analysis of recent literature reveals that deficit irrigation can maintain oil yield at a level exceeding 80% of that achieved by fully-irrigated trees. Additionally, water savings resulting from deficit irrigation can range from approximately 15% to 50% of the volume of water applied.

This information is supported by studies conducted by Caruso et al. (2013), Gispert et al. (2013), Gómez-del-Campo (2013), Iniesta et al. (2009), and R. Gucci & Rapoport .(2007) and Gucci et al. (2007).

The correlation between oil content and additional water is often modest (R. Gucci & Rapoport, 2007), (Gucci et al., 2007).It is advisable to implement this method in our research region after confirming its effectiveness through scientific experimentation.

4.3 Free fatty acids

The results of this study show that free fatty acid levels in all our studied MEVOO samples fall within the recommended limits defined by the International Olive Council (IOC), which advises a maximum free acidity of 0.80 g of oleic acid per 100 g of oil.

Specifically, the free fatty acid examination in this study yielded readings ranging from 0.15 to 0.55 **.** Similar results were found in various studies: Xiang et al. (2017) reported a range of 0.14% to 0.28% in virgin olive oil samples from imported types in Liangshan, China, and Touati et al. (2022) found free acidity levels between 0.19 and 0.3 g in Algerian cultivars Chemlal and Sigoise. In the dry area, Rouina et al. (2020) found that Tunisian cultivar oils (Olea europaea L. cv. Zelmati) had free acidity levels between 0.13 and 0.33 g.

Additionally, studies by Baccouri et al. (2008) and Lodolini et al. (2017) on Tunisian and Palestinian local olive oil also demonstrated compliance with international standards.

Our recorded values are lower than those acidity levels found in Moroccan Picholine and Arbequina cultivars, with Gagour et al. (2022) reporting 0.62% and 0.8% oleic acid per 100 g of oil, respectively.

These discrepancies in acidity levels across different studies might be attributed to factors such as the types of olives used, farming techniques, and extraction methodologies.

The low acidity index readings in this study resulted from extracting fresh and healthy olive fruits, regardless of the cultivar (Mariotti & Peri, 2014).

A lot of different irrigation methods did not seem to change the free acidity, peroxide value, or fatty acid composition of olive oil (Stefanoudaki et al., 2001; Ghrab et al., 2014), also, Bourazanis et al. (2016) found that adding salt water did not really raise acidity levels.

4.4 Optical density (K232 and K270)

The UV absorbance coefficients (K232, K270) of conjugated bonds can be utilized to ascertain the presence or absence of precursors and the initiation of oxidation.

This information aids in predicting the stability of the oil (Hadj et al., 2018), the analysis of the UV absorption coefficients (K232, K270) revealed a range of values between (1.14 and 2.73 and 0.10 to 0.30 nm, respectively).

The K232 absorption coefficients of MEVOO samples from Tablout 1, Belgentiéroise 1, Belgentiéroise 2, Manzanilla 1, Rougette M 2, Manzanilla 2, Abani 1, Azeradj 2, Frontoio 2, and Abani 2 respectively, above the threshold of 2.5 established by the International Olive Council (2019).

Nevertheless, all other samples of olive oil stay inside the predetermined threshold. This signifies that the oil has a low capacity to be stored for a long period of time, since it includes a larger amount of secondary oxidation products (Wolff, 1968).

The observed specific extinction coefficients exceeded those obtained by Torres and Maestri, 2006, the K232 values for specific types of virgin olive oil in Argentina varied between 1.61 and 1.93 nm, our result is different too from the results obtained by Ruiz-Domínguez et al. (2013) for olive oil varieties from the Valencia region in Spain.; In this Spanish study, the K232 values ranged from 1.17 to 2.21 nm, and the K270 coefficient ranged from 0.08 to 0.21 nm.

The K232 and K270 values showed that there were significant variations among the cultivars, as well as the interaction between the cultivar and maturity index, . According to a paper by Issaoui et al.(2010) , hotter locations have higher peroxide levels and increased K232 and K270 extinction compared to cool regions.

Tanouti et al. (2011) discovered that the values of the extension coefficient are affected by several variables, such as the delayed harvesting of olives, the extended exposure of olives and extracted oil to air and light, and the heating of the paste during crushing.

Above all this , the use of water with more than ECw ~ 3 dSm^{-1} value, like in our study case(6.07 dSm^{-1}), accelerated the oxidation of the oil causing (Romero-Trigueros et al., 2019), although most of these studies have shown that the irrigation regime had negligible or no effects on this two spectrophotometric indices (K232, K270 and ΔK) (Gucci et al., 2019).

4.5 Pigments

The presence of chlorophyll and carotenoids in olive oil has a significant impact on its color. Chlorophyll gives the oil a green hue, while carotenoids contribute to its yellow color (Asheri et al., 2015).

According to Criado et al. (2008), color is a crucial sensory attribute that consumers assess,both chlorophylls and carotenoids are acknowledged for their strong antioxidant properties. Chlorophylls specifically have a concentration range of 100-1000 mg/kg(Boskou, 2015).

Regarding the levels of carotenoids and chlorophyll in our MEVOO samples of olive oil; are spanning from 1.75 mg/kg to 10.12 mg/kg and 3.03 mg/kg to 0,03 mg/kg respectively with the Frantoio cultivar produced olive oil with a significant amount of total chlorophylls and carotenoid.

Our study results are consistent with those obtained by Asheri et al.(2015) in his study on the impact of olive cultivars on pigment content in oil in arid regions of Iran, where the Frantoio cultivar was found to have the highest levels of chlorophyll and carotenoids.

On the other hand, the Sigoise MEVOO had the lowest concentration of carotenoids and chlorophylls.

The chlorophyll and carotenoids concentrations in our olive oil ranged from are lower than the values reported by (Touati et al., 2022), which range from 0.59 to 5.56 mg/kg and 9.62–24.30 mg/kg, and of respectively, these fluctuations in chlorophyll levels may be related to the degree of maturity of the olives (Boulfane et al., 2015).

The decrease in chlorophyll concentration is attributed to the degradation of chlorophyll into pheophytins throughout the ripening process of olives, resulting in the characteristic yellow color of the oil(El Moudden et al., 2020).

This suggest that the levels of pigment are influenced by the particular cultivar and the geographic location. In their study, Baccouri et al. (2008) noted a gradual decrease in the levels of these two pigments as the ripening process progressed in the photosynthetic pathway, ultimately resulting in the production of anthocyanins towards the end of ripening.

The obtained results were consistent with the findings of Oueslati et al. (2009), who observed a reduction in oil chlorophyll content for olive trees in a warmer environment.

According to many findings, plants that are exposed to higher temperatures see a decrease in the production of chlorophyll(Hemantaranjan et al., 2014; Neves et al., 2019).

The authors suggest that the decrease in chlorophyll levels in olive trees exposed to hot desert conditions may be due to the inhibition of enzymes involved in chlorophyll production and/or a deficit of magnesium, which is necessary for chlorophyll synthesis.

Moreover, Abbas et al. (2017) documented that the degradation of pigments by photo-oxidation under intense radiation is a significant factor contributing to chlorophyll destruction in plants thriving in hot climates. Similarly,(Chen et al., 2012) found that when plants were exposed to high temperatures, the decrease in chlorophyll fluorescence was caused by the production of reactive oxygen witch led to disruptions in the structure of chloroplasts and thylakoid membranes.

4.6 Total polyphenol content

When compared to other studies, our results show variability in polyphenol content. Specifically, the phenol content in our samples exceeds the values reported by Zarrouk et al.(2008) for Tunisian olive oil, which ranged from 188 to 213 mg/kg, this indicates that our samples, particularly the Abani 1 MEVOO sample, have a higher antioxidant potential compared to those Tunisian oils.

However, our findings are lower than those reported by Baccouri et al. (2008) for the Chetoui cultivar olive oil, which ranged from 363.90 to 567.60 mg/kg, this suggests that while our samples contain significant amounts of polyphenols, they do not reach the upper levels observed in the Chetoui cultivar.

Furthermore, in a study by Karabagias et al.(2013) involving 47 olive trees from four Western Greek islands, the polyphenol content was found to vary widely, although specific comparative values were not provided in our discussion.

Additionally, Guerfel et al. (2012) reported a total polyphenol content in Chemlali oil reaching 890 ± 9.50 mg/kg, which is significantly higher than any values observed in our study.

This illustrats the remarkable antioxidant capacity of the Chemlali oil compared to our samples, the findings of our study are consistent with the research carried out by Servili et al. (2007) on the samples we collected during the initial twenty days of October, when irrigation was consistently used.

The mean polyphenol concentration for these samples was 212.57 ppm, which was the lowest value compared to the average levels of other oil samples extracted in the remaining two months of our investigation.

This study revealed a detrimental relationship between the overall phenolic content in virgin olive oil and the irrigation regimen.

Likewise, Berenguer et al. (2006), Gómez-Rico et al. (2009), and El Yamani et al.(2020)found that olive oils derived from trees subjected to restricted irrigation have elevated concentrations of polyphenols in comparison to those that receive ample water. García et al. (2020) observed that the total phenol content is extremely responsive to water stress and typically declines in well-watered situations.

D'Amato et al. (2014) also noted that irrigation systems have the potential to decrease the polyphenol content, as well as the levels of pigments such as chlorophylls and carotenoids. The positive impacts of restricted irrigation on the quality of oil have been extensively recorded in previous studies (Caruso et al., 2017a, 2017b; Gómez-del-Campo, 2013a; Gómez-Rico et al., 2009b; Servili et al., 2007; Tovar et al., 2001), the investigations consistently demonstrate that a lack of water largely affects the phenolic component, which aligns with our findings.

The mean polyphenol concentration of oil samples extracted during November, a period of water stoppage, was 318.88 ppm, surpassing the average polyphenol levels in oil samples collected during the well-watered and regular irrigation period in October.

However, some measures of quality are mostly unchanged or display uneven variations across different treatments and years.

The studies conducted by Artajo et al. (2006), Caruso et al. (2014) ,Cirilli et al. (2017), and Servili et al. (2007) have emphasized the negative correlation between oil biophenols and tree water status, this illustrates the significant impact of water availability on the phenolic content and metabolism in the fruit fruit (Cirilli et al., 2017; Tovar et al., 2002). the oil phenols responded to water deficit (Caruso et al., 2014; Servili et al., 2007), we recommend to applying an early water deficit will be more effective in increasing those concentrations than a late deficit, because many scientific finding confirms that early stages of fruit growth are not only important for cell division processes and final fruit size in stone fruits (Gucci et al., 2009; Rapoport et al., 2004, 2017), but also influence the phenolic composition and concentration at harvest.

Alagna et al. (2012)associated different concentrations of phenolics in the fruit of several cultivars with transcripts putatively involved in secoiridoid biosynthesis, these authors hypothesized a regulatory role of these transcripts on secoiridoid accumulation during fruit development as they were almost exclusively present at early stages of fruit development(Alagna et al., 2012).

There is also evidence that during early phases of fruit growth, the phenolic composition is related to activities of β-glucosidase and peroxidase probably through their effects on oleuropein catabolism (Cirilli et al., 2017). It is likely that water deficit modifies both transcription and translation processes although it remains to be established whether it is more effective on either biosynthetic or degradative pathways of biophenols.

Secoiridoids (oleuropein and its derivatives, ligstroside and its derivatives), simple phenols (tyrosol, hydroxytyrosol), and flavonoids (luteolin and derivatives, apigenin and derivatives, rutin, and dismetin) are the most abundant phenolic fractions in the fruit and oil of olive trees (Alagna et al., 2012; Cirilli et al., 2017; Talhaloui et al., 2016), although their content and proportion vary greatly with the cultivar (Alagna et al., 2012; Talhaloui et al., 2016), which can decrease or increase as the fruits ripen, depending on the cultivar (Fernández-Poyatos et al., 2021; Yorulmaz et al., 2013).

Since the oil concentration of phenolic compounds is tightly related to the initial concentration in the fruit (Alagna et al., 2012; Talhaloui et al., 2016), the transfer rate between matrices during the oil extraction process may play a key role in determining the phenolic concentration and composition in the oil (Talhaloui et al., 2016).

Artajo et al. (2006) reported that the partitioning of phenolic compounds between olive phenolic concentrations are not used to classify oils (EU, 2003) these compounds play a key role in olive oil quality (Servili & Montedoro, 2002).

Biophenols are perceived sensorially as bitter and pungent. They are also strong antioxidants and thus high phenolic concentrations prolong storage life and shelf life of oils.

Maintaining high levels of poliphenols is beneficial for oil stability and human health (Servili et al., 2007; Servili & Montedoro, 2002), The phenolic compounds in oil act as antioxidants mainly at the initial stage of autoxidation (M. Deiana et al., 2002).

4.7 Composition of Fatty Acids

Gas chromatography analysis of methyl esters of total fatty acids facilitated the detection of several fatty acids in every analyzed sample of olive oil (**Table 13**).

The precise composition of fatty acids in the analyzed oils is presented in **Table 13**. The statistics suggest that the oils examined have a fatty acid composition that, on average, meets the commercial requirements established by the International Olive Council (2019) for extra virgin olive oil. Nevertheless, the Belgentiroise 2 and Belgentiroise 2 MEVOO samples had linoleic acid (C18:2) and linolenic acid (C18:3) levels that slightly exceed the maximum allowable limits set by the IOC (≤20% and ≤1.00%), reaching 24.33% and 1.12%–1.56%, respectively. The outcomes of our investigation are inferior to the findings reported (Asheri et al., 2015) in the arid region of Qom, Iran.

In addition, the linolenic acid levels in the oil from all the cultivars investigated are greater than the values reported for the 'Koroneiki' cultivar from Greece (0.26%), as well as the 'Arbequina' (0.63%) and 'Arbosana' (0.54%) cultivars from Spain (Allalout et al., 2009).

Gutiérrez et al. (1999) found that oleic acid is converted to linoleic acid by the action of oleate desaturase throughout the process of fruit ripening, resulting in an increase in the amount of linoleic acid.

The olive samples exhibited a variation in palmitic acid content, ranging from 10.28% to 19.94%. The findings of our investigation surpass those of a research done in China on imported cultivars at Liangshan, where the maximum palmitic acid content recorded was 14.24%.

In addition, our results deviate from the findings of Ayad et al. in their study on Chemlal cultivars, whereby the maximum recorded palmitic acid content was similarly 14.24%. Oleic acid is the predominant fatty acid present in various oil samples, with a concentration exceeding 77.1% in Manzanilla 2 MEVOO sample.

The percentages of the other samples vary from 56.98% to 77.01%. These rates are within the moderate categorization range for extra virgin olive oils, which is between 55% and 83%.

Moreover, Table 3 presents a detailed analysis of the main fatty acids included in these fats. The fatty acid composition of the samples consisted of linoleic acid (C18:2) ranging from 5.15% to 24.11%, palmitoleic acid (C16:1) ranging from 1.14% to 2.71%, stearic acid ranging from 2.10% to 2.54%, and linolenic acid ranging from 0.57% to 1.12%.

The levels of primary fatty acids discovered in this investigation were in agreement with those reported by other authors (Dabbou et al., 2010; Manai-Djebali et al., 2012; Tanouti et al., 2011; Touati et al., 2022; Xiang et al., 2017).

The concentration of gadoleic acid (C20:1) in our olive samples ranged from 0.14% to 0.37%. Our research suggests that the levels of gadoleic acid acquired in China (ranging from 0.27% to 0.53%) are lower than the levels we obtained. Arachidic acid exhibits greater concentrations compared to the findings documented for gadoleic acid (ranging from 0.05% to 0.15%).

The arachidic acid content in our samples varies from 0.13% to 0.45%. Our findings suggest that our results are comparatively lower than the results reported in previous research, which ranged from 0.39% to 0.57%, as well as the results reported by (Touati et al., 2022).

Small amounts of lipids, not exceeding 0.2%, have been detected, including heptadecanoic acid (C17:0) and heptadecenoic acid (C17:1).

Overall, the irrigation methods had minimal or no impact on the levels of free acidity, or fatty acid content of olive oil (Stefanoudaki et al., 2001; Ghrab et al., 2014).

We have conducted a comparative analysis of our findings with those of previous research that have examined diverse olive oil samples from various countries, different olive tree cultivars, and both irrigated and rain-fed olive groves.

The comparison demonstrates that irrigation regimes had minimal or no impact on the levels of free acidity, peroxide value, and fatty acid content of olive oil (Stefanoudaki et al., 2001; Ghrab et al., 2014). Recent studies suggest that genetic factors are the primary cause of variation in the chemical components of extra virgin olive oil (EVOO).

Different olive plant materials have been found to exhibit a high degree of variability in oil composition, as reported in studies by Cerretani et al. (2008), de la Rosa et al. (2016), García-Vico et al. (2017), and León et al. (2018).

Prior studies have indicated that the geographical place of origin influences both the qualitative and quantitative properties of extra virgin olive oil (EVOO) (Ben Mansour et al., 2017).

Various other variables, including the ripening of the olives, influence the fatty acid content of olive oil, as reported by Amanpour, Kelebek, and Selli in 2019. Concerning climatic factors, the circumstances of the growing region, rainfall, and temperature during the oil accumulation phase have an impact on the composition of fatty acids (García-Inza et al., 2014; Issaoui et al., 2010; Rizwan et al., 2019)

5 Conclusion

Our study focused on the chemico-physical characterization of 26 monovarietal extra virgin olive oil (MEVOO) samples derived from 13 cultivars, cultivated at an irrigated orchard under arid climate of the El Outaya region, Biskra province, Algeria.

The analysis revealed substantial variability in the chemical and physical properties of the olive oil samples.

This variability underscores the significant influence of both cultivar selection and irrigation practices on the quality and characteristics of olive oil produced in arid regions, the vaste differcification between the cultivars spesialy in their Fatty acids composition give the farmers or the scientists the chance to select between the cultivars to installed new olive growing area or create a new cultivars.

The principal component analysis of the MEVOO samples from the therteen studied cultivars showed a similarity of physicochemical characteristics ,quality indices and fatty acides composition between Frantoio 1,B.Soumam 1,B.Soumam 2,Rougette .M1,Rougette .M2 . On the other hand, between Abani 2,Tablout 1,Tablout 2,Chemlal 1,Chemlal2,Azeradj 1, and between ;Manzanilla 2,Manzanilla 1,B.Lafayette 1,B.Lafayette 2,Blanquette.G1,Blanquette.G2,Azeradj 2 ,Belgentiéroise 2,Ferkani 2 and between Sigoise 1,Sigoise 2,Belgentiéroise 1,Frantoio 2 as a last group of our MEVOO samples . On the whole,

Statistical analysis showed that physicochemical parameters and fatty acides composition were influenced by the variety factor , The study we conducted, after performing the statistical analysis of our results, showed that every two samples taken from the same variety appeared in the same group in the PCA statistical test classification.

Our study focused on investigating whether the factor influencing the quality of the oil is the variety or the maturity index of the olives.

The results showed that 18 samples of olive oil, with two samples per variety in the same group, were obtained from a total of 26 single-variety olive oil samples.

This indicates that the variety of the olive tree affects 69.23% of the studied samples taken from varieties planted in the same orchard, under the same soil and climatic conditions, receiving the same technical and agricultural care.

General Conclusion, Recommendation & Perspectives

General conclusion

The cultivation of olive trees in arid environments clearly poses both difficulties and prospects. In this analysis, we summarise the main discoveries and consequences to create a comprehensive conclusion that not only combines the knowledge acquired but also outlines a direction for individuals involved in the olive sector.

In the first chapter of our study, exploring the Olive Orchards of Biskra, we revealed a complex network of agricultural methods, a wide range of olive varieties, and the delicate balance between traditional and innovative approaches.

The initial chapter explored the intricate terrain of olive cultivation, illustrating the significance of knowledge, cooperation, and the choice of adapted cultivars in managing dry weather conditions.

It emphasised the necessity of continuous training programmes to equip farmers with the knowledge and expertise required for implementing sustainable practices.

The simultaneous presence of conventional wisdom and contemporary methodologies provides a unique opportunity for idea exchange, leading to the advancement and adaptability of olive farming.

The second chapter focuses on the morphometric and agronomic characterization of 13 olive varieties, including 10 Algerian varieties and 3 foreign varieties from Spain, Italy, and France.

The study underscores the importance of varietal selection for optimizing olive yield and quality in arid regions. Varieties such as B. soumam and Belgentiéroise, with higher fruit weights and favourable pulp-to-stone ratios, show significant promise for cultivation in Biskra region due to their potential for higher economic returns.

The differences in leaf morphology among the varieties suggest that certain ones may be better suited to withstand harsh climatic conditions, enhancing resilience and sustained productivity.

Uniform edaphoclimatic conditions, farming methods like irrigation, and genetic differences influence the agronomic performance of these varieties. Selecting appropriate varieties that combine high fruit weight, favorable pulp-to-stone ratios, and suitable leaf morphology can significantly improve olive production in region of Biskra.

In arid regions such as Biskra, irrigation plays a critical role in the growth and development of olive trees. Adequate water supply significantly influences fruit weight, size, and overall quality.

Varieties such as B. soumam, with a fruit weight of 6.4133 g, and Belgentiéroise, with a fruit weight of 5.9067 g, benefited from consistent irrigation, leading to optimal growth conditions and improved fruit development. Efficient irrigation practices also enhance the pulp-to-stone ratio, which is crucial for both table olives and oil production.

However, the response to irrigation can vary among different varieties due to their genetic makeup, future studies should explore tailored irrigation strategies for different olive varieties to maximize their potential and resilience in arid environments. Effective irrigation management is essential for optimizing yield and ensuring the sustainability of olive cultivation in these challenging conditions.

The third chapter focuses on the chemico-physical characterization of 26 monovarietal extra virgin olive oil (MEVOO) samples derived from 13 cultivars grown in the arid climate of El Outaya, Biskra province, Algeria.

The analysis revealed substantial variability in the chemical and physical properties of the olive oil samples, this variability give the significant influence of both cultivar selection and irrigation practices on the quality of olive oil produced in arid regions.

The diverse fatty acid composition among the cultivars provides opportunities for farmers and scientists to select appropriate cultivars for new olive-growing areas or to develop new cultivars.

Two types of MEVOO samples were separated into different groups by principal component analysis (PCA). These groups were named Frantoio 1, B. Soumam 1, B. Soumam 2, and Rougette M1 and M2.

The morphological, agronomical, and physicochemical characterization of the varieties studied in the two chapters were summed up. Varieties like B. soumam and Belgentiérois, which are in the second commercial quality category with 156 and 169 fruits per kg, respectively, had high fruit weights (6.4133 g and 5.9067 g) and good pulp-to-stone ratios (8.0848 and 5.0186), which made them very promising for making money.

Also, types like Azeradj and Blanquet, which are in the third commercial quality category, showed a lot of promise with high pulp-to-stone ratios (8.3976 and 8.0721) and average industrial yields (6.05% and 7.46%).

Ferkani and Belgentiérois achieve high industrial yields (10.38% and 10.58%). The variability in leaf morphology among the varieties suggests that some are better adapted to withstand harsh climatic conditions, offering resilience and sustained productivity.

Additionally, there is an urgent need for further investigation and advancement in the areas of selecting different varieties, managing irrigation, and improving post-harvest processing methods.

By embracing a wide range of indigenous olive types and utilizing developments in genetic research, we can discover new possibilities for resilience and productivity.

Customized irrigation plans, guided by precision agricultural techniques and climate data, can increase water efficiency and alleviate the effects of water scarcity on olive cultivation's the first chapter to our study, exploring the olive orchards of Biskra has revealed a complex network of agricultural methods, a wide range of olive varieties, and the delicate balance between traditional and innovative approaches.

The initial chapter explored the intricate terrain of olive cultivation, emphasising the importance of knowledge, cooperation, and the choice of resilient cultivars in managing the dry weather conditions, it emphasized the necessity of continuous training programmes to equip farmers with the knowledge and expertise required for implementing sustainable practices.

The simultaneous presence of conventional wisdom and contemporary methodologies provides a unique opportunity for idea exchange, leading to the advancement and adaptability of olive farming.

Recommendations And Perspective

Investment in Education and Capacity-Building Initiatives

- ✓ Establish comprehensive training programs tailored to the specific needs of olive farmers in arid regions. These programs should encompass topics such as water management, soil conservation, pest and disease management, and post-harvest handling.
- ✓ Implement farmer field schools, demonstration plots, and participatory research projects to facilitate knowledge exchange and the adoption of best practices among farmers.
- ✓ Foster collaboration between farmers, researchers, and policymakers to co-create knowledge and drive innovation in the olive sector.

Promotion of Sustainable Agricultural Practices

- ✓ Advocate for the adoption of sustainable agricultural practices, including organic farming methods, integrated pest management, and soil conservation techniques.
- ✓ Encourage the use of precision agriculture technologies, such as controlled deficit irrigation and remote sensing, to optimize water use efficiency and minimize environmental impacts.
- ✓ Support research and extension efforts focused on developing climate-resilient crop varieties and agronomic practices suitable for arid conditions.

Enhancement of Varietal Selection and Genetic Research

- ✓ Invest in research and development initiatives aimed at identifying and breeding olive varieties adapted to arid climates. Prioritize traits such as drought tolerance, disease resistance, and fruit quality.
    - ✓ Collaborate with international research institutions and breeding programs to access diverse germplasm and genetic resources for olive improvement.
    - ✓ Establish field trials and demonstration plots to evaluate the performance of new olive varieties under local growing conditions and disseminate successful cultivars to farmers.

Improvement of Water Management and Irrigation Practices

- ✓ Develop tailored irrigation strategies based on the water requirements of different olive varieties and microclimates. Implement precision irrigation technologies to optimize water use efficiency and minimize water wastage.

- ✓ Promote the use of water-saving techniques such as drip irrigation, mulching, and rainwater harvesting to supplement traditional irrigation methods.
- ✓ Provide training and technical assistance to farmers on irrigation scheduling, water budgeting, and soil moisture monitoring to ensure efficient use of water resources.

Enhancement of Post-Harvest Processing and Quality Assurance

- ✓ Invest in post-harvest processing infrastructure and technologies to improve the quality and safety of olive oil products. Upgrade milling facilities, storage tanks, and bottling lines to meet international quality standards.
- ✓ Implement quality assurance programs, certification schemes, and traceability systems to ensure the authenticity and integrity of olive oil products. Provide training and support to producers on quality control, sensory evaluation, and product labeling.
- ✓ Foster partnerships between olive growers, processors, and distributors to streamline supply chains, reduce transaction costs, and increase market access for high-quality olive oil products.

Support for Market Development and Export Promotion

Facilitate access to domestic and international markets for olive oil producers through trade agreements, market development initiatives, and promotional campaigns.

- ✓ Establish market intelligence systems and market information networks to provide producers with timely information on market trends, consumer preferences, and pricing dynamics.
- ✓ Foster collaboration between public and private sector stakeholders to identify and address barriers to market entry, such as trade regulations, tariffs, and certification requirements.

Continued Research and Innovation

- ✓ Encourage investment in research and innovation across the entire olive value chain, from breeding and production to processing and marketing.
- ✓ Support interdisciplinary research projects that address pressing challenges facing the olive industry, such as climate change, water scarcity, pest and disease management, and market access.

- ✓ Foster collaboration between academia, government agencies, industry associations, and non-profit organizations to leverage expertise, resources, and networks for collective impact.

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Annexes

PCA RESULTS

Code	Parameter	Extracted Eigenvectors ; Coefficients of PC1	Extracted Eigenvectors; Coefficients of PC2	Principal Component Number	Eigenvalue	Percentage of Variance (%)	Cumulative (%)
P1	Palmic acid(C16:0)	0,3817	0,1641	1	5,62681	35,16757	35,16757
P2	Oleic acid(C18:1)	-0,33632	0,28966	2	2,9897	18,68562	53,85319
P3	Saturate fatty acid (SFA	0,39071	0,13685	3	1,86618	11,66365	65,51684
P4	AG mono-insaturate	-0,32257	0,31586	4	1,58687	9,91793	75,43476
P5	AG di-insaturate	0,16107	-0,45924	5	1,37213	8,57578	84,01054
P6	AG three- unsaturate	0,05514	-0,32357	6	0,80564	5,03523	89,04578
P7	Unsaturate fatty acid (UFA)	-0,37163	-0,18295	7	0,55861	3,49133	92,5371
P8	UFA/SFA	-0,39312	-0,13589	8	0,45388	2,83675	95,37385
P9	Free fatty acid contents(%)	0,06513	-0,38378	9	0,31082	1,94262	97,31647
P10	Total phenols (ppm)	0,25422	0,16967	10	0,19671	1,22943	98,54591
P11	Carotenoids (ppm)	0,01543	0,20665	11	0,11725	0,73278	99,27869
P12	Chlorophyll (ppm)	0,13642	0,38045	12	0,08746	0,54663	99,82532
P13	K232(1%)	0,07699	-0,10478	13	0,02367	0,14792	99,97324
P14	K270(1%)	0,1994	-0,05614	14	0,0038	0,02375	99,99699
P15	Industrial yeild (%)	0,10983	0,12131	15	4,82E-04	0,00301	100
P16	Maturity Index	0,13186	-0,10381	16	6,74E-31	4,21E-30	100

Abstract

This study represents the first comprehensive research on olive cultivation in the arid regions of Algeria, comprising three main chapters. In the first chapter, we conducted a detailed survey to collect accurate information on olive cultivation practices in the arid regions, particularly focusing on the province of Biskra. The survey aimed to explore various cultural practices, the range of olive varieties cultivated, and the orientation of olive production, whether for table olives or oil production. We also identified and analyzed the common problems faced by olive growers in these arid regions.

In the second chapter, we conducted a detailed morphometric characterization of 13 different olive varieties cultivated under identical agricultural and environmental conditions. This characterization included measurements and analysis of the fruit, pit, and leaf dimensions for each variety. These detailed morphometric data are essential for understanding the physical characteristics and production potential of each variety under the same conditions.

In the third chapter, we focused on the chemical and physical characterization of the olive oil produced from these varieties. Using the cold extraction method, we obtained 26 samples of monovarietal extra virgin olive oil. We then conducted a comprehensive analysis of their physical and chemical properties, including acidity, peroxide value, and polyphenol content.

Regarding water stress, our study showed that the impact of irrigation and water stress on olive trees was significant in terms of fruit size and quality. Trees subjected to different levels of water stress showed notable differences in productivity and oil quality. We specified different irrigation frequencies in the studied orchard, with irrigation occurring every two weeks from February until mid-October and once a month from mid-October until November. No irrigation was recorded during December. The results showed that this irregular irrigation frequency throughout the olive tree's vegetative cycle (reduced irrigation in autumn and none in winter) affected oil quality, with higher total polyphenol content in November samples than in October samples. In our opinion, deficit irrigation at certain stages of olive tree growth is necessary to improve olive products.

As a general result of our study, we observe that olive cultivation in arid regions is a fertile and beneficial agricultural sector in all respects, with minimal costs due to the olive tree's adaptability and resistance to salinity and drought. Olive production, whether for table olives or olive oil, is very successful in the region. The size of olive fruits obtained in irrigated orchards, for most of the varieties studied in our research area, which is a southern province with a very dry and hot climate, was larger compared to those obtained in the rain-fed orchards of the northern provinces. This is mainly due to the decline in fruit quality there, caused by climate change, lack of rainfall, and the absence of irrigation systems. Moreover, the olive oil obtained from all the studied varieties was classified as extra virgin. Our results provide strong motivation for olive cultivation in arid regions and serve as a primary starting point to define key steps for advancing this agricultural sector and developing agriculture in arid regions, of course, after conducting more in-depth studies, especially concerning appropriate farming practices and the most productive and adapted varieties.

The primary goal of our study is to improve olive cultivation practices in arid regions by providing valuable information and guidance to farmers. By identifying and recommending high-yield olive varieties well adapted to the harsh conditions of arid regions, we hope to enhance the overall productivity and sustainability of olive cultivation. Our findings can help improve variety selection, cultivation practices, and olive oil production techniques, benefiting the agricultural sector in these regions.

Keywords: Olive cultivation, Arid regions, Water stress, Irrigation, Fruits & olive oil, Variety

ملخص:

تمثل هذه الدراسة أول بحث شامل حول زراعة الزيتون في المناطق الجافة بالجزائر، وتتألف من ثلاثة فصول رئيسية. في الفصل الأول، أجرينا دراسة استقصائية مفصلة لجمع معلومات دقيقة حول ممارسات زراعة الزيتون في المناطق الجافة، مع التركيز بشكل خاص على ولاية بسكرة. هدفت الدراسة الاستقصائية إلى استكشاف مختلف الممارسات الزراعية، وأنواع الزيتون المزروعة، وتوجهات إنتاج الزيتون سواء للاستهلاك المباشر أو لإنتاج الزيت. كما قمنا بتحديد وتحليل المشاكل الشائعة التي يواجهها مزارعو الزيتون في هذه المناطق الجافة.

في الفصل الثاني، قمنا بإجراء توصيف مورفومتري مفصل لـ 13 صنفًا مختلفًا من الزيتون المزروع في ظروف زراعية وبيئية متطابقة. شمل هذا التوصيف قياس وتحليل أبعاد الثمار، النوى، والأوراق لكل صنف. تعتبر هذه البيانات المورفومترية التفصيلية ضرورية لفهم الخصائص الفيزيائية وإمكانيات الإنتاج لكل صنف في نفس الظروف.

في الفصل الثالث، ركزنا على التوصيف الكيميائي والفيزيائي لزيت الزيتون المنتج من هذه الأصناف. باستخدام طريقة الاستخلاص على البارد، حصلنا على 26 عينة من زيت الزيتون البكر الممتاز من صنف واحد. ثم أجرينا تحليلًا شاملاً لخصائصها الفيزيائية والكيميائية، بما في ذلك الحموضة، قيمة البيروكسيد، ومحتوى البوليفينول.

فيما يتعلق بالإجهاد المائي، أظهرت دراستنا أن تأثير الري والإجهاد المائي على أشجار الزيتون كان كبيرًا من حيث حجم وجودة الثمار. أظهرت الأشجار التي تعرضت لمستويات مختلفة من الإجهاد المائي اختلافات ملحوظة في الإنتاجية وجودة الزيت. قمنا بتحديد ترددات ري مختلفة في البستان المدروس، حيث تم الري مرة كل أسبوعين من فبراير حتى منتصف أكتوبر، ومرة واحدة في الشهر من منتصف أكتوبر حتى نوفمبر. لم يتم تسجيل أي ري خلال شهر ديسمبر. أظهرت النتائج أن هذا التردد غير المنتظم للري على مدار دورة النمو (الري المخفض في الخريف وعدم الري في الشتاء) أثر على جودة الزيت، حيث كان محتوى البوليفينول في عينات نوفمبر أعلى من عينات أكتوبر. في رأينا، الري المتقن في مراحل معينة من نمو شجرة الزيتون ضروري لتحسين منتجات الزيتون.

كنتيجة عامة لدراستنا، نرى أن زراعة الزيتون في المناطق الجافة هي قطاع زراعي خصب ومفيد من جميع النواحي بتكاليف قليلة، وذلك بسبب قدرة شجرة الزيتون على التكيف ومقاومتها للملوحة والجفاف. إنتاج الزيتون، سواء كان زيتون المائدة أو زيت الزيتون، ناجح جدًا في المنطقة. كان حجم ثمار الزيتون التي تم الحصول عليها في البساتين المروية لمعظم الأصناف التي تمت دراستها في منطقتنا، وهي محافظة جنوبية ذات مناخ جاف جدًا وحار، أكبر مقارنة بتلك التي تم الحصول عليها في البساتين البعلية في المحافظات الشمالية. ويرجع ذلك أساسًا إلى تدهور جودة الثمار هناك بسبب التغير المناخي، وقلة الأمطار، وعدم وجود أنظمة ري. بالإضافة إلى ذلك، كان الزيت المستخرج من جميع الأصناف المدروسة من فئة الزيت البكر الممتاز. تقدم نتائجنا دافعًا قويًا لزراعة الزيتون في المناطق الجافة وتعتبر نقطة انطلاق رئيسية لتحديد الخطوات الأساسية لتطوير هذا القطاع الزراعي وتطوير الزراعة في المناطق الجافة، بالطبع بعد إجراء دراسات أكثر تعمقًا، خاصة فيما يتعلق بالممارسات الزراعية المناسبة والأصناف الأكثر إنتاجية وتكيفًا.

الهدف الرئيسي من دراستنا هو تحسين ممارسات زراعة الزيتون في المناطق الجافة من خلال توفير معلومات وتوجيهات قيمة للمزارعين. من خلال تحديد والتوصية بأصناف زيتون عالية الإنتاجية تتكيف جيدًا مع الظروف الصعبة للمناطق الجافة، نأمل في تعزيز الإنتاجية والاستدامة العامة لزراعة الزيتون. يمكن أن تساعد نتائجنا في تحسين اختيار الأصناف، الممارسات الزراعية، وتقنيات إنتاج زيت الزيتون، مما يفيد القطاع الزراعي في هذه المناطق.

الكلمات المفتاحية :زراعة الزيتون، المناطق الجافة، الإجهاد المائي، الري، ثمار الزيتون وزيت الزيتون، الأصناف.

Résumé :

Cette étude est la première recherche exhaustive sur la culture de l'olivier dans les régions arides d'Algérie, composée de trois chapitres principaux. Dans le premier chapitre, nous avons mené une enquête détaillée pour collecter des informations précises sur les pratiques de culture de l'olivier dans les régions arides, en nous concentrant particulièrement sur la province de Biskra. L'enquête visait à explorer diverses pratiques culturales, la gamme de variétés d'oliviers cultivées et l'orientation de la production d'olives, que ce soit pour les olives de table ou la production d'huile. Nous avons également identifié et analysé les problèmes courants rencontrés par les producteurs d'olives dans ces régions arides.

Dans le deuxième chapitre, nous avons réalisé une caractérisation morphométrique détaillée de 13 variétés d'oliviers différentes cultivées dans des conditions agricoles et environnementales identiques. Cette caractérisation comprenait des mesures et une analyse des dimensions des fruits, des noyaux et des feuilles pour chaque variété. Ces données morphométriques détaillées sont essentielles pour comprendre les caractéristiques physiques et le potentiel de production de chaque variété dans les mêmes conditions.

Dans le troisième chapitre, nous nous sommes concentrés sur la caractérisation chimique et physique de l'huile d'olive produite à partir de ces variétés. En utilisant la méthode d'extraction à froid, nous avons obtenu 26 échantillons d'huile d'olive extra vierge monovariétale. Nous avons ensuite réalisé une analyse complète de leurs propriétés physiques et chimiques, y compris l'acidité, la valeur de peroxyde, la teneur en polyphénols, etc.

Concernant le stress hydrique, notre étude a montré que l'impact de l'irrigation et du stress hydrique sur les oliviers était significatif en termes de taille et de qualité des fruits. Les arbres soumis à différents niveaux de stress hydrique ont montré des différences notables en termes de productivité et de qualité de l'huile. Nous avons spécifié différentes fréquences d'irrigation dans le verger étudié, avec une seule irrigation chaque quinzaine de jours et ce, du mois de février jusqu'au la mi-octobre et une fois par mois du mi-octobre jusqu’au novembre. Alors que, durant le mois de décembre nous avons enregistrés aucune irrigation. Les résultats ont montré que cette irrégularité de fréquence d’irrigation le long du cycle végétatif de l’olivier (irrigation reduite en automne voir nule en hiver) cela affecte la qualité de l'huile, avec une teneur totale en polyphénols dans les échantillons de novembre plus élevée que dans les échantillons d'octobre. À notre avis, l'irrigation déficitaire à certaines étapes de la croissance de l'olivier est nécessaire pour améliorer les produits de l'olivier.

Comme résultat général de notre étude, nous voyons que la culture de l'olivier dans les régions arides est un secteur agricole fertile et bénéfique à tous égards à des coûts minimaux en raison de l'adaptabilité de l'olivier et de sa résistance à la salinité et à la sécheresse. La production d'olives, qu'il s'agisse d'olives de table ou d'huile d'olive, est très réussie dans la région. La taille des fruits d'olivier obtenus dans les vergers irrigués dans la plupart des variétés étudiées dans notre zone d'étude, qui est une province du sud avec un climat très sec et chaud, était grande par rapport à celle obtenue dans les vergers en sec des provinces du nord. Cela est principalement dû à la baisse de la qualité des fruits là-bas en raison du changement climatique, du manque de précipitations et du manque de systèmes d'irrigation. De plus, l'huile d'olive obtenue dans toutes les variétés étudiées était de la classe extra vierge. Nos résultats sont une très forte incitation à la culture de l'olivier dans les régions arides et un point de départ principal pour définir les principales étapes pour faire avancer ce secteur agricole et développer le secteur agricole dans les régions arides, bien sûr, après avoir approfondi les études, en particulier en ce qui concerne les pratiques agricoles appropriées et les variétés les plus productives et adaptées.

L'objectif principal de notre étude est d'améliorer les pratiques de culture de l'olivier dans les régions arides en fournissant des informations et des directives précieuses aux agriculteurs. En identifiant et en recommandant des variétés d'oliviers à haut rendement bien adaptées aux conditions difficiles des régions arides, nous espérons améliorer la productivité et la durabilité globale de la culture de l'olivier. Nos résultats peuvent aider à améliorer la sélection des variétés, les pratiques culturales et les techniques de production d'huile d'olive, bénéficiant au secteur agricole dans ces régions.

Mots-clés : L'oléiculture, Régions arides, Stress hydrique, Irrigation, Fruits & huile d'olive, Variété