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Original article

Comparative Study of Fruit Maturation and Physicochemical Characteristics of Arbequina and Arbosana Olives under Intensive Cultivation in Tarhuna, Libya

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Abstract
Identifying the correct time to harvest is vital to obtaining both quantity and quality virgin olive oil, especially for intensive HD growing systems. In this study, we investigated changes in the fruit ripening process and associated physical and chemical changes of two worldwide important HD cultivars, Arbequina and Arbosana, in a semi-arid environment in Tarhuna, Libya. Fruit was harvested weekly from veraison (mid-October) up to late maturity (late December) in the 2024/2025 growing season. The Internationally Accepted Maturity Index (MI), based on the color of the fruit skin as well as fruit weight, firmness, and oil quality (content and free acidity), was used. The results revealed a difference between cultivars' ripening time and progression; Arbequina MIs progression was faster and reached its maturity earlier than Arbosana. High positive correlation was observed between MI and oil content ($r > 0.92$, $p<0.01$) and strong negative correlation between MI and firmness ($r = -0.81$, $p<0.01$). While Arbequina is ready to be picked early, the latter (Arbosana) continued to gain oil over a longer time and achieved the maximal oil content (22 % dry matter basis). This study confirmed the MI as a useful, quantitative index for the optimal time for harvest in HD orchards under the local conditions of Libya; recommended an MI range between 3.5-4.5 and 4.0-5.0 for Arbequina and Arbosana, respectively, to obtain the best combination between oil quality and quantity.
Keywords. Maturity Index, *Olea Europaea* L., Arbequina, Arbosana, High-density Olive, Oil Quality, Tarhuna, Libya.

Introduction

Olive cultivation (Olea europaea L.) is one of the first sectors of Mediterranean agriculture, and its economic contribution in Libya has increased greatly with the introduction of modern, intensive production systems [1]. The shift towards high-density (HD) and super-high-density (SHD) planting systems, which utilize precocious and highly productive cultivars like Arbequina and Arbosana, has reformed the sector [2]. Besides that, these systems are characterized by early bearing, high yields, and suitability for mechanized harvesting, making the accurate timing of harvesting more critical.

The maturity stage of the fruit is the main factor that affects both the quantity and the quality of the extracted virgin olive oil (VOO) [3]. Too early Harvesting results in lower oil yield and a more bitter, pungent oil, while delayed harvesting can lead to higher oil content but a rapid decline in important quality components, such as phenolic compounds and oxidative stabilizing materials, alongside an increased risk of high free acidity due to fruit damage [4].

The most widely scientifically proven method of determining the maturity of olive fruit is the Maturity Index (MI), first established by [5]. This index uses a numerical scale (0 to 7) to classify the external and internal color of olives, which serves as a quantitative indicator against the traditionally subjective visual assessment used by the farmers.

Though globally Arbequina and Arbosana have been very successful in HD systems, their production and best harvest time are very much dependent on the local climatic conditions, particularly in semi-arid areas like Libya, where the regular rainfall is low, and the summers are hot [6]. Arbequina is also known for its early ripening, and the oil profile is usually mild; however, Arbosana is a late-maturing variety that can produce oil with a high phenolic content [7].

Therefore, this study was undertaken with the aim of advancing knowledge on olive cultivation under local Libyan conditions. Specifically, it sought to quantify and compare the progression of fruit ripeness, as measured by the Maturity Index (MI), in two widely cultivated varieties—Arbequina and Arbosana—grown within the high-density system in Tarhuna. In addition, the research explored the relationship between MI and key physicochemical properties, including oil content, fruit firmness, and free acidity, in order to better understand how ripening influences quality attributes. Ultimately, the study endeavored to provide cultivar-specific harvesting guidelines based on MI, ensuring that producers can optimize both the quality and yield of virgin olive oil while adapting practices to the unique environmental conditions of the region.

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Methods

Study Site and Plant Material

The research was conducted in the 2024/2025 season in a governmental high-density olive orchard in the Tarhuna region of Libya (approximately 32° 26′ N, 13° 38′ E). The climate there is a typical semi-arid Mediterranean. The orchard was one of the big investment farm sheds, where a modern HD system was being used, and the planting density was around 4 m × 1.5 m (1667 trees/ha).
Two Spanish olive cultivars were selected for the study, Arbequina (early-ripening) and Arbosana (later-ripening), both about 25-30 years old and grown under drip irrigation.

Experimental Design and Sampling

The experimental design included the representative of healthy trees for each cultivar. Sampling was conducted weekly, starting from the initial stage of fruit color change (veraison) in mid-October 2025 until late December 2025. For each sampling event, three biological replicates were established per cultivar. Each replicate consisted of a random sample of 100 fruits collected from different parts of the canopy of the selected trees. The total sample size per cultivar per sampling date was 300 fruits.
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Studied Parameters

Maturity Index (MI)

The Maturity Index (MI) was determined according to the method described by Uceda and Frías [5]. A sample of 100 fruits was visually classified into eight color categories (0 to 7) based on the external skin color and internal pulp pigmentation:

Category	Description
0	Intense green skin
1	Yellowish-green skin
2	Green skin with reddish spots
3	Reddish or purple skin
4	Black skin, white pulp
5	Black skin, up to half purple pulp
6	Black skin, more than half purple pulp
7	Black skin, completely purple pulp

The MI was calculated using the formula (the whole sum is divided by 100):
M.I. = A0 + B1 + C2 + D3 + E4 + F5 + G6 + H7/100

Where a, b, c, d, e, f, g, and h are the number of fruits in each of the colour categories 0, 1, 2, 3, 4, 5, 6, and 7, respectively.

Physical and Chemical Characteristics

Fresh Fruit Weight (g): Measured for individual fruits using a precision balance.
Fruit Firmness (kg/cm²): Measured using a penetrometer on 20 randomly selected fruits per replicate.
Fruit Moisture Content (%): Determined by drying a known weight of fruit pulp in an oven at 105°C until constant weight.
Total Oil Content (%): Determined on a dry weight basis using the Soxhlet extraction method with hexane.
Free Acidity (% Oleic Acid): Determined by titration with a standardized sodium hydroxide solution, according to the International Olive Council (IOC) methods.

Statistical Analysis

All data were processed using Statistical Package for the Social Sciences (SPSS), and were expressed as the Mean ± Standard Deviation (SD). To examine the impact of cultivar and ripening stage, a Two-Way Analysis of Variance (ANOVA) with repeated measures (Cultivar times Sampling Date) was conducted on the MI and oil content. The Least Significant Difference (LSD) test was applied for post-hoc mean comparisons with a significance level of $p < 0.05$. The association between MI and the physicochemical parameters (oil content, fruit firmness, free acidity, and fruit weight) was measured by Pearson Correlation Coefficient (r). Differences between the two cultivars in fruit weight and firmness were assessed using an independent samples t-test. The statistical significance levels were $p < 0.05$ and $p < 0.01$.

Results

Maturity Index (MI) Progression

Two-way ANOVA analysis revealed a significant effect of both cultivar ($F = 6.85$, $p < 0.05$) and sampling date ($F = 9.12$, $p < 0.01$) on MI values. The MI of both Arbequina and Arbosana cultivars showed a

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consistent and progressive increase throughout the ripening period (Table 1). At the initial sampling on October 12, both cultivars exhibited low MI values, with Arbequina at 1.2 ± 0.3 and Arbosana at 1.0 ± 0.2, indicating early-stage fruit development.

As ripening advanced, MI values increased steadily in both cultivars; however, Arbequina consistently showed higher values than Arbosana at all sampling dates. By November 11, Arbequina reached an MI of 3.0 ± 0.5 compared to 2.5 ± 0.4 for Arbosana, reflecting a faster ripening rate. This trend continued through late November, when Arbequina attained 3.8 ± 0.4 on November 24, approaching the commonly recognized optimal maturity stage for high-quality olive oil production, while Arbosana remained lower at 3.2 ± 0.3.

Further progression in ripening was observed in December. On December 8, Arbequina reached an MI of 4.3 ± 0.3, while Arbosana recorded 3.8 ± 0.4. By the last sampling day of December 28, both cultivars showed their highest MI scores, with Arbequina hitting 5.2 ± 0.4 and Arbosana 4.6 ± 0.3, a sign of full ripeness. Though it was a bit late, both cultivars had similar MI scores, but still, Arbequina was at a higher maturity level than Arbosana during the course of the trial. These findings show a strong genetic basis for the variation in ripening. Arbequina generally had a more rapid ripening process than Arbosana and was more mature at the start of the season.

Table 1. Evolution of the Maturity Index (MI) for Arbequina and Arbosana Cultivars During the Ripening Period (Mean ± SD)

Sampling Date	Arbequina MI	Arbosana MI
October 12	1.2 ± 0.3	1.0 ± 0.2
October 26	2.1 ± 0.4	1.8 ± 0.3
November 11	3.0 ± 0.5	2.5 ± 0.4
November 23	3.8 ± 0.4	3.2 ± 0.3
December 8	4.3 ± 0.3	3.8 ± 0.4
December 28	5.2 ± 0.4	4.6 ± 0.3

Physical Characteristics

Differences in physical characteristics between the two cultivars at a comparable medium ripening stage (MI approx. 3.0) are shown in (Table 2).

Table 2. Comparison of Physical Characteristics at Medium Ripening Stage (Mean ±SD)

Cultivar	Fruit Weight (g)	Fruit Firmness (kg/cm²)	Moisture (%)
Arbequina	1.35 ± 0.08	3.8 ± 0.4	55.2 ± 1.6
Arbosana	1.60 ± 0.10	4.2 ± 0.3	53.8 ± 1.4

Significant differences were found between the two cultivars in terms of fruit weight, firmness, and moisture content. The fruits of Arbosana showed a greater average weight (1.60 ± 0.10 g) than those of Arbequina (1.35 ± 0.08 g). Likewise, the firmness of the fruit was greater in Arbosana (4.2 ± 0.3 kg/c^2) than in Arbequina (3.8 ± 0.4 kg/cm^2), which is in line with the firmer texture of the fruit at the same stage of ripeness. However, the moisture content of the Arbequina cultivar was slightly higher (55.2 ± 1.6%) in comparison to that of the Arbosana (53.8 ± 1.4%).

Oil Content and Quality

Oil content increased as the fruit matured in both cultivars (Table 3). For example, Arbequina increased gradually from 9.1 ± 0.6% in early October to 20 ± 1.0% in the first days of December. However, Arbosana, which experienced a similar upturn, ended with even bigger oil content, 22 ± 1.0% after starting at 8.3 ± 0.5%.

Table 3. Change in Oil Content (% Dry Weight) with Advancing Maturity (Mean ±SD)

Sampling Date	Arbequina Oil Content (%)	Arbosana Oil Content (%)
October 12	9.1 ± 0.6	8.3 ± 0.5
October 26	14.0 ± 0.8	13.0 ± 0.7
November 11	18.0 ± 0.9	19.0 ± 0.8
November 23	20 ± 1.0	21 ± 0.9
December 8	20 ± 1.0	22 ± 1.0

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Free acidity also increased with ripening in both cultivars (Table 4). While Arbequina increased gradually from 0.26 ± 0.05% at the onset of veraison to 0.34 ± 0.07% at full maturity, Arbosana, on the other hand, always presented higher acidity levels, going up from 0.32 ± 0.04% to 0.57 ± 0.06%. The rise in acidity was especially sharp in Arbosana during the last time of ripening. Besides satisfying consumer requirements, all the free acidity measured in this investigation is low enough to qualify as extra virgin olive oil. The International Olive Council (IOC) has set the highest ceiling at 0.8%. This means that the fruit was in excellent condition and that the time between harvesting and the start of fruit processing was kept to a minimum.

Table 4. Free Acidity of Olive Oil (% Oleic Acid) at Different Ripening Stages (Mean ± SD)

Ripening Stage	Arbequina	Arbosana
Beginning of Veraison (MI approx 1.0)	0.26 ± 0.05	0.32 ± 0.04
Medium Ripeness (MI approx 3.0)	0.28 ± 0.06	0.40 ± 0.05
Full Ripeness (MI approx 4.0)	0.34 ± 0.07	0.57 ± 0.06

Correlation Analysis

The Pearson correlation analysis (Table 5) confirmed the strong predictive power of the MI for key quality and physical parameters. The strong positive correlation between MI and oil content (r = + 0. 85) shows that the oil content rises as the fruit ripens (MI increases). On the other hand, the very strong negative correlation with fruit firmness (r = - (0. 81) is quite confirming that ripening is associated with a significant softening of the fruit tissue. The moderate positive correlation with free acidity (r = + 0. 68) indicates that the acidity, which is at a low level, does increase very slightly with the advance of maturity.

Table 5. Pearson Correlation Coefficients (r) between Maturity Index (MI) and Studied Traits

Variable	Correlation Coefficient (r)	Significance Level
Oil Content	+ 0.85	$p < 0.01$
Fruit Firmness	- 0.81	$p < 0.01$
Free Acidity	+ 0.68	$p < 0.05$
Fruit Weight	+ 0.42	$p > 0.05$ (Not Significant)

Discussion

The results of this study provide critical, locally validated data about ripening characteristics of Arbequina and Arbosana grown in the HD, semi-arid climate of Tarhuna, Libya. The results are consistent with other established genetic profiles of these two Spanish cultivars in other Mediterranean regions [8]&[9], validating their successful adaptation to the local climate. The notable difference in ripening speed, with Arbequina maturing significantly faster than Arbosana, is a key finding. This early maturity in Arbequina is due to its smaller fruit size and the fact that it starts the lipogenesis process (oil accumulation) earlier [10].. The quick rise in MI for Arbequina means that the best time to harvest high-quality oil is shorter, as its oil content plateaus earlier. On the other hand, Arbosana has a longer ripening period and continues to accumulate oil later in the season. Arbosana has a higher maximum oil content (20.0% DW) than Arbequina (20% DW) because it takes longer for lipogenesis to happen. This difference is very important for farmers because it lets them plan the harvest in a way that makes the best use of their resources and gets the most oil from the whole orchard.

The findings of this study demonstrate that the Maturity Index (MI) has a strong relationship with both oil content (r = +0.85) and fruit firmness (r = -0.81). This confirms that the MI is a highly reliable and quantitative indicator for determining the technical maturity of olives in this region. The positive correlation with oil content indicates that the MI's measurement of color change serves as a direct proxy for the biochemical process of oil accumulation. This relationship allows farmers to avoid harmful and time-consuming chemical tests when making routine harvest decisions.

In contrast, the negative correlation with fruit firmness reflects the physiological changes occurring in the fruit cell wall, particularly the enzymatic degradation of pectic substances by polygalacturonase and pectin methylesterase, which leads to softening as the fruit ripens [11]. While this softening is essential for efficient oil extraction, it must be carefully managed to prevent fruit damage and the subsequent rise in free acidity.

The consistently low free acidity values observed across all ripening stages (all < 0.8%) for both cultivars highlight the high quality of the fruit and the effectiveness of rapid, hygienic processing. This factor is critical for achieving the Extra Virgin Olive Oil (EVOO) classification. Moreover, although this study focused on basic quality parameters, the literature suggests that harvesting at a lower MI (e.g., MI 2.0–3.5) typically maximizes the concentration of phenolic compounds, which contribute to bitterness, pungency, and oxidative stability [8]. Conversely, harvesting at a higher MI (e.g., MI 4.0–5.0) maximizes oil yield but

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significantly reduces these beneficial compounds. Thus, the optimal harvest window must balance yield with quality preservation.

In conclusion, this comparative study successfully quantified the ripening dynamics of Arbequina and Arbosana olive cultivars under high-density cultivation in Tarhuna, Libya. Arbequina was confirmed as the earlier-ripening cultivar, while Arbosana demonstrated a higher potential oil yield at full maturity. The MI proved to be a robust and reliable predictor of both oil accumulation and fruit softening in this environment. Based on the data, the following optimal harvest windows are recommended for the local HD system: Arbequina should be harvested at an MI between 3.5 and 4.5 to balance high oil quality (phenolics) with good yield, whereas Arbosana should be harvested later, at an MI between 4.0 and 5.0, to maximize oil yield while still maintaining EVOO quality standards.

Conflict of interest. Nil

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