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Production of Early and Normal Harvest Olive Oils Under Industrial Conditions and Comprehensive Comparison of the Oils Produced

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ABSTRACT

The aim of this study was to compare early and normal harvest olive oils generated from the same orchard and produced in the same industrial plant under completely controlled conditions. The early harvest was on October 04, 2021, and the normal harvest was on December 08, 2021, which was used regularly in the region. The oil yield was lower in the early harvest (11.37%) than in the normal harvest (13.67%). Fruit color, dimensions, and total oil content were significantly different. Normal harvest olive oil contained higher levels of biophenol but lower free fatty acid and peroxide values. Although the fatty acid compositions were similar, the total sterol content of the normal harvest sample was higher (2379 vs. 1981 mg/kg). Alpha-tocopherol was higher in early harvest (101.25 mg/kg) than that of the normal harvest (86.35 mg/kg) sample. Volatile aromatic composition data showed some differences, and most profoundly, *Z*-3-hexenal was enhanced, but 2-hexenal was decreased towards the normal harvest date. There were no negative sensory attributes in the samples, and the early harvest sample had higher scores for fruity-green, bitter, and pungent attributes. Consumer tests indicated more liking for early harvest samples with full scores for appearance/color and smell/scent.

Practical Applications: Olives harvested early and at normal ripeness from the same orchard were processed under identical industrial conditions and compared. The oil yield was significantly lower in the early harvest samples. Notable compositional differences were observed in free fatty acidity, sterol and alpha-tocopherol content, and volatile aromatic compounds. The early harvest oil received higher sensory scores for fruity-green, bitterness, and pungency. Additionally, consumer preference scores were higher for the early harvest oil. To ensure fair pricing for producers and effective communication with consumers, this study suggests the importance of accurate labeling based on analytical and sensory indicators, along with the consideration of relevant new regulations.

Abbreviations: ANOVA, analysis of variance; AOCS, American Oil Chemists' Society; EFSA, European Food Safety Authority; EVOO, extra virgin olive oil; FFA, free fatty acid; FID, flame ionization detector; GC, gas chromatography; HPLC, high-performance liquid chromatography; ISO, International Organization for Standardization; LDL, low-density lipoprotein; MS, mass spectrometry; PV, peroxide value; SPME, solid-phase microextraction; TLC, thin layer chromatography; VOO, virgin olive oil.

[Correction added on 19 February 2026, after first online publication: The copyright line was changed.]

1 | Introduction

Olive oil is one of the main edible oils produced worldwide by olive trees (*Olea europaea* L.) and is commonly found in the Mediterranean region. It is a virgin oil produced by physical processes without any refining operations. Olive oil is an excellent source of monounsaturated oleic acid and is rich in phytosterols, phenolics, tocopherols, triterpene alcohols, phospholipids, and hydrocarbons. It is now generally accepted that regular and correct consumption of olive oil helps prevent cardiovascular diseases, metabolic syndrome, diabetes, and hypertension. Furthermore, olive oil has been created as a special cuisine owing to its unique flavor and aromatics. Olive oil is preferred because of its positive health effects, easy digestibility, special flavor and aroma, and suitability for various uses [1, 2].

Consequently, studies on the selection of the best quality olive oils and quality traits have been conducted extensively. Its general quality is related to the production in the primary sector, processing technology, process variables, and storage conditions. Many studies have been published on olive oil quality and tree cultivars, pedoclimatic conditions of orchards, agricultural practices, harvest olive ripeness level, type of harvesting, olive oil extraction techniques, conditions and duration of storage, and packaging technology [3, 4]. This study focused on the differences between early and normal harvest olives from the same trees in terms of the quality of oil generated in a real processing facility under identical conditions.

In a study, olives were harvested in mid-October, mid-November, and end-November, and oils were extracted in the laboratory for comparison. The fatty acid profiles did not change significantly; however, the phenolic content decreased as the harvest date was postponed [5]. Similarly, in a study by Franco et al. [6], early harvested olive oils had significantly higher concentrations of tyrosol, hydroxytyrosol, vanillic acid, *p*-coumaric acid, luteolin, and apigenin. In another study [7], Dalmatian olives were harvested in October and November 2016, and the oils were extracted in the laboratory. The phenolic content in the Buhavica and Oblica varieties was twofold higher but not different in the Drobnica variety and twofold lower in the Lastovka variety. Furthermore, sensory differences were not related to harvest date but to the varieties. The Italian varieties of Carolea, Grossa di Gerace, Ottobratica, and Sinopolese were harvested in mid-October and mid-November, and the oils extracted in the laboratory were compared. For most of the quality traits, no significant difference was quantified, but in late harvest, the phenolic and tocopherol contents decreased [8]. Early harvest olive oils have been shown to have better indices for free fatty acidity (FFA), peroxide value (PV), polyphenol content, bitterness, and sharpness, but their yield was significantly lower [4]. Karagoz et al. [9] indicated that as the harvest date was delayed, the level of *E*-2-hexanal increased, but that of hexanal decreased.

Although the literature showed and explained the differences among the early, normal, and late harvest olive oils, most studies lacked the total control of samples from the orchards to the factory. The research question of this study was to determine the effect of harvest date (early harvest vs. normal harvest) on olive oil composition, nutrition, volatile aromatics, and sensory quality. In fact, there have been similar studies in the literature, as discussed briefly above, but this study differs from them by the total control of factors. The monovarietal olive orchard was owned by one of the authors of this study and was reserved for this study. The same orchard and trees were used to harvest the olives on early and normal harvest dates according to the harvesting habits of the region, and both harvests with repetitions were processed in the same olive oil production factory under real industrial production conditions. All production was completed under the same controlled conditions. As a result, early harvest oil was compared with normal harvest oil produced under industrial production conditions. Currently, in the Turkish olive oil market and most probably around the Mediterranean, early harvest oils are sold at higher prices and claimed to have higher nutritional quality and aroma [4, 9, 10]. Hence, this study provides an answer to these claims, and the aim was to provide information about the effects of early harvest on olive oil quality under industrial conditions with total control of factors from tree to bottle.

2 | Materials and Methods

2.1 | Materials

The monovarietal Edremit variety olive orchard located (33 decare parcel could be viewed at: https://parselsorgu.tkgm.gov.tr/#ara/idari/166756/112/34/1650149146666) in Bahadınlı village of Balıkesir-Burhaniye (Türkiye) were reserved for this study in 2021 season. The early harvest was done on October 04, 2021, and the normal harvest was done on December 08, 2021, with a regular random hand-picking technique on trees with workers. During harvest, the workers were instructed not to harvest all olives but to leave half on the trees for the second harvest. The harvested olives were immediately brought to an olive oil factory on the same day. Olive samples were brought to the laboratory for fruit analysis. All standards, solvents, and chemicals used in this study were purchased from both Sigma-Aldrich (St. Louis, USA) and Merck (Darmstadt, Germany).

2.2 | Production of the Olive Oils

The harvested olives were processed on the same harvest day as the two parallel productions in the Adalı Efe Olive Oil Factory (Factory Government Registration No.: TR-10-K-022393) located in Bahadınlı village of Burhaniye-Balıkesir (Türkiye). Oil was generated using a dual-phase decanter system. The system used 20 t/day capacity HAUS trade twin malaxator with DMV 2342 decanter. Meteorological data for each production day are also provided. During the early harvest production day (October 04, 2021), the weather was 16.8°C, with 61% humidity and 13 m/s wind velocity. Likewise, during the normal harvest production day (December 08, 2021), there was 10.1°C with rain (100% humidity) and 5 m/s wind velocity. The production parameters of the factory during processing are summarized in Table 1. For both productions, there was no external heating or water addition during malaxing, and all parameters provided in Table 1 were gained at the moment of production in the plant by the automated system. After each production for both harvest dates, olive oil samples from parallel productions were immediately collected and placed in brown-colored and capped glasses. The olive and produced olive oil samples are shown in Figure 1. All samples

TABLE 1 | Plant processing parameters for early and normal harvest olive oil production.

Replication	Plant temperature (°C)	Date	Arrival time	Start time	Entering olive amount (kg)	Washing water temperature (°C)	Malaxator number	Time to enter malaxator	Paste temperature (°C)	Time to exit malaxator	Decantor torque	Seperator exit time	Amount of gained oil (kg)	Yield (%)	Free fatty acidity (%)
Early harvest productions															
First	22.8	4.10.2021	16:30	17:00	158.0	21.5	1	17:08	27.1	17:25	4084	17:50	18.20	11.52	0.40
Second	22.4	4.10.2021	16:30	17:26	151.4	21.8	2	17:34	25.6	17:51	4084	18:16	17.00	11.23	0.38
Normal harvest productions															
First	13.1	8.12.2021	15:45	16:05	384.0	17.2	1	16:16	19.2	16:33	4084	17:17	49.20	12.81	0.34
Second	12.9	8.12.2021	15:45	17:00	337.0	16.1	2	17:09	19.0	17:28	4084	18:18	49.00	14.54	0.30

were immediately brought to the laboratory and analyzed. The samples were refrigerated during the analysis.

2.3 | Olive Fruit and Seed Analyses

The color of the olive fruits and their seeds was measured using a Minolta CR-400 Colorimeter (Osaka, Japan) on the surface several times, and the values of L (brightness), a^* (redness/greenness), and b^* (yellowness/blueness) were recorded. Weight of the fruits and seeds was also measured with a Sartorius balance on 20 randomly selected fruits. The dimensions (length and width) of the randomly selected olive fruit and seed samples were measured using a digital caliper (Leo, Nikko, China). After crushing the olive fruits, the total moisture content of the flesh was determined using a Radwag MA 50R infrared (IR) moisture analyzer (Radom, Poland), and the percentage of moisture content was recorded. Similarly, the total oil content of the crushed olive fruits was extracted using an automatic Soxhlet (SER 148 Solvent Extractor, VELP Scientifica, Italy) device, and the percentage of oil in dry matter was calculated.

2.4 | Physicochemical Properties of the Olive Oils

The color values (L, a^*, b^*) of the olive oil samples were measured several times for each sample using a Minolta CR-400 Colorimeter (Osaka, Japan) regularly calibrated against its white tile. The refractive index of olive oil samples was measured with an Abbe 5 (Bellingham and Stanley, UK) refractometer, specific gravity of the oils was measured with an oil pycnometer by American Oil Chemists' Society (AOCS) method Cc 10c–95, specific absorbance at 232 and 270 nm and delta K values of samples were measured with a Shimadzu UV-1800 spectrophotometer (Shimadzu, Japonya) according to AOCS method Ch 5–91, FFA values were measured with AOCS method Ca 5a–40, PVs were measured with AOCS method Cd 8–53, and the iodine and saponification numbers were measured with AOCS methods Cd 1–25 and Cd 3–25, respectively [11]. The unsaponifiable content was determined with International Organization for Standardization (ISO) 3596 method [12].

The total biophenol (polyphenol) content of the olive oil samples was assessed using the COI/T.20/Doc No. 29 method [13]. Accordingly, 2 g of the oil sample was mixed with 1 mL syringic acid standard solution, and then biophenols were extracted with 5 mL of methanol/water (80:20, v/v) solvent twice, and the mixture was kept for 15 min in an ultrasonic water bath. Finally, the aqueous phase was separated by centrifugation at 3800 × g for 30 min. The extracted and collected phenolic fraction was then analyzed with an Agilent 1260 Infinity 2 high-performance liquid chromatography (HPLC), donated with a Spherisorb ODS-2 C18 reverse-phase (4.6 mm × 25 cm) column, UV detector, and 280 nm integrator.

2.5 | The Fatty Acid, Phytosterol, Tocopherol, and Phenolic Compositions of the Olive Oils

The fatty acid composition of the olive oils was determined using the AOCS Ce 2–66 method [11]. Fatty acid methyl esters

FIGURE 1 | Examples of early harvest and normal harvest olive fruits and olive oil produced from these fruits: (A) early harvest, (B) normal harvest.

were prepared according to the method described by David et al. [14]. The fatty acid compositions were determined using a gas chromatograph (GC)–flame ionization detector (FID) (Agilent Technologies 7890B, Palo Alto, CA, US) with HP 88 capillary column (100 m × 0.25 mm ID × 0.2 μm film thickness, J&W Scientific, CA, US). The working conditions of the GC were 1 μL injection volume, 1:50 injector split ratio, 2 mL/min flow rate for hydrogen as a carrier gas, hydrogen (40 mL/min) and dry air (450 mL/min) as detector gases, 250°C inlet temperature, and 280°C detector temperature. The oven temperature program was 120°C for 1 min, 175°C (10°C/min) for 10 min, 210°C (5°C/min) for 5 min, and 230°C (5°C/min) for 5 min. Fatty acids were identified and quantified using an FAME standard mixture (37-component, C4–C24, Supelco, Bellefonte, PA, US).

Sterol composition of the oils was determined according to the TSE ISO 12228 method [15]. First, the unsaponifiable matter was collected, and the sterol fractions were separated using thin layer chromatography (TLC). The sterol fractions were analyzed using a GC–FID (Agilent Technologies 7890 B, Palo Alto, CA, US) with a DB5 capillary column (30 m × 0.25 mm ID × 0.1 μm film thickness, J &W Scientific, CA, US). The working conditions of the GC were 1 μL injection volume, 1:100 injector split ratio, 0.8 mL/min flow rate of hydrogen as carrier gas, hydrogen (30 mL/min), and dry air (400 mL/min) as detector gases, 290°C inlet temperature, and 300°C detector temperature. The oven temperature program consisted of 60°C for 2 min, 220°C (40°C/min) for 1 min, and 310°C (5°C/min) for 30 min. α-Cholestanol was added to the sample as an internal standard and was used to calculate the quantities of sterols. Commercial sterol standards were used to identify the peaks.

The tocopherol compositions of the oil samples were determined following the method of Grilo et al. [16] with minor modifications.

An oil sample (200 μL) was diluted to 5 mL with dichloromethane, vortexed for 30 min, and transferred into a vial for injection. Tocopherol compositions were analyzed by reverse-phase HPLC (Shimadzu, Kyoto, Japan) with an Inertsil ODS-3 column (250 mm × 4.6 mm ID × 5 μm, GL Sciences, Japan) and RF-20A fluorescent detector. The mobile phase was methanol/water (97:3, v/v), and isocratic elution at a flow rate of 1.6 mL/min was used. The detector was set to 290 and 330 nm wavelengths for excitation and emissions. Commercial tocopherol standard ampules (Merck, Darmstadt, Germany) of 100 mg were used for identification and quantification.

To extract the phenolic fractions from the olive oil samples, 3 g of oil was dissolved in 3 mL hexane, and this mixture was loaded into an SPE cartridge (CNWBOND Poly-Sery, Germany) that was previously conditioned with 5 mL hexane and 5 mL methanol. First, the nonpolar fractions were eluted with 5 mL hexane, and then the phenolic fraction was eluted with 10 mL ethanol [17]. Finally, the phenolic fractions were analyzed following the method described by Moulehi et al. [18]. Briefly, sulfuric acid/water (2:98, v/v) (A) and acetonitrile (B) were used as the mobile phases with flow gradients of 0.1–18 min 80% A, 18–24 min 70% A, 24–30 min 67.5% A, 30–36 min 45% A, 36–40 min 0% A, 40–45 min 60% A, 45–47 min 80% A. The determinations were achieved with a reverse-phase HPLC (Shimadzu, Kyoto, Japan) equipped with a Zorbax Eclipse Plus C18 column (250 mm × 4.6 mm × 5 μm) and SPD-M20A diode array detector (280 nm). Commercial phenolic standards with a minimum 95%–98% purity (Sigma-Aldrich and Fluka, St. Louis, US) were used for identification and quantification.

2.6 | The Volatile Aromatic Compositions of the Olive Oils

The volatile aromatic compounds in the olive oil samples were quantified following our previous method [19]. A Shimadzu GC-2010 Plus GC equipped with a mass spectrometry (MS)-QP2010 plus mass spectrometer (Shimadzu, Kyoto, Japan) was used. The volatiles were collected on a fused silica solid-phase microextraction (SPME) CAR/PDMS (75 mm fused silica, Supelco, Bellefonte, PA, USA) fiber. First, 2 g of olive oil sample was weighed into a 15 mL clear PTFE/silicone (Supelco) vial, and the vial was placed into a water bath set 60°C and kept in a water bath for 15 min without fiber and 30 min with the fused silica SPME fiber inserted. The volatile-adsorbed fiber was then inserted into the injection port of the GC, and the volatiles were desorbed at 250°C for 5 min. An Rx-5Sil MS capillary column (30 m–0.25 mm × 0.25 mm; catalogue no.: Restek 13623, Restek, Bellefonte, PA, USA) was used for compound separation. The injection and detector were at 250°C, and helium flow rate was 1.61 mL/min as carrier gas. The column was held at 40°C for 2 min and then increased to 250°C at a heating rate of 4°C/min and then kept for 5 min at that temperature. The temperatures of the ion source and the transfer line were 200°C and 250°C. Electron impact mass spectra were recorded at the ionization energy of 70 eV. The mass spectra analyses were performed in scan mode in the 40–300 amu mass range. Finally, the volatile compounds were tentatively identified with the libraries of the National Institute of Standards and Technology [20] and Wiley of Mass Spectral Data [21]. Retention times and % area values of the determined volatiles were provided.

2.7 | Sensory Descriptive Analyses of the Olive Oils

Sensory descriptive tests of the olive oil samples were performed following the International Olive Oil Council method COI/T.20/Doc. No. 15/Rev. 10 [22]. The same descriptive terms and scales were used for this study. Eleven panelists (seven women and four male, aged 21–52) were incorporated in the study. The panel was trained under the moderation of panel leaders at different sittings held within a week for at least 10 h. Signed consent forms were provided to the panel members. The consent form indicated that the samples were virgin, safe, and completely food-grade and could be ingested. Sensory tests were completed under daylight with samples in lid closed glasses coded with three-digit numbers. Duplicate oil samples for each replicate were tested on different days. During the tests, the panelists were provided water, unsalted crackers, and expectoration cups.

2.8 | Consumer Tests of the Olive Oils

The appearance/color, smell/scent, taste/flavor, and overall liking of the olive oil samples were tested with 50 volunteer consumers (22 women, 38 men, 20–62-year-old) using a 5-point hedonic scale (1 = dislike extremely, 5 = like extremely). The same consent forms were provided. The coded samples were served together with water, unsalted crackers, and expectoration cups. The duplicate samples were tested on different days.

2.9 | Statistics

The early and normal harvest olive oil samples were produced twice, and each analysis for each production was performed in triplicate, except for the consumer tests that were performed in duplicate. The collected data were analyzed with analysis of variance (ANOVA), and the early and normal harvest oils were compared using Tukey's test. Sensory data were analyzed using the non-parametric Kruskal–Wallis test. Minitab Ver. 16.1 [23] software packages were used. The confidence level was set at 95% in this study.

3 | Results and Discussion

3.1 | Properties of the Early and Normal Harvest Olive Fruits and Fruit Stones

The measured properties of the early and normal harvest olive fruits and their stones are summarized in Table 2. There were significant differences between the color values of the two olives. As the fruit ripened, the L value (brightness) significantly reduced. It can also be observed from Figure 1 that the fruit darkened from early to normal harvest date. Similarly, in early harvest fruit, there was green color (−17.84 a^* value), but it turned to slightly red as a^* value got 3.59 in normal harvest fruit. The dominant yellow color (41.54 b^* value) in early harvest fruit changed to 0.32 b^* value,

TABLE 2 | Basic physical properties of early and normally harvested olive fruits and their stones.

	Early harvest		Normal harvest	
	Olive fruit	**Fruit stone**	**Olive fruit**	**Fruit stone**
Color *L* value	65.87 ± 4.92	45.23 ± 1.98	27.25 ± 0.34	51.43 ± 5.04
Color *a** value	−17.84 ± 1.71	8.23 ± 0.94	3.59 ± 1.33	11.79 ± 2.28
Color *b** value	41.54 ± 5.26	25.64 ± 0.85	0.32 ± 0.09	27.58 ± 2.65
Weight (g)	2.47 ± 0.44	0.65 ± 0.40	3.91 ± 1.10	0.71 ± 0.10
Width (mm)	14.70 ± 1.20	8.24 ± 1.02	16.54 ± 2.51	8.69 ± 0.37
Length (mm)	19.06 ± 2.32	13.84 ± 0.78	21.59 ± 0.75	13.54 ± 0.35
Moisture (%)	51.05 ± 0.01	—	52.44 ± 1.75	—
Oil (% dry matter)	36.75 ± 0.52	—	45.85 ± 5.06	—

indicating that almost all yellow pigments were decreased in the normal harvest sample. In addition to the *b** value, some color differences between the fruit stones were observed (Table 2). The fruit weight increased to 3.91 g from 2.47 g, indicating a 58% weight enhancement. Similar findings have been reported previously [4]. Although the normal harvest fruit had some higher fruit dimensions, they were not significantly different from those of the early harvest fruit. Clearly, most changes occurred in the fruit flesh rather than in the stone. The most significant difference was for the oil content, and normal harvest fruit had a significantly higher oil (45.85%) than that of the early harvest (36.75%) fruit. This is an expected finding because as the fruit matures, more oil accumulation occurs in the flesh. A similar finding was reported in Dritta olives, in which the oil content increased from 44.9% at the end of September to 63.1% at the end of November [24].

3.2 | Physicochemical Properties of the Early and Normal Harvest Olive Oils

The plant processing parameters of the two replicates of early and normal harvest processing dates are summarized in Table 1. The differences (e.g., paste temperatures) between the two production times were based on the operation date, at which plant temperatures differed according to the climatic temperature. The fully automated production system provided the processing parameters, and no external interference was applied. Many control parameters were given, but the most important one was oil yield (%). Oil yield is the percentage of the total oil obtained from the total olives entering the process line. Although the early harvested olives yielded 11.37% oil, the oil yield was 13.67% in the normal harvest olives. Because the plant processing system was the same for both productions except the date-related differences (environmental and paste temperatures), all differences could be attributed to olive harvesting time and discussed accordingly in the subsequent sections. This finding agrees with the data provided in Table 2, indicating that normal harvest olive fruits contain higher amounts of olive oil. Of course, oil yield is not the same as oil content, but it is the oil obtained under the given processing conditions and is affected by the fruit matrix and the nature of the oil in the fruit.

Table 3 indicates some important physicochemical properties of olive oils produced from early and normal harvest fruits.

TABLE 3 | Physicochemical properties of the early and normal harvest olive oils.

	Early harvest	Normal harvest
Biophenol (polyphenol, mg/kg)	138.00 ± 5.00^{b}	156.50 ± 5.50^{a}
Iodine number (g I_2/g)	78.61 ± 0.38^{b}	81.48 ± 0.30^{a}
Refractive index (20°C)	1.4680 ± 0.00^{a}	1.4670 ± 0.50^{a}
Specific gravity (g/mL, 20°C)	0.9130 ± 0.00^{a}	0.915 ± 0.02^{a}
Peroxide value (meq O_2/kg)	6.03 ± 0.02^{a}	2.13 ± 0.55^{b}
Color *L* value	26.92 ± 1.87^{a}	27.28 ± 2.14^{a}
Color *a** value	−1.23 ± 0.10^{a}	0.56 ± 0.50^{b}
Color *b** value	6.33 ± 0.50^{a}	6.62 ± 0.80^{a}
Saponification number (mg KOH/g)	193.55 ± 0.98^{a}	191.34 ± 0.95^{b}
Unsaponifiable matter (g/kg)	7.06 ± 0.08^{b}	8.16 ± 1.61^{a}
Free fatty acidity (oleic %)	0.21 ± 0.02^{a}	0.13 ± 0.05^{b}
Absorbency in ultra-violet (232 nm)	1.88 ± 0.21^{a}	1.57 ± 0.01^{b}
Absorbency in ultra-violet (270 nm)	0.13 ± 0.01^{a}	0.07 ± 0.02^{b}
Absorbency in ultra-violet (delta *K*)	−0.0032 ± 0.00^{b}	−0.004 ± 0.00^{a}

Note: Small letters within a column for each group of components followed by different superscript letters are statistically different ($p \leq 0.05$, $n = 6$).

Biophenol or polyphenol content was significantly higher in the normal harvest oil (156.50 mg/kg) than in the early harvest oil (138.00 mg/kg). The total biophenol content includes the natural and oxidized derivatives of oleuropein and ligstroside, lignans, flavonoids, and phenolic acids, and the range of measurement has been reported from 30 to 800 mg/kg [13]. It is a nutri-

tional quality criterion, and higher values are preferred owing to expected beneficial effects in inflammation, cardiovascular diseases, cancer, atherosclerosis, microbial activity, and cellular oxidative stress [25]. Apparently, as fruit matures towards normal harvest time, the biophenol content is simultaneously enhanced. The difference between the iodine numbers could indicate the total amounts of unsaturated and saturated fatty acids, and the normal harvest oil had higher values (Table 3). The refractive indices and specific gravities of the samples were not different and were within the expected ranges for olive oils [26]. The PV of early harvest oil was significantly higher. This phenomenon can be explained by the decrease in lipoxygenase enzyme activity as fruit ripens [27]. The measured color values showed significant differences from the CIE color values (Table 3, Figure 1). Early harvest oil was much greener than the normal harvest sample ($-a^*$ values), whereas the amount of yellow color was the same. These findings were usually concurred with previous studies [4, 7]. The saponification numbers were also different, and the early harvested sample had a slightly higher value, possibly because of the higher content of saturated fatty acids. The unsaponifiable content, which includes short-chain hydrocarbons, squalene, sterols, tocopherols, and other unidentified components [26], was higher (8.16 g/kg) in normal harvest oil than that of the (7.06 g/kg) early harvest oil. One of the main quality and classification criteria of olive oils, the FFA value, was also lower in the normal harvest sample, and both samples had FFA values below 0.8%, indicating the extra virgin category [22]. Some FFA present in early harvest oil were esterified and lowered as the fruit ripened to the normal harvesting date (Table 3). The literature indicates that the harvesting date does not significantly affect FFA in VOO (virgin olive oil) samples [28]. The ultraviolet absorbance (232 and 270 nm and Delta *K*) values indicate that both samples were extra virgin in quality. K_{232} indicates the amount of conjugation in unsaturated fatty acids, and K_{270} indicates the amount of secondary oxidation, or the aldehydes and ketones produced because of secondary oxidation. These indices may also indicate the presence of refined oils [26]. The normal harvest sample had lower indices, which was also in accordance with the PVs (Table 3). Bengana et al. [28] showed that K_{232} first decreases and then increases during maturation. Generally, all findings concur with the available literature.

3.3 | Fatty Acid, Phytosterol, Tocopherol, and Phenolics Composition of the Early and Normal Harvest Olive Oils

The compositional data of the main and minor components of the olive oil samples are presented in Table 4. Although there were some small differences, the fatty acid compositions usually resembled each other. The amounts of palmitic, palmitoleic, heptadecenoic, linolenic, and lignoseric acids decreased in normal harvest oil, whereas the amounts of heptadecanoic, stearic, oleic, and linoleic acids were lower in the early harvest sample. It was indicated that during fruit maturation, due to the enhancement of accumulated total oil, palmitic and linolenic acid decreased proportionally, which is called the dilution effect in horticulture science [4, 29]. On the other hand, the enhancement of oleic and linoleic acids towards normal harvest might be due to the activity of desaturase enzymes [4, 29]. A similar stearic acid enhancement during maturation, like in this study, was reported in the study by

TABLE 4 | Fatty acids, phytosterols, tocopherols, and phenolics compositions of the early and normal harvest olive oils.

Fatty acids (%)	Early harvest	Normal harvest
Myristic acid (C14:0)	0.02 ± 0.01[a]	0.02 ± 0.01[a]
Palmitic acid (C16:0)	13.67 ± 0.05[a]	11.77 ± 0.13[b]
Palmitoleic acid (C16:1)	0.87 ± 0.10[a]	0.66 ± 0.01[b]
Heptadecanoic acid (C17:0)	0.13 ± 0.01[b]	0.15 ± 0.01[a]
Heptadecenoic acid (C17:1)	0.23 ± 0.01[a]	0.21 ± 0.00[b]
Stearic acid (18:0)	2.53 ± 0.06[b]	2.99 ± 0.05[a]
Oleic acid (C18:1)	71.49 ± 0.02[b]	71.81 ± 0.10[a]
Linoleic acid (C18:2)	9.55 ± 0.50[b]	10.87 ± 0.15[a]
Linolenic acid (C18:3)	0.63 ± 0.10[a]	0.56 ± 0.02[b]
Arachidic acid (C20:0)	0.42 ± 0.10[b]	0.49 ± 0.03[a]
Gadoleic acid (C20:1)	0.26 ± 0.10[a]	0.27 ±0.00[a]
Behenic acid (C22:0)	0.11 ± 0.31[a]	0.12 ± 0.00[a]
Lignoseric acid (C24:0)	0.09 ± 0.01[a]	0.05 ± 0.01[b]
Sterols (%)		
Brassicasterol	nd	nd
Campesterol	3.65 ± 0.50[a]	3.07 ± 0.10[b]
Delta-7-avenesterol	1.18 ± 0.20[b]	1.36 ± 0.20[a]
Delta-7-stigmastenol	0.47 ± 0.00[a]	0.38 ± 0.20[b]
Delta-5-avenasterol	9.89 ± 0.10[b]	13.65 ± 0.50[a]
Eritrodiol + Uvaol	1.33 ± 0.00[b]	1.64 ± 0.40[a]
Cholesterol	0.14 ± 0.20[a]	0.14 ± 0.10[a]
Stigmasterol	0.31 ± 0.10[a]	0.18 ± 0.50[b]
Beta-sitosterol	94.00 ± 0.00[a]	94.5 ± 0.10[a]
Total sterol (mg/kg)	1981 ± 35.00[b]	2379 ± 65.50[a]
Tocopherols (mg/kg)		
Alpha-tocopherol	101.25 ± 1.75[a]	86.35 ± 3.95[b]
Beta-tocopherol	nd	nd
Delta-tocopherol	nd	nd
Gamma-tocopherol	nd	nd
Total tocopherol	101.25 ± 1.75[a]	86.35 ± 3.95[b]
Phenolics (mg/kg oil)		
Gallic acid	nd	nd
Hydroxytyrosol	0.15 ± 0.05[b]	0.45 ± 0.15[a]
Catechin	1.50 ± 1.50	nd
Tyrosol	0.65 ± 0.05[a]	0.25 ± 0.05[b]
Caffeic acid	0.10 ± 0.00	nd
Epicatechin	0.20 ± 0.02	nd
Syringic acid	nd	nd
Oleuropein	nd	nd
Quercetin	1.00 ± 0.10	nd
Kaempferol	nd	0.45 ± 0.45

Note: Small letters within a column for each group of components followed by different superscript letters are statistically different ($p \leq 0.05$, $n = 6$).
Abbreviation: nd, not detected.

Beltrán et al. [30]. In general, the fatty acid compositions of the oil samples were in good agreement with the given limit values in the Turkish olive and olive pomace oil codices [31]. Likewise, the fatty acid composition data concur with other studies [8, 24].

There were small differences in phytosterol composition between the samples (Table 4). In both samples, the main sterol was beta-sitosterol, which was not affected by the harvest date. Generally, delta-7-avenesterol, delta-5-avenasterol, and eritrodiol + uvaol enhanced in the normal harvest time. The most significant finding for sterol composition was that the normal harvest sample had higher total sterols (2379 mg/kg) than the early harvest sample (1981 mg/kg). In a previous study [8], during maturation, a decrease in the amount of beta-sitosterol and an increase in the amount of delta-5-avenasterol were related to denatured enzymes. In this study, a similar pattern was evident for delta-5-avenasterol, but not for beta-sitosterol. Because phytosterols are considered healthy bioactive components [2], the normal harvest sample could be credited better for nutrition.

In both samples, only alpha-tocopherol was quantified, and it was higher (101.25 mg/kg) in the early harvest sample than in the normal harvest sample (86.35 mg/kg). Previous studies have reported higher [6, 32] and equal [33] amounts of tocopherols in olive oil samples. Piscopo et al. [8] indicated no effect of harvest date on tocopherol content, whereas Bengana et al. [28] reported a decrease during maturation. In this study, tocopherol content decreased from early to normal harvest dates in the olive oil samples. Because tocopherols are strong natural antioxidants and fat-soluble vitamins, higher concentrations in olive oils are preferred for extended shelf life and nutritional quality [26].

A total of 10 different phenolics were identified, but only 7 (hydroxytyrosol, catechin, tyrosol, caffeic acid, epicatechin, quercetin, and kaempferol) were quantified in the olive oil samples (Table 4). The olive oil samples in this study did not contain gallic acid, syringic acid, or oleoropein. This finding was interesting because Saitta et al. [34] reported the presence of oleouropein aglycon, syringic acid, ferulic acid, and coumaric acid in 34 olive oil samples. Contrarily, samples in this study included catechin, epicatechin, quercetin, and kaempferol, and those 34 samples included none of them. This could be due to the analytical techniques used. From early harvest to normal harvest, catechin, caffeic acid, epicatechin, and quercetin were lost, whereas kaempferol existed only in the normal harvest sample (Table 4). In this study, hydroxytyrosol was enhanced, and tyrosol was decreased from the early to the normal harvest date. A decrease in the hydroxytyrosol content has been previously reported [35, 36]. Further amounts of hydroxytyrosol (0.15 and 0.45 mg/kg) and tyrosol (0.65 and 0.25 mg/kg) were far lower than the reported range in 34 olive oil samples [34]. This might be due to the analytical capability in this study. Previous studies have reported a wide range of phenolic compounds in olive oils, possibly due to great variations in variety, region, climate, agricultural practices, harvest times, and analytical factors [2, 26, 35, 36]. The total biophenol content of the early and normal harvest samples was as 138.0 and 156.5 mg/kg (Table 3), respectively. Total biophenols include many substances other than the individual phenolic compounds analyzed, and they are used as quality criteria for the nutritional value of the samples. Generally, the phenolic composition of olive oil samples depends mostly on genotype and agricultural practices rather than harvest date, but some studies have indicated higher total phenolic content in early harvest and a subsequent but slow decrease during maturation [36, 37]. It must be noted that the total biophenol content and phenolic composition were measured using different instruments and different techniques in this study. The European Food Safety Authority (EFSA) declared that the daily consumption of 5 mg hydroxytyrosol or its derivatives (oleuropein and tyrosol) could protect humans against low-density lipoprotein (LDL)-oxidation damage [38].

3.4 | Volatile Aromatic Composition of the Early and Normal Harvest Olive Oils

The quantified volatile aromatic compositions of the two olive oil samples are presented in Table 5. In both samples, 41 different compounds were identified; the early harvest sample included 37, and the normal harvest sample included 30 different volatile aromatics. The most abundant molecules were *Z*-3-hexenal (19.09% and 35.79%), 2-hexenal (12.89% and 4.65%), and 5-octadecene (9.55% and 23.47%) in the early and normal harvest VOO samples, respectively. All identified volatile compounds were previously listed as determined volatiles in olive oils [26, 39]. The aroma of VOO originates from aldehydes, alcohols, esters, hydrocarbons, ketones, and other molecules. The majority of compounds were C5 and C6 volatiles. Further, it was stated that the input of each molecule to the perceived aroma was not directly related to its concentration but to its odor threshold value. The odor threshold is the unit of the minimum human perception concentration of each aromatic in a certain medium. The molecular structure, isoform, hydrophobicity, volatility, and presence of functional groups provide each compound with potency for the odor threshold [40]. Consequently, olive oil aroma is the sum of all aromatic volatile compounds present [41]. It was also indicated that high-quality VOO samples showed distinct green and fruity aroma notes together with a bitter-pungent sensation. These attributes are correlated with cut grass, leaf, tomato, and apple aromas and are highly positively correlated with *Z*-3-hexenal, *E*-2-hexenal, and their alcohols [39, 42].

It was observed from Table 5 that the compounds 2-propenal, formic acid, hexyl ester, nonane, alpha-pinene, 2-heptenal, beta-myrcene, octanal, L-limonene, benzeneacetaldehyde, farnesene, and *E*-caryophyllene were quantified in the early harvest sample but absent in the normal harvest sample. Clearly, by fruit maturation towards a normal harvest date, some compounds are lost due to degradation, bioconversion, or other reasons. Similarly, ethyl acetate, 2-ethyl furan, *Z*-2-pentenal, and 2-hydroxy benzoic acid methyl esters were not quantified in the early harvest sample but were present in the normal harvest sample. The most important change was observed with *Z*-3-hexenal, and it was enhanced significantly towards the normal harvest date. In contrast, the concentration of 2-hexenal decreased from the early to the normal harvest date. Karagoz et al. [9] showed that different olive cultivars in Türkiye showed different behaviors during fruit maturity, and *Z*-3-hexenal and 2-hexenal content decreased in some cultivars and increased in some other cultivars during maturation. Similar findings have been reported in other studies [41, 42]. In a detailed study [43], the inconsistent behavior of major aromatic volatiles with fruit maturity was observed. It

TABLE 5 | Volatile aromatic compound compositions of early and normal harvest olive oils.

RT (min)	Volatile compound	Aroma definition*	Early harvest		Normal harvest	
			Mean peak area	Mean value (%)	Mean peak area	Mean value (%)
1.377	Ethanol	Strong alcoholic, medical	204 632 ± 1235[a]	0.96	90 515 ± 950[b]	0.34
1.440	2-Propenal	Fruity, almond cherry	51 920 ± 805	0.19	nd	0.00
1.575	1,3-Pentadiene, (*Z*)-	Acrid odor	154 472 ± 1515[a]	0.85	102 272 ± 1715[b]	0.39
1.766	Acetic acid	Sharp pungent, sour, vinegar	166 580 ± 850[a]	0.70	51 335 ± 944[b]	0.16
1.925	Ethyl acetate	Ethereal, fruity, sweet, green	nd	0.00	26 549 ± 1215	0.10
2.557	1-Penten-3-one	Pungent, etherial, peppery, garlic, mustard, and onion	344 788 ± 1230[b]	1.42	75 0796 ± 1180[a]	2.79
2.706	3-Pentanone	Ethereal acetone	58 576 ± 556[b]	0.28	137 436 ± 1900[a]	0.54
2.760	Furan, 2-ethyl-	Chemical-like, beany bready	nd	0.00	76 723 ± 783	0.24
3.476	2-Pentenal, (*E*)-	Pungent, green, fruity apple-like	52 921 ± 1305[a]	0.22	66 142 ± 1300[a]	0.25
3.985	*Z*-2-pentenol	Ethereal, fruity	nd	0.00	12 507 ± 875	0.06
4.010	2-Penten-1-ol, (*Z*)-	Green	45 579 ± 355[b]	0.17	76 675 ± 289[a]	0.29
4.597	*Z*-3-hexenal	Green, grassy, fruity, apple	4 541 835 ± 1700[b]	19.09	9 614 898 ± 1486[a]	35.79
6.133	2-Hexenal, (*E*)-	Green leafy	2 971 975 ± 5600[a]	12.89	1 279 409 ± 6320[b]	4.65
6.250	3-Hexen-1-ol, (*Z*)-	Green, grassy, melon rind-like	472 456 ± 1825[b]	2.09	757 293 ± 1349[a]	2.77
6.614	Benzene, 1,2-dimethyl-	Geranium	94 303 ± 980[a]	0.34	47 970 ± 750[b]	0.18
6.735	1-Hexanol	Pungent, etherial, fruity	71 551 ± 1260[a]	0.26	62 539 ± 1265[a]	0.23
6.744	Formic acid, hexyl ester	Apple, plum, banana, sweet	34 671 ± 755	0.19	nd	0.00
7.698	Nonane	Gasoline	1 870 373 ± 3205	10.25	nd	0.00
8.044	2,4-Hexadienal	Fatty, sweet, green	588 868 ± 2965[a]	2.15	171 308 ± 3808[b]	0.60
8.820	Alpha-pinene	Gresh, camphor, sweet pine	525 439 ± 1650	2.88	nd	0.00
9.735	2-Heptenal, (*E*)-	Green, fatty	25 617 ± 582	0.09	nd	0.00
9.890	2(5*H*)-furanone, 5-ethyl-	Spice	578 785 ± 3200[a]	2.12	152 814 ± 3005[b]	0.52
10.972	Beta-myrcene	Peppery, terpenic, spicy	52 332 ± 973	0.24	nd	0.00

(Continues)

TABLE 5 | (Continued)

RT (min)	Volatile compound	Aroma definition*	Early harvest		Normal harvest	
			Mean peak area	Mean value (%)	Mean peak area	Mean value (%)
11.225	3-Ethyl-1,5-octadiene	Earthy mushroom	229 949 ± 5100[b]	0.93	934 350 ± 6000[a]	3.43
11.511	Octanal	Aldehydic, waxy, orange peel	54 847 ± 1645	0.20	nd	0.00
11.601	3-Hexen-1-ol, acetate, (*Z*)-	Fresh green, sweet fruity	809 804 ± 1555[a]	3.17	421 186 ± 1500[b]	1.60
11.893	Acetic acid, hexyl ester	Fruity, green, apple	324 148 ± 3100[a]	1.29	86 270 ± 1800[b]	0.33
12.472	L-Limonene	Terpenic, pine, herbal	78 399 ± 520	0.43	nd	0.00
13.009	Benzeneacetaldehyde	Green, sweet floral hyacinth	49 557 ± 655	0.18	nd	0.00
13.181	1,3,6-Octatriene, 3,7-dimethyl-, (*E*)-	Sweet herbal	46 066 ± 1300[b]	0.17	93 090 ± 905[a]	0.35
15.446	Nonanal	Waxy, rose, fresh orris	133 966 ± 1008[a]	0.56	49 762 ± 905[b]	0.18
18.786	Benzoic acid, 2-hydroxy, methyl ester	Wintergreen mint	nd	0.00	46 825 ± 850	0.15
19.327	5-Octadecene, (*E*)-	Fatty, soapy	2 447 440 ± 450[b]	9.55	6 429 982 ± 820[a]	23.47
25.400	Alpha-copaene	Woody, spicy, honey	76 882 ± 845[a]	0.28	46 653 ± 555[b]	0.18
25.814	Alpha-thujene	Woody, green, herbal	394 180 ± 1345[a]	1.52	82 059 ± 1230[b]	0.29
27.578	Beta-cedrene	Cedarwood, woody	866 678 ± 795a	3.39	140 754 ± 1004[b]	0.44
27.981	Beta-farnesene <(*E*)-	Woody, citrus, herbal, sweet	350 418 ± 2054	1.28	nd	0.00
27.990	*E*-caryophyllene	Sweet, woody, spice clove dry	50 206 ± 845	0.28	nd	0.00
29.648	Beta-farnesene	Citrus, herbal lavender	442 313 ± 350[b]	1.69	764 390 ± 621[a]	2.84
29.817	Alpha-cedrene	Woody, cedar, sweet, fresh	408 907 ± 955[a]	1.50	84 584 ± 1300[b]	0.27
30.260	Beta-cedrene	Cedarwood, woody	554 424 ± 1867[a]	2.13	145 671 ± 2115[b]	0.52

Note: Small letters within a row for each component followed by different superscript letters are statistically different between the harvest times ($p \leq 0.05$, $n = 6$).

Abbreviation: nd, not detected; RT, retention time.

*Aromatic definitions of the volatile compounds were found from the web page. http://www.thegoodscentscompany.com/index.html#.

was indicated that the concentration of the volatiles changed not only by fruit maturity but also by variety and location. Generally, they showed an increase in alcohols during maturation, whereas a decrease in C6 alcohols was observed. They concluded that volatiles described with "grass" were decreased over harvesting period, but those described with "leaf" attribute showed inconsistent behavior.

Clearly, early harvest VOO samples are richer in different volatile compounds, and both samples contain sufficient quantities of *Z*-3-hexenal, *E*-2-hexenal, and hexanal that provide positive sensory attributes. Furthermore, both samples contained no or very low amounts of branched aldehydes and alcohols, C6–C10 dienals, C7–C11 unsaturated aldehydes, and C8 ketones that were correlated with negative aroma attributes in olive oil [44]. Another study [43] indicated the changes as a rise in the concentrations of 1-penten-3-ol and a decrease in hexanal, *E*-3-hexenol, *Z*-3-hexen-1-ol, and *Z*-2-hexenol as maturity increased. Furthermore, the content of *E*-2-hexenal, as well as many other compounds, except *E*-2-hexenol and hexyl acetate, decreased as maturity progressed. Of course, the maturity level was a factor in these studies. In this study, fruits were not over-matured, and only the early and normal harvest samples were compared. Concentrations of *E*-2-hexenal and hexyl acetate decreased, and *Z*-3-hexen-1-ol increased from the early to normal harvest date (Table 5) in this study.

Although early and normal harvest olive oil samples showed some differences in volatile aromatic composition, it was important to observe their sensory quality by a trained panel and their perception by the consumers.

3.5 | The Sensory Analysis of the Early and Normal Harvest Olive Oils

The trained panel evaluated the sensory attributes of the early and normal harvested olive oil samples, and the data are shown in Table 6. The panel utilized the methodology of COI/T.20/Doc. No. 4 "Sensory Analysis: General Basic Vocabulary" [22]. Both samples were absent for negative (fusty/muddy sediment, musty/humid/earthy, winey-vinegary acid/sour, frostbitten olives, rancid, and other negative attributes) attributes. The panel decided that all negative attributes were absent in these samples. The four positive attributes differed significantly among the samples. The "fruity" descriptor was evaluated as fruity-green and fruity-ripe descriptors. The fruity term identifies sensory characteristics from sound and fresh olives, either ripe or unripe [22]. The early harvest sample had a significantly higher (9.55) fruity-green score than the normal harvest (6.80) sample. In contrast, the fruity-ripe score of the normal harvest sample (8.75) was significantly higher than that of the early harvest sample (5.80) (Table 6). As clearly shown in Figure 1 and the color data in Table 2, the early harvested sample had significantly higher green color components and higher concentrations of 2-hexenal (12.89% vs. 4.65%), which is characteristic of green leafy aroma descriptions. In contrast, the concentration of *Z*-3-hexenal was significantly higher (35.79%) than that in the early harvest sample (19.09%). A similar pattern was evident for 5-octadecene (9.55% and 23.47%), which is also related to the aroma of ripe olive fruit. *Z*-3-hexenal is a characteristic descriptor of the fruit-ripe attribute. Obviously, as fruit matures, the green components of fruity decrease and the ripe components are enhanced. Similar findings have been previously reported [35, 41]. Another positive attribute, bitter, decreased from the early to the normal harvest date (Table 6). The bitter taste is a primary taste obtained from green or turning-color olives and is perceived in the papillae region of the tongue [22]. It is known to be related to common olive phenolics, flavonoids, alkaloids, and some volatile aromatic compounds. It was indicated that bitter taste was positively correlated with secoiridoid content, such as oleuropein aglycon and 1-penten-3-one volatiles, and negatively correlated with *Z*-3-hexen-1-ol and hexenal [41, 45]. Although the total biophenol content of the early harvest sample (138.0 mg/kg) was lower than that of the normal harvest sample (156.5 mg/kg), the sensory bitterness did not show the same trend. Consequently, sensory bitter perception was affected not only by phenolics but also by other components. It was stated that phenol concentrations lower than 220 mg/kg correspond to non-bitter (almost imperceptible), 220–340 mg/kg correspond to slight bitterness, 340–420 mg/kg correspond to bitter oils, and phenol contents higher than 410 mg/kg correspond to very bitter oils [45]. Accordingly, both samples in this study were non-bitter. Pungency as a positive attribute is a biting tactile sensation from oils produced at the start of the season that are still unripe and perceived in the whole mouth cavity, particularly in the throat [22]. Ligstroside aglycon, oleocanthal, hexanol, and 1-penten-3-one are positively correlated, and *E*-2-hexenal is negatively correlated with pungent attributes [41, 45].

When all sensory attributes were considered together (Table 6), it could be claimed that the early harvest sample was better because it had higher scores for the three main positive attributes and had no defects. The fruit ripening was naturally higher in the normal harvest sample. Generally, the sensory data in this

TABLE 6 | Sensory evaluation data of early and normal-harvest olive oils.

	Early harvest	Normal harvest
Fusty/Muddy sediment	Absent	Absent
Musty/Humid/Earthy	Absent	Absent
Winey-vinegary acid/sour	Absent	Absent
Frostbitten olives (wet wood)	Absent	Absent
Rancid	Absent	Absent
Other negative attributes*	Absent	Absent
Fruity-green	9.55 ± 0.50^{a}	6.80 ± 0.30^{b}
Fruity-ripe	5.80 ± 0.20^{b}	8.75 ± 0.50^{a}
Bitter	7.55 ± 1.50^{a}	6.00 ± 1.40^{b}
Pungent	8.70 ± 0.70^{a}	6.65 ± 0.40^{b}

Note: Small letters within a row followed by different superscript letters are statistically different ($p \leq 0.05$, $n = 6$).

*Metallic, dry hay, grubby, rough, brine, heated or burnt, vegetable water, esparto, cucumber greasy.

TABLE 7 | Consumer (n = 50) test results of early and normal-harvest olive oils.

	Early harvest	Normal harvest
Appearance/Color	5.00 ± 0.10^{a}	3.87 ± 0.00^{b}
Smell/Scent	5.00 ± 0.00^{a}	4.55 ± 0.10^{b}
Taste/Flavor	4.80 ± 0.10^{b}	5.00 ± 0.10^{a}
Overall liking	4.95 ± 0.00^{a}	4.25 ± 0.10^{b}

Note: Small letters within a row followed by different superscript letters are statistically different ($p \leq 0.05$, $n = 4$).

study concur with the sensory data provided in the literature [46–48]. The relationship between descriptive sensory data, volatile aromatic compounds, and other constituents of olive oil is well-studied. In this study, early and normal harvested olive oils produced under the same industrial conditions were compared. Although expected correlations were observed for some quality traits, no clear relationship was evident. Consumers always make the ultimate decision for olive oil and all foods; hence, a limited number of consumer tests were completed for these two samples.

3.6 | The Consumer Tests of the Early and Normal Harvest Olive Oils

Table 7 presents the consumer hedonic test findings for the olive oil samples. Before the consumer tests, no information about the samples (olive variety, location of production, harvest date, price, etc.) was provided to consumers. They judged the attributes based only on their perceptions. Voluntarily incorporated consumers were regular olive oil users. Except for taste/flavor perception, early harvest samples were liked more by the 50 consumers incorporated into the test. Appearance/color of early harvest samples was liked by most (score of 5.0), possibly due to a higher green color tone (Figure 1, Table 3). Most consumers appreciate the greener color of the extra virgin olive oil (EVOO) samples [26]. The smell/scent score of the early harvest sample was maximum (5.00) and higher than that of the normal harvest sample (4.55). As discussed earlier, the early harvest sample had higher concentrations of 2-hexenal, which is defined by the green aroma notes. Of course, there are many other aromatic volatiles that are summed together to produce the perceived aroma. Eventually, consumers liked the smell of the early harvest sample. The taste/flavor score of the normal harvest sample was maximum (5.00) and higher than that of the other samples (4.80). It is known that (Table 6) the fruity-ripe attribute was higher in the normal harvest sample, and ripe fruit taste/aroma might drive consumers to like the taste of that sample. Eventually, overall consumer liking was also significantly higher for the early harvest sample (Table 7). Delgado and Guinard [49] found that bitterness and pungency were negative drivers of consumer liking, and fruity, nutty, and tea-like flavors were positive properties for consumer liking of olive oils. Consumption motives and consumer preferences associated with different consumer segments are based on different perceptual orientations and consumer values [49].

4 | Conclusions

In this study, we compared early and normal harvest olive oils produced from the same orchard or even the same trees under the same production conditions within a real industrial olive oil production plant. The olive harvesting dates were the beginning of the October as "early harvest" and the first week of December as the "normal harvest" used to be performed in the region. Furthermore, the handpick harvesting type, containers used, way to carry the olives to the plant, and all other production line operations in the factory were the same. This study differed from similar studies in the literature in that it was fully controlled from field to bottle and was carried out under industrial conditions. The results showed that the oil yield was significantly lower in the early harvest sample. As important physicochemical parameters, the biophenol content was higher, and the PV, FFA, and ultraviolet absorbance were lower in the normal harvest sample. The total sterol content of normal harvest oil was higher (2379 mg/kg) than that of the early harvest (1981 mg/kg), but the alpha-tocopherol content showed an opposite trend, and it was higher in the early harvest (101.25 mg/kg) than in the normal harvest sample (86.35 mg/kg). Small differences were observed in the phenolic constituents of the samples. Volatile aromatic compositions showed significant differences, and most distinctly, the concentrations of *Z*-3-hexenal were enhanced and 2-hexenal were decreased towards the normal harvest time. Furthermore, some volatiles were lost during the normal harvest, whereas some new volatiles were generated. The trained panel evaluated the sensory properties, indicating that both samples lacked negative attributes, and fruity-green, bitter, and pungent scores were lower in the normal harvest sample. Consumer tests indicated that early harvest samples were more liked, with higher scores of appearance/color and small/scent attributes. Overall, the study proved that normal harvest olive oils contain more nutrients (biophenols, sterols, and some volatiles) but have lower sensory scores. Most importantly, overall consumer preferences were higher for early harvest oil. Clearly, consumer liking was based mostly on sensory attributes, especially the green-turbid color and fruity-green smell. It is well known that early harvest olive oils are sold at higher prices than the normal harvest oils. This is understandable for producers who have a lower yield of early harvest oil with a higher selling price. Similarly, consumers could prefer early harvest oils because of their turbid-green color, higher green aroma, and higher cost. Consumers can decide their buying decisions according to the expected sensory quality—nutrition information—price interrelationships. Consequently, this study suggests true consumer communication and government-controlled labeling to save liable commerce in the olive oil sector.

Author Contributions

Alper Aydın: review and editing, methodology, investigation, formal analysis. **Emin Yılmaz**: writing – review and editing, writing – original draft, visualization, supervision, resources, project administration, methodology, investigation, formal analysis, data curation.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data will be made available upon request.

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