

Research Article

Effects of Debitting Treatments on Some Secondary Metabolites' Bioaccessibility, Fatty Acid, and Aroma Profiles of Semidried Gemlik Variety Black Olives

Senanur Durgut Malçok ¹, Cüneyt Tunçkal ², Azime Özkan Karabacak ^{3,4},
Gülderen Coşgun ⁵, Mehmet Torun ⁶ and Canan Ece Tamer ¹

¹Department of Food Engineering, Faculty of Agriculture, Bursa Uludağ University, Gorukle, Bursa 16059, Türkiye

²Electric and Energy Department, Air Conditioning and Refrigeration Technology Program, Yalova Community College, Yalova University, Yalova 77100, Türkiye

³Gemlik Asım Kocabiyik Vocational School, Food Processing Department, Food Technology Program, Bursa Uludağ University, Gemlik, Bursa 16600, Türkiye

⁴Science and Technology Application and Research Center, Bursa Uludağ University, Gorukle, Bursa 16059, Türkiye

⁵Department of Food Engineering, Institute of Science and Technology, Akdeniz University, Antalya 07058, Türkiye

⁶Faculty of Engineering, Food Engineering Department, Akdeniz University, Antalya 07058, Türkiye

Correspondence should be addressed to Azime Özkan Karabacak; azimeozkan@uludag.edu.tr

Received 12 June 2024; Accepted 31 January 2025

Academic Editor: Cristina Anamaria Semeniuc

Copyright © 2025 Senanur Durgut Malçok et al. Journal of Food Quality published by John Wiley & Sons Ltd. This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

Table olives are an important component of the Mediterranean diet and are known to be highly beneficial to health due to their rich content of phenolic compounds, high levels of monounsaturated fatty acids, vitamin E, phytosterols, squalene, minerals, and fiber. However, their natural bitterness caused by the presence of oleuropein makes them unpalatable in their raw form. Throughout history, various methods have been tried and developed to remove the bitterness of olives. In this study, Gemlik variety black olives underwent a heat pump drying (HPD) process at 40°C for semidrying, followed by different debittering treatments of dry salting and brining, and then samples were stored at 4°C for 5 days. The raw olive sample was found to be the richest in total phenolic content (TPC), oleuropein content, total antioxidant activity (TAA), and total monomeric anthocyanin (TMA) content. The debittering treatments reduced TPC; especially, dry salting led to the highest loss. However, the in vitro gastrointestinal (GI) digestion process increased TPC, indicating that phenolic compounds are still being extracted and released during digestion. DPPH and FRAP values of the predigestion (Ud) samples varied between 102.62 µmol TE/g dw and 224.62 µmol TE/g dw and between 12.67 and 127.96 µmol TE/g dw, respectively. Among the table olives processed using different debittering treatments, the one stored at +4°C exhibited the highest values for TAA and TMA content. All debittering treatments led to reductions in TAA and TMA levels. However, the in vitro small intestinal-digested (Isid) samples showed variations in TAA values, with an increase observed in TAA values for all samples determined by FRAP method. Similarly, TMA values ranged from 12.74 to 30.05 mg/kg in the Ud samples, while TMA values of the samples after in vitro GI digestion ranged from 36.06 mg/kg to 103.28 mg/kg. The treatments used lead to a decrease in oleuropein concentration and an increase in hydroxytyrosol and tyrosol levels. In the evaluation of the fatty acid composition of raw and table olives, 11 different fatty acids including oleic, palmitic, linoleic, stearic, elaidic, palmitoleic, and arachidic were detected in all samples. A total of 57 aroma compounds were detected in the samples, of which 55 were successfully identified. Among the samples, the one subjected to dry salting was the most preferred in terms of sensory evaluation. These findings suggest that when reduced salt consumption is a priority, low-temperature drying process in combination with other debittering treatments can result in olives with an improved flavor and enhanced functionality, providing a healthy black table olive option for consumers.

Keywords: aroma profile; bioaccessibility; black olive; debittering; heat pump drying; oleuropein

1. Introduction

Table olives are one of the most important food products in the world with a total of 2,659,000 tons of production during the years 2023–2024 [1].

Table olives are an important constituent of the Mediterranean diet, which have been linked to numerous health benefits, most of which are related to their phenolic compounds [2], high vitamin E, phytosterols, squalene [3], minerals, and fiber content [4]. Consuming table olives have been linked to a number of health benefits, including the reduction of inflammation, certain cancers, and coronary heart disease due to their high concentration of phenolics and monounsaturated fatty acids. It has been suggested that eating 5–10 table olives daily could provide enough polyphenols for an adult [5].

Because raw olives naturally contain phenolic compounds, especially the bitter glucoside oleuropein, reducing their levels and transforming them into other nonbitter components are necessary to produce an edible drupe [6]. Over the centuries, several methods have been developed for debittering of olives. The natural bitter compounds found in table olives are hydrolyzed using an acid, alkali, or enzyme to produce nonbitter hydrolysis products [7].

The stage of ripening at harvest (green and black), commercial preparations (treated, natural, darkened by oxidation, dehydrated and/or shriveled, and specialties), and styles (whole, pitted, stuffed, salad, and other) can all be used to classify table olives. According to trade preparations, three commercial processing techniques account for around 80% of global production: treated green olives (or Spanish style green olives), ripe olives darkened by oxidation (Californian style), and natural (mainly black) olives in brine (traditional Gemlik style). In any event, processing encourages a progression in both terms of quality and quantity in table olives' phenolics, affecting their texture, chemical, microbiological, and organoleptic profiles and health-promoting properties [8–12]. Furthermore, current industrial table olive processing techniques, such as the Californian and Spanish style processing, can use more than 7571 L of water per ton of olives and produce extremely hazardous wastewater, making them some of the most water-intensive techniques in the food industry. Additionally, NaOH debittering of table olives is not permitted in several countries [13]. Innovation in olive processing technology is required due to rising consumer demand for healthier foods that are produced sustainably, as well as industrial interest in reducing process duration, water consumption, and cost [7]. Therefore, in our study, different processing methods were evaluated from an innovative perspective, aiming to minimize the disadvantages of olive processing methods.

Dry-salted black olives are one of the many types of table olives, although they are not widely produced despite customers' growing interest in them [14]. They have been produced in the Mediterranean basin since antiquity from overripe fruit whose surface color is fully black. The fruit is then placed between layers of coarse salt for one to 2 months,

causing the olives to lose the majority of their moisture [15]. Additionally, the high osmotic pressure of the salt causes the tissues to rupture bringing the enzyme polyphenol oxidase into contact with the oleuropein, and the oxidation of the phenolic compound causes the olives to become debittered [6, 16]. After the removal of salt, olives are washed and allowed to dry at room temperature, and then they are ready to be eaten [15, 17]. The olives lose weight and their salt content increased during the dry salting process, which lowers their water activity [15]. Due to the restructuring of galacturonan pectic polysaccharides in the fruit's cell walls, changes in texture and an increase in the strength of the flesh have also been noted [18, 19]. In addition, the sensory evaluation of these dry-salted olives revealed that they have less acidity, less crisp, and a little bit more bitter than Spanish style green olives [15].

At the moment, the commercial debittering process entails soaking the olives in NaOH solution to hydrolyze the ester bond between the phenolic hydroxytyrosol and the rest of the oleuropein molecule [20]. Olives are directly placed in brine without any alkali treatment in natural olive processing. Bitterness is removed during storage because of the diffusion of oleuropein to the brine and further acid hydrolysis [21], which is a biological degradation of oleuropein by the lactic acid bacteria activity [22] as well as a direct oxidation of the glucoside compound [13].

Due to the increasing preference of consumers for natural and organic products [23] that do not undergo harsh chemical treatments, directly brined olives, without preliminary debittering with alkali solutions, are increasing in popularity in the market [24]. NaOH-free debittering (NaOH-FDP) has benefits such as maintaining some phenolic compounds, which leads to positive nutritional features like higher antioxidant activity. Additionally, compared to debittering with NaOH ($3.9\text{--}7.5\text{ m}^3/\text{ton}$), substantially less effluent is produced in the NaOH-FDP process ($0.9\text{--}1.9\text{ m}^3/\text{ton}$) [25]. Furthermore, today's industry places a high priority on producing table olives with less salt [26].

Some nations also use hot air-drying to produce dehydrated black olives, such as Italy, where the "Ferrandina" method entails blanching, salting, and oven-drying of ripe olives [19, 27]. Additionally, fermented black olives are dehydrated in ovens in Peru [28], and in some locations of Algeria, harvested black olives are sun-dried [29].

The application of heat treatments in the processing of table olives appears to play a crucial role in the development of innovative products with improved sensory attributes [30]. Green table olives can be transformed into a longer-lasting snack through the implementation of drying techniques [31], which have been shown to effectively reduce bitterness during the drying process [29]. It was stated that oleuropein content and bitterness of olives could be minimized with reduction of water content to 15%–20% by drying after pretreatment such as brining, soaking in water and/or brine, dry salting, piercing, and/or scratching [19, 27, 32]. In conventional dryers, energy loss is significant

because the drying air at high temperatures has to be thrown out. Heat pump dryers reuse this waste energy and are preferred because of their advantages, such as high performance coefficients and the ability to work at low temperatures that improves the quality of the dried product [33, 34].

This study investigated the use of heat pump drying (HPD) for semidrying of Gemlik variety black olives. Olives were dried at 40°C with 1.0 m/s air velocity. Three postdrying treatments were tested: dry salting, brining, and cold storage. By this way, debittering period was shortened compared to traditional methods, with olives became edible after 5 days. The study examined the effects of abovementioned treatments on phenolic content, anthocyanins, antioxidant activity, and their bioaccessibility, oleuropein, tyrosol, and hydroxytyrosol, fatty acids, aroma profiles, and sensory properties. To the best of our knowledge, this is the first research applying HPD for debittering Gemlik variety olives and analyzing these quality parameters.

2. Materials and Methods

2.1. Materials. Gemlik variety olive fruits grown in the Gemlik district of Bursa, Turkey, were used. The initial moisture content of the table olives was determined to be 35.36% using an oven (Shimadzu-MOC63u, Kyoto, Japan) set at $105 \pm 3^\circ\text{C}$ for moisture analysis (AOAC 925.10).

2.2. Methods

2.2.1. Drying Procedure. Approximately 30 min before the initiation of the drying process, the dryer was operated to establish a stable drying environment. The HPD system was explained in our previous study, illustrated with a figure [35]. Olive fruits were subjected to drying at a constant air velocity of 1.0 m/s and a temperature of 40°C, which was determined by preliminary experiments. The air flow rate during the drying experiments was determined using the Testo 405-V1 and Testo 410-2 instruments. Initially, the tray was loaded with 12.230 kg of olive fruits once the dryer achieved stability. Throughout the drying process, weight loss was measured using a load cell and recorded into a computer at four-minute intervals. The psychometric diagram was employed to derive the relative humidity, temperature, and enthalpy values (h). The ambient temperature of the drying system was maintained at 24°C with an average humidity of $55 \pm 5\%$. The drying process was continued until the moisture content of the olive fruits decreased from the initial value of 35.36%–15.02%. Each experiment was replicated three times to ensure the robustness and consistency of the findings. The semidried process took a total of 51,25 h.

2.2.2. Preparation of Table Olives Treated With Different Methods. Following the semidrying (HPD) process, olive fruits were subjected to three different treatments. The first-group fruits were immersed in a brine solution containing 10% (w/v) salt. The second group (dry-salted) was prepared

with 50 g of salt per 450 g of olive fruits. When these two groups were stored at ambient temperature, the third-group nonsalted semidried olives were stored in a refrigerator at +4°C. Each batch of products underwent these treatments for 5 days. After 5 days of storage under these conditions, the olive fruits were analyzed.

2.3. Analysis Methods

2.3.1. Physical Analysis. The number of olive fruit per kg was determined by weighing randomly selected 100 g of olives and after counting them, then multiplying with 10. Width and height of 20 olive samples were measured by a caliper with 0.1 mm precision. The average values of these dimensions were calculated. The moisture content of the samples was measured using a digital moisture analyzer (MA150; Sartorius, Göttingen, Germany).

2.3.2. Total Phenolic Content (TPC) Analysis. First, after making certain modifications to Kamiloglu and Capanoglu [36]’s method, undigested portions of table olives were extracted. In the process of chemical extraction, 5 mL of extraction solution comprising 75% aqueous methanol and 0.1% formic acid was introduced to 2 g of samples. The samples were subjected to ultrasonic treatment in a water bath (Bandelin Sonorex RK 510 H, Germany). Following a 15-min interval, the samples were centrifuged (Sigma 3K 30, Germany) at 2700 g and 4°C for 10 min, resulting in the collection of supernatants in test tubes. This process was repeated four times with the addition of 5 mL extraction solution each time, and all supernatants were subsequently combined to yield a final extract volume of 20 mL per sample. The extracts were then stored at -20°C prior to TPC and TAA analyses. With the use of an ultraviolet–visible spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan), TAA and TPC of table olives were determined. The TPC of the olive sample was determined using the Folin–Ciocalteu method with some modifications [36]. The results were given as mg of gallic acid equivalent (GAE) per 100 g of dry weight.

2.3.3. Total Antioxidant Activity (TAA) Analysis. According to Kumaran and Karunakaran [37] and Benzie and Strain [38], the TAA of samples was examined using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) assays, respectively. TAA results in both the DPPH and FRAP methods were expressed as μmol trolox equivalent (TE) per gram of dry weight. A high correlation coefficient of $R^2 = 0.9972$ and $R^2 = 0.9992$ was observed for the DPPH and FRAP methods, respectively.

2.3.4. Total Monomeric Anthocyanin (TMA) Analysis. The pH differential method was used to determine TMA. Prepared extracts were used for TPC and TAA. First, a test tube was filled with 0.1 mL of sample and 0.025 M of potassium chloride buffer (pH 1). In a different test tube, 0.1 mL of the sample was combined with sodium acetate

buffer (4.5 M, pH 4.5). At 512 nm and 700 nm, the samples' absorbance was measured. The outcome was computed as follows:

$$\text{TMA (mg/kg)} = A \cdot \text{MW} \cdot \text{DF} \cdot (1000/\epsilon \cdot l)$$

$$A = (A_{\lambda_{512}} - \lambda_{700}) \text{pH}_{1,0} - (A_{\lambda_{512}} - \lambda_{700}) \text{pH}_{4,5}$$

MW = Molecular weight of the relevant anthocyanin (for cyanidin-3-glucoside: 449.2).

DF = Dilution factor.

ϵ = Coefficient of absorbance (for cyanidin-3-glucoside: 26,900).

l = Spectrophotometer cuvette of layer thickness (cm) [39].

2.3.5. HPLC Analysis. Oleuropein, tyrosol, and hydroxytyrosol contents of olives were analyzed using high-performance liquid chromatography/UV-Vis detector (HPLC/UV-Vis) (Agilent Technologies, 1260 Infinity) equipped with Inertsil ODS-4 5- μm column [4.6 $\times$ 250 mm (UP)] as previously defined in the literature [20]. All extracted samples were passed through 0.45- μm membrane filter and injected into HPLC. For measurement at 280 nm, the following solutions with flow rate of 1 mL/min and injection volume of 10 μL were used: 2% acetic acid (65% eluent A) and acetonitrile/methanol (1:1, v/v; 35% eluent B). Column retention times and characteristic UV spectra were used to identify these phenolics.

2.3.6. In Vitro Gastrointestinal Digestion. The method of Minekus et al. [40] was modified to prepare in vitro gastrointestinal digestion of the olives. Sample digestions in the gastric and intestinal tracts were simulated. The porcine pepsin solution (25,000 U/mL, Sigma-Aldrich P6887; USA), calcium chloride, and simulated gastric fluid were combined during the gastric phase. Hydrochloric acid was then used to bring the pH of this solution down to 3.0. The mixture was then incubated for two hours at 37°C in a shaking water bath (Mettmert SV 1422, Mettmert GmbH & Co., Germany). Aliquots of 4 mL were taken for each test tube. The simulated intestinal fluid, pancreatin solution (800 U/mL, Sigma Aldrich P3292), and bile solution (160 mM) were combined with the gastric phase's leftovers. Sodium hydroxide was used to bring the pH to 7.0. The intestinal phase was incubated in a shaking water bath at 37°C for 2 hours. The mixture was then filtered and centrifuged at 3500 rpm for 10 min, and the supernatant was collected. The simulations after the intestinal and stomach digestion phases were stored at -20°C until analysis.

2.3.7. Fatty Acid Composition. The fatty acid methyl esters' (FAMES) content of olive samples was determined according to the procedure applied in [41]. This method allows digestion of fresh tissue, transmethylation of lipids, and one-step extraction of FAMES, eliminating the need for oil extraction prior to the preparation of FAMES [42]. First, 50 mg of olive sample was placed in a glass test tube. A

reagent mixture of 5 mL methanol:heptane:toluene:2,2-dimethoxypropane:H₂SO₄ (39:34:20:5:2 by volume) was added to the tubes and boiled at 80°C for 2 h. After cooling at room temperature, two phases formed in the tubes, the supernatant containing FAMES was collected in vials and analyzed by GC-MS (QP2010-Plus, Shimadzu, Kyoto, Japan). TRB5-MS (30 m $\times$ 0.25 mm $\times$ 0.25 μm) column and temperature program were used for the separation of the components: 140°C for 6 min, 3°C/min increment to 215°C, 2 min at 215°C, 5°C/min. increment to 250°C, and 10 min at 220°C. The carrier gas velocity was 1.13 mL/min., the injection temperature was 250°C, and the ion source temperature was 250°C. Fatty acid determination of the samples was carried out using the instrument software (GC-MS solution 5.60) by running the C7-C24 alkane standard under the same conditions as in the method and comparing the retention indices with the Wiley 10 and NIST 02 libraries.

2.3.8. Aroma Profile. The aroma profile of olive samples was determined by a modification method described by Balci-Torun and Özdemir [43]. For this purpose, 0.5 g of olive samples were weighed into 20-mL vials and the volatile compounds of the samples were absorbed by the HS-SPME method using 50/30 μm DVB/CAR/PDMS fiber (Supelco 57348-U, Bellefonte, Pennsylvania, USA). Absorption of volatile components into the fiber was performed at 40°C, 250 rpm agitation for 15 min. Volatile components were desorbed at 200°C for 10 min. GC-MS analyses were performed using a GC-MS (QP2010-Ultra, Shimadzu, Kyoto, Japan) with SPME methods by AOC-5000Auto Sampler-Plus (Shimadzu, Kyoto, Japan). Separations were performed using a TRB5-MS column (30 m $\times$ 0.25 mm i.d. $\times$ 0.25 μm film thickness) with helium at 1.56 mL/min. as carrier. The analysis was performed in split mode (1:20). The column temperature was programmed as follows: 3 min at 40°C, followed by an increase of 4°C/min. to 240°C, held for 10 min. The temperatures of ion source and injection were 200°C, 250°C, and 275°C. The electron impact voltage was 70 eV, and the scan mass range (m/z) was 30–500. Identification of aroma compounds was determined by comparison of mass spectral data from Wiley 10, NIST library, and retention index.

2.3.9. Sensory Analysis. Seven panelists from the Food Engineering Department of Bursa Uludağ University (Bursa, Turkey) participated in the sensory evaluation. Three-digit numbers were used to code each sample. Only debittered olives were tested during the sensory evaluation; raw olives were excluded. The panelists assessed the table olives' color, odor, bitterness, saltiness, acidity, hardness, and general acceptability. A scale with 9 points was applied.

2.3.10. Statistical Analysis. Utilizing the IBM SPSS Statistics 23 software (IBM SPSS, USA), statistical analysis was carried out. Duncan's multiple range test and the analysis of variance (ANOVA) were used to identify significant differences between means at the 5% significance level. The findings of

each measurement were expressed as the mean $\pm$ standard deviation after being carried out in triplicate.

Due to the number of independent variables in the study, the results were processed using XLSTAT software (Addinsoft, New York, USA) to facilitate interpretation. Aroma results were then assessed through principal component analysis (PCA) and hierarchical cluster analysis (HCA).

3. Results and Discussion

3.1. Physical Analysis. The number of fruits in 1 kg of table olives was determined to be 270. The average width of the olive fruit was measured as 18.5 mm, while the average length was measured as 22.5 mm.

3.2. Total Phenolic Content. TPC results of the raw material and debittered table olives are given in Table 1.

The results showed that raw material had the highest TPC. Reduction ratio of TPC was between 60.41% and 90.23% after all treatments. All of the raw olives were semidried to the same moisture level before applying different treatments. Although mild drying temperature (40°C) was applied, loss of phenolic compounds was observed. The fact that polyphenols are heat-labile and that prolonged heat treatments (51.25 h) might result in irreversible chemical changes in phenolic compounds may help to explain the TPC losses in dried table olives [44]. TPC can also be deteriorated as a result of other factors such as the activity of oxidative enzymes (polyphenol oxidase, peroxidase), organic acid content, sugar concentration, and pH [45]. In addition, different processing methods in this study also caused the phenolic loss to be variable. In literature, it was stated that the cultivar [46], degree of ripeness [47], irrigation schedules [48], and, the most significantly, the techniques utilized for processing table olives are only a few of the many variables that might alter the phenolic composition of table olives. Additionally, the hydrolysis of phenolics, which can be catalyzed chemically (as with base or acid) or enzymatically (e.g., glycosidases), the oxidation of phenolic compounds by phenol oxidases, and the polymerization of free phenolics were all effects of processing methods on the phenolic composition of olives [49]. The findings of the current investigation indicated that there were variations in the phenolic composition of table olives based on the processing techniques. While the TPC value was the best preserved in Sample 4, the highest loss was in Sample 2. The reason for the TPC results are best preserved in Sample 4 than others may be related to the higher water solubility of the phenolics [50, 51]. Comparing the processing methods of Sample 2 and others, it was concluded that lower TPC was obtained in Sample 2. Moisture contents of the samples 1, 2, 3, and 4 were determined as 35.36%, 22.86%, 20.19%, and 17.38%, respectively. From these results, it is understood that the most moisture loss after processing the table olives was seen in Sample 2, while the least was seen in Sample 4. Based on these data, highest TPC loss in Sample 2 might be accounted for by the considerable

water loss seen during the dry salting procedure [52]. Moreover, in Sample 4, the highest preservation of TPC compared to other processing methods is associated with the lowest moisture loss.

TPC of raw material increased in 1.26 and 1.78 times after gastric and small intestinal phases, respectively. For processed samples, significant increases in gastric and small intestinal TPC digestion were observed ($p < 0.05$). After gastric and small intestinal digestion, TPC values of samples 2, 3, and 4 increased between 5.02 and 8.15, 2.27 and 4.92, and 1.07 and 2.30 times, respectively. These results indicated that the TPC of the table olives varied depending on the treatment and digestion stages. These increases in Igd phase show that phenolic compounds are still being extracted during gastric digestion and that those compounds that are released stayed stable in the acidic environment of the stomach [53]. Additionally, increases in the TPC were seen in some earlier investigations during intestinal digestion, and this was attributed to longer food contact times with intestinal fluids and intestinal enzymes that facilitated the release of phenolic chemicals. New phenolic compounds released into the environment increase the TPC value [53–55]. Phenolic compounds are food components that have many positive effects on human health and have been suggested to reduce the risk of some types of cancer, cardiovascular disease, asthma, and diabetes. Phenolic compounds have potent antioxidant activity and are reported to prevent the proliferation of cancer cells, reduce lipid oxidation, and lower cholesterol levels. The increase in phenolic compounds released from the food matrix after digestion increases the utilization of these health beneficial components and reveals the importance of determining the changes that occur in the food matrix with digestion with various digestion models [55]. From our results, the dry-salted table olives (Sample 2) had the lowest bioaccessible TPC. This was followed by samples 4 and 3, respectively. The lowest TPC digestion in Sample 2 may be explained by the fact that osmotic dehydration continues after semidrying with the dry salting process. Additionally, fermentation procedure may be contributed to increase in TPC bioaccessibility. From these results, it can be concluded that brining is more efficient for TPC bioaccessibility than dehydration and cold storage. The digestion process for all samples, especially the small intestinal digestion stage, seemed to release and increase the concentration of phenolic compounds.

3.3. Phenolic Compounds: Oleuropein and Its Hydrolyzed Components; Tyrosol and Hydroxytyrosol. Oleuropein, the most prominent phenolic present at harvest, is typically blamed for the bitterness in fresh olives [56]. Fresh olives are processed to lessen their bitterness and make them edible. The oleuropein concentration presents after processing determines the residual bitter flavor of processed table olives, which is a key quality valued by consumers. Oleuropein is degraded into tyrosol and hydroxytyrosol both in the body and in the olive fruit. Oleuropein undergoes hydrolysis during fruit maturity and processing and is degraded by lipase activity and transformed to hydroxytyrosol after consumption [57].

TABLE 1: Changes in TPC of raw and debittered table olives during *in vitro* digestion.

Samples*	Ud (mg GAE/100 g dw)**	Igd (mg GAE/100 g dw)**	Isid (mg GAE/100 g dw)**
1	857.58 ± 40.73 ^{aB}	1087.87 ± 33.13 ^{aB}	1528.21 ± 8.61 ^{aA}
2	83.82 ± 23.38 ^{dC}	420.83 ± 38.30 ^{bB}	683.29 ± 60.97 ^{dA}
3	188.22 ± 34.44 ^{cC}	427.60 ± 8.22 ^{bB}	925.74 ± 81.35 ^{bA}
4	339.54 ± 41.63 ^{bC}	365.01 ± 22.57 ^{cB}	782.20 ± 24.66 ^{cA}

Note: Values followed by different lower letters within the same column and different capital letters within the same row are significantly different ($p < 0.05$).

*1: Raw olive, 2: dry-salted olive after semidrying, 3: brined olive after semidrying, 4: cold-stored (+4°C) olive after semidrying.

***In vitro* gastric-digested: Igd, *in vitro* small intestinal-digested: Isid, undigested: Ud.

Changes in oleuropein and its hydrolyzed components, tyrosol and hydroxytyrosol of raw and table olives, are given in Table 2. After semidrying and processing with different methods, oleuropein concentration continued to decrease and fell down between 17.28 and 32.08 mg/100 g dw.

It was seen that oleuropein was not completely hydrolyzed in each of the processes applied to table olives after semidrying. While this component was reduced at most in the brining (Sample 3), the least loss was in those stored at +4°C. The fact that only dehydration occurred in Sample 4 due to semidrying explains the largest amount of oleuropein remaining. When Sample 2 and Sample 3 are compared, dry salting caused degradation of oleuropein in a lesser extent. The hydrolysis of oleuropein after brining was the highest. However, oleuropein was not completely degraded because duration of processes takes a short time as 5 days. Similar with our results, Zoidou et al. [58] observed that the particular processing of naturally black dry-salted olives from Throuba Thassos resulted in dehydration rather than fermentation, and as expected, some oleuropein remained unhydrolyzed.

The changes in phenolic compounds during processing include the decrease in oleuropein levels and the increase in hydroxytyrosol and tyrosol [59]. The removal of water and processes like salting leads to the hydrolysis of oleuropein, resulting in the emergence of tyrosol and hydroxytyrosol. Fermentation of olives can also accelerate the hydrolysis process and contribute to the increased formation of tyrosol and hydroxytyrosol. Additionally, microorganisms present during processing and fermentation can play a role in the hydrolysis of oleuropein and the formation of tyrosol and hydroxytyrosol. Factors such as processing techniques, storage temperature, and duration can also influence the content of tyrosol and hydroxytyrosol in olives. In the literature, there is an evidence indicating that the levels of tyrosol and hydroxytyrosol in processed olives are higher compared to the content of oleuropein found in fresh olives [60].

When compared to other table olives, the dry-salted type (Sample 2) had the lowest hydroxytyrosol and was generally low in TPC. This could be explained by the significant water loss observed during the dry salting process, which caused a decline in hydroxytyrosol levels in the olive [52]. Similar with our results, Yildiz and Uylaser [49] found that the lowest hydroxytyrosol was found in black dry-salted Gemlik variety olives, which were also generally low in phenolic compounds. According to Boskou et al. [5], hydroxytyrosol levels in black table olives (Kalamon, Amfissa, and

Tsakistes), green table olives (Crete), and varicolored table olives (Throubes Crete) ranged from 22 to 66 mg/100 g, 114 mg/100 g, and 2 mg/100 g, respectively. Another study found that the hydroxytyrosol levels in green table olives, black table olives, and varicolored table olives varied from 219.8 to 283.2 mg/100 g dw, 35.5–83.34 mg/100 g, and 85.78 mg/100 g, respectively. Although Ben Othman et al. [47] stated that hydroxytyrosol was not found in dry-salted table olives, in our study, tyrosol was not present in dry-salted semidried sample (Sample 2).

3.4. TAA. TAA analysis of table olives was conducted using both the DPPH and FRAP methods. The DPPH results are provided in Table 3. The DPPH values of Ud samples ranged from 102.62 µmol TE/g dw to 224.62 µmol TE/g dw. Among the Ud samples, the raw olive sample exhibited the highest DPPH value, indicating its highest antioxidant activity compared to other samples. Moreover, when comparing the DPPH values of *in vitro* digested and Ud samples, the raw table olives were found to have the highest DPPH values even after *in vitro* digestion. Similar to our findings, Ben Othman et al. [47] reported a decrease in antioxidant activity by 50%–72% in “Chetoui” variety olives processed through spontaneous and controlled fermentation at three different ripening stages. The FRAP results of the table olives are presented in Table 3. The TAA results obtained using the FRAP method ranged from 12.67 to 127.96 µmol TE/g dw in Ud samples. Raw olives (Sample 1) exhibited the highest TAA values determined by FRAP method. Furthermore, the processing techniques employed in this study resulted in reductions in DPPH and FRAP values across the samples. Correlatively, the impact of heat treatment on tocopherols, total phenolics, antioxidant activity, and the fatty acid composition of green and black olives was investigated by Mihajlović et al. [61]. Their results highlighted that all tocopherol isomers and total phenolic content as well as antioxidant activity were significantly reduced after oven-heating. Also, according to Hunter and Fletcher [62], there can be differences between FRAP and DPPH results depending on the reaction mechanism, substrate type, oxidant and target species, reaction circumstances, and oxidation initiator criteria. The category of natural antioxidants encompasses polyphenols, which represent the most abundant antioxidants in our dietary intake. It has been reported that the processes applied to olives have a reducing effect on the TPC [5]. Consistent with these findings, our study also revealed that the same drying conditions but

TABLE 2: Changes in oleuropein, tyrosol, and hydroxytyrosol of raw and table olives.

Samples*	Oleuropein (mg/100 g dw)	Tyrosol (mg/100 g dw)	Hydroxytyrosol (mg/100 g dw)
1	58.65 ± 0.66 ^a	nd	452.71 ± 0.08 ^b
2	23.88 ± 1.27 ^c	nd	325.99 ± 0.50 ^d
3	17.28 ± 0.82 ^d	59.470.13 ^b	379.32 ± 0.24 ^c
4	32.08 ± 0.50 ^b	103.12 ± 0.17 ^a	553.08 ± 0.41 ^a

Note: Values followed by different lower letters within the same column are significantly different ($p < 0.05$).

Abbreviation: nd, not detected.

*1: Raw olive, 2: Dry-salted olive after semidrying, 3: Brined olive after semidrying, 4: Cold-stored (+4°C) olive after semidrying.

TABLE 3: Changes in TAA values of raw and table olives during *in vitro* digestion.

Sample*	Ud (mg GAE/100 g dw)**	Igd (mg GAE/100 g dw)**	Isid (mg GAE/100 g dw)**
DPPH			
1	224.62 ± 13.23 ^{aA}	46.85 ± 2.49 ^{aC}	158.53 ± 12.75 ^{aB}
2	104.79 ± 2.22 ^{cA}	10.44 ± 0.32 ^{dC}	19.20 ± 2.14 ^{bB}
3	102.62 ± 2.29 ^{cA}	22.73 ± 4.14 ^{cB}	18.96 ± 0.24 ^{bB}
4	133.44 ± 1.54 ^{bA}	29.18 ± 2.78 ^{bB}	17.54 ± 2.62 ^{bC}
FRAP			
1	127.96 ± 1.14 ^{aC}	185.61 ± 3.49 ^{aB}	250.42 ± 5.91 ^{aA}
2	20.54 ± 0.14 ^{cC}	57.30 ± 5.06 ^{cB}	72.03 ± 1.05 ^{cA}
3	12.67 ± 1.66 ^{dC}	72.78 ± 4.68 ^{bB}	95.98 ± 4.25 ^{bA}
4	48.27 ± 0.43 ^{bB}	45.39 ± 2.93 ^{dB}	92.72 ± 0.92 ^{bA}

Note: Values followed by different lower letters within the same column and different capital letters within the same row are significantly different ($p < 0.05$).

*1: Raw olive, 2: Dry-salted olive after semidrying, 3: Brined olive after semidrying, 4: Cold-stored (+4°C) olive after semidrying.

***In vitro* gastric-digested: Igd, *in vitro* small intestinal-digested: Isid, Undigested: Ud.

different processes applied to olives decreased the TPC. This observation parallels with the changes in the TAA values.

Sample 4, which was subjected to semidrying and kept in +4°C, demonstrated the best preservation of TAA with 40.59% decrease in DPPH value compared to the raw olive sample. Also, Sample 3, brined olive after semidrying, exhibited the most substantial reduction in DPPH value, with a decrease of 54.31%. In a study [30] similar to our research, the TAA of dried and brined dried olives was explored. The findings revealed that olives subjected to brining exhibited a diminished presence of effective antioxidant compounds. The observed reduction in the antioxidant constituents of olives subjected to brining can be attributed to two main factors. Firstly, the osmotic release during fermentation in the brine leads to changes in the olive's composition. Subsequently, during the drying process, an oxidative reaction takes place, further contributing to the decline in the antioxidant content of the olive pulp. Some studies [2, 6] indicate that the brine released during the debittering process is a valuable source of bioactive compounds. This finding suggests that during the brining process, bioactive constituents from the fruit transfer into the brine, potentially leading to a reduction in the fruit's TAA. Also, in our study, a decrease in the TAA values of table olives (Sample 2) subjected to dry salting after semidrying was observed. This decline is consistent with findings in the literature suggesting the degradation of phenolic compounds during the dry salting process. For instance, in a study conducted by Ramirez et al. [6], debittering process with different olive/salt ratios (0.88, 1.4, 2.0, and 3.0) was

investigated in Manzanilla variety table olives. During this process, changes in the phenolic profile of the olive fruit were observed. The researchers reported that the osmotic pressure applied by coarse salt during dry salting led to the rupture of olive tissues, resulting in the interaction of phenolic compounds with oxidative enzymes, particularly PPO.

Ud Sample 4 showed a decrease of 62.27% in FRAP values when compared to raw olives. This reduction was comparatively lower than that observed in the other samples. Because after semidrying, these olives were not treated with salt, they are just stored at refrigerated condition. Also, the FRAP values of Ud Sample 2 and Ud Sample 3 displayed more substantial reductions of 83.94% and 90.09%, respectively, in comparison with the raw table olives. According to Dag et al. [63], the phenolic compounds of Barnea and Koroneiki olive varieties were better preserved when stored at +4°C compared to storage at room temperature. Additionally, in Koroneiki olives, even after 24 days of storage at +4°C, the fatty acids could be well-preserved. This finding is consistent with the higher TAA values observed in olives processed at +4°C after semidrying, as compared to other processed olives. These findings highlight the impact of various processing methods on the TAA of table olives, and such observations are essential for understanding the potential health benefits and storage stability of olive products.

The ability of a substance to be removed from the food matrix and subsequently made available for intestinal cell absorption is known as bioaccessibility [64]. Igd process led to a decrease in DPPH values across all samples, with the

highest reduction of 90.04% experienced in Sample 2 and the lowest reduction of 77.85% observed in Sample 3. Furthermore, a comparison between Ud samples and Isid samples revealed that the Isid process caused reductions in DPPH values. Comparing the DPPH values of samples after Igd and Isid revealed variations in the results. Specifically, Sample 1 and Sample 2 exhibited an increase in DPPH values after Isid compared to Igd, while Sample 4 showed a decrease. Sanchez-Rodriguez et al. [64] observed a 95% decrease in DPPH values after *in vitro* digestion of Manzanilla table olives. Various factors can influence the behavior of phytochemicals during digestion. The degradation of phytochemicals is one of the impacts of digestion [65]. The breakdown of phytochemicals may have led to a drop in the DPPH values of Igd samples. The Cornezuelo table olives have previously been linked to outcomes that are comparable to those observed in the current investigation. For instance, a significant drop in DPPH levels was seen following a simulation of gastrointestinal digestion [66]. When comparing the FRAP values of Ud samples with Igd samples, it was observed that FRAP values of Igd samples increased in all samples except Sample 4, where no statistically significant difference was detected ($p > 0.05$). D'Antuono et al. [67] investigated the polyphenol bioaccessibility of Bella di Cerignola table olives after Igd. The amounts of hydroxytyrosol, luteolin, and apigenin significantly decreased following Igd. Nevertheless, in this study, the amounts of verbascoside and isoverbascoside increased after *in vitro* intestinal digestion. This effect was found to be associated with the proper extraction and higher solubility of table olive polyphenols in aqueous environments, such as digestive fluids, compared to the lipid phase. The findings of our study indicate that the observed increases and decreases during Igd are associated with the stability of antioxidant compounds. Following Isid, the FRAP values of the samples were found to be significantly higher both compared to Igd samples and Ud samples ($p < 0.05$). The FRAP results have revealed that after Isid, the olive matrix has a protective effect on certain antioxidant compounds. These substances may function as antioxidants in the intestine or undergo biotransformation and absorption in the large intestine [68]. Particularly, the most notable increase in FRAP values after Isid was observed in Sample 3 when compared to the Ud samples. However, when comparing the samples after Igd and Isid, the most substantial increase of 104.27% was found in Sample 4. The release of polyphenols could have an additional effect of TAA values after digestion [65]. This could account for the rise in FRAP values following Isid.

3.5. TMA. The TMA results of the table olives ranged from 12.74 to 30.05 mg/kg in Ud samples. The data presented in Table 4 indicated that the applied processing methods had a discernible impact on the TMA results of the samples. Upon comparing the Ud samples, it was observed that raw olives (Sample 1) exhibited the highest TMA value, whereas the lowest TMA value was obtained from Sample 2, which was dry-salted after semidrying. Notably, a considerable decrease of 57.60% was determined between TMA values of

Sample 1 and Sample 2. Piga et al. [69] investigated the changes in anthocyanin content in Kalamata and Semidana table olives subjected to a brining (7% salt) process. They reported that during the first 15 days of brining, anthocyanins degraded rapidly. This finding could be attributed to the water-soluble nature of anthocyanins. It was observed that the Sample 3 processed with brining after semidrying exhibited a lower TMA value compared to the raw material. Particularly at the end of the purple stage, cyanidin-3-rutinoside and cyanidin-3-glucoside build in olive fruits. Also, cyanidin-3-glucoside is sensitive to thermal treatment [70]. In our study, the TMA value decreased after all applied processes. This decrease could be attributed to the partial degradation of cyanidin 3-glucoside.

When comparing the TMA values of Ud table olives with those after Igd, it was evident that all samples demonstrated an increase in TMA values. The TMA values of the samples after Igd varied significantly, ranging from 36.06 mg/kg to 103.28 mg/kg. The highest increase of TMA (264.99%) was observed in Sample 2, indicating a substantial response to Igd. Also, Sample 3 exhibited the lowest increase of TMA (123.42%) in comparison with the other samples. When comparing the TMA values of the samples after Isid digestion with the Ud samples, it was observed that Isid led to an increase in TMA values for all samples. However, when comparing the TMA values of the samples after Igd with the Isid results, the outcomes showed fluctuations. In the cases of Sample 1 and Sample 3, there was an increase in TMA values after Isid digestion compared to their states after Igd. On the other hand, Sample 2, which was semidried and dry-salted, exhibited a reverse trend, with a decrease of 33.56% in TMA values. As for Sample 4, although its TMA values after Igd and Isid were higher compared to the Ud state, no statistically significant difference was observed between the two digestive processes ($p > 0.05$). In conclusion, Isid increased the TMA values for all samples, but the effects were variable when compared to the results of Igd. Recent studies have indicated that small differences in the chemical structures and physicochemical properties of anthocyanins can lead to variations in their bioaccessibility. For instance, acylated anthocyanins may exhibit significantly different stability and bioaccessibility compared to nonacylated ones. Additionally, the presence of acyl groups in anthocyanins may alter their biological activities during food processing, storage, or digestion [71]. Moreover, the observed increase in TMA bioaccessibility in our study can be attributed to the prolonged contact of the food matrix with digestive fluids, which leads to the release of bioactive compounds through interactions with fluids and enzymes (lipase and pancreatin). Under these conditions, anthocyanins may exhibit greater stability [54].

3.6. Fatty Acid Composition. Fatty acid composition of raw and table olives is given in Table 5. The results have shown that 11 different fatty acids were identified in all samples, among which oleic, palmitic, linoleic, stearic, elaidic, palmitoleic, and arachidic were found in every sample and these results are consistent with those of previous studies [72, 73].

TABLE 4: Changes in TMA of raw and table olives during *in vitro* digestion.

Samples*	Ud (mg/kg)**	Igd (mg/kg)**	Isid (mg/kg)**
1	30.05 ± 2.45 ^{aC}	103.28 ± 1.08 ^{aB}	143.27 ± 2.20 ^{aA}
2	12.74 ± 2.38 ^{cC}	46.50 ± 0.25 ^{cA}	30.89 ± 2.33 ^{cB}
3	16.14 ± 1.71 ^{bcC}	36.06 ± 3.17 ^{dB}	65.29 ± 2.51 ^{bA}
4	20.42 ± 3.59 ^{bB}	64.45 ± 4.00 ^{bA}	68.38 ± 1.77 ^{bA}

Note: Values followed by different lower letters within the same column and different capital letters within the same row are significantly different ($p < 0.05$).

*1: Raw olive, 2: dry-salted olive after semidrying, 3: brined olive after semidrying, 4: cold-stored (+4°C) olive after semidrying undigested.

***In vitro* gastric-digested: Igd, *in vitro* small intestinal-digested: Isid, undigested: Ud.

Oleic acid, the primary fatty acid in olives, was the most abundant fatty acid found, with the highest concentration being 71.72% in the Sample 4, and the lowest at 67.31% in raw olives. The most significant factor affecting the reduction of shelf life in foods with high fat content and those containing vegetable oils is lipid oxidation. The increase in unsaturated groups in fatty acids leads to increased oxidation [74]. Upon examining Table 5, it is evident that there is a more pronounced change in the amounts of linoleic acid, a polyunsaturated fatty acid, and oleic acid, the dominant monounsaturated fatty acid in olives, compared to saturated fatty acids. The amount of linoleic acid was detected at its highest at 12.77% in raw olives, while the greatest decrease (39.55%) was observed in Sample 4 which was stored at +4°C after HPD treatment. Mihajlović et al. [61] reported that in their study, olive samples dried at 180°C for 20 min experienced a reduction in unsaturated fatty acids, which is consistent with the results obtained here. When comparing the samples (2 and 3) that underwent salting after HPD treatment with those stored directly in the cold after drying, it was observed that the salting process applied to samples 2 and 3, due to its reduction of water activity, is beneficial in preventing the oxidation of polyunsaturated fatty acids in the olives. It was determined that there was no statistical difference between saturated fatty acids and mono-unsaturated fatty acids in olive samples produced with raw and different production methods. Avci et al. [75] reported the SFA content of Gemlik variety olives as 16.79% and MUFA content as 73.87% in the study in which the quality characteristics of olives grown in Turkey were determined, which is similar to the findings obtained.

3.7. Aroma Profile. The flavor profile of olives subjected to different treatments was determined using mass spectral data obtained from the retention index and Wiley 10, NIST library, and given in Table 6. In the samples, a total of 57 aroma compounds were detected, with 55 of them being identified. Ethanol was the second highest aroma component in raw olives, while it was found in the highest proportion in all processed samples. Ethanol, which accounted for 10.21% in raw olives, was detected at 16.95%, 54.26%, and 34.09%, respectively, after dry salting, brining, and storage at +4°C processes. Selli et al. [76] and Reiners and Grosch [77] reported in their studies that alcohol dehydrogenase activity plays a significant role in the formation of alcohols that are important for the aroma of olive oil. Sabatini et al. [78] reported that in olive fermentation, acetic acid is formed as a result of the oxidation of ethanol by *Acetobacter*. When analyzing the

results from Table 6, it was found that in raw olives, only acetic acid, methyl ester was detected. In processed olives, with the increase in ethanol, the formation of acetic acid and acetic acid, ethyl ester was detected, indicating a relationship between the presence of ethanol and the formation of acetic acid. When the aroma profile of the samples was examined, the processed samples were found to contain identified aroma components such as 2,3-butanedione, acetoin, 2,3-butanediol, butenoic acid, 2-methyl- butenoic acid, 2-methyl-, ethyl ester, benzeneacetaldehyde, butanoic acid, 2-methyl-,2-methylbutyl ester, and farnesene. In foods, the deamination of amino acids results in the biosynthesis of higher alcohols with more than two carbon atoms [79]. In olive samples, the biotransformation reaction of amino acids led to the formation of 3-methyl-1-butanol, a natural aroma component, which imparted a fruity and fermented aroma to the samples [80]. Initially present at 1.06% in raw olives, the level of 3-methyl-1-butanol increased to 9.72% after HPD followed by dry salting, making it the second most dominant aroma component in this product group. Ridolfi et al. [81] and Dabbou et al. [82] reported that the presence of 1-hexanol and hexanal in raw and brined olives is due to the production of these compounds through the activation of the lipoxygenase enzyme in the fruit's polyunsaturated fatty acids. Upon examining the results in Table 6, it was found that raw olives, responsible for grassy and fruity flavors, have higher concentrations of hexanal and 1-hexanol compared to other samples and that the quantities of these compounds decrease with the processing applied. When examining the amount of limonene in the aroma composition, it was observed that it decreased in comparison with raw olives due to the applied HPD and other processing parameters; however, the dry salting process preserved a higher amount of limonene compared to other processes. The brining application was determined to cause the highest rate of limonene loss. While farnesene is not found in fresh olives, it has been detected at 0.24% in dry-salted samples, 1.36% in brined olives, and 0.97% in samples stored at +4°C after HPD application. In a similar study, Selli et al. [76] identified farnesene in Gemlik olives subjected to black dry salting and reported that this compound is responsible for floral and grassy aromas.

PCA was applied to the volatile compound results to determine similarities and differences related to production conditions for dry-salted, brined olives, raw olives, processed after HPD treatment and stored at +4°C. With the PCA model applied to of 57 volatile compounds, a total of 77.03% was explained by the principal components PC-1 and PC-2 and the results were found significant for the analysis.

TABLE 5: Changes in fatty acid composition of raw and table olives (% area).

Samples*	1	2	3	4
<i>Fatty acids (% area)</i>				
Lauric acid (C12:0)	n.d ^b	n.d ^b	n.d ^b	0.22 ^a ± 0.02
Palmitoleic acid (C16:1)	0.63 ^a ± 0.00	0.74 ^a ± 0.04	0.70 ^a ± 0.10	0.65 ^a ± 0.02
Palmitic acid (C16:0)	12.67 ^{ba} ± 0.44	13.19 ^a ± 0.01	12.99 ^{ba} ± 0.04	11.59 ^b ± 0.12
Methyl cis-10-heptadecenoate	n.d ^c	n.d ^c	0.18 ^b ± 0.00	0.30 ^a ± 0.01
Heptadecanoic acid (C17:0)	n.d ^b	n.d ^b	n.d ^b	0.18 ^a ± 0.00
Linoleic acid (C18:2)	12.77 ^a ± 0.17	11.53 ^b ± 0.03	10.76 ^c ± 0.03	7.72 ^d ± 0.16
Oleic acid (C18:1 cis-9)	66.99 ^a ± 1.21	68.47 ^a ± 0.09	68.90 ^a ± 0.73	71.35 ^a ± 0.33
Elaidic acid (Cis18:1 trans-9)	2.58 ^a ± 0.04	2.53 ^a ± 0.09	2.33 ^{ba} ± 0.06	2.09 ^b ± 0.04
Stearic acid, (C18:0)	3.70 ^a ± 0.05	3.09 ^b ± 0.04	3.32 ^b ± 0.04	3.67 ^a ± 0.02
Arachidic acid (C20:0)	0.66 ^a ± 0.28	0.45 ^a ± 0.05	0.82 ^a ± 0.44	0.53 ^a ± 0.08
Oleic acid, (2,2-dimethyl-1,3-dioxolan-4-yl) methyl ester	n.d ^b	n.d ^b	n.d ^b	1.70 ^a ± 0.16
SFA	17.03 ^a ± 1.08	16.72 ^a ± 0.01	17.12 ^a ± 0.62	16.18 ^a ± 0.07
MUFA	70.52 ^a ± 1.77	71.80 ^a ± 0.01	72.04 ^a ± 0.80	74.20 ^a ± 0.48
PUFA	12.77 ^a ± 0.24	11.53 ^b ± 0.04	10.76 ^c ± 0.05	7.22 ^d ± 0.22

Note: Different letters indicate that the results are significantly different ($p < 0.05$) depending on the treatments.

Abbreviation: n.d., not detected.

*1: raw olive, 2: dry-salted olive after semidrying, 3: brined olive after semidrying, 4: cold-stored (+4°C) olive after semidrying.

TABLE 6: Changes in volatile compounds of raw and table olives (%Area).

No	RT	Samples* Volatile compounds (% area)	1	2	3	4
<i>Aldehydes</i>						
1	1.277	Acetaldehyde	1.16	2.01	1.95	1.01
2	1.655	Propanal, 2-methyl-	1.45	2.55	2.22	1.52
3	2.330	Butanal, 3-methyl-	1.59	7.32	3.40	9.39
4	2.438	Butanal, 2-methyl-	2.19	6.77	3.84	5.22
5	3.779	2-Butenal, 2-methyl-	n.d.	n.d.	n.d.	0.24
6	5.178	Hexanal	8.92	2.35	0.72	1.72
7	6.888	2-Hexenal, (E)-	4.27	n.d.	n.d.	n.d.
8	14.024	Benzeneacetaldehyde	n.d.	0.35	0.61	0.37
9	23.251	2,4-Undecadienal	0.53	n.d.	0.34	n.d.
10	24.016	2,4-Decadienal, (E,Z)-	n.d.	n.d.	0.39	n.d.
		Total (% area)	20.11	21.35	13.47	19.47
<i>Alcohols</i>						
11	1.358	Ethanol	10.21	16.95	54.26	34.09
12	2.639	2-Propanol, 1-methoxy-	1.06	0.22	0.16	0.27
13	2.866	Dimethylsilanediol -	7.15	2.79	3.14	2.55
14	3.622	1-Butanol, 3-methyl-	1.06	9.72	5.01	5.15
15	3.699	1-Butanol, 2-methyl-	0.95	6.19	2.99	2.79
16	4.432	1-Pentanol	n.d.	0.19	n.d.	0.16
17	7.091	3-Hexen-1-ol, (Z)-	2.52	n.d.	n.d.	0.27
18	7.465	2-Hexenol	1.39	n.d.	n.d.	n.d.
19	7.576	1-Hexanol	7.83	0.72	0.23	0.55
20	13.772	Benzenemethanol	0.52	0.21	0.15	0.24
21	15.229	2-Heptanol, 2,6-dimethyl-	0.21	n.d.	n.d.	n.d.
22	16.762	Benzenethanol	0.54	1.27	0.86	0.50
		Total (% area)	33.44	38.26	66.80	46.57
<i>Ketones</i>						
23	1.444	2-Propanone	3.64	1.80	2.97	1.65
24	1.802	2,3-Butanedione	n.d.	0.44	0.39	0.16
25	2.766	2-Pentanone	0.83	0.29	n.d.	n.d.
26	3.092	Acetoin	n.d.	4.73	0.60	5.50
27	14.245	Cyclopropane, 1,1-dimethyl-2-(3-methyl-1,3-butadienyl)-	0.53	0.18	0.26	0.81
		Total (% area)	5.00	7.44	4.22	8.12
<i>Terpenes</i>						
28	8.135	Styrene	n.d.	n.d.	n.d.	0.31
29	13.419	Limonene	3.35	1.53	0.38	1.13
30	20.162	5-Octadecene, (E)-	12.19	7.24	1.50	3.47
31	30.169	Farnesene	n.d.	0.24	1.36	0.97
		Total (% area)	15.54	9.01	3.24	5.88

TABLE 6: Continued.

		Samples*				
No	RT	Volatile compounds (% area)	1	2	3	4
Carboxylic acids						
32	1.547	Acetic acid, methyl ester	1.17	0.54	0.75	0.52
33	1.827	Acetic acid	n.d.	0.23	0.91	0.30
34	1.986	Acetic acid, ethyl ester	n.d.	0.32	0.48	0.81
35	2.091	1-Propanol, 2-methyl-	1.19	2.19	1.33	1.16
36	4.177	Propanoic acid, 2-methyl-, ethyl ester	n.d.	n.d.	n.d.	0.16
37	4.623	Butanoic acid, 2-methyl-, methyl ester, (+.-.)-	n.d.	0.42	n.d.	0.10
38	4.802	2,3-Butanediol	n.d.	2.42	n.d.	5.72
39	5.086	2,3-Butanediol	n.d.	0.84	1.09	2.19
40	6.848	Butanoic acid, 2-methyl-, ethyl ester	n.d.	0.50	0.29	0.65
41	7.218	Butanoic acid, 2-methyl-	n.d.	0.75	0.42	0.24
42	12.027	Hexanoic acid	0.46	0.58	0.21	0.51
43	12.932	Propanoic acid, 2-methyl-, 3-methylbutyl ester	n.d.	2.52	0.85	n.d.
44	13.065	Propanoic acid, 2-methyl-, 2-methylbutyl ester	n.d.	3.26	1.25	n.d.
45	16.285	Butanoic acid, 2-methyl-, 3-methylbutyl ester	n.d.	0.95	0.26	n.d.
46	16.404	Butanoic acid, 2-methyl-, 2-methylbutyl ester	n.d.	0.77	0.25	0.24
		Total (% area)	2.82	16.29	8.09	12.60
Other volatile compounds (% area)						
47	1.517	Dimethyl sulfide	1.08	0.81	0.96	0.74
48	1.852	n-Hexane	4.92	0.80	n.d.	0.34
49	4.273	Benzene, methyl-	2.01	0.54	0.32	0.33
50	5.139	Octane	1.00	n.d.	n.d.	2.52
51	6.058	Hexane, 1-methoxy-	2.60	0.58	n.d.	0.61
52	6.204	3-Hexene, 1-methoxy-, (Z)-	0.96	0.11	n.d.	0.17
53	9.155	Oxime-, methoxy-phenyl_	8.80	4.34	2.92	2.10
54	10.784	N-benzylidene-dimethylammonium chloride	n.d.	0.47	n.d.	0.39
55	16.854	(E)-4,8-Dimethyl-1,3,7-nonatriene	n.d.	n.d.	n.d.	0.20
56	22.082	Unidentified component	0.69	n.d.	n.d.	n.d.
57	28.057	Unidentified component	1.02	n.d.	n.d.	n.d.
		Total (% area)	23.08	7.65	4.20	7.40

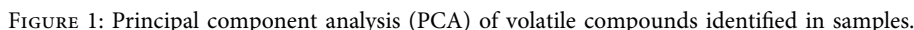
Abbreviation: nd, not detected.

*1: Raw olive, 2: Dry-salted olive after semidrying, 3: Brined olive after semidrying, 4: Cold-stored (+4°C) olive after semidrying.

When Figure 1 is analyzed, it is seen that the samples are grouped in 3 different groups. 2-Hexenal, (E)-; 2-Hexenol; 2-Heptanol, 2,6-dimethyl-; 1-Hexanol; 3-Hexen-1-ol, (Z)- and n-Hexane identified in the aroma profile of raw olives in Group 1 showed positive correlation with PC-1 component. In brined olives in Group 2, 2,4-Decadienal, (E, Z)-; 2-Propanone; 2,4-Undecadienal; Acetic acid, methyl ester and Acetic acid components showed high positive correlation with PC-2 component and formed a separate group. N-benzylidene-dimethylammonium chloride; 1-Pentanol; 5-Octadecene, (E)-; Acetoin; 2,3-Butanediol, [R-(R*, R*)]-; Butanal, 3-methyl-; Hexane, 1-methoxy-; Octane and 2-Butenal, 2-methyl- components showed negative correlation with PC-1 and PC-2 components and formed a single cluster and formed Group 3. The separation of brined olives from other processed olives was due to the high levels of 2,4-Decadienal, (E, Z)-; 2-Propanone; 2,4-Undecadienal; Acetic acid, methyl ester; Acetic acid and Ethanol in the flavor compositions (Figure 1). In the study, samples dry-salted and stored at +4°C formed a single cluster, while raw olives and brined olives were in different clusters.

HCA was used to evaluate the volatile components of olives subjected to three different processing methods and raw olives, to determine the differences among the samples. The resultant dendrogram, shown in Figure 2, indicates that raw olives and processed olives formed two primary groups. Among the processed samples, those stored at 4°C for 5 days and those with 10% dry salt added exhibited similar characteristics, while the brined sample was placed in a different subgroup. This finding corroborates the results of the PCA, indicating that the processing conditions significantly influence the volatile composition of olives, creating distinct clusters based on aroma profiles.

3.8. Sensory Analysis. Sensory analysis plays a crucial role in evaluating the quality of table olives and understanding consumers' preferences. Through sensory analysis, researchers can assess the impact of different processing methods on the sensory characteristics of table olives and identify the most favorable attributes that align with consumer preferences. Sensory analysis was conducted using



techniques. Results of the study done by Ongen et al. [31] showed that drying green table olives at 50°C for 22 h in a tray dryer produces a final product that is satisfactory and of edible quality. Additionally, samples can be kept for a year without the risk of microbial deterioration. Studies have shown that the best descriptors characterizing table olives are color, hardness, acidity, and saltiness [83].

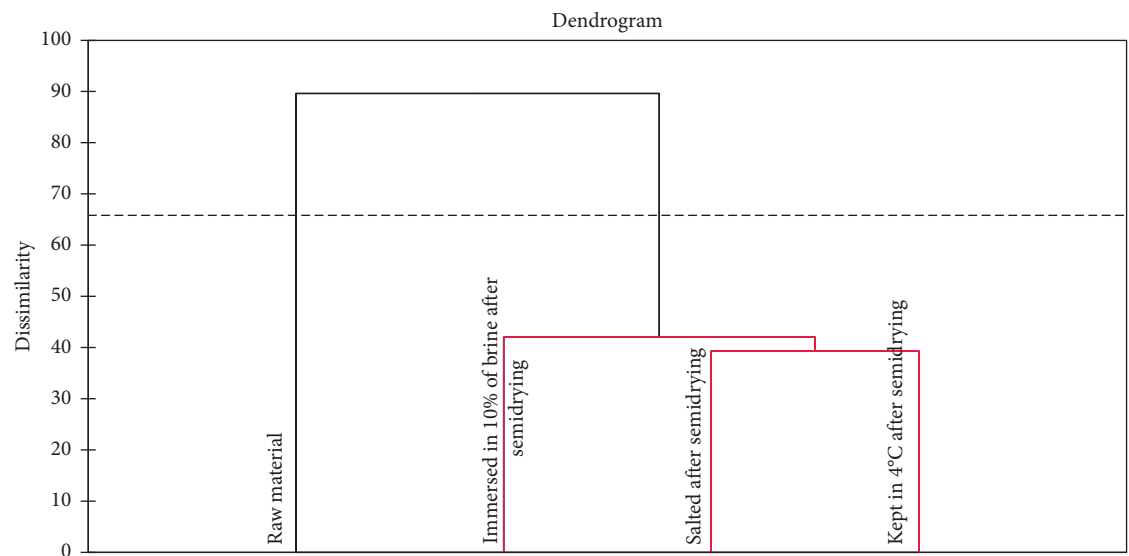


FIGURE 2: Agglomerative hierarchical clustering (AHC) of volatile compounds identified in olive samples.

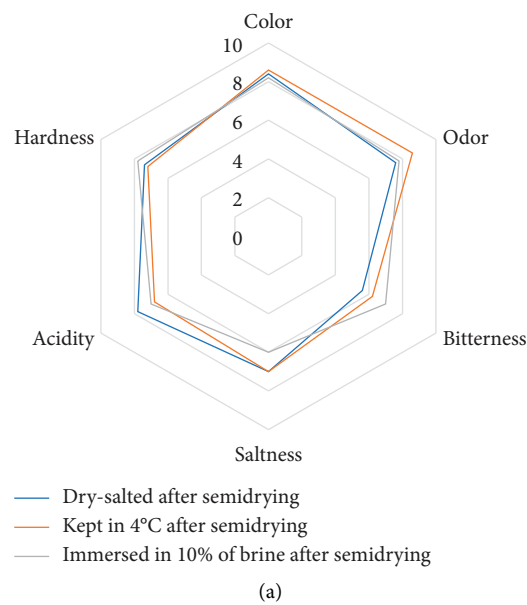


FIGURE 3: Continued.

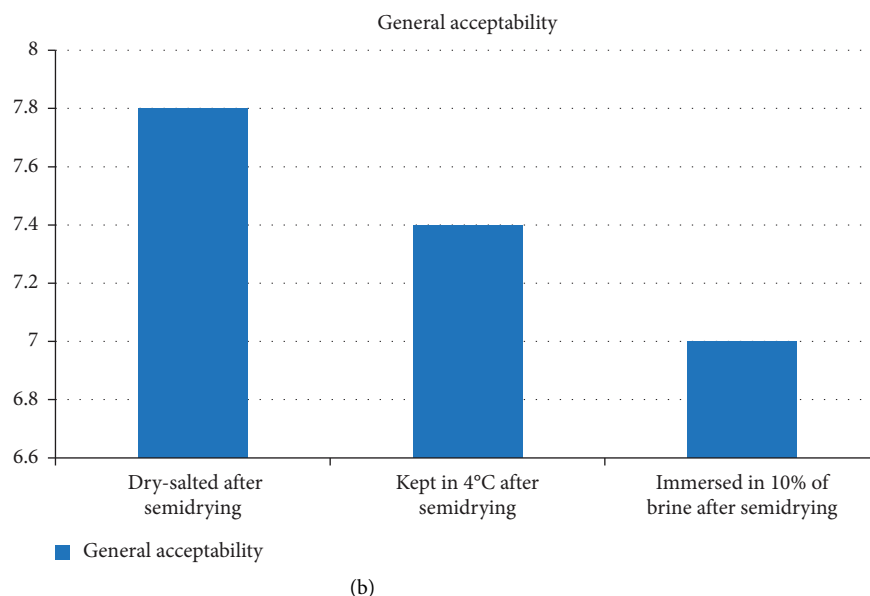


FIGURE 3: Sensory analysis results of table olives: (a) color, odor, bitterness, saltiness, acidity, and hardness and (b) general acceptability results.

The sensory attributes of table olives, including color, odor, bitterness, saltiness, acidity, and hardness, as well as overall acceptability, are presented in Figure 3. There was no statistically significant difference in color values among the table olives. The olives processed at +4°C received the highest preference for their odor. Panelists rated the olives immersed in 10% of brine after semidrying as the most preferred in terms of bitterness. Indeed, the sample immersed in 10% of brine after semidrying (Sample 3) contained the lowest amount of the bitterness compound, oleuropein. The preference for the sample containing the minimum amount of oleuropein indicated the consumer's inclination toward olives with reduced bitterness. Regarding saltiness evaluation, Sample 3 received a lower score in terms of saltiness. Sample 2 that was dry-salted after semidrying was rated as the most preferred in terms of acidity, followed by Sample 3 and Sample 4. Sample 3 was the one that received the highest rating for the hardness parameter. According to Marsilio et al. [27], after heat treatment, the olive tissues were softer and a connection between protopectin content and firmness was discovered. In oven-dried olives, a firming of the olive tissues was seen as a result of pectin's de-esterification and lower solubility as a result of an increase in calcium bridging in cell walls. When considering the general acceptability criteria, the dry-salted sample received the highest preference, followed by the one processed at +4°C. The sample immersed in 10% of brine after semidrying was rated as the least favorable.

Overall, the results indicated that the olives salted after semidrying were the most preferred, while the sample immersed in 10% of brine after semidrying was the least preferred. Kanavouras et al. [84] conducted a sensory evaluation of fermented black olives with 39 panelists. The most influential factor in the panelists' preferences was found to be the saltiness criterion. Similarly, in our study, the sample with the lowest acceptance value in terms of saltiness,

which was also subjected to brining, received the lowest general acceptability score. The saltiness criterion was also found to have a significant impact on overall liking in our study.

4. Conclusions

This study examined the effects of three processing methods (dry salting, brining, and storage at +4°C for 5 days) combined with semidrying (with HPD) on Gemlik variety table olives. The research focused on oleuropein, tyrosol, hydroxytyrosol content, sensory properties, TPC, TAA, TMA, in vitro bioaccessibility, and aroma profiles.

Results showed that raw olives had the highest TPC, TAA, oleuropein content, and TMA values. All processing methods decreased these values. After semidrying, Sample 4 (+4°C storage) maintained the highest TAA and TMA values. After in vitro digestion, DPPH values decreased but FRAP values increased in all samples. Raw olives (Sample 1) showed the most significant increase in FRAP values during digestion. TMA results indicated increased anthocyanin content after digestion in all samples. Oleuropein concentration decreased after semidrying and processing, with the highest loss in brining. Dry-salted olives had the lowest hydroxytyrosol levels. Fatty acid analysis revealed 11 different fatty acids in all samples, with oleic acid being the most abundant. Sample 4 had the highest oleic acid concentration (71.72%), while raw olives had the lowest (67.31%). Aroma analysis identified 55 out of 57 distinct compounds. Ethanol was the most prominent in processed samples. Raw olives contained only acetic acid, methyl ester, while processed olives showed acetic acid and acetic acid, ethyl ester. Sensory evaluation revealed a preference for less bitter olives. The sample subjected to dry salting after semidrying was the most preferred, while the brine-soaked sample was the least preferred.

This study offers an alternative for reduced salt consumption and improved olive processing parameters. The 51.25-h semidrying process followed by 5-day treatment renders olives consumable, providing commercial advantages. This accelerated method enhances organoleptic properties and potentially increases production efficiency, leading to improved capacity utilization and reduced operational costs. Future research could focus on optimizing drying and investigating combinations with various processing techniques.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Senanur Durgut Malçok, Cüneyt Tunçkal, and Gülderen Coşgun: formal analysis and writing – original draft; Azime Özkan Karabacak: writing – original draft, writing – review and editing, and supervision; Mehmet Torun: writing – review and editing and supervision; Canan Ece Tamer: writing – review and editing, supervision, and conceptualization.

Funding

No funding was received for this research.

References

- [1] Anonim, "Market Situation in the Olive Oil and Table Olives Sectors," *European Commission* (2024): https://agriculture.ec.europa.eu/system/files/2023-12/market-situation-olive-oil-table-olives_en.pdf.
- [2] M. Kourtı, M. V. Alvanou, Z. Skaperda, et al., "Antioxidant and DNA-Protective Activity of an Extract Originated from Kalamon Olives Debittering," *Antioxidants* 12, no. 2 (2023): 333, <https://doi.org/10.3390/antiox12020333>.
- [3] F. Visioli, A. Poli, and C. Gall, "Antioxidant and Other Biological Activities of Phenols from Olives and Olive Oil," *Medicinal Research Reviews* 22, no. 1 (2002): 65–75, <https://doi.org/10.1002/med.1028>.
- [4] S. M. Lee, K. Kitsawad, A. Sigal, D. Flynn, and J. X. Guinard, "Sensory Properties and Consumer Acceptance of Imported and Domestic Sliced Black Ripe Olives," *Journal of Food Science* 77, no. 12 (2012): S439–S448, <https://doi.org/10.1111/j.1750-3841.2012.03001.x>.
- [5] G. Boskou, F. N. Salta, S. Chrysostomou, A. Mylona, A. Chiou, and N. K. Andrikopoulos, "Antioxidant Capacity and Phenolic Profile of Table Olives from the Greek Market," *Food Chemistry* 94, no. 4 (2006): 558–564, <https://doi.org/10.1016/j.foodchem.2004.12.005>.
- [6] E. Ramirez, P. Garcia-Garcia, A. de Castro, C. Romero, and M. Brenes, "Debittering of Black Dry-Salted Olives," *European Journal of Lipid Science and Technology* 115, no. 11 (2013): 1319–1324, <https://doi.org/10.1002/ejlt.201300167>.
- [7] R. L. Johnson and A. E. Mitchell, "Reducing Phenolics Related to Bitterness in Table Olives," *Journal of Food Quality* 12 (2018).
- [8] G. Blekas, C. Vassilakis, C. Harizanis, M. Tsimidou, and D. G. Boskou, "Biophenols in Table Olives," *Journal of Agricultural and Food Chemistry* 50, no. 13 (2002): 3688–3692, <https://doi.org/10.1021/jf0115138>.
- [9] P. Conte, C. Fadda, A. Del Caro, P. P. Urgeghe, and A. Piga, "Table Olives: An Overview on Effects of Processing on Nutritional and Sensory Quality," *Foods* 9, no. 4 (2020): 514, <https://doi.org/10.3390/foods9040514>.
- [10] V. Marsilio, C. Campestre, and B. Lanza, "Phenolic Compounds Change during California-style Ripe Olive Processing," *Food Chemistry* 74, no. 1 (2001): 55–60, [https://doi.org/10.1016/S0308-8146\(00\)00338-1](https://doi.org/10.1016/S0308-8146(00)00338-1).
- [11] V. Marsilio, L. Seghetti, E. Iannucci, F. Russi, B. Lanza, and M. Felicioni, "Use of a Lactic Acid Bacteria Starter Culture during Green Olive (*Olea Europaea* L cv *Ascolana tenera*) Processing," *Journal of the Science of Food and Agriculture* 85, no. 7 (2005): 1084–1090, <https://doi.org/10.1002/jsfa.2066>.
- [12] E. Melliou, J. A. Zweigenbaum, and A. E. Mitchell, "Ultrahigh-Pressure Liquid Chromatography Triple-Quadrupole Tandem Mass Spectrometry Quantitation of Polyphenols and Secoiridoids in California-Style Black Ripe Olives and Dry Salt-Cured Olives," *Journal of Agricultural and Food Chemistry* 63, no. 9 (2015): 2400–2405, <https://doi.org/10.1021/jf506367e>.
- [13] A. Garcia, C. Romero, E. Medina, P. Garcia, A. De Castro, and M. Brenes, "Debittering of Olives by Polyphenol Oxidation," *Journal of Agricultural and Food Chemistry* 56, no. 24 (2008): 11862–11867, <https://doi.org/10.1021/jf802967y>.
- [14] P. Garcia-Serrano, M. Brenes-Alvarez, C. Romero, E. Medina, P. Garcia-Garcia, and M. Brenes, "Physicochemical and Microbiological Assessment of Commercial Dehydrated Black Olives," *Food Control* 145 (2023): 109417, <https://doi.org/10.1016/j.foodcont.2022.109417>.
- [15] E. Z. Panagou, "Greek Dry-Salted Olives: Monitoring the Dry-Salting Process and Subsequent Physico-Chemical and Microbiological Profile during Storage under Different Packing Conditions at 4 and 20°C," *LWT: Food Science and Technology* 39, no. 4 (2006): 323–330, <https://doi.org/10.1016/j.lwt.2005.02.017>.
- [16] M. Brenes, P. Garcia-Serrano, M. Brenes-Alvarez, E. Medina, P. Garcia-Garcia, and C. Romero, "Dehydrated Black Olives from Unfermented and Alkali Treated Green Olives," *LWT: Food Science and Technology* 172 (2022): 114177, <https://doi.org/10.1016/j.lwt.2022.114177>.
- [17] N. Degirmencioglu, O. Gurbuz, A. Degirmencioglu, Y. Sahan, and H. Ozbey, "Effect of MAP and Vacuum Sealing on Sensory Qualities of Dry-Salted Olive," *Food Science and Biotechnology* 20, no. 5 (2011): 1307–1313, <https://doi.org/10.1007/s10068-011-0180-9>.
- [18] S. M. Cardoso, I. Mafra, A. Reis, et al., "Effect of Dry-Salt Processing on the Textural Properties and Cell Wall Polysaccharides of Cv. Thasos Black Olives," *Journal of the Science of Food and Agriculture* 88, no. 12 (2008): 2079–2086, <https://doi.org/10.1002/jsfa.3317>.
- [19] S. M. Cardoso, I. Mafra, A. Reis, et al., "Traditional and Industrial Oven-Dry Processing of Olive Fruits: Influence on Textural Properties, Cell Wall Polysaccharide Composition, and Enzymatic Activity," *European Food Research and Technology* 229, no. 3 (2009): 415–425, <https://doi.org/10.1007/s00217-009-1074-4>.
- [20] M. Brenes and A. de Castro, "Transformation of Oleuropein and its Hydrolysis Products during Spanish-style Green Olive

- Processing," *Journal of the Science of Food and Agriculture* 77, no. 3 (1998): 353–358.
- [21] E. Medina, C. Romero, M. Brenes, P. Garcia, A. de Castro, and A. Garcia, "Profile of Anti-lactic Acid Bacteria Compounds during the Storage of Olives Which Are Not Treated with Alkali," *European Food Research and Technology* 228, no. 1 (2008): 133–138, <https://doi.org/10.1007/s00217-008-0916-9>.
 - [22] M. Servili, L. Settanni, G. Veneziani, et al., "The Use of *Lactobacillus pentosus* 1MO to Shorten the Debitting Process Time of Black Table Olives (Cv. Itrana and Leccino): A Pilot-Scale Application," *Journal of Agricultural and Food Chemistry* 54, no. 11 (2006): 3869–3875, <https://doi.org/10.1021/jf053206y>.
 - [23] J. M. Moreno-Baquero, J. Bautista-Gallego, A. Garrido-Fernandez, and A. Lopez-Lopez, "Mineral and Sensory Profile of Seasoned Cracked Olives Packed in Diverse Salt Mixtures," *Food Chemistry* 138, no. 1 (2013): 1–8, <https://doi.org/10.1016/j.foodchem.2012.10.027>.
 - [24] B. Lanza, M. G. Di Serio, E. Iannucci, F. Russi, and P. Marfisi, "Nutritional, Textural and Sensorial Characterisation of Italian Table Olives (*Olea europaea* L. Cv. 'Intosso d'Abruzzo')," *International Journal of Food Science and Technology* 45, no. 1 (2010): 67–74, <https://doi.org/10.1111/j.1365-2621.2009.02104.x>.
 - [25] A. Kyriacou, K. E. Lasaridi, M. Kotsou, C. Balis, and G. Pilidis, "Combined Bioremediation and Advanced Oxidation of Green Table Olive Processing Wastewater," *Process Biochemistry* 40, no. 3–4 (2005): 1401–1408, <https://doi.org/10.1016/j.procbio.2004.06.001>.
 - [26] J. Bautista-Gallego, K. Rantsiou, A. Garrido-Fernandez, L. Coccolin, and F. N. Arroyo-Lopez, "Salt Reduction in Vegetable Fermentation: Reality or Desire?" *Journal of Food Science* 78, no. 8 (2013): R1095–R1100, <https://doi.org/10.1111/1750-3841.12170>.
 - [27] V. Marsilio, B. Lanza, C. Campestre, and M. De Angelis, "Oven-dried Table Olives: Textural Properties as Related to Pectic Composition," *Journal of the Science of Food and Agriculture* 80, no. 8 (2000): 1271–1276.
 - [28] E. De Florio Ramirez and L. Chipana Bergamini, *Deshidratación de Aceituna Negra (Olea europaea. L.) Variedad Sevillana: Tacna* (Ciencia & Desarrollo, 2019).
 - [29] A. Boukhiar, K. Kechadi, R. Abdellaoui, N. Iguergaziz, M. Guemmane, and S. Benamara, "Drying Ability of Whole Black Olive (*Olea Europaea* L.) Fruits in Kabylia Region (North-East Algeria)," *Indian Journal of Traditional Knowledge* 16, no. 1 (2017): 89–94.
 - [30] A. Piscopo, A. De Bruno, A. Zappia, and M. Poiana, "Antioxidant Activity of Dried Green Olives (*Carolea* cv.)," *LWT: Food Science and Technology* 58, no. 1 (2014): 49–54, <https://doi.org/10.1016/j.lwt.2014.03.013>.
 - [31] G. Ongen, S. Sargin, D. Tetik, and T. Kose, "Hot Air Drying of Green Table Olives," *Food Technology and Biotechnology* 43, no. 2 (2005): 181–187.
 - [32] A. Piga, F. Gambella, M. Agabbio, V. Vacca, and G. D'Hallewin, "Effect of Different Pre-treatments on Drying of Green Table Olives (*Ascolana tenera* var.)," *Grasas y Aceites* 51, no. 3 (2000): 173–176, <https://doi.org/10.3989/gya.2000.v51.i3.475>.
 - [33] Y. Deng, Y. Wang, J. Yue, et al., "Thermal Behavior, Microstructure and Protein Quality of Squid Fillets Dried by Far-Infrared Assisted Heat Pump Drying," *Food Control* 36, no. 1 (2014): 102–110, <https://doi.org/10.1016/j.foodcont.2013.08.006>.
 - [34] I. Doymaz, "Influence of Infrared Drying on Some Quality Properties of Nashi Pear (*Pyrus pyrifolia*) Slices," *Erwerbs-obstbau* 65, no. 1 (2023): 47–54, <https://doi.org/10.1007/s10341-022-00786-4>.
 - [35] S. D. Malçok, A. Ö. Karabacak, E. Bekar, C. Tunçal, and C. E. Tamer, "Influence of a Hybrid Drying Combined with Infrared and Heat Pump Dryer on Drying Characteristics, Colour, Thermal Imaging and Bioaccessibility of Phenolics and Antioxidant Capacity of Mushroom Slices," *Journal of Agricultural Engineering* 54, no. 3 (2023): 1537, <https://doi.org/10.4081/jae.2023.1537>.
 - [36] S. Kamiloglu and E. Capanoglu, "In Vitro Gastrointestinal Digestion of Polyphenols from Different Molasses (Pekmez) and Leather (Pestil) Varieties," *International Journal of Food Science and Technology* 49, no. 4 (2014): 1027–1039, <https://doi.org/10.1111/ijfs.12396>.
 - [37] A. Kumaran and R. Joel karunakaran, "Antioxidant and Free Radical Scavenging Activity of an Aqueous Extract of Coleus Aromaticus," *Food Chemistry* 97, no. 1 (2006): 109–114, <https://doi.org/10.1016/j.foodchem.2005.03.032>.
 - [38] I. F. F. Benzie and J. J. Strain, "The Ferric Reducing Ability of Plasma (FRAP) as a Measure of "antioxidant Power": The FRAP Assay," *Analytical Biochemistry* 239, no. 1 (1996): 70–76, <https://doi.org/10.1006/abio.1996.0292>.
 - [39] J. Lee, R. W. Durst, R. E. Wrolstad, et al., "Determination of Total Monomeric Anthocyanin Pigment Content of Fruit Juices, Beverages, Natural Colorants, and Wines by the pH Differential Method: Collaborative Study," *Journal of AOAC International* 88, no. 5 (2005): 1269–1278, <https://doi.org/10.1093/jaoac/88.5.1269>.
 - [40] M. Minekus, M. Alvinger, P. Alvito, et al., "A Standardised Static In Vitro Digestion Method Suitable for Food: an International Consensus," *Food & Function* 5, no. 6 (2014): 1113–1124, <https://doi.org/10.1039/c3fo60702j>.
 - [41] R. Garcés and M. Mancha, "One-step Lipid Extraction and Fatty Acid Methyl Esters Preparation from Fresh Plant Tissues," *Analytical Biochemistry* 211, no. 1 (1993): 139–143, <https://doi.org/10.1006/abio.1993.1244>.
 - [42] L. León, L. Martín, and L. Rallo, "Repeatability and Minimum Selection Time for Fatty Acid Composition in Olive Progenies," *HortScience* 39, no. 3 (2004): 477–480, <https://doi.org/10.21273/hortsci.39.3.477>.
 - [43] F. Balci-Torun and F. Ozdemir, "Encapsulation of Strawberry Flavour and Physicochemical Characterization of the Encapsulated Powders," *Powder Technology* 380 (2021): 602–612, <https://doi.org/10.1016/j.powtec.2020.11.060>.
 - [44] L. Zhou, Z. Cao, J. Bi, et al., "Degradation Kinetics of Total Phenolic Compounds, Capsaicinoids and Antioxidant Activity in Red Pepper during Hot Air and Infrared Drying Process," *International Journal of Food Science and Technology* 51, no. 4 (2016): 842–853, <https://doi.org/10.1111/ijfs.13050>.
 - [45] I. O. Minatel, C. V. Borges, M. I. Ferreira, H. A. G. Gomez, C.-Y. O. Chen, and G. P. P. Lima, "Phenolic Compounds: Functional Properties, Impact of Processing and Bioavailability," *Phenolic Compd. Biol. Act* 8 (2017): 1–24.
 - [46] R. Malheiro, S. Casal, A. Sousa, et al., "Effect of Cultivar on Sensory Characteristics, Chemical Composition, and Nutritional Value of Stoned Green Table Olives," *Food and Bioprocess Technology* 5 (2012): 1733–1742, <https://doi.org/10.1007/s11947-011-0567-x>.
 - [47] N. B. Othman, D. Roblain, N. Chammen, P. Thonart, and M. Hamdi, "Antioxidant Phenolic Compounds Loss during the Fermentation of Chetoui Olives," *Food Chemistry* 116, no. 3 (2009): 662–669, <https://doi.org/10.1016/j.foodchem.2009.02.084>.
 - [48] M. P. Romero, M. J. Tovar, J. Girona, and M. J. Motilva, "Changes in the HPLC Phenolic Profile of Virgin Olive Oil from Young Trees (*Olea europaea* L. Cv. *Arbequina*) Grown under Different Deficit Irrigation Strategies," *Journal of*

- Agricultural and Food Chemistry* 50, no. 19 (2002): 5349–5354, <https://doi.org/10.1021/jf020357h>.
- [49] G. Yıldız and V. Uylaşer, "Profile and Total Content of Phenolics and Antioxidant Activity of Commercial Table Olives from Turkey," *Quality Assurance and Safety of Crops & Foods* 7, no. 5 (2015): 635–642, <https://doi.org/10.3920/qas2014.0430>.
 - [50] F. A. Ahmed and R. F. Ali, "Bioactive Compounds and Antioxidant Activity of Fresh and Processed White Cauliflower," *BioMed Research International* 2013 (2013): 1–9, <https://doi.org/10.1155/2013/367819>.
 - [51] J. He and M. M. Giusti, "Anthocyanins: Natural Colorants with Health-Promoting Properties," *Annual Review of Food Science and Technology* 1 (2010): 163–187, <https://doi.org/10.1146/annurev.food.080708.100754>.
 - [52] M. Brenes, L. Rejano, P. Garcia, A. H. Sanchez, and A. Garrido, "Biochemical Changes in Phenolic Compounds during Spanish-style Green Olive Processing," *Journal of Agricultural and Food Chemistry* 43, no. 10 (1995): 2702–2706, <https://doi.org/10.1021/jf00058a028>.
 - [53] N. Özdemirli and S. Kamiloglu Beştepe, "Kavun Çekirdeği Şerbetinde (Sübye) Fenolik Bileşiklerin Biyoerişilebilirliğinin Değerlendirilmesi," *Gıda* 47, no. 6 (2022): 1130–1139, <https://doi.org/10.15237/gida.gd22083>.
 - [54] J. Bouayed, L. Hoffmann, and T. Bohn, "Total Phenolics, Flavonoids, Anthocyanins and Antioxidant Activity Following Simulated Gastro-Intestinal Digestion and Dialysis of Apple Varieties: Bioaccessibility and Potential Uptake," *Food Chemistry* 128, no. 1 (2011): 14–21, <https://doi.org/10.1016/j.foodchem.2011.02.052>.
 - [55] S. Kamiloglu, "Taze Ve Dondurulmuş Elmalarda Ve Elma Posasında Polifenol Biyoerişilebilirliğinin Değerlendirilmesi," *Gıda* 44, no. 3 (2019): 409–418, <https://doi.org/10.15237/gida.gd19026>.
 - [56] M. J. Amiot, A. Fleuriot, and J. J. Macheix, "Importance and Evolution of Phenolic Compounds in Olive During Growth and Maturation," *Journal of Agricultural and Food Chemistry* 34, no. 5 (1986): 823–826, <https://doi.org/10.1021/jf00071a014>.
 - [57] C. D. Goldsmith, D. R. Bond, H. Jankowski, et al., "The Olive Biophenols Oleuropein and Hydroxytyrosol Selectively Reduce Proliferation, Influence the Cell Cycle, and Induce Apoptosis in Pancreatic Cancer Cells," *International Journal of Molecular Sciences* 19, no. 7 (2018): 1937, <https://doi.org/10.3390/ijms19071937>.
 - [58] E. Zoidou, E. Melliou, E. Gikas, A. Tsarbopoulos, P. Magiatis, and A.-L. Skaltsounis, "Identification of Throuba Thassos, A Traditional Greek Table Olive Variety, As a Nutritional Rich Source of Oleuropein," *Journal of Agricultural and Food Chemistry* 58, no. 1 (2010): 46–50, <https://doi.org/10.1021/jf903405e>.
 - [59] S. Charoenprasert and A. Mitchell, "Factors Influencing Phenolic Compounds in Table Olives (*Olea europaea*)," *Journal of Agricultural and Food Chemistry* 60, no. 29 (2012): 7081–7095, <https://doi.org/10.1021/jf3017699>.
 - [60] A. Bianco and N. Uccella, "Biophenolic Components of Olives," *Food Research International* 33, no. 6 (2000): 475–485, [https://doi.org/10.1016/s0963-9969\(00\)00072-7](https://doi.org/10.1016/s0963-9969(00)00072-7).
 - [61] D. Mihajlović, S. Čolić, J. Marković, et al., "Heat Treatment Effect on Tocopherols, Total Phenolics and Fatty Acids in Table Olives (*Olea europaea* L.)," *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 51, no. 1 (2023): 13029, <https://doi.org/10.15835/nbha51113029>.
 - [62] K. J. Hunter and J. M. Fletcher, "The Antioxidant Activity and Composition of Fresh, Frozen, Jarred and Canned Vegetables," *Innovative Food Science & Emerging Technologies* 3, no. 4 (2002): 399–406, [https://doi.org/10.1016/s1466-8564\(02\)00048-6](https://doi.org/10.1016/s1466-8564(02)00048-6).
 - [63] A. Dag, S. Boim, Y. Sobotin, and I. Zipori, "Effect of Mechanically Harvested Olive Storage Temperature and Duration on Oil Quality," *HortTechnology* 22, no. 4 (2012): 528–533, <https://doi.org/10.21273/horttech.22.4.528>.
 - [64] L. Sanchez-Rodriguez, M. Cano-Lamadrid, A. A. Carbonell-Barrachina, F. Hernandez, and E. Sendra, "Impact of Gastrointestinal *In Vitro* Digestion and Deficit Irrigation on Antioxidant Activity and Phenolic Content Bioaccessibility of 'Manzanilla' Table Olives," *Journal of Food Quality* 2020 (2020): 1–6, <https://doi.org/10.1155/2020/6348194>.
 - [65] X. Li, L. Yu, Y. Xie, et al., "Effect of Different Cooking Methods on the Nutrient, and Subsequent Bioaccessibility and Biological Activities in *Boletus Auripes*," *Food Chemistry* 405 (2023): 134358, <https://doi.org/10.1016/j.foodchem.2022.134358>.
 - [66] M. P. Fernandez-Poyatos, A. Ruiz-Medina, and E. J. Llorent-Martinez, "Phytochemical Profile, Mineral Content, and Antioxidant Activity of *Olea europaea* L. Cv. Cornezuelo Table Olives. Influence of *In Vitro* Simulated Gastrointestinal Digestion," *Food Chemistry* 297 (2019): 124933, <https://doi.org/10.1016/j.foodchem.2019.05.207>.
 - [67] I. D'Antuono, A. Bruno, V. Linsalata, et al., "Fermented Apulian Table Olives: Effect of Selected Microbial Starters on Polyphenols Composition, Antioxidant Activities and Bioaccessibility," *Food Chemistry* 248 (2018): 137–145, <https://doi.org/10.1016/j.foodchem.2017.12.032>.
 - [68] A. Y. Vazquez-Sanchez, R. Corfield, N. Sosa, D. Salvatori, and C. Schebor, "Physicochemical, Functional, and Sensory Characterization of Apple Leathers Enriched with *Acachul (Ardisia Compressa Kunth)* Powder," *LWT: Food Science and Technology* 146 (2021): 111472, <https://doi.org/10.1016/j.lwt.2021.111472>.
 - [69] A. Piga, A. Del Caro, I. Pinna, and M. Agabbio, "Anthocyanin and Colour Evolution in Naturally Black Table Olives during Anaerobic Processing," *LWT: Food Science and Technology* 38, no. 4 (2005): 425–429, <https://doi.org/10.1016/j.lwt.2004.06.011>.
 - [70] Z. Tan, B. Halter, D. Liu, E. R. Gilbert, and M. A. Cline, "Dietary Flavonoids as Modulators of Lipid Metabolism in Poultry," *Frontiers in Physiology* 13 (2022): 863860, <https://doi.org/10.3389/fphys.2022.863860>.
 - [71] Y. Liu, D. Zhang, Y. Wu, et al., "Stability and Absorption of Anthocyanins from Blueberries Subjected to a Simulated Digestion Process," *International Journal of Food Sciences & Nutrition* 65, no. 4 (2014): 440–448, <https://doi.org/10.3109/09637486.2013.869798>.
 - [72] V. Uylaşer, B. İncedayı, C. E. Tamer, N. Yılmaz, and Ö. U. Çopur, "Physico-Chemical Properties and Fatty Acid Composition of Gemlik Variety Olives" (2009).
 - [73] M. El Riachy, A. Hamade, R. Ayoub, F. Dandachi, and L. Chalakh, "Oil Content, Fatty Acid and Phenolic Profiles of Some Olive Varieties Growing in Lebanon," *Frontiers in Nutrition* 6 (2019): 94, <https://doi.org/10.3389/fnut.2019.00094>.
 - [74] A. B. Amaral, M. V. d. Silva, and S. C. d. S. Lannes, "Lipid Oxidation in Meat: Mechanisms and Protective Factors—A Review," *Food Science and Technology* 38, no. suppl 1 (2018): 1–15, <https://doi.org/10.1590/fst.32518>.
 - [75] H. Avcı, Y. Uğur, and S. Erdoğan, "Evaluation of Fatty Acid Compositions and Physicochemical Quality Parameters of Ancient and Recent Olive (*Olea europaea* L.) Oil Varieties of Southeast Anatolia," *International Journal of Chemistry and Technology* 2, no. 2 (2018): 76–88, <https://doi.org/10.32571/ijct.455519>.

- [76] S. Selli, H. Kelebek, S. Kesen, and A. S. Sonmezdag, "GC-MS Olfactometric and LC-DAD-ESI-MS/MS Characterization of Key Odorants and Phenolic Compounds in Black Dry-salted Olives," *Journal of the Science of Food and Agriculture* 98, no. 11 (2018): 4104–4111, <https://doi.org/10.1002/jsfa.8927>.
- [77] J. Reinert and W. Grosch, "Odorants of Virgin Olive Oils with Different Flavor Profiles," *Journal of Agricultural and Food Chemistry* 46, no. 7 (1998): 2754–2763, <https://doi.org/10.1021/jf970940b>.
- [78] N. Sabatini, E. Perri, and V. Marsilio, "An Investigation on Molecular Partition of Aroma Compounds in Fruit Matrix and Brine Medium of Fermented Table Olives," *Innovative Food Science and Emerging Technologies* 10, no. 4 (2009): 621–626, <https://doi.org/10.1016/j.ifset.2009.05.001>.
- [79] M. Herrero, C. Quirós, L. A. García, and M. Díaz, "Use of Flow Cytometry to Follow the Physiological States of Microorganisms in Cider Fermentation Processes," *Applied and Environmental Microbiology* 72, no. 10 (2006): 6725–6733, <https://doi.org/10.1128/aem.01183-06>.
- [80] M. Etschmann, W. Bluemke, D. Sell, and J. Schrader, "Biotechnological Production of 2-phenylethanol," *Applied Microbiology and Biotechnology* 59 (2002): 1–8, <https://doi.org/10.1007/s00253-002-0992-x>.
- [81] M. Ridolfi, S. Terenziani, M. Patumi, and G. Fontanazza, "Characterization of the Lipoxygenases in Some Olive Cultivars and Determination of Their Role in Volatile Compounds Formation," *Journal of Agricultural and Food Chemistry* 50, no. 4 (2002): 835–839, <https://doi.org/10.1021/jf0109118>.
- [82] S. Dabbou, M. Issaoui, F. Brahmi, et al., "Changes in Volatile Compounds during Processing of Tunisian-style Table Olives," *Journal of the American Oil Chemists' Society* 89, no. 2 (2012): 347–354, <https://doi.org/10.1007/s11746-011-1907-8>.
- [83] M. M. González, T. Navarro, G. Gómez, R. A. Pérez, and C. De Lorenzo, "Análisis sensorial de aceituna de mesa: II. Aplicabilidad práctica y correlación con el análisis instrumental, Sensory assessment of table olives: II. Practical application and correlation with instrumental analysis," no. 3 (2007), 231–236.
- [84] A. Kanavouras, M. Gazouli, L. Tzouvelekis Leonidas, and C. Petrakis, "Evaluation of Greek-style Black Table Olives in Salt Varying Brines," *Grasas y Aceites* 56, no. 2 (2005): 106–115, <https://doi.org/10.3989/gya.2005.v56.i2.117>.