Chapter 12

Modern Techniques in the Production of Table Olives

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Abstract

The olive tree (*Olea europaea* L.) is one of the most important trees in the world, and olive oil and table olives are consumed extensively as a basic ingredient of the Mediterranean diet. Table olives are prepared from the fruit of a variety of cultivated olive trees, and, after removing their bitterness by several methods, they are preserved by natural fermentation or other methods before packing. Currently, scientists and consumers alike are interested in and prefer fresh and healthy table olives that have been minimally and safely processed. The aim of this chapter is to provide information about the modern food-processing techniques that are used to improve the quality characteristics of table olives.

Keywords: table olives, washing, pesticide, debittering, non-thermal processing, salt reduction, packaging

1. Introduction

Table olives are the most important and popular fermented vegetable in the food industry, especially in Spain, Turkey, Italy, Egypt, Morocco, and Greece. They are produced in two ways, that is, (1) by treating green olives with an alkaline solution, which is known as the Spanish style of treatment and (2) by treating olives in an alkaline oxidation process, which is known as the California style of treatment. The olives may be directly brined, or they can be used untreated [1–4]. Also, they can be prepared by other traditional methods (e.g., dry-salting and cracking), industrial processing, or homemade production using various fermentation conditions (e.g., temperature, aeration, and salt content) based on their degree of maturation (i.e., green, turning color, or black) [5–8]. Modern food-processing technologies often rely on non-thermal processes, and fresh fruit, such as olives, are passed through various processing steps to remove soil and pesticide residues and to reduce the microbial load. These processing steps include cleaning, trimming, peeling, coring, slicing, shredding, washing, sanitizing, packaging, and storage. The final product can be stored at a low temperature or packaged using vacuum packaging (VP) and/or modified atmosphere packaging (MAP). These techniques control the growth of fungi, thereby minimizing the potential for producing mycotoxins. The use of low-temperature storage (<4°C) can increase the product's shelf life [4, 5, 9]. In recent years, scientists and consumers have been interested in fresh, healthy foods that are safe and have been minimally processed by novel preservation technologies. In this chapter, we describe the current methods that are used to process table olives.

2. Preprocessing of olives

2.1. Surface disinfection processes

Surface disinfection processes have the potential for eliminating undesirable microbial species by (i) modification of the composition of the surfaces of the olives by dipping/spraying with antimicrobial solutions or with substances that prevent enzymatic or physical deterioration, (ii) modification of the microecology of the food's surface by curing or bioprotection, (iii) isolation of the food's surface from the environment by packaging or coating with an edible substance, (iv) removal of contaminants from the surfaces of the olives by washing or blowing them with air, (v) modification of the redox potential of the food's surface by washing with aqueous solutions that contain chlorine or hydrogen peroxide, or by ultraviolet radiation (UV) or pulsed light [10], and (vi) using modified atmosphere packaging (MAP) or active packaging to modify the composition and redox potential of the atmosphere in contact with the surfaces of the olives [5, 6].

2.2. Chlorine-based agents

Chlorine-based agents are often used to disinfect olives due to their bactericidal properties and cost efficiency [4, 11]. Such agents include sodium hypochlorite (NaClO), calcium hypochlorite ($Ca(ClO)_2$), and chlorine gas (Cl_2). Industrial applications of chlorinated water, at the conditions of 50–200 ppm free chlorine, 1–2 min, and pH = 6.0–7.5, are used extensively to wash fruits and vegetables, but its effectiveness in reducing the population of microorganisms is limited (<2 log colony-forming unit—cfu), and it has the potential to react with organic materials to form harmful by-products.

2.3. Gaseous chlorine dioxide (ClO_2)

Gaseous chlorine dioxide (ClO_2) at the concentration of 0.1 ppm in high-pH solutions can reach and penetrate microorganisms better than aqueous sanitizers, and it has about 2.5 times the oxidation capacity of chlorine [11]. However, the residual concentration of ClO_2 in foods should not exceed 3 mg/L [12], because it can cause sensory changes [11].

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2.4. Ozone (O_3)

Ozone (O_3) is a natural and strong oxidant in the atmosphere, and it is used for sterilization, virus inactivation, deodorization, decolorization, decomposition of organic matter, degradation of mycotoxins, and oxidizing pesticides to reduce their adverse effects on people [13]. Ozone is 1.5 times stronger than chlorine as an oxidizing agent [14], and, to disinfect food products, it is recommended that water containing 2–10 ppm of ozone be used for up to 5 min at a slightly acidic pH [11]. The Code of Federal Regulations indicates that "ozone may be safely used in the treatment, storage, and processing of foods" [15]. Weak organic acids may inhibit microorganisms to a greater extent than strong acids, depending on the type of acid used, the pH of the medium, and the concentration and temperature of the acid solution [4]. However, high concentrations of organic acids, such as acetic acid and lactic acid, must be used to affect the undesirable microorganisms, but even the minimum effective doses of these acids are likely to have adverse effects on the sensory quality of the produce [11].

In considering other non-thermal disinfectant approaches, Gök and Pazır [16] evaluated the effects of tap water, NaClO (15, 30, 50, and 80 ppm for 1 min), electrolyzed oxidizing water (EOW), and ultraviolet (UV) irradiation processes (at distances of 10, 15, and 20 cm and UV irradiation times of 5, 10, 15, 20, and 30 min) for disinfecting the surfaces of black Gemlik olives. According to the results of their research, the highest efficiency was obtained at a chlorine concentration of 80 ppm for 20 min with the product at a distance of 10 cm from the UV lamp. However, the use of UV light may not be practical because the water used to wash the fresh produce would have considerable UV absorbance due to the presence of organic matter or suspended particles that could absorb or shield the UV rays [11].

2.5. Pesticides

Most pesticide residues are retained on the surface of the peels of fruits and vegetables, and whether the pesticides are removed, reduced, or retained depends on their solubility in water. The pesticides also can be removed by various other processes, such as peeling, brushing, blanching, juicing, cooking, milling, hydrostatic pressure, boiling, baking, drying, pasteurization, malting, brewing, fermentation, canning, oil extraction, and refining [13].

Agrochemicals, which include insecticides, herbicides, and fungicides, are used extensively in the olive plantations of Mediterranean countries, and they are intended to decrease losses during production and at harvest time by protecting the olive trees from insects, such as *Daucus oleae* [17–19]. However, the residues of these pesticides can persist to the harvest stage, so they may contaminate the olives that are used to produce table olives and olive oil [17, 18, 20]. The possible contamination of olives by pesticides generally is due to the inappropriate use of the pesticides, for example, using dosages that are too high. This often occurs because the producers do not respect the guidelines for the use of pesticides, resulting in a contamination if flight olives mix with soil olives during harvesting [18, 21]. Therefore, to protect human health and to improve the quality of olive products, different regulations that establish maximum residue limits (MRLs) in olives have been established by both the European Union (EU) and the Food and Agriculture Organization (FAO) of the United Nations [17, 18].

Olives that have fallen from the tree to the ground are used as table olives and to produce olive oil, but they have higher levels of pesticide residue than olives that are collected directly from the tree. Thus, washing the olives by dipping them into water to remove or reduce pesticide residues is a preliminary step that is used when producing table olives and olive oil. The most commonly recommended chemical agents for removing hydrophobic pesticide residues and for improving the effectiveness of washing procedures are chlorine (10–100 ppm), chlorine dioxide (10–500 ppm), ozone (1–3 ppm), hydrogen peroxide (10–100 ppm), weak and strong acids, calcium hypochlorite ($Ca(OCl)_2$, 500 ppm), potassium permanganate ($KMnO_4$, 0.001%), NaCl solution (5–10%), baking soda ($NaHCO_3$, 5–10%), vinegar (0.1%) for several minutes, and ultrasonic cleaners [13, 22–24]. Among these chemical agents, chlorine dioxide (ClO_2) is the most powerful oxidizing agent, and several researchers have shown that it can remove significant amounts of pesticide residues from several foods. It has been observed that several parameters, including ozone dosage, treatment time, temperature, bubble size, oil content, thickness of the surface, the concentration of the pesticide on the olives, and the structural properties of pesticide, can affect the efficiency of pesticide removal. Obviously, better removal efficiency can be obtained if these parameters are optimized [14, 22]. The application of intense UV light also can promote the degradation of some pesticides by direct photolysis due to their potential to absorb light [18]. Nieto et al. [18] attempted to develop a simple UV immersion system (200–280 nm, 150 W) to reduce the amount of pesticides in virgin olive oil depending on the treatment time and temperature (15, 20, 25, and 30°C). While these results indicated the possibility of using UV light as an effective, low-cost process for the destruction of pesticides in olive oil and in table olives, no further progress has been reported in this regard.

3. Debittering process for table olives

Generally, oleuropein is the major phenolic compound in olive cultivars, and it is responsible for the well-known bitterness of olives [25, 26]. However, there are significant decreases in the amount of oleuropein as the olives ripen and are processed [25, 27, 28]. Olives can be consumed only after debittering, which consists of the removal or degradation of oleuropein by the action of lye, some microorganisms, or enzymes. In the natural processing, olives are placed directly in brine without prior debittering with lye solutions, and their bitterness diminishes during storage. Then, the olives are fermented to have their characteristic texture and aroma [27–34]. The action of strains of lactic acid bacteria (LAB) has been proposed as a way to biologically debitter olives, and the direct oxidation of oleuropein also has been proposed [28, 30–33]. Table olives can be debittered with an NaOH solution (1–3%) that hydrolyzes the ester bond of hydroxytyrosol before brining [25, 28, 29]. The debittering treatment is followed by washing with tap water. Then, the olives are placed in a brine solution (6–11%), in which they undergo lactic acid fermentation, which depends on the cultivar, salt content, and temperature [2, 28, 29, 31, 35].

In the rapidly expanding food industry, new and alternative technologies are needed to reduce the debittering process time and to completely replace the use of NaOH and the subsequent neutralizing washes or brine debittering processes. Ultra sound (US) is one of the newest, fastest-growing, non-thermal food analysis and processing methods, and it has no known negative side effects; it uses the energy generated by sound waves (at frequencies too high to be detected by the human ear) [36]. In order to scale up the debittering of olives using US, large tanks are equipped with power US generators at different conditions of power and amplitude [25, 33]. Habibi et al. [36] studied the effects of US-accelerated debittering (UAD, 35 kHz frequency, 40 W power, 10–50 min) of olives at different concentrations of NaOH that is, 1.50, 1.75, and 2.00% (w/v), and at different temperatures, that is, 25, 30, and 35°C. They stated that UAD was a suitable and applicable technique to minimize the time required to debitter olives and to reduce the NaOH concentration [26].

The use of starter cultures, usually based on autochthonous microbiota, still is not a common practice in the fermentation of vegetables or table olives in Europe [37]. The starter cultures for the fermentation of table olives have the following attributes, that is, rapid and predominant growth at low temperatures with increased acid production, homofermentative metabolism, tolerance to salt and phenolic glucosides, and an inhibitory effect on foodborne pathogens [38–40]. At the beginning of the fermentation process, olives that have not been treated with alkali and oleuropeinolytic LAB strains are recommended as the starter for the fermentation of olives and the production of olive oil [35, 41–43]. This enzymatic hydrolysis could be taken into consideration as an alternative processing method to replace lye and/or brine treatment [27, 44–49]. Lactic acid starters should be identified and selected according to their potential for biologically debittering fermented olives and improving their sensorial characteristics [27, 45, 50, 51].

Lactobacillus plantarum showed the highest percentage of strains producing β-glucosidase and esterases, and it was followed by *L. pentosus*, *Pediococcus pentosaceus*, and *L. brevis* [35, 41–43, 47, 52–54]. The growth of LAB can be increased based on the simultaneous inoculation of yeasts [55] and their technological properties, which can remove the natural bitterness of fermented olives [1, 8, 55]. In fact, yeasts can produce some substances that promote the growth of *Lactobacillus* spp. [54], such as vitamins B_1 and B_6, amino acids, and purines. They also can break down the complex carbohydrates that are essential for promoting self-growth, thereby contributing the organoleptic properties of table olives by the production of desirable metabolites and volatile compounds [3, 8, 37, 56, 57]. Also, due to the presence of phenolics [55], yeasts can be used as biocontrol agents for non-desirable yeast species and for the inhibition of pathogens [39, 55]. As a result, the concentrations of salt and preservatives can be reduced, the stability of the packaging conditions can be improved, and the nutritional quality (antioxidant capacity), shelf life of the processed olives, and their beneficial effects on consumers' health can be enhanced [1, 27, 40, 45–49, 51–55]. Several authors have emphasized the importance of the appropriate selection of yeasts and their use in factory conditions, with and without LAB [1, 8, 55, 58–62]. They have reported that the following criteria should be considered for the selection of yeasts and LAB: (i) presence of microbial β-glucosidase and esterases hydrolyse oleuropein [49]; (ii) no production of biogenic amines [63]; (iii) presence of proteolytic and lipolytic activity [64, 65]; and (iv) absence of pectolytic activity [57, 59]. It was reported that, among yeasts, the following exhibited potential for use as starters, that is, *Wickerhamomyces anomalus, Saccharomyces cerevisiae, Kluyveromyces lactis, Debaryomyces hansenii, Candida norvegica, C. diddensiae, C. oleophila, C. boidinii* and *Pichia membranifaciens, P. galeiformis, and P. anomala* [1, 8, 39, 59, 60, 66–72]. Some authors have proposed the use of *Enteroccus* spp., such as *Enterococcus faecium, E. casseliflavus*, and *E. hirae*, as starter cultures for the Spanish-style fermentation of green olives [73–75] with *L. plantarum, L. pentosus*, or *S. cerevisiae*, respectively [39, 73–75]. It should be noted that the use of enterococci, which can cause infections in people, is not recommended by the European Food Safety Authority (EFSA) [75].

4. Reducing salt in the processing of table olives

Sodium is the only mineral element added during the processing of table olives, and the habitual consumption of table olives may be responsible for a significant proportion of daily intake. It has been recommended that the intake of sodium be limited to a maximum of 2400 mg/day [76]. However, the average total daily sodium intake per individual in developed countries is 4000–5000 mg of Na (10,000–12,000 mg of NaCl), which is about 25 times greater than the minimum adult requirement (500 mg of NaCl) [77]. Therefore, a diet that is low in sodium and high in potassium and calcium is recommended to lower blood pressure and to protect against osteoporosis, colon cancer, and cardiovascular diseases [32, 77–80].

Storage and fermentation of vegetable products in brine or dry salt are traditional methods for the preservation of food, and NaCl is used mainly as a preservative, since it causes a reduction of water activity (a_w) to inhibit the growth of undesirable microorganisms, increases the ionic strength of the brine to reduce the solubility of oxygen in water, initiates competitive and selective microbiological growth process, ensures the microbial safety of the final product during storage, and improves the organoleptic properties of food [75, 79, 81]. To date, several studies have investigated the partial or complete substitution for NaCl in fermented green and black olives, and olive juice [58, 76, 80–84]. Products were obtained that had a balanced mineral composition and enhanced nutritional value based on a controlled process that prevented deterioration and spoilage and improved the sensorial characteristics of the products [58, 82–88].

The reduction in Na can be made possible by using substitutes for NaCl, such as potassium chloride (KCl), magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), zinc chloride ($ZnCl_2$), zinc sulfate, and/or zinc perchlorate. Each of these compounds has an antimicrobial effect on pathogens, yeasts, and toxigenic fungi, and each of them also is permitted for the preparation of fortified foods within the current EU legislation (Commission Regulation EU 432/2012) [76, 80–82, 87–90].

Several researchers have partially or completely replaced some of the NaCl with KCl, $CaCl_2$, $ZnCl_2$, and various combinations of these three compounds as preservatives, and they observed better physicochemical and sensory attributes when the non-NaCl proportions were low, and they also reported good fermentation kinetics without any spoilage in green and black table olives [2, 29, 54, 76, 80–83, 86, 92–95].

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5. Increasing the shelf life of table olives by a non-thermal process

Shelf life and food quality are related closely to microbial quality and biochemical and enzymatic reactions; managers and researchers in the food industry are very interested in non-thermal preservation methods [96] that can improve the quality and safety of foods. Some of the non-thermal processes used in the food industry are high-intensity, pulsed electric field (HIPEF); high hydrostatic pressure (HHP); high pressure homogenization (HPH); ultraviolet (UV); ultrasound; osmotic dehydration; supercritical fluid extraction; high field strength electrical pulses; and irradiation. These methods affect the viability of microorganisms and the structure of proteins/enzymes during food processing and storage, but they generally do not have any significant effects on the sensory, nutritional, and health-related qualities of the food [96, 97].

Among the non-thermal technologies, high hydrostatic pressure (HHP) applies pressure to foods (liquid and solid) in the range of 50–1000 MPa, depending on the particular food being processed [96, 98]. Generally, a moderate pressure (up to 200–300 MPa) decreases the rate of reproduction and growth of microorganisms, whereas higher pressures (300–700 MPa) inactivate microbial activity [97]. The ingredients that foods contain and the physical conditions of the food can provide a baroprotective effect on microorganisms [99], and they also can lower water activity (a_w), pH (≤4.5), the nature of the solute (i.e., sugar or salt), and temperature (above or below the ambient temperature), thereby influencing the extent to which food must be treated to eliminate/inactivate vegetative cells and to control pathogenic microorganisms [95, 99].

The pressure resistance of microorganisms is at its maximum value in the temperature range of 15–30°C, particularly with regard to bacterial spores [99], and the pressure resistance of bacteria is highly variable [100, 101]. The first research on the effect of high pressure on food was conducted in the nineteenth century describing an increase in the shelf life of food products that were stored at pressures far in excess of atmospheric pressure; however, there are very few studies on the application of HHP on fermented vegetable foods [96, 97, 100, 102, 103].

Contamination of olives may be due to olive harvesting directly from the soil, poor hygiene and unsanitary procedures by field and processing personnel, inadequate cleaning and sanitizing of processing equipment, and failure to wash the olives prior to brining [98]. At the end of these processing steps and irrespective of the packaging material, the industry usually uses a thermal pasteurization step to extent shelf life and to stabilize table olives microbiologically [104]. The protective effect of different levels of HHP (250–600 MPa for 5–30 min) reduced the yeast and mold populations, the mycotoxin level (citrinin), and extended the shelf lives of table olive products [96, 98, 102, 105]. Also, Tokuşoğlu et al. [97] reported that no hazardous microorganisms were found on the olives, with the exceptions of yeasts and molds that were found to be less than 10^6 CFU/g, which was in compliance with the International Olive Oil Council's (IOOC's) trade standard for table olives.

Olives have a high functional potential due to the presence of essential micronutrients, essential fatty acids (oleic acid), and biologically active phytochemicals, such as phenols, tocopherols, and phytosterols [96, 97], but thermal processing of table olives induces some deterioration in their quality, resulting in softening of their tissue, changing their green color to brown, developing a cooking taste, and degrading active biocompounds [102]. Optimization of the HHP conditions is important for bioactive compounds' stability, quality, and quantity. Very limited information is available in the literature about the use of the non-thermal method, HHP, as an alternative to thermal processing, on the quality of table olives [98]. According to the research results, the total phenolic and hydroxytyrosol levels were increased by factors of 2.1–2.5 and 0.8–2.0, respectively, while oleuropein decreased after HHP [97]. Similar results also were reported for Cornezuelo olives treated by HHP. However, olives treated by HHP had higher stability in terms of pH and free acidity values, and the HHP treatment can be used to prevent the formation of gas in the packed olives and to improve the sensory characteristics of Cornezuelo dressed olives [103].

The color makes a key contribution to the marketability of table olives, and since a vivid green color is an essential characteristic of the product, especially in Spanish-style processing [98, 106]; it must be noted that HHP treatments caused a moderate degradation of the color of the processed olives [96, 98, 102, 103]. Possible techniques for preserving and improving the color of HHP-treated olives include the addition of ascorbic acid (15 g/L) and purging with gaseous nitrogen [8].

6. Effect of packaging methods on the shelf life of table olives

Packaging of table olives is a way to improve their economic value and expand markets. Table olives, as a final product, may be marketed in bulk to local markets or exported abroad. There is a tendency to pack olives in glass or plastic containers, tins, and polyethylene, aluminum, or multi-laminated pouches. These materials are filled with brine that contains pH regulators, preservatives, antioxidants, anti-softening additives, and, in some cases, gases (CO_2, N_2). Subsequently, pasteurization or sterilization is used to stabilize the product microbiologically [4, 5, 107, 108]. Alternatively, physical treatments can be used [103]. In vacuum packaging, the product is placed in a pack with low oxygen permeability, the air is evacuated, and the package is sealed. Since it is not possible to evacuate all of the air (0.3–3% of it may remain after sealing), the gaseous atmosphere of the vacuum package is likely to change during storage (due to microbial and product metabolism and gas permeation); therefore, the atmosphere in the package over time may be different from the original atmosphere [4]. MAP or vacuum packaging (VP) can be applied to increase the quality and shelf life of products that are designed to be "natural" or reduced in preservatives by "hurdle effect" technologies; improved presentation and visibility of the product; and reduced production, storage, and transport costs due to better utilization of labor and equipment. Nevertheless, the costs of gas packaging machinery, gases, packaging materials, and analytical equipment to measure gas mixtures are many disadvantages of MAP [109]. The use of MAP and VP for the storage of table olives at ambient or low temperature has been well noted and proven in several studies [4–6, 107, 108, 110–113]. As reported by these researchers, dipping the olives in anti-microbial solutions (potassium sorbate—1.0%, chlorine dioxide—10 ppm, or organic acid—1.0–2.0 acetic or lactic)

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before packaging, storing them at 4°C, and storing them under pressure in a CO_2 atmosphere-controlled microbial activity effectively, especially the population of yeasts, and it minimized the production of mycotoxins as well as obtaining the best quality characteristics of the final products.

7. Improving functionality of table olives by probiotic cultures

Fermented vegetables are being considered as a splendid source and vehicle of probiotic microorganisms [41, 114]. The fermentation of table olives usually is the result of the competitive and synergic metabolic activities of the autochthonous microbiota, together with a variety of contaminating microorganisms from the fermentation environment [8, 115]. The LAB microbiota of table olives also are characterized by the presence of *Lactobacillus plantarum*, *L. rhamnosus*, *L. pentosus*, *L. casei*, *L. paracasei*, and heterofermentative cocci, such as *Leuconostoc mesenteroides* [41, 62, 102, 115–119]. The use of table olives as a probiotic source has been explored in several studies [98, 102, 116, 120–123], which, through *in vitro* methods, has evaluated the probiotic and technological characteristics of autochthonous LAB isolated from the fermentation of table olives. In addition to the probiotic characteristics of LAB, and yeasts as adjunct culture, these starters must possess appropriate technological characteristics, that is, adequate growth rate, rapid and high lactic acid production, ability to adhere to the outer peeling of the olives, sugar consumption and tolerance, or synergy with other components of the starter, to produce functional olives [1, 55, 59, 66, 98, 114, 120, 122–125]. To deliver health benefits, probiotic foods must contain an adequate amount of live bacteria (at least 10^6–10^7 CFU/g) and must prolong their viability at the end of the fermentation process [98, 122] and after long-term storage of the fermented product, provided that the latter has acceptable organoleptic characteristics. Viewed from this perspective, an edible portion of about 80–100 g of olives must contain $>10^9$ live cells of selected LAB strains in order to be considered as a probiotic [114]. In this volume, also see chapter how biotechnology can improve a traditional product as table olives.

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