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ANALYSIS OF QUALITY AND SAFETY ASPECTS OF TABLE GREEN OLIVES

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Ethical considerations: When reporting experiments on animals Observation of the ARRIVE guidelines 2.0: Updated guidelines for reporting animal research, published on July 14, 2020 (DOI: 10.1371/journal.pbio.3000410), is applied. The authors ensure that all procedures were performed in compliance with the guidelines for animal care of their institutions or with national/international guidelines.

ABSTRACT

Table olives are pickled products obtained by partial or complete debittering followed by fermentation. This study evaluated the quality and safety of six commercial green table olive products (TaO1–TaO6) using microbiological, antioxidant, physicochemical, colorimetric, and sensory analyses. Microbiological assessment confirmed generally high hygienic quality. Total bacterial count (TBC) was below the detection limit in TaO1–TaO4 and detected only in TaO5 (2.90 log10 CFU/g) and TaO6 (2.76 log10 CFU/g). Yeasts and moulds were detected only in TaO5, while lactobacilli, *Escherichia coli*, and *Staphylococcus* spp. were not detected in any sample. Enterococci were isolated from TaO5 and TaO6. Antioxidant capacity differed significantly among samples ($p = 0.001$), with TaO4 showing the highest Trolox equivalent antioxidant capacity (TEAC) and TaO3 and TaO6 the lowest. Significant differences ($p < 0.05$) were also found in physicochemical properties, color parameters (L*, a*, b*), and sensory characteristics. TaO1 achieved the highest sensory scores for firmness and palatability, whereas TaO5 showed the poorest quality due to off-odors, soft texture, and poor appearance. Overall, the results demonstrate considerable product-specific variation, highlighting the importance of processing, formulation, and packaging for the quality and safety of commercial table olives.

Keywords: antioxidants activity; food quality; microbial safety; olives; sensory analysis

INTRODUCTION

Table olives represent a globally popular food commodity, with particularly high consumption in Mediterranean regions. They are described as fruits obtained from selected cultivars of the olive tree (*Olea europaea* L.) that possess technological and sensory characteristics suitable for processing. These include appropriate size and shape, a favorable flesh-to-stone ratio, desirable texture and flavor, firmness, and ease of pit removal. To render them edible, the natural bitterness of the fruit is reduced through specific treatments, after which the olives are preserved either by spontaneous or controlled fermentation or by thermal processing, with or without the use of preservatives. The

final product may be marketed in the presence or absence of a covering liquid [1].

Fresh olives are not suitable for direct consumption due to the presence of the phenolic compound oleuropein, which imparts an intense bitterness. Therefore, the primary objective of olive processing is the reduction or elimination of this compound, typically achieved through its hydrolysis, resulting in more palatable products. Several technological approaches have been developed to debitter olives, the most common being the Spanish-style, Californian-style, and natural (Greek-style) methods [2].

In the Spanish-style process, which is the most widely applied for green olives, olives are treated with an alkaline solution (approximately 2–3% sodium hydroxide) for a defined period, facilitating the transformation of oleuropein into non-bitter derivatives. Following this treatment, olives are thoroughly rinsed to remove residual alkali and subsequently immersed in brine solutions (9–10% NaCl), where fermentation is driven by indigenous lactic acid bacteria and yeasts over several months [3, 4].

The Californian-style method involves a more complex, multi-step process. Initially, olives are stored in acidic conditions for an extended period. This is followed by a darkening phase, during which fruits are exposed to dilute sodium hydroxide and then washed. Subsequently, olives are treated with iron salts (such as lactate or gluconate) while aeration is applied to promote color development. The resulting black ripe olives typically exhibit a near-neutral pH (6.0–7.0) and require sterilization to ensure microbiological safety [5].

In contrast, the natural or Greek-style approach avoids chemical treatments altogether, relying solely on direct brining to initiate spontaneous fermentation [6].

Scientific studies addressing the biodiversity of table olive microbiota report a wide range of bacterial, yeast, and mold species identified using both conventional microbiological methods and advanced molecular approaches, including culture-dependent and culture-independent techniques. To ensure microbiological safety and protect consumers from potential hazards, table olive processing facilities are required to implement comprehensive food safety management systems. Among these, the HACCP (Hazard Analysis and Critical Control Points) system, as established by the Codex Alimentarius, represents a fundamental preventive approach focused on identifying, evaluating, and controlling chemical, physical, and biological hazards throughout the production process [7].

In addition, adopting internationally recognized standards, such as ISO certification, is essential for modern food enterprises. These certifications demonstrate that the company has effectively developed, documented, and implemented standardized procedures for production, processing, and packaging, ensuring product safety, quality, and regulatory compliance [1].

Comprehensive physicochemical analysis of table olives is essential for evaluating their quality attributes, detecting defects or spoilage, and ensuring adherence to food safety standards. Additionally, these products are rich in bioactive constituents, particularly polyphenols and triterpenic acids, which significantly influence both sensory characteristics and potential health benefits. Detailed characterization of these compounds offers valuable information that can support process optimization and help maintain consistent product quality [6].

Therefore, the aim of this study was to perform a comprehensive evaluation of the quality and safety of green table olives commercially available on the Slovak market. Six anonymized samples originating from different countries were subjected to microbiological examination, including the determination of total bacteria count, yeasts and moulds, coliform bacteria, *Lactobacillus* spp., *Escherichia coli*, *Staphylococcus* spp. and *Enterococcus* spp. In addition, antioxidant activity, salt content, instrumental colour characteristics, and sensory properties were evaluated. The study aimed to assess the microbiological safety, physicochemical quality, and sensory attributes of table olives and to compare the overall quality of products available to consumers.

MATERIALS AND METHODS

Collection of samples

Analyzed samples of table olives were obtained from the retail market network of the Slovak Republic and originated from various countries. Samples were anonymized and evaluated within a single production batch for each product.

A total of six commercial green table olive products (n = 6), including both plain olives and olives enriched with additional ingredients, were examined. The samples were packaged in three different types of packaging materials: glass jars (TaO1, TaO2, TaO3), polypropylene (PP) plastic containers (TaO5, TaO6), and a metal can (TaO4).

The total product weight ranged from 152 to 295 g, while the drained weight ranged from 75 to 170 g. According to the manufacturer's declaration, the red pepper paste content was 18% in sample TaO2 and 8.2% in sample TaO5. Following purchase, samples were transported to the laboratory and stored in their original unopened packaging under the conditions specified on the product label until analysis. After opening, samples were immediately processed for laboratory analyses.

For sensory evaluation, 35 g of olives (approximately 6–10 fruits, depending on fruit size) were prepared from each sample. Prior to physicochemical and microbiological analyses, additional ingredients (almonds, red pepper, and capers) were removed, and pits were excluded where applicable.

The following samples were analyzed:

TaO1 – table olives stuffed with almonds
TaO2 – green olives stuffed with red pepper 1
TaO3 – plain green table olives in brine
TaO4 – green pitted olives stuffed with capers
TaO5 – green olives stuffed with red pepper 2
TaO6 – green pitted table olives

Product characteristics differed among samples. Sample TaO1 contained 220 g of product, including 120 g of olives, whereas samples TaO2 and TaO3 contained 85 g of olives. Sample TaO4 had a declared volume of 212 mL and contained 85 g of olives, while pouch-packaged samples TaO5 and TaO6 contained 80 g and 75 g of olives, respectively.

Cultivation and microbial analyses

Samples intended for microbiological analysis were randomly selected from collected packages. The packaging material was aseptically opened, and samples were collected under sterile conditions using a scalpel and pipette. The contents were homogenized, and 10 g of each sample was aseptically transferred into sterile containers, followed by the addition of 90 mL of sterile 0.1% peptone water. Homogenization was performed using a Stomacher 400 (Seward Medical, London, UK). Subsequently, tenfold serial dilutions were prepared in accordance with STN EN ISO 6887-1 [8]. Microbiological analyses were then performed following relevant legislative requirements: Commission Regulation (EC) No. 2073/2005 on microbiological criteria for foodstuffs and the Decree of the Ministry of Agriculture of the Slovak Republic No. 06267/2006-SL [9]. The following microbiological parameters were determined: total bacteria count (TBC) (STN ISO 4833-1) [10], yeasts and moulds (STN ISO 21527-1) [11], coliform bacteria (STN ISO 4832) [12], *Lactobacillus* spp. (STN ISO 15214) [13], *Escherichia coli* (ISO 16649-1) [14], *Staphylococcus* spp. (STN ISO 6888-1) [15], and *Enterococcus* spp. by cultivation on Slanetz and Bartley agar according to validated laboratory procedures [16].

Appropriate decimal dilutions of the homogenized olive samples were prepared under aseptic conditions. For the determination of the total bacteria count, coliform bacteria, *Lactobacillus* spp., and *Escherichia coli*, 1.0 mL of the selected dilution was inoculated into sterile Petri dishes using the pour plate technique, followed by the addition of the corresponding molten culture medium according to the respective standards. For the enumeration of yeasts and moulds and *Staphylococcus* spp., 0.1 mL of the selected dilution was inoculated onto the surface of the appropriate solid culture medium using the spread plate technique. *Enterococcus* spp. were determined by inoculating 0.1 mL of the selected dilution onto the surface of Slanetz and Bartley agar using the spread plate technique in accordance with the validated laboratory method. All microbiological analyses were carried out in duplicate. Microbial counts were expressed as log10 CFU/g.

Antioxidant activity

The antioxidant activity of the samples was determined using a slightly modified DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay according to Várady et al. [17]. The method was adapted from the original protocol, which was performed in 96-well plates. In the present study the plates were not used. However, the reagent ratios were kept identical, and only the experimental format was modified. Olive samples (1 g) were mechanically crushed using a mortar. Subsequently, 10 ml of methanol was added, and the mixture was thoroughly homogenized for 5 minutes to extract the target compounds. The resulting mixture was filtered through filter paper (Whatman No. 40, Cytiva, Marlborough, USA) to obtain a clear filtrate for further analysis. Serial dilutions (2 mL) of each sample were prepared in absolute methanol. Then, 2 mL of freshly prepared 1 mM DPPH (Sigma-Aldrich, Saint Louis, USA) solution in methanol (MikroCHEM, Pezinok, Slovakia) was added. Trolox (Sigma-Aldrich, Saint Louis, USA) was used as a positive control. The reaction mixture

was incubated in the dark at room temperature for 30 minutes. Absorbance was read at 517 nm on a T65 UV-Visible Spectrophotometer (PG Instruments, Lutterworth, United Kingdom). Results were expressed as Trolox equivalent antioxidant capacity (mg TEAC/g sample). The samples were determined in a wet state without prior drying. All analyses were performed in triplicate.

Determination of salt content

All fortified olive samples and brine samples were analyzed for salt content using the Mohr titration method in six replicates. An aliquot of 1 mL of brine was transferred into an Erlenmeyer flask, followed by the addition of 0.5 mL of 5% potassium chromate as an indicator. The burette was filled with 0.1 N $AgNO_3$ solution. The sample was titrated with standardized $AgNO_3$ until the first appearance of a persistent pale red-brown color, which remained stable for at least 30 seconds. The volume of titrant consumed was recorded. The following formula was used to calculate the amount of salt.

$$NaCl\ content\ (\%) = \frac{V \times N \times F \times 0.0585 \times 100}{m}$$

V: Consumption of 0.1 N $AgNO_3$ in titration (mL)
N: Normality of $AgNO_3$
F: Factor of 0.1 N $AgNO_3$
m: mass of sample (g)

Determination of color

Color parameters were determined using the CIE L*a*b* color space (Commission Internationale de l'Eclairage, 1986) with a Minolta Chroma Meter CR-410 (Minolta, Osaka, Japan), supported by CM-S100w SpectraMagic NX software (Konica Minolta Sensing Inc., Sensing Americas, Inc., Ramsey, USA). For each sample, three parameters were measured: L* (lightness), a* (green–red axis), and b* (blue–yellow axis). Measurements were performed on the surface of the olives. In samples containing almonds, the almonds were mechanically removed to avoid distortion of color measurements. Samples were arranged on Petri dishes to ensure a uniform and representative measurement surface. Each sample was measured six times; the result is the average ± standard deviation [18]. All analyses were performed in triplicate.

Sensory evaluation

Descriptive sensory analysis was performed to determine the sensory profile of olives according to the methodology of Lawless and Heymann [19]. A trained panel of seven evaluators assessed selected sensory attributes, including appearance, aroma, taste, and texture. The intensity of each attribute was rated using a 7-point intensity scale ranging from 0 to 6, where 0 = imperceptible, 1 = very slightly perceptible, 2 = slightly perceptible, 3 = perceptible, 4 = clearly perceptible, 5 = strongly perceptible, and 6 = very strongly perceptible. Table olive samples were presented to the panelists in a randomized order. Results were expressed as mean values obtained from seven assessors.

Statistical evaluation of experiment results

One-way analysis of variance (ANOVA) and Tukey's test for multiple comparisons with a 95% confidence interval ($p < 0.05$) were used for evaluation using GraphPad Prism 10.6.1(892) 2025 statistical software (GraphPad Software, San Diego, CA, USA).

Table 1. Results of quantitative determination of selected microorganisms expressed as log10 CFU/g

Sample	PCA agar	DRBC agar	MRS agar	ENDO agar	TBX agar	BP agar	SB agar
TaO1	-	-	-	-	-	-	-
TaO2	-	-	-	-	-	-	-
TaO3	-	-	-	-	-	-	-
TaO4	-	-	-	-	-	-	-
TaO5	2.90	3.83	-	-	-	-	3.99
TaO6	2.76	-	-	-	-	-	4.14

- = not detected (below detection limit); PCA – Plate Count Agar; DRBC – Dichloran Rose Bengal Chloramphenicol Agar; MRS – de Man, Rogosa and Sharpe Agar; ENDO – Endo Agar; TBX – Tryptone Bile X-Glucuronide Agar; BP – Baird-Parker Agar; SB – Slanetz and Bartley Agar

RESULTS

The microbiological quality of the analyzed samples of table olives, based on the detection of individual microorganisms, was determined to be at a very high level of quality and safety (Table 1). The total number of microorganisms in samples TaO1, TaO2, TaO3, and TaO4 was below the detection limit. Total bacterial count (TBC) was determined in TaO5 and in TaO6. Yeasts and moulds were detected only in sample TaO5. *Lactobacilli* were below the detection limit in all samples. Coliform bacteria were below the detection limit in all samples. *Escherichia coli* was not detected in any of the tested samples. *Staphylococcus* spp. were not detected in any sample. *Enterococci* were successfully cultured from samples TaO5 and TaO6.

The antioxidant activity of the analysed table olive samples is presented in Table 2. Statistically significant differences were observed among all samples ($p = 0.05$). The highest antioxidant activity was recorded in sample TaO4 (3.0705 ± 0.069 mg TEAC/g), which differed significantly from all other samples. In contrast, the lowest values were observed in samples TaO6 (0.570 ± 0.063 mg TEAC/g) and TaO3 (0.7295 ± 0.032 mg TEAC/g), which formed a statistically similar group.

Intermediate antioxidant activity was detected in samples TaO2 with significant differences observed among them as indicated by differing superscripts. The results demonstrate considerable variability in antioxidant capacity among the analysed olive samples, likely reflecting differences in composition, processing methods, or added ingredients.

Table 2. Results of antioxidant activity of table olive samples

Sample	mg TEAC/g of sample (mean± SD)
TaO1	0.902 ± 0.034^{c}
TaO2	1.563 ± 0.092^{b}
TaO3	0.7295 ± 0.032^{d}
TaO4	3.0705 ± 0.069^{a}
TaO5	1.016 ± 0.060^{c}
TaO6	0.57 ± 0.063^{d}
p	0.05

$^{a, b, c, d}$ – values in the column with different superscripts are statistically different ($p < 0.05$).

The results of the physicochemical analysis of brine and olive samples are summarized in Table 3. In the case of brine samples, statistically significant differences ($p < 0.05$) were observed among all analyzed groups. The highest mean value was recorded in sample TaO6 (5.446 ± 0.063 NaCl %), which differed significantly from all other samples. Similarly, sample TaO5 (4.693 ± 0.048 NaCl %) showed significantly higher values compared to the remaining groups. In contrast, sample TaO3 (2.976 ± 0.066 NaCl %) exhibited the lowest mean value and formed a distinct statistical group. Samples TaO1 (3.460 ± 0.025 NaCl %), TaO2 (3.390 ± 0.064 NaCl %), and TaO4 (3.570 ± 0.063 NaCl %) did not differ significantly from each other and were classified within the same homogeneous group. Overall, the brine samples showed considerable variability between individual products.

For olive samples, statistically significant differences ($p < 0.05$) were also identified; however, the variability among samples was less pronounced compared to brine. The highest mean values were observed in samples TaO5 (1.359 ± 0.042 NaCl %) and TaO6 (1.361 ± 0.043 NaCl %), which formed a homogeneous group. The lowest values were recorded in samples TaO2 (1.252 ± 0.043 NaCl %) and TaO3 (1.254 ± 0.043 NaCl %), without significant differences between them. Samples TaO1 (1.340 ± 0.045 NaCl %) and TaO4 (1.299 ± 0.045 NaCl %) showed intermediate values and overlapped statistically with both lower and higher groups. These findings indicate that while significant differences exist among samples, the extent of variability was notably higher in brine than in olive flesh. Although samples with the highest NaCl concentrations in brine (TaO5 and TaO6) also contained the highest NaCl levels in olive flesh, the differences observed in olive flesh were much less pronounced, suggesting that the salt concentration of the brine is not directly reflected in the final salt content of the olives.

Table 3. Salt content determination in brine and table olives (mean ± SD)

Sample	Brine (NaCl %)	Table olives (NaCl %)
TaO1	3.460 ± 0.025^{c}	1.340 ± 0.045^{ab}
TaO2	3.390 ± 0.064^{c}	1.252 ± 0.043^{c}
TaO3	2.976 ± 0.066^{d}	1.254 ± 0.043^{c}
TaO4	3.570 ± 0.063^{c}	1.299 ± 0.045^{bc}
TaO5	4.693 ± 0.048^{b}	1.359 ± 0.042^{a}
TaO6	5.446 ± 0.063^{a}	1.361 ± 0.043^{a}

Values are presented as mean ± SD (n = 3). SD – standard deviation. $^{a, b, c, d}$ – values within a column with different superscript letters differ significantly ($p < 0.05$).

The color parameters (L*, a*, b*) of the analyzed table olive samples are presented in Table 4. Statistically significant differences ($p < 0.05$) were observed among samples for all measured color coordinates.

For the lightness parameter (L*), the highest value was recorded in sample TaO2 (47.55 ± 1.2), indicating the brightest appearance, while the lowest values were observed in samples TaO3 (44.17 ± 0.63) and TaO6 (44.16 ± 0.30), which formed a statistically similar group.

Regarding the a* parameter (green–red axis), sample TaO4 (2.81 ± 0.21) showed significantly higher values, indicating a shift toward red coloration, whereas sample TaO3 (−2.48 ± 0.5) exhibited negative values, reflecting a greenish hue. The remaining samples showed positive but lower a* values and formed a statistically similar group.

For the b* parameter (yellow–blue axis), the highest yellowness was observed in sample TaO5 (23.07 ± 0.52), which differed significantly from most other samples. In contrast, the lowest b* values were found in samples TaO1 (19.44 ± 0.17) and TaO6 (19.42 ± 1.28), indicating lower intensity of yellow coloration. The remaining samples (TaO2, TaO3, and TaO4) exhibited intermediate values with partial statistical overlap.

Overall, the results demonstrate notable variability in color characteristics among the olive samples, which may be influenced by differences in raw material, processing methods, or the presence of added ingredients.

The sensory profile of the analyzed green olive samples is presented in Figure 1. Based on sensory evaluation, differences were observed among the olive samples in terms of appearance, aroma, taste, and texture. Sample TaO1 was assessed as the largest and firmest, whereas sample TaO5 exhibited the poorest visual quality, being soft, broken, and disintegrated. Samples TaO2 and TaO6 showed more uniform size and good firmness, with TaO6 also displaying color variability within the fruits. Regarding aroma, sample TaO5 was characterized by the presence of off-odors, whereas the remaining samples exhibited a typical olive aroma without noticeable defects.

In terms of taste, sample TaO1 received the highest rating, being perceived as palatable and free of bitterness, while samples TaO2 and TaO4 were characterized by a bitter taste. Sample TaO3 exhibited defects, including the presence of stems and difficulties in pit removal, which reduced its overall quality. Sample TaO5 was negatively evaluated due to its atypical taste and overall poor sensory quality, whereas sample TaO6 showed a less intense but also less appealing flavor profile.

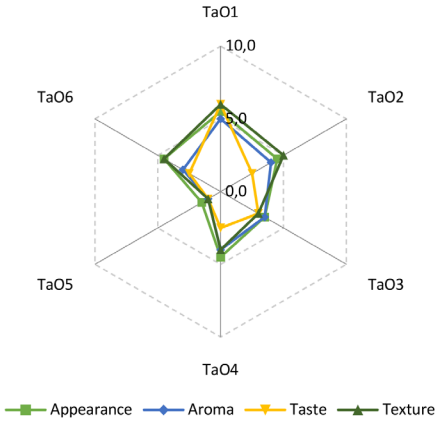


Fig. 1. Sensory profile of green olive samples

Regarding packaging, differences were identified in both type and labeling quality. Samples TaO1–TaO3 were packaged in glass containers, TaO4 in a metal can, and TaO5–TaO6 in flexible pouches. In samples TaO4 and TaO6, issues with label readability were noted, specifically an illegible product name (gold lettering on a dark background), which may negatively affect consumer information.

Table 4. Results of color measurement (L*, a*, b*) of table olive samples

Sample	L* (mean ± SD)	a* (mean ± SD)	b* (mean ± SD)
TaO1	46.88 ± 0.37^{ab}	0.69 ± 0.06^{b}	19.44 ± 0.17^{c}
TaO2	47.55 ± 1.2^{a}	0.96 ± 0.06^{b}	20.07 ± 1.10^{bc}
TaO3	44.17 ± 0.63^{c}	-2.48 ± 0.5^{c}	21.76 ± 3.17^{ab}
TaO4	46.25 ± 0.86^{b}	2.81 ± 0.21^{a}	20.46 ± 1.08^{bc}
TaO5	45.58 ± 0.10^{bc}	0.70 ± 0.03^{b}	23.07 ± 0.52^{a}
TaO6	44.16 ± 0.30^{c}	0.19 ± 0.01^{b}	19.42 ± 1.28^{c}

Values are presented as mean ± SD (n = 3). Different upper indices ($^{a–c}$) within the bars indicate statistically significant differences between samples ($p < 0.05$). SD – standard deviation.

DISCUSSION

The present study evaluated the quality and safety aspects of commercially available green table olives, focusing on microbiological status, antioxidant activity, physicochemical properties, color parameters, and sensory attributes. The results revealed considerable variability among samples, which is likely attributable to differences in processing technologies, formulation, and added ingredients. Moreover, the observed differences were not limited to a single quality parameter but were consistently reflected across microbiological, physicochemical, and sensory analyses, indicating substantial product-specific variation among commercially available olives.

From a microbiological perspective, the analyzed samples demonstrated a generally high level of safety and quality. The absence of *Escherichia coli*, *Staphylococcus* spp., and coliform bacteria in all samples indicates good hygienic practices during processing and handling. Similar findings were reported by Benítez-Cabello et al. [20] and Mougiou et al. [21], who observed low levels of pathogenic microorganisms in properly fermented table olives. The detection of total bacterial count together with yeasts and moulds in sample TaO5 may suggest ongoing microbial activity or incomplete fermentation processes. Although lactic acid bacteria were not detected in the present study, previous studies have highlighted that yeasts and lactic acid bacteria are the dominant microorganisms during olive fermentation [4]. The presence of enterococci in samples TaO5 and TaO6 may be associated with environmental contamination or insufficient process control, as also discussed by De Castro et al. [22]. Among all analysed products, TaO5 showed the least favourable microbiological profile, as it was the only sample in which total bacterial count, yeasts, moulds and enterococci were detected simultaneously. In contrast, TaO6 contained only total bacterial count and enterococci, while the remaining products showed no detectable microbial contamination. These findings demonstrate considerable variability in microbiological quality among commercial products despite their belonging to the same product category. The antioxidant activity results showed significant variability among samples, with TaO4 exhibiting the highest values. This variability is likely related to differences in phenolic compound content, particularly oleuropein derivatives and hydroxytyrosol, which are known to contribute to antioxidant activity. According to Brenes et al. [5], processing methods such as alkaline treatment and fermentation significantly influence the retention or degradation of phenolic compounds. The lower antioxidant activity observed in samples TaO3 and TaO6 may be explained by processing conditions or dilution effects caused by brining and storage. Similar trends have been reported by Panagou et al. [23], who emphasized that both cultivar and technological processing strongly affect antioxidant potential. Interestingly, the product with the highest antioxidant activity (TaO4) also showed no detectable microbiological contamination, whereas TaO6 combined one of the lowest antioxidant activities with detectable microbial counts, illustrating that commercial processing may influence multiple quality parameters simultaneously.

Physicochemical analysis revealed greater variability in brine composition compared to olive flesh. This finding suggests that brine formulation and processing conditions play a crucial role in determining the final product characteristics. High variability in brine parameters has also been documented by Sánchez-Gómez et al. [2], who highlighted the influence of salt concentration, pH, and fermentation dynamics on product quality. The relatively lower variability observed in olive flesh indicates a more stable internal composition, less affected by external processing conditions. In the present study, TaO5 and TaO6 contained the highest salt concentrations in brine, confirming that manufacturers apply different brining strategies. However, although higher NaCl concentrations were observed in samples TaO5 and TaO6, no consistent relationship between salt concentration and microbiological, colour, or sensory characteristics could be identified based on the present results. This suggests that product quality is influenced by multiple technological factors rather than salt concentration alone. Color analysis demonstrated statistically significant differences among samples in all measured parameters (L*, a*, b*). The highest lightness observed in TaO2 suggests better preservation of visual quality, whereas the negative a* values in TaO3 indicate a shift toward green coloration, which is typical for less oxidized or differently processed olives. According to McLaren [24], color parameters in food products are influenced by pigment composition, processing, and storage conditions. The high b* value in TaO5 indicates increased yellowness, which may be associated with ingredient addition or pigment degradation. These findings are consistent with studies showing that processing methods, such as

oxidation and fermentation, significantly affect olive color [1]. Although colour differences do not necessarily indicate reduced product safety, they further demonstrate the considerable technological variability among the analysed commercial products.

Sensory evaluation further confirmed the variability among samples, particularly in texture, taste, and overall acceptability. Sample TaO1 was rated as the most favorable, likely due to its firm texture and balanced flavor profile. In contrast, sample TaO5 exhibited defects such as soft texture, off-odor, and atypical taste, which may be linked to microbial activity or improper processing. Similar sensory defects have been described by Panagou et al. [23], who reported that spoilage microorganisms and fermentation imbalances can negatively affect organoleptic properties. The bitterness observed in samples TaO2 and TaO4 may be associated with incomplete hydrolysis of oleuropein, as described by Perpetuini et al. [1]. Importantly, the poor sensory quality of TaO5 corresponded well with its microbiological findings, making it the only product that consistently exhibited inferior quality across both microbiological and sensory analyses. Although causality cannot be confirmed within the present study, this agreement suggests that inadequate fermentation or storage conditions may have contributed to the observed deterioration in product quality. Conversely, TaO1 combined the best sensory acceptability with the absence of detectable microbial contamination, supporting the importance of appropriate processing and preservation practices.

Additionally, differences in packaging type and labeling quality were identified, which may influence consumer perception and product quality. Glass packaging (TaO1–TaO3) is generally associated with better product stability and consumer preference, whereas flexible packaging may increase the risk of mechanical damage and quality deterioration. Variability in olive content relative to packaging size further highlights inconsistencies in product standardization across manufacturers [20, 21]. However, the relatively small number of analysed products does not allow definitive conclusions regarding the influence of packaging material alone, and further studies including a larger number of commercial samples would be required.

The results of this study are in agreement with previously published research, confirming that the quality of table olives is strongly influenced by processing technology, microbial activity, and formulation factors. The detected variability among commercial products underscores the importance of standardized production practices and strict quality control to ensure consistent product safety and quality. In particular, TaO5 consistently represented the least favourable product, combining the highest microbial counts with the poorest sensory evaluation. The agreement between independent microbiological and sensory analyses strengthens the conclusion that processing conditions substantially influence the final quality of commercial table olives.

CONCLUSIONS

The present study demonstrated considerable variability among commercially available green table olives in terms of microbiological safety, antioxidant activity, physicochemical properties, color characteristics, and sensory quality. Most products exhibited high microbiological quality, whereas TaO5 and TaO6 showed detectable microbial counts, with TaO5 also exhibiting yeasts, moulds, and the poorest sensory quality. In contrast, TaO1 achieved the highest sensory scores, while TaO4 showed the highest antioxidant capacity. These findings indicate that processing technology, formulation, and packaging substantially influence the final quality of commercial table olives. Particular attention should therefore be paid to fermentation control, microbial stability during storage, and optimization of brine composition to ensure consistent product quality. Further studies correlating processing variables with microbiological, chemical, and sensory characteristics are warranted to support the development of best-practice guidelines for commercial table olive production.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

Conflict of Interest

The authors declare no conflict of interest.

Generative AI Statement

The authors used ChatGPT (OpenAI) solely for language editing and improving grammar.

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Authors' Contributions

M.K., J.V.: writing – original draft, resources, conceptualization, writing – review & editing. JV: methodology, investigation, writing – original draft. **M.V., M.K., J.V., J.Z.:** methodology, investigation, conceptualization, writing – original draft, data curation. **E.D., J.V.:** writing – review & editing, resources.

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