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# Authenticity of avocado and olive oils used as ingredients in commercially processed foods

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ABSTRACT

Avocado oil and olive oil are increasingly incorporated into processed foods as premium ingredients, reflecting consumer interest in their perceived health attributes and preference relative to vegetable oils. To date, most studies have focused on bottled oils sold directly to consumers, whereas oils used as ingredients in processed foods have received little analytical attention. This study evaluated the authenticity of avocado oil and olive oil used as ingredients in commercially processed foods, oils extracted from 74 commercial chips, mayonnaise, and salad dressings labeled as containing avocado oil or olive oil were evaluated using established compositional markers, including fatty acids and sterols. Eighty-nine percent of avocado oil–labeled products exhibited compositional patterns inconsistent with authentic avocado oil, characterized by reduced palmitic acid, palmitoleic acid, cis-vaccenic acid, beta-sitosterol, and clerosterol, and elevated stearic acid, campesterol, stigmasterol, delta-7-stigmastenol and delta-7-avenasterol. These findings suggest that ingredient-level oil claims may represent an underexamined source of economic adulteration in processed foods.

## 1. Introduction

Avocado oil and olive oil are recognized as premium edible oils and are increasingly incorporated into processed foods such as snack products, mayonnaise, and salad dressings. Both oils are derived from fruit tissues and are rich in monounsaturated fatty acids, particularly oleic acid, and are valued for their nutritional properties. Their use is often motivated by consumer interest in perceived nutritional benefits and marketing strategies that differentiate products from those formulated primarily with seed oils. As a result, ingredient statements highlighting avocado oil or olive oil have become more common across a range of processed food categories.

Concerns regarding the authenticity of high-value edible oils are well documented, particularly for bottled olive oil (Baeten et al., 1996; Frankel, 2010; Laroussi-Mezghani et al., 2015) and, more recently, avocado oil (Aras & Rohman, 2025). Numerous studies have demonstrated that products marketed as avocado oil may be partially or wholly substituted with lower-cost vegetable oils or refined oils, resulting in mislabeling and economic adulteration (Green & Wang, 2020; Green & Wang, 2023). In response, a range of analytical approaches based on fatty acid composition, sterol profiles, and other minor components have been developed and applied to assess oil authenticity and support regulatory oversight (A. Fernando et al., 2025; Green & Wang, 2022; Green & Wang, 2023; Hashempour-baltork et al., 2024; Marín-Obispo et al., 2025; Pérez-Calabuig et al., 2023; Rydlewski et al., 2020; Tang et al., 2021; Tang et al., 2024; Wu et al., 2024).

In contrast to bottled oils sold directly to consumers, considerably less attention has been paid to the authenticity of edible oils used as ingredients in processed foods (Grundy et al., 2025). Unlike bottled oils, which can be analyzed directly, oils used as ingredients in processed foods must first be recovered from complex food matrices prior to authenticity assessment. When oils are incorporated into complex food matrices, they are often present with other ingredients and may be subjected to thermal processing, emulsification, or blending (García González et al., 2018; Ramadan, 2015; Ujong et al., 2023). These factors can complicate both analytical assessment and regulatory enforcement, and may reduce transparency regarding the composition of the oil fraction relative to labeled ingredient claims.

Labeling regulations generally require that ingredients be declared by common or usual name (U.S. Food and Drug Administration, 2013); however, the extent to which labeled oils reflect the actual composition of the lipid fraction in finished goods remains largely unknown (Moore

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et al., 2012; Yao & Rodriguez-Saona, 2020). It remains unclear whether products labeled as containing avocado oil or olive oil are formulated primarily with these oils or whether they contain lipid fractions inconsistent with the labeled oil claims. This represents a potential gap in current food control efforts, as consumers may reasonably interpret front-of-package oil claims as signals of meaningful product differentiation. Prior research demonstrates that ingredient-based claims and "free-from" labels can generate halo effects, shaping perceptions of healthiness and sustainability beyond what is objectively warranted (Lozano-Castellón et al., 2022; Priven et al., 2015). As front-of-package marketing increasingly emphasizes premium oils, understanding whether labeled oils meaningfully represent the lipid fraction is essential for consumer transparency.

To our knowledge, this is the first study to systematically evaluate the authenticity of avocado oil and olive oil used as the sole declared edible oil ingredients in commercially processed foods while also examining the effects of representative food-processing operations on authenticity markers. The objective of this study was to evaluate the authenticity of avocado oil and olive oil used as the sole declared edible oil ingredients in commercial processed foods. Oils extracted from chips, mayonnaise, and salad dressings were analyzed using established fatty acid and sterol compositional markers to assess ingredient-level authenticity and determine whether the lipid composition was consistent with the labeled oil claims. This study aims to provide data relevant to ingredient-level oil authenticity and to inform future discussions on labeling accuracy and analytical verification in processed foods.

## 2. Materials and methods

### 2.1. Sample collection

Three food categories that have become increasingly prevalent in the U.S. market were selected: chips, mayonnaise, and salad dressings. These categories were included because avocado oil and olive oil are frequently promoted as premium ingredients in each category, while also representing distinct food matrices and processing conditions. Chips represent thermally processed fried products, mayonnaise represents an emulsified system, and salad dressings represent liquid emulsified formulations. Evaluating multiple product categories allowed assessment of oil authenticity across different commercial applications. Within each category, products were selected based on consumer popularity and market availability. Only products that declared a single oil (e.g. avocado oil or olive oil) in the ingredient statement and did not list additional edible oils were included in the study. Three vegetable oil chip products and three vegetable oil mayonnaise products were also collected as compositional comparators; however, because these products did not claim to contain avocado or olive oil as the sole oil source, they were not included in authenticity classification analyses.

Samples were purchased in 2025 and 2026 from online sources and retail stores in California and stored unopened in the laboratory until analysis. Two separate lots of each product were collected and analyzed, and each lot was analyzed in duplicate. Product information, including declared oil type, ingredient list, retail price, and collection location, is provided in Supplementary Table 1. The brands included in the study are listed in Supplementary Table 2. Lot numbers were recorded and are available from the corresponding author upon request.

### 2.2. Oil extraction

Fat extraction of mayonnaise and salad dressing was performed according to Lagunes-Galvez et al. (2002) with some modifications. Approximately 20 g of mayonnaise or salad dressing were portioned in 50 mL falcon tubes and frozen at -20°C for 24 h. Samples were thawed at room temperature for two hours. The thawed samples were centrifuged at 15,000 x g for 10 min (Sorvall Legend X1; Thermo Scientific, Newington, CT, USA), resulting in an oil layer separating from the other ingredients.

Chips were prepared for oil extraction according to Kadamne and Proctor (2010). Approximately 30 g of chips were blended in a food processor (DLC-2A Mini-Prep Plus; Cuisinart, East Windsor, NJ, USA). Approximately 10 g of crushed chips were weighed and placed in Sartorius cellulose extraction thimbles (33 mm x 130 mm). Fat extraction was performed by the Soxhlet method using Buchi E-800 Universal Extractor (Buchi Corporation, New Castle, USA). The fat was extracted for 25 cycles using n-hexane at 69°C. The residual hexane was further evaporated under the "Drying Step" on Buchi E-800 and left to dry completely in a fume hood until no hexane remained to acquire the extracted fat for subsequent analysis.

### 2.3. Chemical analysis

#### 2.3.1. Fatty acid profile

Fatty acid methyl esters (FAMEs) were prepared according to the IOC official method (COI/T.20/Doc. No 33/Rev.1, International Olive Council, 2017) with modifications. Briefly, in a 12 mL amber vial, approximately 0.03 g of oil was mixed with 3 mL of HPLC grade hexane. 200 µL of 2 mol $L^{-1}$ methanolic potassium hydroxide solution was added and was vortexed for 30 seconds. The solution was left to stratify until the upper layer was clear and was subsequently filtered with a 0.45 µm PTFE filter for analysis.

FAMEs were analyzed using a gas chromatograph equipped with a flame ionization detector (GC-FID) (Agilent 7890A; Agilent Technologies, Wilmington, DE, USA). Separation was achieved using a DB-FastFAME capillary column (90 m × 250 µm × 0.25 µm, Agilent, Santa Clara, CA, USA). Helium was used as the carrier gas at a constant flow rate of 1.9 mL $min^{-1}$. The injector temperature was set at 260°C with a split ratio of 30:1 while the detector temperature was set at 260°C. Hydrogen, air, and nitrogen (make-up gas) flows were set at 40, 400, and 25 mL $min^{-1}$, respectively. The oven temperature program was as follows: initial temperature 75°C for 1 min; ramp at 35°C $min^{-1}$ to 200°C and hold for 14 min; ramp at 2.5°C $min^{-1}$ to 210°C and hold for 5 min; ramp at 12 °C $min^{-1}$ to 230°C and hold for 10 min. The total run time was 47.4 min.

FAMEs were identified by comparison of retention times with a 37-component FAME standard mixture (Supelco, PA, USA). Quantification was performed using peak area normalization and results were expressed as the relative percentage of total identified FAMEs.

#### 2.3.2. Sterol profile

Sterols samples were prepared following the method by Thompson & Merola (1993). 85% aqueous potassium hydroxide and 3% ethanoic pyrogallol were prepared fresh the day of analysis. Approximately 0.2 g of oil sample was pipetted into a 50 mL plastic tube along with 20 µL of the internal standard 5α-Cholestan-3β-ol in ethyl acetate 0.2% w/v). 8 mL of the 3% pyrogallol solution was added along with 0.5 mL of 85% KOH and gently swirled to incorporate. The tubes were shaken in a water-shaker bath (Precision SWB 15; Thermo Scientific, Newington, CT, USA) at 80°C for 20 min and cooled under tap water. 12 mL of deionized water was added to each tube along with 20 mL cyclohexane and manually shaken for 30 seconds. The solution was left to stratify until the organic layer was clear. The organic layer was transferred to glass tubes and dried under nitrogen flow with gentle heating of 35°C to aid evaporation (BT1606; BT Lab Systems, St Louis, MO, USA). The residue was redissolved in 400 µL of derivatization reagent (pyridine/BSTFA with 1% TMCS, 1:1, v/v).

Sterol composition was determined by an Agilent 7890A GC-FID on an Agilent DB-5HT capillary column (30 m × 0.25 mm × 0.1 µm). Helium was used as the carrier gas under constant-flow mode at 1.2 mL $min^{-1}$. The injector temperature was set at 280°C in split mode (split ratio 30:1). The oven temperature was maintained isothermally at 260°C for 50 min with a post-run temperature at 300°C. The FID temperature was 300°C, using the same hydrogen, air, and nitrogen flow

rates as described for the FAMEs GC analysis.

Sterol composition was identified by comparing retention times with those of authentic standards analyzed under identical conditions. 5α-Cholestan-3β-ol and cholesterol were purchased from Sigma-Aldrich (St. Louis, MO, USA) and stigmasterol, brassicasterol, Δ5-avenasterol, and Δ7-avenasterol were purchased from Toronto Research Chemicals (Toronto, ON, Canada). Quantification was performed using the internal standard based on peak area ratios and expressed in percentage. Cholesterol was excluded from total sterol normalization because it originates from egg rather than oil (Kuang et al., 2018).

### 2.4. Authenticity criteria

Fatty acid and sterol compositions of avocado oil are known to vary according to cultivar, geographic origin, maturity, and growing conditions (Hausch et al., 2020; Manaf et al., 2019; Ramos-Aguilar et al., 2021; Rodríguez-Sánchez et al., 2025; Tan et al., 2017; Wu et al., 2024). However, because the origin and varietal composition of avocado oil used as an ingredient in processed foods are not disclosed on product labels, these factors could not be incorporated into the present analysis. Therefore, authenticity classification was based on Codex Alimentarius Standard for Named Vegetable Oils and Olive Oil and Olive Pomace Oils (CXS 210-1999; CXS 33-1981*)* which are intended to encompass expected natural variability (Codex Alimentarius Commission, 2024a, 2024b).

To account for analytical uncertainty, biological variability, and potential processing influences, minor deviations were tolerated in the classification criteria. Deviations limited to a single fatty acid or sterol marker and not exceeding 10% beyond established compositional limits were not considered sufficient to classify a sample as inconsistent and were therefore considered consistent. A sample was considered borderline when no more than two fatty acid or sterol markers marginally exceeded the 10% allowance and lacked concordant deviations across other markers indicative of a non-authentic profile. When a sample was fully consistent in either fatty acids or sterols and borderline in the other, it was considered consistent with authentic oil. Samples that have multiple deviations or patterns inconsistent with authentic reference profiles were classified as inconsistent.

### 2.5. Preparation of model chips and mayonnaise

#### 2.5.1. Model chips preparation

Two retail avocado oils (Marianne's Avocado Oil, packaged in the US from globally sourced materials; Sprouts Farmers Market, product of Mexico and/or Spain) and two retail extra virgin olive oil (California Olive Ranch Extra Virgin Olive Oil, product of California; Sprouts Farmers Market, product of Spain) were used as reference oils for preparation of model products.

Model avocado oil chips samples were prepared and fried according to Zhang et al. (2018). Russet potatoes were purchased from a local grocery store. Potatoes were washed, peeled, and sliced into 1.5 mm thick slices using a mandoline slicer (Vekaya, Hangzhou, China). Sliced potatoes were blanched in boiling water for two min and dried with paper towels to remove surface moisture. Two hundred and fifty mL of pure avocado oil was heated in a 3-qt stainless steel saucepan until 180°C. Eighty grams of blanched potatoes were fried for 7 min, and the excess oil was drained onto paper towels. This process was performed in duplicate. A portion of the avocado oil was analyzed directly prior to frying (pre-frying oil). After frying, the oil absorbed into the potato chips was recovered using the extraction procedure described in Section 2.2 and analyzed (post-frying oil). This process was performed in duplicate.

Olive oil potato chips were prepared in a similar manner. Two hundred and fifty mL of pure extra virgin olive oil was heated to 160°C to avoid excessive thermal degradation. Eighty grams of blanched potatoes were fried for 8 min. A portion of the olive oil was analyzed directly before frying, and post-frying oil was recovered from the fried chips using the extraction procedure described in Section 2.2.

White corn tortillas, containing no added fat, were purchased from a local grocery store. Tortillas were sliced into quarters. Sixty grams of tortilla was fried in 180 mL pure avocado oil at 180°C for 4 min. Post-frying oil was recovered from the tortilla chips using the extraction procedure described in Section 2.2.

#### 2.5.2. Model mayonnaise preparation

Model avocado oil mayonnaise was prepared using pure avocado oil to evaluate potential compositional changes during emulsification and storage. Formulations consisted of whole eggs (18%), vinegar (6%), and oil (76%), following a standardized laboratory-scale procedure according to Metri-Ojeda et al. (2023). Whole eggs and avocado oil were combined using an immersion blender (KHB1231, KitchenAid, Benton Harbor, MI) with continuous mixing to form a stable emulsion. Once an emulsion was achieved, vinegar was added and mixed again to incorporate. Final products were stored in glass jars at 4°C prior to analysis. Oil was subsequently re-extracted using the method described in Section 2.2 to assess whether emulsification or short-term storage altered fatty acid or sterol composition. Model olive oil mayonnaise was prepared the same with using pure extra virgin olive oil.

### 2.6. Statistical analysis

All analytical measurements were performed in duplicate, unless noted otherwise. Results are reported as mean ± standard deviation.

Selected fatty acids and sterols of avocado oil- or olive oil-contained products were compared across three product categories (chips, mayonnaise, and salad dressings). Scatter dot plots were generated in R (R Foundation for Statistical Computing, Vienna, Austria) using Visual Studio Code, displaying individual observations with category medians indicated by dashed lines and shaded regions for the corresponding Codex Alimentarius compositional ranges for authentic oils.

Principal component analysis (PCA) was performed to assess variation in selected fatty acids and sterols among the samples mentioned in 2.1; vegetable oil (VO) comparator samples were included as references. Variables were centered and scaled to unit variance prior to analysis. PCA was conducted in R using Visual Studio Code. Biplots of the first two principal components were generated to display sample scores and variable loadings simultaneously. Samples were colored by oil category, and 95% confidence ellipses were overlaid for avocado oil- and olive oil-containing samples.

Cis-vaccenic acid (C18:1 (n-7)) levels in avocado oil-labeled products were compared between samples classified as compositionally consistent or inconsistent. Individual observations were visualized using a scatter dot plot generated in R with group medians indicated by dashed lines. Differences between groups were evaluated using the non-parametric Wilcoxon rank-sum test due to unequal sample size and non-normal data distribution. Statistical significance was set at $p < 0.05$.

## 3. Results and discussion

### 3.1. Authenticity by product category and declared oil type

Classification was based on an integrated interpretation of fatty acid and sterol markers. Samples were considered consistent when both fatty acid and sterol profiles met the compositional criteria defined in Section 2.4; summary results are presented in Table 1. Among avocado oil–labeled products, 93% of chip samples were classified as inconsistent with authentic avocado oil based on combined fatty acid and sterol criteria. Similarly, 71% of mayonnaise samples and 100% of salad dressing samples were classified as inconsistent. These findings indicate that labeled claims of premium oils in processed foods do not consistently align with the chemical composition of the oil fraction. In contrast, 90% of olive oil–labeled chip products and 100% of olive oil–labeled salad dressings and mayonnaise were classified as consistent

**Table 1**
Authenticity classification results based on fatty acid and sterols criteria described in Section 2.4.

| Product category | Declared oil | N | Consistent (N, %) | Inconsistent (N, %) | Price range ($/oz product) |
|---|---|---|---|---|---|
| **Chips** | Avocado | 28 | 2 (7%) | 26 (93%) | 0.30-2.00 |
| | Olive | 10 | 9 (90%) | 1 (10%) | 0.43-1.70 |
| **Dressings** | Avocado | 12 | 0 (0%) | 12 (100%) | 0.60-1.12 |
| | Olive | 6 | 6 (100%) | 0 (0%) | 0.42-1.12 |
| **Mayonnaise** | Avocado | 14 | 4 (29%) | 10 (71%) | 0.30-1.63 |
| | Olive | 4 | 4 (100%) | 0 (0%) | 0.53-1.07 |

with authentic olive oil. Overall, the rate of inconsistency observed for avocado oil–labeled products was substantially higher than that observed for olive oil–labeled products.

For the two avocado oil chip products classified as consistent, two different production lots were collected to assess lot-to-lot variability. In both cases, only one lot met the criteria for consistency, whereas the second lot was considered inconsistent. These findings indicate measurable lot-to-lot variation and highlight the importance of batch-level verification when assessing ingredient authenticity in processed foods as a company may be sourcing from multiple suppliers for the same ingredient.

One of the studied brands offered both avocado oil and olive oil potato chip products. Neither of the two avocado oil potato chip products tested was consistent with Codex standards, whereas one of the two olive oil potato chip products was consistent. This suggests that formulation practices and ingredient sourcing may differ even within the same brand and product category. At the same time, this may also reflect the comparatively higher compliance and authenticity of olive oil sources relative to avocado oil, as olive oil standards are more established and regulatory oversight and enforcement are considerably more developed than for avocado oil.

Retail prices showed consistent premiums for products labeled as containing avocado oil or olive oil relative to vegetable oil counterparts (Table 1 and Table S1). Chips labeled with avocado oil ranged from $0.30–2.00 per ounce, compared with $0.43–1.70 for olive oil chips and $0.44–0.62 for vegetable oil chips. Avocado oil mayonnaise ranged from $0.30–1.63 per ounce, compared with $0.53–1.07 for olive oil mayonnaise and $0.24–0.75 for vegetable oil mayonnaise. Salad dressings labeled with avocado oil ranged from $0.60–1.12 per ounce, while olive oil dressings ranged from $0.42–1.12 per ounce. Products labeled with avocado oil or olive oil generally commanded higher retail prices than comparable products formulated with vegetable oils.

The two avocado oil chip products classified as consistent were priced at $0.63 and $0.83 per ounce, near or below the average price of all avocado oil chip products in the study. The four consistent avocado oil mayonnaise products were priced at $1.63 per ounce, higher than other avocado oil mayonnaise products studied. Overall, these findings indicate that although products labeled with avocado oil generally commanded a price premium over vegetable oil counterparts, retail price alone was not a reliable indicator of ingredient authenticity and consumers cannot rely on price alone as an indicator of authenticity.

Ingredient-level adulteration may present distinct regulatory challenges. In finished foods, oils are embedded within multi-ingredient systems and may be present at varying inclusion levels. All products included in this study declared only a single edible oil in the ingredient statement and did not disclose blended oil formulations. Thus, consumers would reasonably expect the named oil, particularly when emphasized through front-of-package claims such as “made with 100% avocado oil” to be the primary lipid source of the product. Although third-party verification and certification programs for foods and consumer products exist (e.g., Seed Oil Free Alliance), only two of the olive oil–labeled dressing samples analyzed in this study carried such certification at the time of purchase.

### 3.2. Fatty acid and sterol compositional characteristics of consistent and inconsistent samples

Detailed fatty acid and sterol profiles of oils extracted from commercial products are summarized in Tables S3 and S4. Figs. 1 and 2 show the distribution of key fatty acids and sterols in oils extracted from commercial products labeled as containing avocado oil or olive oil.

Low levels of palmitic acid (C16:0) and palmitoleic acid (C16:1), together with elevated stearic acid (C18:0), are not characteristic of authentic avocado oil. Rather, this pattern is more consistent with substitution or dilution using vegetable oils. Most avocado oil chips and mayonnaise samples, and all avocado oil salad dressings, fell outside the Codex standard ranges for C16:0, C16:1 and C18:0 (shaded regions in Fig. 1a and Supplementary Table S3). These fatty acids were selected because they are included in the Codex standards and exhibited the greatest differences between products classified as consistent and inconsistent with authentic avocado oil compositional ranges; however, classification was based on the complete fatty acid and sterol profiles rather than these markers alone. In contrast, olive oil chips, mayonnaise and salad dressings were consistently within the Codex standard ranges for the same fatty acids (Fig. 1b and Supplementary Table S3), indicating substantially better compliance among the olive oil–labeled products evaluated.

Sterol composition also showed substantial inconsistencies among avocado oil–labeled products. Most samples had campesterol, stigmasterol and Δ7-avenasterol levels outside the Codex standard ranges (shaded regions in Fig. 2a and Supplementary Table S4). Elevated campesterol, stigmasterol and Δ7-avenasterol are consistent with substitution or dilution with vegetable oils. These sterol deviations support the fatty acid findings and indicate widespread compositional inconsistency among the avocado oil–labeled products evaluated.

Sterol composition of the olive oil–labeled samples also showed deviations from Codex standards. Multiple chip samples had campesterol, brassicasterol and apparent β-sitosterol levels outside of the Codex limits (Fig. 2b and Supplementary Table S4). Because brassicasterol is not characteristic of authentic olive oil and is commonly associated with canola oil, its presence above trace levels is particularly indicative of potential substitution or blending (Gül & Seker, 2006). However, if canola oil was an adulterant, a concurrent reduction in C16:0, C16:1, and C18:0 would be expected (Christopoulou et al., 2004), which was not observed (Fig. 1b).

Similar to avocado oil, campesterol is a critical regulatory marker for olive oil authenticity. It has long been recognized as a reliable marker to distinguish olive oil from vegetable oils, which typically contain substantially higher campesterol levels (Codex STAN 33-1981, Codex Alimentarius Commission, 2024b; Srigley et al., 2016; COI/T.15/NC No 3/Rev. 21, International Olive Council, 2025). Olive pomace oil, derived from olive residues and subsequently refined, may exhibit modest alterations in sterol distribution, including slightly elevated levels of brassicasterol. According to the label, two olive oil mayonnaise products were formulated with a blend of olive pomace oil and extra virgin olive oil. These samples showed higher levels of brassicasterol compared with the 100% extra virgin olive oil mayonnaise counterpart from the same brand. However, the sterol profiles of the blended samples did not exhibit the markedly elevated campesterol or brassicasterol levels characteristic of vegetable oils (Codex STAN 33-1981, Codex Alimentarius Commission, 2024b).

### 3.3. Multivariate and targeted discrimination analyses

#### 3.3.1. Principal component analysis of fatty acid and sterol profiles

Principal component analysis (PCA) of fatty acid and sterol profiles demonstrated clear separation between samples classified as consistent and inconsistent with their labeled oil claims (Figs. 3 and 4). For the selected fatty acids (Fig. 3), PC1 explained 37.5% of the total variance and PC2 explained 28.4%. These fatty acids were selected because they

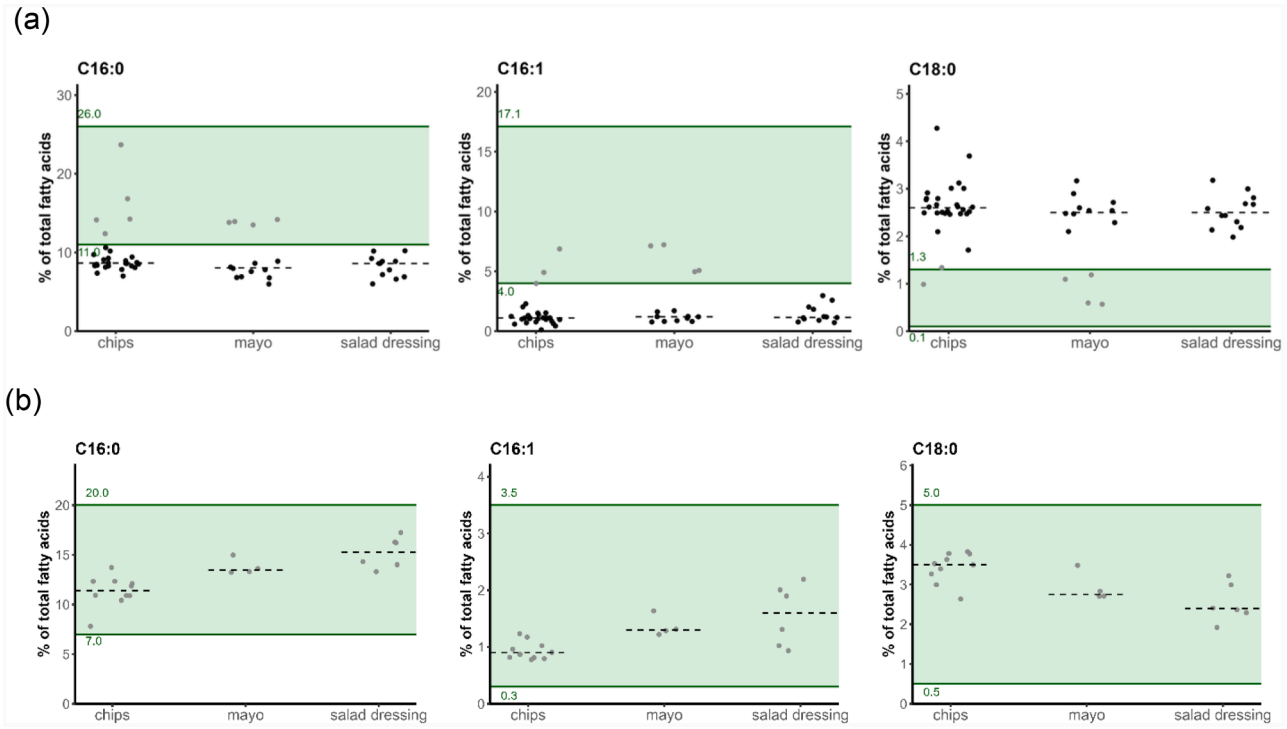


**Fig. 1.** Distribution of representative Codex-regulated fatty acids (palmitic acid C16:0, palmitoleic acid C16:1 and stearic acid C18:0) in oils extracted from commercial products labeled as containing (a) avocado oil (b) olive oil. Points represent individual products (grey = within the specified compositional criterion; black = outside); horizontal bars indicate medians; shaded regions indicate the corresponding Codex Alimentarius compositional ranges for authentic oils.

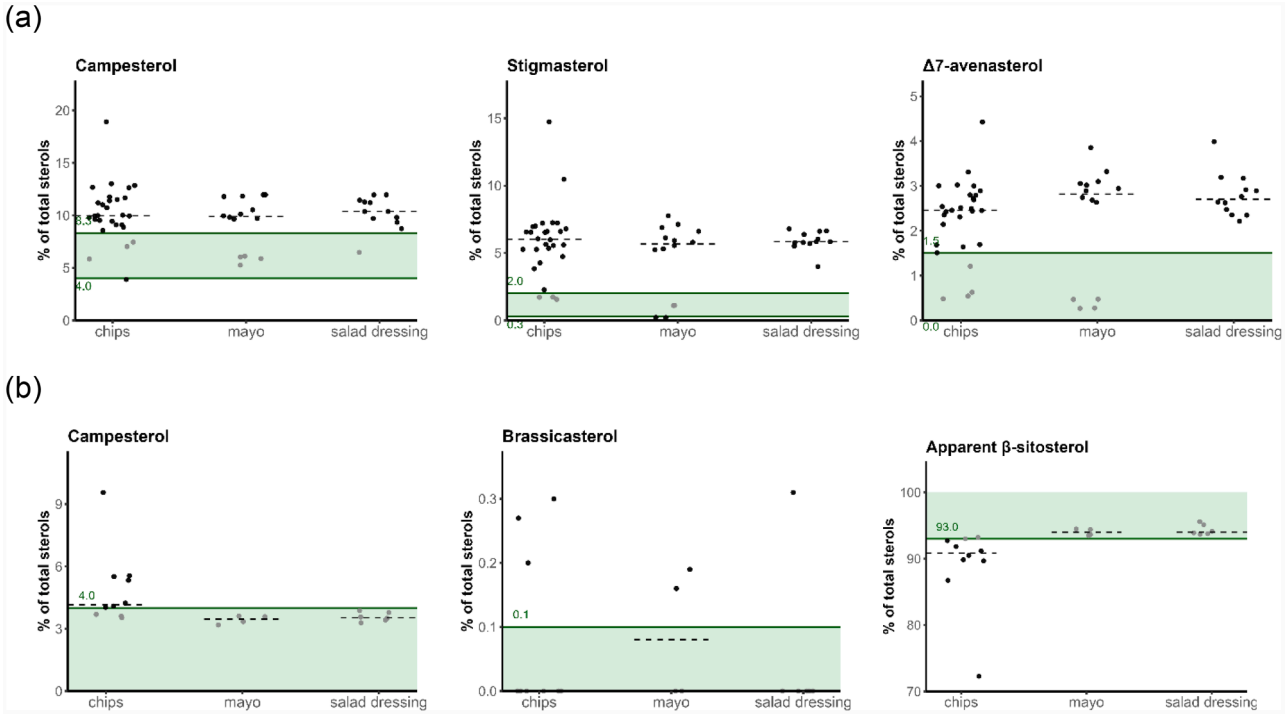


**Fig. 2.** Distribution of key sterols (campesterol, stigmasterol and Δ7-avenasterol; campesterol, brassicasterol and apparent β-sitosterol) in oils extracted from commercial products labeled as containing (a) avocado oil, (b) olive oil, respectively. Points represent individual products (grey = within the specified compositional criterion; black = outside); horizontal bars indicate medians; shaded green regions indicate the corresponding Codex Alimentarius compositional ranges for authentic oils.

exhibited the greatest differences between products classified as consistent and inconsistent and contributed strongly to PCA separation. PC1 was primarily associated with C16:0, C16:1, C18:1 (n-7), and C18:0, whereas PC2 was mainly influenced by C18:1, C18:2, and C18:3. Olive oil (OO) samples showed tighter clustering with a smaller confidence ellipse, with most samples positively correlated with C18:1, consistent

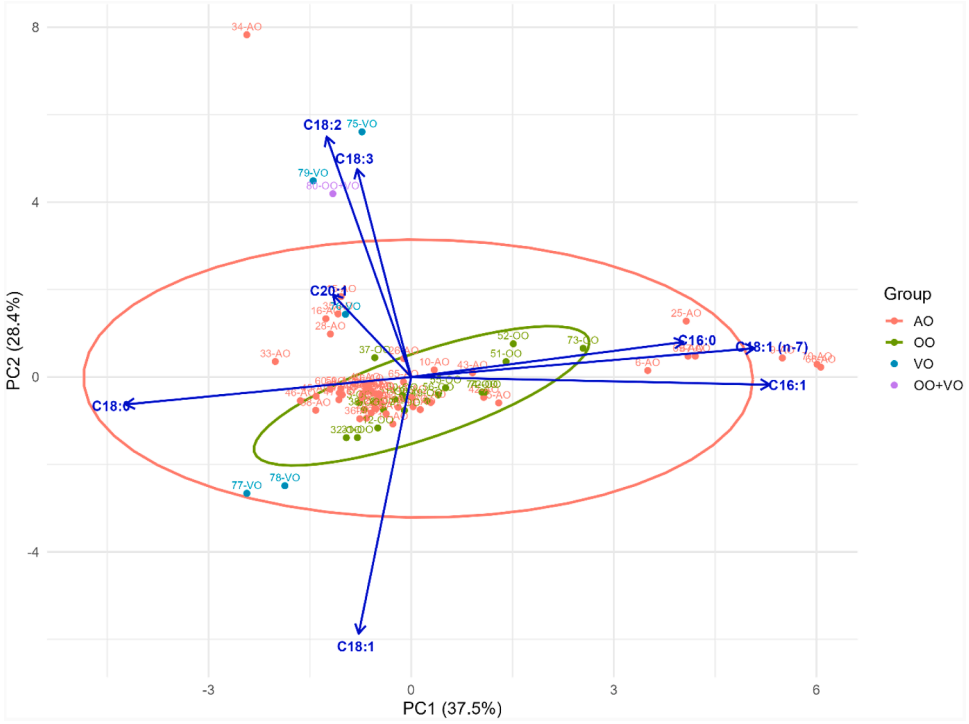


**Fig. 3.** PCA of selected fatty acids. AO: avocado oil-containing samples; OO: olive oil-containing samples; VO: vegetable oil-containing samples; OO+VO: sample containing vegetable oil blend with olive oil as the first ingredient.

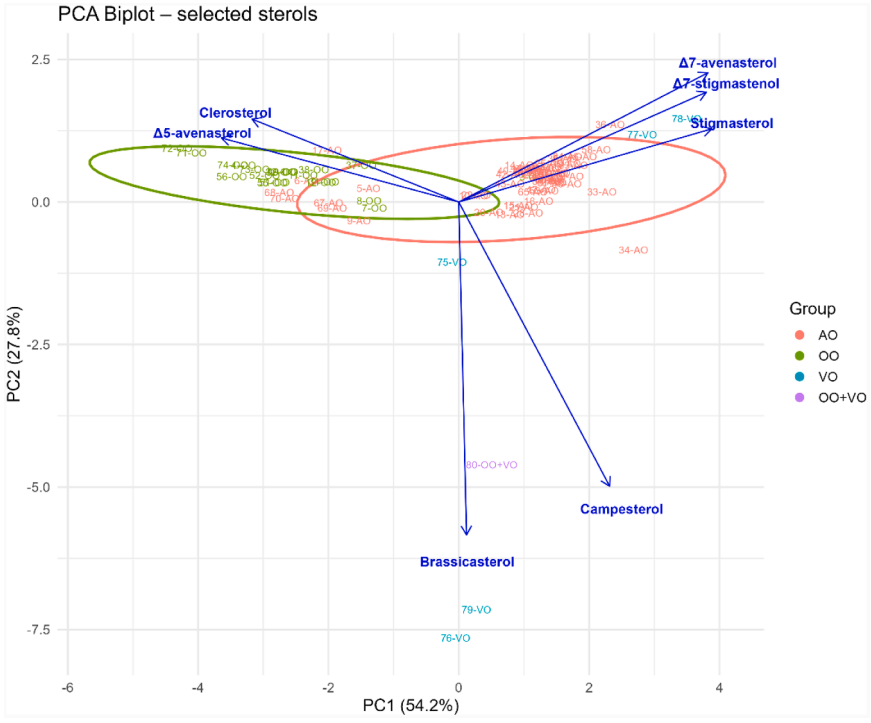


**Fig. 4.** PCA of selected sterols. AO: avocado oil-containing samples; OO: olive oil-containing samples; VO: vegetable oil-containing samples; OO+VO: sample containing vegetable oil blend with olive oil as the first ingredient.

with typical olive oil composition. In contrast, avocado oil (AO) samples had a broader confidence ellipse, reflecting greater variability. Samples 6-AO, 9-AO, 25-AO, 67-AO, 68-AO, 69-AO, and 70-AO were positively associated with C16:1 and C18:1 (n-7), consistent with fatty acid profiles of authentic avocado oil. Sample 34-AO was clearly separated from the AO cluster; its fatty acid profile, characterized by high C18:2 (52.5%) and C18:3 (6.5%) and low C18:1 (24.8%), is consistent with soybean oil composition. Many avocado oil–labeled samples clustered near samples 76-VO (containing canola, corn, soybean, and/or sunflower oil), suggesting that the fatty acid profiles of those products are more consistent with polyunsaturated vegetable oil compositions than with authentic avocado oil.

Selected sterols explained 82.0% of the total variance (PC1: 54.2% and PC2: 27.8%) in Fig. 4. PC1 was primarily associated with clerosterol, Δ5-avenasterol and stigmasterol, whereas PC2 was mainly influenced by brassicasterol and campesterol. OO samples were generally positioned along the direction of Δ5-avenasterol and clerosterol loadings, reflecting higher relative contributions of these sterols, whereas AO samples were more broadly distributed along PC1, indicating greater compositional variability. Samples 5-AO, 6-AO, 9-AO, 17-AO, 67-AO, 68-AO, 69-AO, and 70-AO were positively correlated with Δ5-avenasterol, a sterol typically present at higher levels in avocado oil than in common vegetable oils, supporting their alignment with authentic avocado oil profiles based on sterols. Sample 34-AO, which was clearly separated from the main avocado oil fatty acid cluster in Fig. 3, was again unique in Fig. 4, indicating a sterol composition that differs substantially from the other avocado oil–labeled samples. The consistent separation of Sample 34-AO in both fatty acid and sterol PCA suggests that its lipid composition differs from most of the oil used in AO-labeled products. Its fatty acid and sterol profiles are consistent with soybean oil rather than avocado oil. Avocado oil with 100% substitution of soybean oil was documented in an earlier study (Green & Wang, 2020).

Samples located in the direction of brassicasterol and campesterol loadings exhibited sterol patterns more consistent with vegetable oil characteristics. Samples 76-VO and 79-VO, which listed canola oil as the primary ingredient, showed strong correlations with brassicasterol, a characteristic sterol marker of canola oil. Sample 80-OO+VO also demonstrated strong associations with brassicasterol and campesterol despite olive oil being listed as the first ingredient, suggesting that vegetable oil may be the primary lipid component rather than olive oil.

### 3.3.2. *Targeted evaluation of cis-vaccenic acid C18:1 (n-7) as a discriminatory marker for avocado oil*

C18:1 (n-7) levels differed between consistent and inconsistent avocado oil–labeled products (Fig. 5). Oils extracted from samples classified as consistent had values clustering around 4-6% range. In contrast, inconsistent samples showed substantially lower levels, between 1-2%, aligning with typical vegetable oil profiles. Mean C18:1 (n-7) content was 5.3 ± 1.0% in consistent samples compared with 1.7 ± 0.5% in inconsistent samples ($p < 0.001$). C18:1 (n-7) is characteristically elevated in avocado oil relative to most common vegetable oils (Green & Wang, 2022), the clear separation observed here supports its strong discriminatory capacity as a targeted marker for distinguishing authentic avocado oil from products containing vegetable oils.

## 3.4. *Processing-induced changes in fatty acid and sterol composition*

Key fatty acids and sterols in oils recovered from laboratory-prepared chips and mayonnaise are presented in Tables 2–4, with complete compositional profiles provided in Table S5. Under laboratory-scale frying (160–180°C, ≤8 min) and emulsification conditions, minor changes relative to the original oils were observed.

For avocado oil subjected to frying (Table 2), absolute changes in major fatty acids were less than 0.6%. Notably, C18:1 (n-7), a key discriminatory marker for avocado oil authenticity (Fig. 5), decreased by only 0.1% following frying in both potato and tortilla chips. C16:0, C16:1 and C18:0 that differentiated consistent and inconsistent samples

**Table 2**
Selected fatty acids and sterols (%) of avocado oil before frying and after recovery from laboratory-prepared avocado oil potato (AP) and tortilla (AT) chips.

| Marker | Codex limit | Pre-frying | AP | Δ (AP) | AT | Δ (AT) |
|---|---|---|---|---|---|---|
| C16:0 | 11.0-26.0 | 19.3 ± 0.0 | 19.5 ± 0.0 | 0.2 | 19.5 ± 0.1 | 0.2 |
| C16:1 | 4.0-17.1 | 7.1 ± 0.0 | 7.1 ± 0.0 | 0.0 | 7.0 ± 0.0 | -0.1 |
| C18:0 | 0.1-1.3 | 1.0 ± 0.0 | 1.0 ± 0.0 | 0.0 | 1.0 ± 0.0 | 0.0 |
| C18:1 | 42.0-75.0 | 58.5 ± 0.0 | 58.3 ± 0.0 | -0.2 | 57.9 ± 0.2 | -0.6 |
| C18:1 (n-7) | NA | 4.2 ± 0.0 | 4.1 ± 0.0 | -0.1 | 4.1 ± 0.0 | -0.1 |
| C18:2 | 7.8-19.0 | 12.1 ± 0.0 | 12.0 ± 0.0 | -0.1 | 12.7 ± 0.3 | 0.6 |
| C18:3 | 0.5-2.1 | 1.3 ± 0.0 | 1.4 ± 0.0 | 0.1 | 1.3 ± 0.0 | 0.0 |
| Brassicasterol | ND-0.5 | 0.3 ± 0.0 | 0.3 ± 0.0 | 0.0 | 0.3 ± 0.0 | 0.0 |
| Campesterol | 4.0-8.3 | 7.8 ± 0.0 | 7.6 ± 0.0 | -0.2 | 8.0 ± 0.1 | 0.2 |
| Stigmasterol | 0.3-2.0 | 0.9 ± 0.0 | 1.0 ± 0.0 | 0.1 | 1.1 ± 0.1 | 0.2 |
| Clerosterol | 1.0-2.5 | 1.3 ± 0.0 | 1.5 ± 0.1 | 0.2 | 1.6 ± 0.0 | 0.3 |
| β-sitosterol | 79.0-93.4 | 79.4 ± 0.1 | 77.8 ± 0.2 | -1.6 | 77.7 ± 0.3 | -1.7 |
| Δ5-avenasterol | 2.0-8.0 | 5.6 ± 0.0 | 6.3 ± 0.1 | 0.7 | 5.2 ± 0.1 | -0.4 |
| Δ5,24-stigmastadienol | NA | 3.2 ± 0.1 | 4.1 ± 0.1 | 0.9 | 4.0 ± 0.1 | 0.8 |
| Δ7-avenasterol | ND-1.5 | 0.5 ± 0.0 | 0.5 ± 0.0 | 0.0 | 0.5 ± 0.0 | 0.0 |

Values are expressed as the relative percentage of total fatty acids or total sterols (mean ± SD). Δ represents absolute percentage point change (post − pre-frying). NA denotes fatty acid or sterol is not in the current Codex standards. C16:0, palmitic acid; C16:1, palmitoleic acid; C18:0, stearic acid; C18:1, oleic acid; C18:1(n-7), cis-vaccenic acid; C18:2, linoleic acid; C18:3, α-linolenic acid.

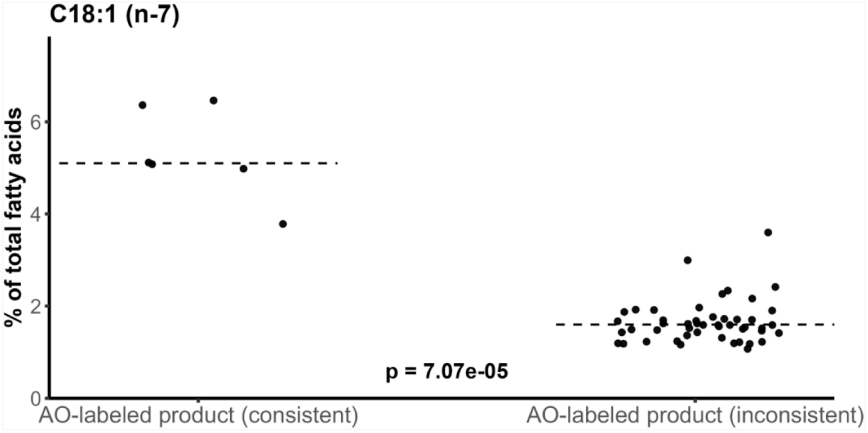


**Fig. 5.** Cis-vaccenic acid C18:1(n-7) content (% of total fatty acids) in oils extracted from avocado oil–labeled products classified as consistent or inconsistent. Each point represents an individual product. Dashed lines indicate group medians.

**Table 3**
Selected fatty acids and sterols (%) of olive oil before frying and after recovery from laboratory-prepared olive oil potato chips (OP).

| Marker | Codex limit | Pre-frying | OP | Δ |
|---|---|---|---|---|
| C16:0 | 7.0-20.0 | 11.8 ± 0.0 | 11.9 ± 0.0 | 0.1 |
| C16:1 | 0.3-3.5 | 1.1 ± 0.0 | 1.1 ± 0.0 | 0.0 |
| C18:0 | 0.5-5.0 | 3.7 ± 0.0 | 3.7 ± 0.0 | 0.0 |
| C18:1 | 53.0-85.0 | 73.8 ± 0.0 | 74.0 ± 0.1 | 0.2 |
| C18:1 (n-7) | NA | 2.3 ± 0.0 | 2.3 ± 0.0 | 0.0 |
| C18:2 | 2.5-21.0 | 7.6 ± 0.0 | 7.6 ± 0.0 | 0.0 |
| C18:3 | ≤ 1.0 | 0.7 ± 0.0 | 0.8 ± 0.0 | 0.1 |
| Brassicasterol | ≤ 0.1 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 |
| Campesterol | ≤ 4.0 | 3.0 ± 0.4 | 3.3 ± 0.0 | 0.3 |
| Stigmasterol | < campesterol | 0.9 ± 0.0 | 1.5 ± 0.0 | 0.6 |
| β-sitosterol | NA | 85.7 ± 0.3 | 81.4 ± 0.2 | -4.3 |
| Δ5-avenasterol | NA | 8.5 ± 0.1 | 11.7 ± 0.2 | 3.2 |
| Δ7-stigmastenol | ≤ 0.5 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 |
| Apparent β-sitosterol | ≥ 93.0 | 95.1 ± 0.4 | 94.4 ± 0.0 | -0.7 |

Values are expressed as the relative percentage of total fatty acids or total sterols (mean ± SD). Δ represents absolute percentage point change (post − pre-frying). NA denotes fatty acid or sterol is not in the current Codex standards. C16:0, palmitic acid; C16:1, palmitoleic acid; C18:0, stearic acid; C18:1, oleic acid; C18:1(n-7), cis-vaccenic acid; C18:2, linoleic acid; C18:3, α-linolenic acid.

**Table 4**
Selected fatty acids and sterols (%) of avocado oil before emulsification and after recovery from laboratory-prepared avocado oil mayonnaise (AM).

| Marker | Codex limit | Pre-emulsification | AM | Δ |
|---|---|---|---|---|
| C16:0 | 11.0-26.0 | 17.3 ± 0.0 | 17.0 ± 0.0 | -0.3 |
| C16:1 | 4.0-17.1 | 6.5 ± 0.0 | 6.4 ± 0.1 | -0.1 |
| C18:0 | 0.1-1.3 | 1.0 ± 0.0 | 1.1 ± 0.0 | 0.1 |
| C18:1 | 42.0-75.0 | 59.2 ± 0.0 | 59.4 ± 0.1 | 0.2 |
| C18:1 (n-7) | NA | 4.8 ± 0.0 | 4.8 ± 0.0 | 0.0 |
| C18:2 | 7.8-19.0 | 14.5 ± 0.0 | 14.7 ± 0.1 | 0.2 |
| C18:3 | 0.5-2.1 | 0.9 ± 0.0 | 0.9 ± 0.0 | 0.0 |
| Brassicasterol | ND-0.5 | 0.2 ± 0.0 | 0.1 ± 0.0 | -0.1 |
| Campesterol | 4.0-8.3 | 7.1 ± 0.0 | 7.2 ± 0.0 | 0.1 |
| Stigmasterol | 0.3-2.0 | 1.0 ± 0.0 | 0.9 ± 0.0 | -0.1 |
| Clerosterol | 1.0-2.5 | 1.2 ± 0.0 | 1.2 ± 0.0 | 0.0 |
| β-sitosterol | 79.0-93.4 | 83.5 ± 0.1 | 83.0 ± 0.2 | -0.5 |
| Δ5-avenasterol | 2.0-8.0 | 4.1 ± 0.0 | 4.2 ± 0.0 | 0.1 |
| Δ5,24-stigmastadienol | NA | 1.2 ± 0.0 | 1.7 ± 0.1 | 0.5 |
| Δ7-avenasterol | ND-1.5 | 0.5 ± 0.0 | 0.6 ± 0.1 | 0.1 |

Values are expressed as the relative percentage of total fatty acids or total sterols (mean ± SD). Δ represents absolute percentage point change (post − pre-emulsification). NA denotes fatty acid or sterol is not in the current Codex standards. C16:0, palmitic acid; C16:1, palmitoleic acid; C18:0, stearic acid; C18:1, oleic acid; C18:1(n-7), cis-vaccenic acid; C18:2, linoleic acid; C18:3, α-linolenic acid.

(Fig. 1a) did not change more than 0.2%. Most sterols showed only minor changes, with the largest decrease observed for β-sitosterol (−1.6 for potato chips and −1.7% for tortilla chips). This trend is consistent with previous reports indicating that β-sitosterol is particularly susceptible to heat-induced degradation during thermal processing (Salta et al., 2008). Δ7-avenasterol, a sterol for which many of the inconsistent avocado oil-labeled chips exceeded the Codex limit, remained unchanged during the frying process.

For olive oil frying experiments (Table 3), fatty acid changes were ≤0.2% for major markers while β-sitosterol (−4.3%) and Δ5-avenasterol (+3.2) had the largest shifts. In industrial frying operations, oil turnover rate and fatty acid composition are expected to influence the extent of processing-induced sterol modification. Oils with higher degrees of unsaturation, such as polyunsaturated vegetable oils, are more susceptible to degradation during repeated thermal exposure than monounsaturated-rich oils such as avocado or olive oil, with natural antioxidants such as tocopherols, frying technique and oxygen exposure further influencing sterol stability (Salta et al., 2008; Soupas et al., 2007; Winkler et al., 2007; Xu et al., 2009). Despite modest redistribution, the combined fatty acid and sterol profile remained clearly characteristic of olive oil and did not approach the compositional patterns typical of common vegetable oils.

Emulsified model mayonnaise prepared with avocado oil showed minimal compositional changes. Absolute differences in fatty acids were ≤0.3%, and sterol shifts were ≤0.5% (Table 4). Clerosterol, a sterol for which many of the avocado-labeled mayonnaise samples showed levels below the Codex limit of 1.0 was unaffected by emulsification, indicating the inconsistency was not caused by formulation processing. Even smaller changes were observed in mayonnaise prepared with olive oil (Table 5), with fatty acid differences ≤0.2% and sterol shifts ≤0.3%. In both avocado oil and olive oil mayonnaise models, C18:1(n-7) remained unchanged following emulsification and short-term refrigerated storage. These findings are consistent with the lack of high-temperature exposure and the limited oxidative stress associated with short-term emulsified product preparation.

These model product experiments indicate that typical frying and emulsification conditions do not substantially alter oil authenticity markers. Although thermal exposure can induce modest sterol degradation or redistribution, the magnitude of change observed here was small. Similar studies of frying oils report sterol losses typically below ~15%, even under extended frying conditions (Winkler et al., 2007). Thus, the minor changes observed in the model systems are insufficient to explain the significant compositional deviations detected in the inconsistent products.

A limitation of this study is the geographic scope and sample size. Products were purchased in California retail stores and online and therefore may not fully represent national market variability. In addition, products were evaluated at a single time point; results reflect only the two specific lots analyzed and are not intended to represent ongoing manufacturing practices or lot-to-lot variability.

## 4. Conclusion

This study evaluated the authenticity of avocado oil and olive oil used as the sole declared edible oil in commercially processed foods. By extracting lipids from chips, mayonnaise, and salad dressings and assessing fatty acid and sterol profiles against established compositional reference ranges, we identified substantial differences between labeled oil claims and measured oil composition, particularly among avocado oil–labeled products. Laboratory frying and emulsification experiments showed minor shifts in authenticity markers, indicating that typical

**Table 5**
Selected fatty acids and sterols (%) of olive oil before emulsification and after recovery from laboratory-prepared olive oil mayonnaise (OM).

| Marker | Codex limit | Pre-emulsification | OM | Δ |
|---|---|---|---|---|
| C16:0 | 7.0-20.0 | 15.2 ± 0.0 | 15.0 ± 0.0 | -0.2 |
| C16:1 | 0.3-3.5 | 1.3 ± 0.0 | 1.3 ± 0.0 | 0.0 |
| C18:0 | 0.5-5.0 | 2.2 ± 0.0 | 2.3 ± 0.0 | 0.1 |
| C18:1 | 53.0-85.0 | 69.8 ± 0.0 | 69.6 ± 0.1 | -0.2 |
| C18:1 (n-7) | NA | 2.9 ± 0.0 | 2.9 ± 0.0 | 0.0 |
| C18:2 | 2.5-21.0 | 9.7 ± 0.0 | 9.9 ± 0.0 | 0.2 |
| C18:3 | ≤ 1.0 | 0.6 ± 0.0 | 0.6 ± 0.0 | 0.0 |
| Brassicasterol | ≤ 0.1 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 |
| Campesterol | ≤ 4.0 | 3.7 ± 0.0 | 3.8 ± 0.1 | 0.1 |
| Stigmasterol | < campesterol | 1.1 ± 0.0 | 1.0 ± 0.0 | -0.1 |
| β-sitosterol | NA | 74.7 ± 0.1 | 74.4 ± 0.5 | -0.3 |
| Δ5-avenasterol | NA | 17.7 ± 0.1 | 17.8 ± 0.4 | 0.1 |
| Δ7-stigmastenol | ≤ 0.5 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 |
| Apparent β-sitosterol | ≥ 93.0 | 94.1 ± 0.0 | 93.8 ± 0.1 | -0.3 |

Values are expressed as the relative percentage of total fatty acids or total sterols (mean ± SD). Δ represents absolute percentage point change (post − pre-emulsification). NA denotes fatty acid or sterol is not in the current Codex standards. C16:0, palmitic acid; C16:1, palmitoleic acid; C18:0, stearic acid; C18:1, oleic acid; C18:1(n-7), cis-vaccenic acid; C18:2, linoleic acid; C18:3, α-linolenic acid.

processing conditions do not explain the magnitude of deviations observed in the studied products.

Although products labeled with premium oils were generally sold at higher retail prices, price was not predictive of compositional consistency. These findings highlight ingredient-level oil authenticity in processed foods as an under-monitored area of food integrity. Increased analytical scrutiny of ingredient authenticity in processed products may improve labeling transparency and help maintain consumer confidence in premium oil claims.

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## Supplement contents

The article "Authenticity of avocado and olive oils used as ingredients in commercially processed foods" has one supplementary file:

Table S1. Product information, declared oil type, additional ingredients, retail price and collection location for all products analyzed.

Table S2. A list of brands included in the study.

Table S3. Fatty acid profiles of all samples.

Table S4. Sterol profiles of all samples.

Table S5. Fatty acid and sterol profiles of the model products.

## Human and animal rights

The authors declare that the work described has not involved experimentation on humans or animals.

## CRediT authorship contribution statement

**Natalie Lopez-Alvarez:** Data curation, Investigation, Validation, Writing – review & editing, Supervision. **Xueqi Li:** Formal analysis, Software, Visualization, Writing – original draft, Writing – review & editing. **Benjamin Vizgordiski:** Data curation, Investigation, Writing – review & editing. **Selina C. Wang:** Conceptualization, Formal analysis, Investigation, Methodology, Resources, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2026.102389.

## Data availability

Data will be made available on request.

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