Journal of Agricultural Sciences (Tarim Bilimleri Dergisi) 2025, 31 (1) : 126 – 136 DOI: 10.15832/ankutbd.1458732

Journal of Agricultural Sciences
(Tarim Bilimleri Dergisi)

J Agr Sci-Tarim Bili
e-ISSN: 2148-9297
jas.ankara.edu.tr

Evaluation of Oxidation Stability of Organic and Conventional Hazelnut Oils

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ARTICLE INFO
Research Article
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Received: 25 March 2024 / Revised: 08 August 2024 / Accepted: 16 August 2024 / Online: 14 January 2025

Cite this article
Şahin S, Topçu C Ü (2025). Evaluation of Oxidation Stability of Organic and Conventional Hazelnut Oils. *Journal of Agricultural Sciences (Tarim Bilimleri Dergisi),* 31(1):126-136. DOI: 10.15832/ankutbd.1458732

ABSTRACT
In this study, the oxidation stabilities of organic hazelnut oils (OHO) were compared to conventional hazelnut oils (CHO). For this purpose, oxidation parameters such as peroxide value (PV), free fatty acid (FFA), anisidine value (AV), volatile lipid oxidation compounds (VLOC), fatty acid composition, and total antioxidant capacity (TAC) of the hazelnut oil samples were investigated under conditions of accelerated storage. At the beginning of storage, OHO had lower PV, higher AV, TAC and linoleic acid content than CHO and similar FFA, VLOC, palmitic, stearic, and oleic acids contents to CHO. As expected, PV, FFA and AV increased in OHO and CHO during storage, while TAC decreased. No significant difference between OHO and CHO was observed in terms of FFA, TAC, palmitic and stearic acid contents at the accelerated storage condition. When compared to CHO, OHO showed lower oleic acid and higher linoleic acid at the end of storage. During storage, the highest AV and PV were determined in OHO. Results reveal that OHO has lower oxidation stability than CHO. According to these results, it can be recommended to consume the OHO without being exposed to long-term oxidation.

Keywords: Oxidation stability, Organic hazelnut oil, Accelerated storage

1. Introduction

The ongoing rise in the global population has led to an increase in the need for food. To meet this increasing need for food, several farming practices have been implemented to increase productivity in agricultural activities. Some of these practices are the use of chemical fertilizers, herbicides, and pesticides. Conventional agriculture is a farming system including the use of chemical fertilizers, herbicides, pesticides, and GMO (genetically modified organisms) (Unluturk et al. 2021). Since the 1950s, conventional farming has produced a significant increase in productivity, but at the same time has also resulted in higher environmental pressures (Mondelaers et al. 2009). Organic farming has surfaced as a viable alternative to counteract the adverse impacts of conventional agriculture on both human health and the environment (Unluturk et al. 2021). Organic agriculture practices to uphold natural equilibrium and strives to yield high-quality food free from residues that may pose risks to human and animal health. To achieve this goal, it refrains from utilizing chemical fertilizers, pesticides, and GMO (Mondelaers et al. 2009). Therefore, products obtained from organic farming are considered safer and healthier by consumers and the interest in these foods is increasing day by day despite their higher prices. The increasing demand for organic foods has led to an increase in organic production. According to the latest available data on organic farming worldwide, the area used for organic agricultural production continues to increase and currently, 1.6 percent of the world's farmland is organic (Willer et al. 2023). The rapid development in organic products has prompted scientists to study the nutritional quality of organic products. In this regard, some researchers investigated differences in nutrient content and bioactive compounds of food items produced through organic and conventional methods. Many researchers compared the nutrient content and bioactive compounds content in organic vs. conventional food products in the following species: virgin olive oils (Jimenez et al. 2014); apples (Weibel et al. 2000); apple juice (Heinmaa et al. 2017); strawberry (Anttonen et al. 2006), red oranges (Tarozzi et al. 2006): peach and pear (Carbonaro et al. 2002); tomatoes (Juroszek et al. 2009); sunflower oil (Perretti et al. 2004). Recently, Karaosmanoğlu (2022) determined the chemical differences between organic and conventional hazelnuts. While numerous studies have explored the chemical composition of organic products, a significant gap exists in the literature concerning their storage stability.

Hazelnut (*Corylus avellana* L.) stands as the second most extensively cultivated tree nut globally, following almonds (Alasalvar & Shahidi 2009). Considering world hazelnut production, a total of 1 077 117 tons of hazelnuts were produced in 2021 and 684 000 tons of this was grown in Türkiye. With this production amount, Türkiye meets 64% of the world hazelnut production as the leading hazelnut-producing country (Food and Agriculture Organization 2023). The main component of unshelled hazelnut kernels is fat varying between 54 and 66% (Li & Parry 2011; Karaosmanoğlu 2022; Şahin et al. 2022).

Hazelnut oil contains very high amounts of mono- and polyunsaturated fatty acids (Alasalvar et al. 2006; Karaosmanoğlu, 2022; Şahin et al. 2022); which are known to be effective in preventing heart diseases (Alasalvar & Shahidi 2009). Among the fatty acid constituents, oleic acid is the primary constituent, ranging from 78 to 85% (Karaosmanoğlu 2022; Şahin et al. 2022; Şahin 2023; Tüfekci & Karataş 2018). Hazelnut oil is also used in the kitchen for its slightly nutty taste, in pharmacy and medicine for its cholesterol-lowering and vasoconstrictive effects, in the food industry for baking and as a massage oil in cosmetics (Krist 2020). Moreover, hazelnut oil is recognized for its ability to resist oxidation (Şahin 2023).

Primary goal of this study was to compare stability of organic hazelnut oil during accelerated oxidation with conventional hazelnut oil in terms of the free fatty acid, peroxide value, anisidine value, fatty acid composition, total antioxidant capacity, and volatile lipid oxidation compounds.

2. Material and Methods

2.1. Materials

The organic refined hazelnut oil (OHO) and conventional refined hazelnut oil (CHO) were supplied from Altaş Oil Company (Ordu, Turkey). OHO was certified by Letis Organic Quality Certifier (certificate no 1646/2023-01). Sodium thiosulfate, DPPH, potassium methoxide, trolox, potassium iodide, chloroform, ethyl alcohol, sodium carbonate, and diethyl ether were acquired from Sigma Aldrich. Butanol, p-anisidine, isooctane, and sulfuric acid were supplied by Merck.

2.2. Methods

2.2.1. Accelerated storage conditions

The organic and conventional hazelnut oils were stored in accelerated storage conditions, as outlined in literature (Petersen et al. 2012a). Briefly, the oils were filled into 100 mL brown glass bottles and kept in a drying cabinet at 80 °C for 14 days with the glass bottles caps open. The oil samples were taken from the drying cabinet for analysis at two-day intervals (0, 2, 4, 6, 8, 10, 12 and 14 days) and maintained in a frozen state until the analysis was conducted.

2.2.2. Peroxide value (PV) analysis

PV was determined using the DGF method (Deutsche Gesellschaft für Fettwissenschaft 2002). For this purpose, 2-2.5 grams of the oil samples were dissolved in an equal volume of isooctane: acetic acid. The distilled water and saturated solution of potassium iodide were introduced into the mixture. Subsequently, the resulting combination underwent titration against sodium thiosulfate using a starch indicator.

2.2.3. Free fatty acid analysis (FFA)

The quantification of FFA in the samples was conducted according to the AOAC method (American Oil Chemists' Society 1997). Briefly, the oil samples were mixed with an equal volume of diethyl ether: ethyl alcohol and titrated with sodium hydroxide (0.1 N).

2.2.4. p-anisidine value analysis

The measurement of the p-anisidine value followed the standard procedure specified in AOCS Cd 18-90 (American Oil Chemists' Society 2017). For this purpose, 2 g of oil samples were dissolved in isooctane (25 mL). 5 mL of the dissolved samples were mixed well with 1 mL of p-anisidine solution (2 M in acetic acid). Absorbance of the mixture was measured at 350 nm by UV-visible spectrophotometer (Perkin Elmer 710, USA).

2.2.5. Fatty acid analysis

Fatty acid composition of oil samples was conducted by gas chromatograph (GC) method according to the literature (Şahin & Özata, 2022) using a GC 2010 (Shimadzu, Tokyo, Japan) equipped with a flame ionization detector (FID). For this purpose, fatty acids were converted to fatty acids methyl esters (FAMEs). FAMEs were separated with a GC capillary column (TR-CN100 column, 60 m × 0.25 mm I.D., 0.20 µm film thickness: Technorama, Spain). The oven of GC (Shimadzu, Tokyo, Japan) was programmed from 140 °C (kept for 5 min) to 250 °C at 4 °C /min and kept at the final temperature for 15 min. The injector temperature was 250 °C and the injection volume was 1µL. The split ratio was 1:100. The carrier gas was nitrogen with a flow rate of 30 mL/min. The standard FAME (Restek, USA) was used for identification of FAMEs in the oil samples.

2.2.6. Identification of volatile substances

To determine the volatile substances of oil samples, a HS-SPME-GC-MS (headspace solid phase microextraction-gas chromatography-mass spectroscopy) method as outlined by Petersen et al. (2012a) with minor adjustments was applied. A Rxi-

5MS capillary column (30 m × 0.25 mm × 0.25 µm; Restek) was used separation of volatile compounds. 3 g of oil samples were weighed into a 10 mL vial. A carboxen/polydimethylsiloxane (CAR/PDMS) SPME fiber (Supelco, Bellefonte, PA, USA) was inserted into the vial at 40 °C for 60 min. The SPME fiber was then desorbed at 270 °C for 5 min. The carrier gas was helium with a flow rate of 0.6 mL/min. The oven temperature was initially set at 40 °C and maintained for 6 minutes. Subsequently, it was raised to 100 °C at a rate of 5 °C per minute. Following this, a more rapid increase to 300 °C was implemented at a rate of 30 °C per minute. The final temperature of 300 °C was sustained for 2 minutes. Concurrently, the ion source temperature was held constant at 230 °C, while the transfer line temperature was maintained at 250 °C. The split ratio was set at 1:5. The ionization voltage was 70 eV. The mass spectra were obtained using electron ionization (m/z 35-350). Identification of volatile compounds in the oil samples involved a comparison between the mass spectra of unidentified peaks and those present in the NIST mass spectral library (NIST MS Search Software). This comparative analysis was employed to determine the presence and characteristics of specific compounds based on their mass spectral patterns.

2.2.6. Total antioxidant capacity (TAC) analysis

The assessment of the TAC in oil samples was conducted using DPPH radical scavenging method as outlined by Şahin & Özata (2022). The oil samples were dissolved in n-butanol. 40 µL of the dissolved sample were mixed with 1500 µL of DPPH solution (0.6 mM in n-butanol). After incubation at room temperature for 30-minute, absorbance of the mixed solution was determined at 515 nm using an UV-visible spectrophotometer (Perkin Elmer 710, USA). TAC was given as millimoles of (±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (trolox) equivalents per liter (mmol TE/L).

2.2.7. Analysis of data

The data underwent analysis through repeated measures two-way ANOVA, employing Tukey's honest significant difference multiple comparison test with a significance level set at $P<0.05$. The statistical analysis was performed using SPSS Statistics software, version 26.0. (IBM, USA).

3. Results and Discussion

The free fatty acid (FFA) values (%) of organic hazelnut oil (OHO) and conventional hazelnut oil (CHO) are reported in Table 1. FFA values of OHO and CHO were 1.04 – 1.66% and 1.01 – 1.64%, respectively. As anticipated, FFA values showed an increase during accelerated storage, corresponding with longer storage periods. When FFA values of organic hazelnut oil and conventional hazelnut oils were compared, statistical analysis revealed a significant difference between the oils specifically on the 6th and 8th days of the storage period, while the oils had the same FFA values on the other days of storage.

Table 1- Increase in the free fatty acid (FFA) values of organic and conventional hazelnut oils under accelerated storage

	Duration of storage (in days)							
	0	*2*	*4*	*6*	*8*	*10*	*12*	*14*
OHO	1.04 ± 0.03^{aA}	1.22 ± 0.01^{bA}	1.32 ± 0.04^{cA}	1.41 ± 0.00^{cdA}	1.44 ± 0.04^{dA}	1.58 ± 0.00^{eA}	1.63 ± 0.00^{eA}	1.66 ± 0.03^{eA}
CHO	1.01 ± 0.01^{aA}	1.24 ± 0.00^{bA}	1.32 ± 0.03^{cA}	1.47 ± 0.00^{dB}	1.52 ± 0.00^{deB}	1.57 ± 0.01^{efA}	1.63 ± 0.00^{fgA}	1.64 ± 0.01^{gA}

The reported values denote means with corresponding standard deviations. Statistically significant differences ($P\leq .05$) are indicated when values in the same columns are associated with distinct capital letters or values in the same rows are marked by different lower-case letters. Abbreviations: OHO, organic hazelnut oil; CHO, conventional hazelnut oil.

Peroxide values of the oil samples are given in Figure 1. The peroxide value (PV) of OHO varied from 7.97 meq/kg to 66.66 meq/kg, while CHO had PV ranging from 12.55 meq/kg to 48.69 meq/kg. It was observed that the peroxide formation in OHO significantly increased up to 12th days of oxidation, followed by a tremendous significantly decrease on the 14th day. PV of CHO significantly increased until the 4th days of oxidation, significantly decreased on the 6th day, then unchanged between the 6th and 8th days, then significantly increased again until the 10th days, then remained unchanged between the 10th and 12th days, and significantly decreased after the 12th days. On the other hand, Yalcin (2011) reported a regular rise in PV of hazelnut oil stored at lower temperature (40 °C) up to 120 days. This unexpected decrease in PV after prolonged oxidation at high temperature observed in our study may be related to the volatilization of some lipid peroxidation products, formed in the earlier stages of oxidation (Wanasundara et al. 1994). Similar decreases in PV due to long time oxidation at high temperature were reported by Iqbal & Bhanger (2007). They stored the sunflower oil at 65 °C and observed that PV increased up to 20th days and decreased

on the 24th day. Crapiste et al. (1999) also suggested that PV in sunflower oil heated at 67 °C increased during storage, reached its maximum value on the 41st days of storage and thereafter decreased due to decomposition of lipid hydroperoxides. When they stored the oil at low temperature (37 °C and 47 °C), they observed that PV went on increasing with the increase in storage time. OHO had significantly lower PV than CHO up to 6th days of storage, while PV in OHO were significantly higher than CHO on the 8th, 10th, and 12th days of storage. The highest PV (66.67 ± 0.002 meq/kg) was observed in OHO on the 12th day of oxidation. Although OHO had the highest PV, it showed significantly lower PV (9.493 ± 0.001 meq/kg) than CHO (21.28 ± 0.019 meq/kg) at the end of storage (14th day).

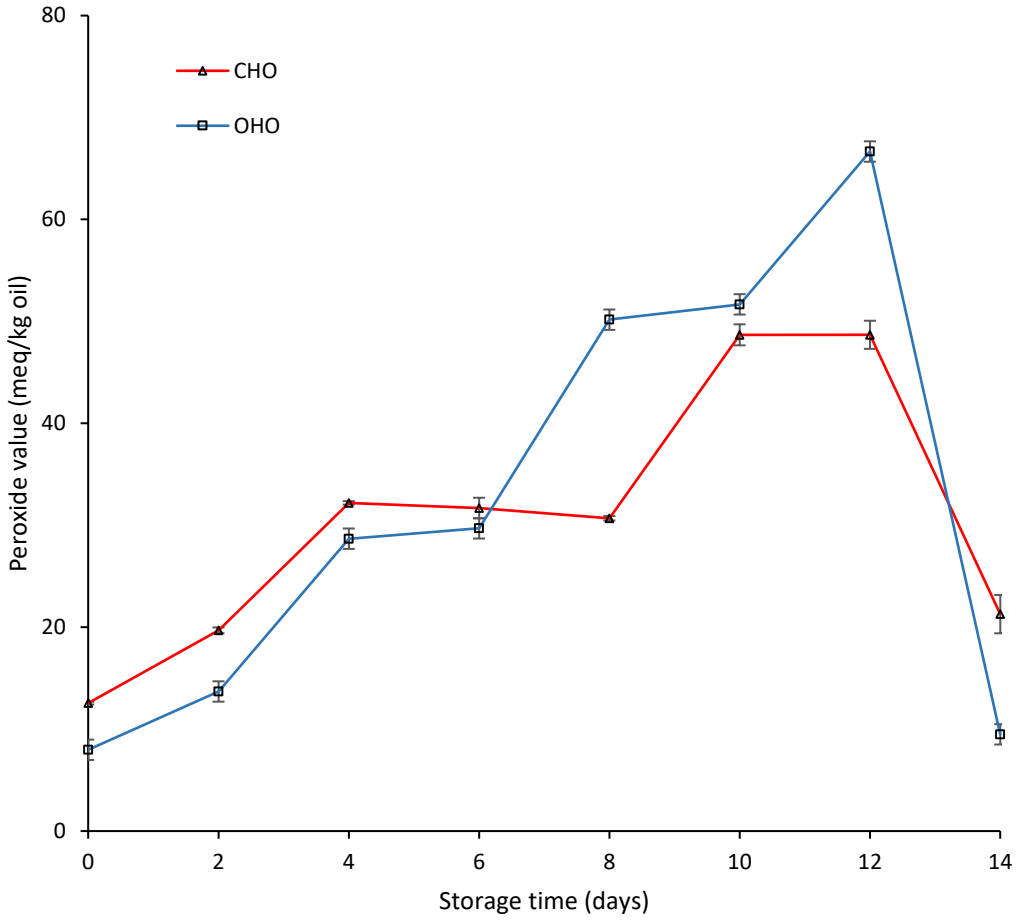

Figure 1- Increase in the peroxide values (meq/kg) of organic and conventional hazelnut oils under accelerated storage. Values are means ± (100 x standard deviation). Abbreviations: OHO, organic hazelnut oil; CHO, conventional hazelnut oil

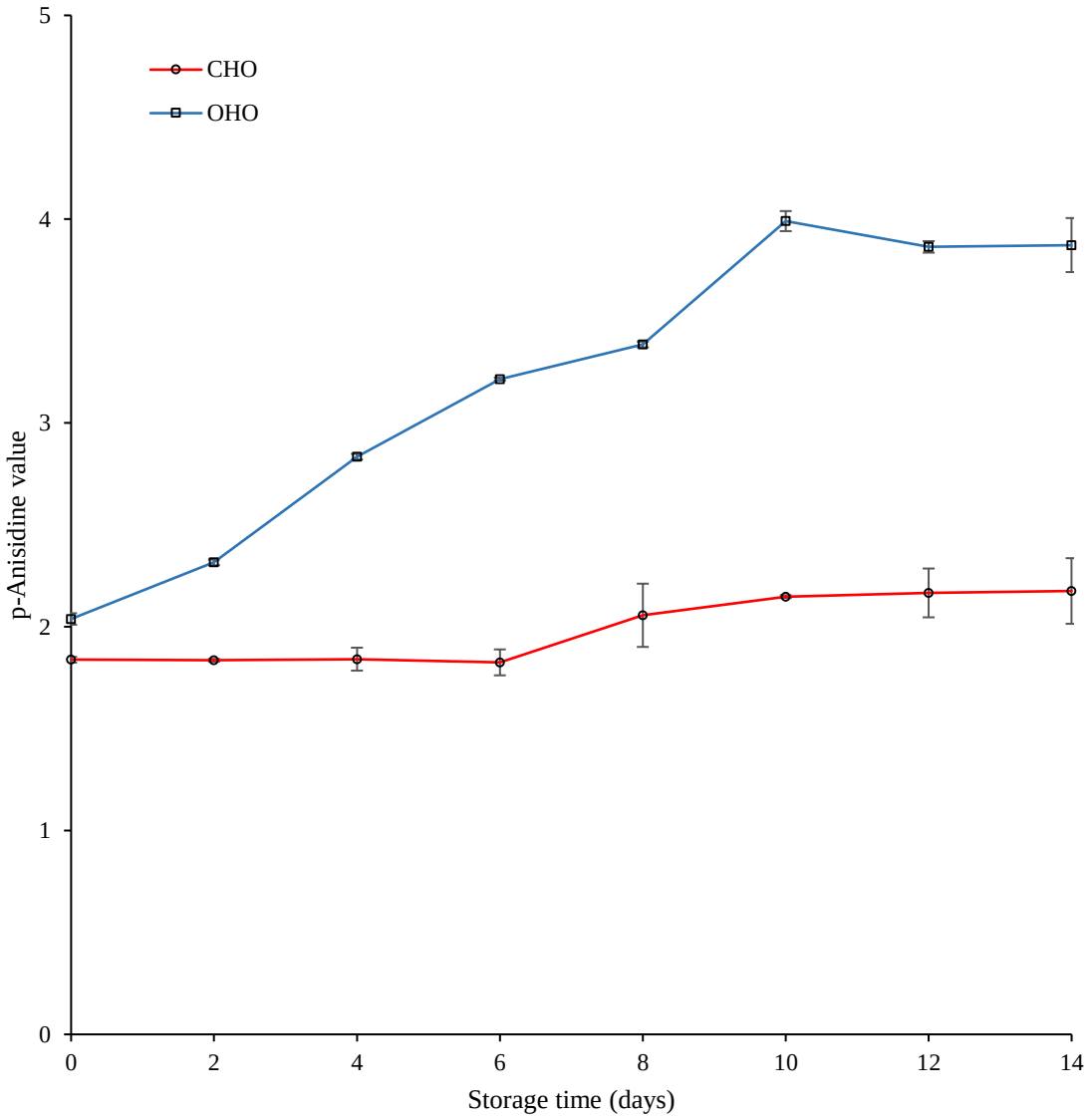

Figure 2- Relative increase in p-anisidine value (AV) of organic and conventional hazelnut oils under accelerated storage. Values are means ± (10 x standard deviation). Abbreviations: OHO, organic hazelnut oil; CHO, conventional hazelnut oil

The main secondary products of lipid peroxidation are the aldehydes such as hexanal, and propanal (Ayala et al. 2014). P-anisidine value (AV) is used as an indicator for secondary oxidation. AVs of OHO and CHO during storage are shown in Figure 2. OHO had significantly higher AVs compared to CHO during accelerated storage. In OHO, AVs significantly increased up to 10 days of storage, then significantly decreased on the 12th days of storage, and remained stable thereafter. AVs in CHO did not change until the 6th day of storage, then started to increase until the 10th days of oxidation, then unchanged until the end of storage. As observed in OHO, AVs in CHO also did not increase after 10 days of storage. Similar change in AVs during accelerated storage was reported by Petersen et al. (2012a) for sunflower oil and by Petersen et al. (2012b) for high-oleic rapeseed oil. The reduction in anisidine formation at long time oxidation may be related to the observation of Petersen et al. (2012a), who reported that some aldehydes such as hexanal, a secondary product of lipid oxidation, decomposed and decreased in conventional sunflower oil after 8 days of accelerated storage. These findings for AVs also align with the peroxide results mentioned earlier, where the peroxide values of oils increased during the initial stages of oxidation but decreased in the later stages, likely due to the breakdown of lipid oxidation products.

Antioxidative capacities of OHO and CHO during accelerated storage were given in Table 2. In terms of total antioxidant capacity, a significant difference was detected between OHO and CHO only at the beginning of storage, and no significant difference was observed throughout storage. Initially, OHO showed a higher antioxidative capacity (0.25 mmol /L TE) compared to CHO (0.20 mmol /L TE). Recently, Karaosmanoğlu (2022) reported that the hazelnuts grown under organic production system exhibited a higher antioxidative capacity than the hazelnuts grown with conventional production system and suggested that a decrease in the amounts of antioxidants of hazelnuts may be due to pesticides used in conventional production.

Table 2- Changes in total antioxidant capacity (mmol/L TEAC) of organic and conventional hazelnut oils during accelerated storage

	Duration of storage (in days)							
	0	*2*	*4*	*6*	*8*	*10*	*12*	*14*
OHO	0.25 ± 0.01^{aA}	0.15 ± 0.01^{bA}	0.10 ± 0.00^{cA}	0.07 ± 0.01^{cA}	0.05 ± 0.01^{cA}	0.05 ± 0.01^{cA}	0.06 ± 0.00^{cA}	0.05 ± 0.01^{cA}
CHO	0.20 ± 0.01^{aB}	0.13 ± 0.00^{bA}	0.12 ± 0.01^{bA}	0.06 ± 0.00^{cdA}	0.04 ± 0.00^{dA}	0.06 ± 0.01^{cdA}	0.08 ± 0.01^{cA}	0.06 ± 0.00^{cdA}

The reported values denote means with corresponding standard deviations. Statistically significant differences ($P \leq .05$) are indicated when values in the same columns are associated with distinct capital letters or values in the same rows are marked by different lower-case letters. Abbreviations: OHO, organic hazelnut oil; CHO, conventional hazelnut oil.

As can be seen in Table 2, total antioxidative capacity in OHO decreased until the 4th day of storage, then remained stable. Total antioxidative capacity of CHO decreased until the 2nd day of storage, remained constant between the 2nd and 4th days of storage, then decreased again until the 6th day and thereafter remained constant. These results mean that although the total antioxidant capacity for both OHO and CHO declined in the early stages of oxidation, it remained unchanged in the later stages of oxidation. This may be due to the fact that almost all antioxidant effective substances are used to prevent oxidation in the early stages of oxidation. The results observed here are also in agreement with the results of PV and AV. Indeed, PVs and AVs of OHO and CHO increased at the first time of exposure to oxidation, then AVs did not change, and PVs decreased.

The reported values denote means with corresponding standard deviations. Statistically significant differences ($P \leq .05$) are indicated when values in the same rows are associated with distinct lower letters Abbreviations: OHO, organic hazelnut oil; CHO, conventional hazelnut oil; TSFA, total saturated fatty acids; TMUFA, total monounsaturated fatty acids; TPUFA, total poly unsaturated fatty acids; TUFA, total unsaturated fatty acids.

As shown in Table 3, the predominant fatty acids in both hazelnut oil samples are palmitic (C 16:0), stearic (C 18:0), oleic (C 18:1 ω9), and linoleic acid (C 18:2 ω 6). Similarly, Karaosmanoglu & Ustun (2021) and Karaosmanoğlu (2022) determined these four fatty acids (palmitic, stearic, oleic and linoleic acids) as the dominant fatty acids in organic and conventional hazelnuts. In our study, oleic acid constituted the largest quantity among all fatty acids (79.74% for OHO and 81.39% for CHO), followed by linoleic acid (10.51% for OHO and 8.89% for CHO), palmitic acid (6.15% for OHO and 6.04% for CHO), and stearic acid (2.85% for both OHO and CHO).

It was observed that total monounsaturated fatty acids (TMUFA) contents in OHO and CHO were similar (80.11% and 81.78%, respectively), while OHO had higher total polyunsaturated fatty acids (TPUFA) compared to CHO (10.61% for OHO and 8.99% for CHO; Table 3). This can be explained by the fact that OHO contains similar oleic acid and more linoleic acid compared to CHO. Total saturated fatty acid content (TSFA) in OHO was the same as CHO (9.3% for OHO and 9.23% for CHO; Table 3). This result related to their similar palmitic and stearic acid contents. Similar results for TMUFA, TPUFA, and TSFA contents of organic and conventional hazelnut oils have been shown before by Karaosmanoglu & Ustun (2021) who analyzed chemical composition of commercially important hazelnut varieties such as Çakıldak, Foşa, Mincane, Palaz, Sivri and Tombul. In contrast, Karaosmanoğlu (2022) reported slightly higher TMUFA content and slightly lower TPUFA and TSFA contents for organic and conventional Tombul hazelnuts than the TMUFA, TPUFA and TSFA levels found in this work. The TUFA/TSFA ratio in OHO and CHO was determined as 9.75% and 9.83%, respectively (Table 3). These values were found to be less than the values determined by Karaosmanoğlu (2022) for organic and conventional Tombul hazelnuts (11.54 % and 12.85 %, respectively) and by Ghirardello et al. (2013) for Tonda Gentile delle Langhe hazelnuts grown in Italy (12.03 %). The reason for these differences observed in the fatty acid contents may be due to the different origins and varieties of hazelnuts examined in these studies. Indeed, it has been reported in previous studies that the fatty acid composition in hazelnuts varies depending on the origin, variety and growing conditions of the hazelnuts (Li & Parry 2011; Şahin et al. 2022; Karaosmanoğlu 2022).

Table 3- Fatty acid composition (%) of organic and conventional hazelnut oils

Fatty acids	*OHO*	*CHO*
$C_{14:0}$	0.03 ± 0.01a	0.04 ± 0.01a
$C_{15:0}$	0.01 ± 0.00a	0.02 ± 0.01a
$C_{16:0}$	6.15 ± 0.24a	6.04 ± 0.27a
$C_{16:1}\ \Delta^{9}$	0.19 ± 0.02a	0.19 ± 0.03a
$C_{17:0}$	0.04 ± 0.00a	0.05 ± 0.01a
$C_{17:1}\ \Delta^{10}$	0.06 ± 0.01a	0.06 ± 0.00a
$C_{18:0}$	2.85 ± 0.02a	2.85 ± 0.00a
$C_{18:1}\ \Delta^{9}$	79.74 ± 0.67a	81.39 ± 0.25a
$C_{18:2}\ \Delta^{9,12}$	10.51 ± 0.46a	8.89 ± 0.06b
$C_{18:3}\ \Delta^{9,12,15}$	0.10 ± 0.00a	0.10 ± 0.00a
$C_{20:0}$	0.16 ± 0.00a	0.16 ± 0.00a
$C_{20:1}\ \Delta^{11}$	0.12 ± 0.00a	0.14 ± 0.00a
$C_{22:0}$	0.02 ± 0.01a	0.03 ± 0.00a
$C_{24:0}$	0.04 ± 0.00a	0.04 ± 0.00a
TSFA	9.30	9.23
TMUFA	80.11	81.78
TPUFA	10.61	8.99
TUFA	90.72	90.77
TUFA/TSFA	9.75	9.83
Oleic/linoleic	7.59	9.15

Table 4 shows the changes of the predominant fatty acids including palmitic, stearic, oleic, and linoleic acids in the organic and conventional hazelnut samples during accelerated storage. No significant changes were observed in the amounts of predominant fatty acids in both hazelnut samples during storage. It was found that the production system (organic and conventional) did not significantly affect the palmitic and stearic acid contents. Similarly, Karaosmanoglu & Ustun (2021) did not detect statistically significant differences in palmitic and stearic acid contents between organic and conventional hazelnuts depending on the production system. In addition, Perretti et al. (2004) did not observe a significant difference between sunflower seed oils produced from conventionally cultivated crops and organically cultivated ones with regards to palmitic and stearic acid contents. In contrast, Karaosmanoğlu (2022) reported that the palmitic and stearic acid contents in hazelnuts were affected by the production system.

Table 4- Changes in the fatty acid contents (%) of organic and conventional hazelnut oils during accelerated storage

	Duration of storage (in days)							
	0	*2*	*4*	*6*	*8*	*10*	*12*	*14*
Palmitic acid								
OHO	6.15 ± 0.24^{aA}	6.19 ± 0.26^{aA}	6.08 ± 0.26^{aA}	6.03 ± 0.05^{aA}	5.83 ± 0.23^{aA}	5.97 ± 0.25^{aA}	5.72 ± 0.02^{aA}	5.98 ± 0.02^{aA}
CHO	6.04 ± 0.27^{aA}	5.79 ± 0.04^{aA}	5.72 ± 0.07^{aA}	5.67 ± 0.31^{aA}	5.68 ± 0.01^{aA}	5.81 ± 0.19^{aA}	5.60 ± 0.17^{aA}	6.12 ± 0.17^{aA}
Stearic acid								
OHO	2.85 ± 0.02^{aA}	2.83 ± 0.04^{aA}	2.81 ± 0.01^{aA}	2.82 ± 0.01^{aA}	2.81 ± 0.01^{aA}	2.84 ± 0.03^{aA}	2.87 ± 0.01^{aA}	2.93 ± 0.17^{aA}
CHO	2.85 ± 0.00^{aA}	2.89 ± 0.06^{aA}	2.87 ± 0.02^{aA}	2.79 ± 0.01^{aA}	2.82 ± 0.07^{aA}	2.88 ± 0.05^{aA}	2.89 ± 0.04^{aA}	2.93 ± 0.12^{aA}
Oleic acid								
OHO	79.74 ± 0.67^{aA}	78.34 ± 0.02^{aA}	78.69 ± 0.78^{aA}	78.32 ± 0.36^{aA}	78.64 ± 0.22^{aA}	78.97 ± 0.32^{aA}	79.43 ± 0.40^{aA}	78.37 ± 0.23^{aA}
CHO	81.39 ± 0.25^{aA}	80.89 ± 0.14^{aB}	80.63 ± 0.17^{aA}	80.62 ± 0.11^{aB}	80.88 ± 0.47^{aB}	80.60 ± 0.22^{aB}	80.79 ± 0.28^{aA}	81.10 ± 0.48^{aB}
Linoleic acid								
OHO	10.51 ± 0.46^{aB}	10.53 ± 0.14^{aB}	10.06 ± 0.32^{aB}	10.31 ± 0.56^{aB}	9.87 ± 0.09^{aB}	9.99 ± 0.01^{aB}	9.54 ± 0.31^{aB}	9.99 ± 0.40^{aB}
CHO	8.89 ± 0.06^{aA}	8.74 ± 0.02^{aA}	8.56 ± 0.32^{aA}	8.67 ± 0.01^{aA}	8.39 ± 0.44^{aA}	8.51 ± 0.43^{aA}	8.19 ± 0.27^{aA}	8.54 ± 0.36^{aA}

The reported values denote means with corresponding standard deviations. Statistically significant differences ($P \leq .05$) are indicated when values in the same columns are associated with distinct capital letters or values in the same rows are marked by different lower-case letters. Abbreviations: OHO, organic hazelnut oil; CHO, conventional hazelnut oil

Hazelnut oils are primarily composed of oleic acid (Alaşalvar et al. 2006; Karaosmanoglu & Ustun 2021; Karaosmanoğlu 2022; Şahin et al. 2022; Şahin 2023). During accelerated storage, the amount of the oleic acid in OHO varied from 78.32 to 79.74 %, while the oleic acid content in CHO ranged between 80.60 and 81.39 % (Table 4). These values are lower than the oleic acid contents (84.64% for organic hazelnut and 84.59% for conventional hazelnut) found by Karaosmanoğlu (2022) but are similar to the values reported by Karaosmanoglu & Ustun (2021). As shown in Table 4, OHO exhibited lower oleic acid than CHO at all periods of storage, but this difference observed between organic and conventional oils was not significant on the 0^{th}, 4^{th}, and 12^{th} days of storage ($P>0.05$). Similarly, it has been shown before that there was no significant difference between organic and conventional hazelnuts in terms of oleic acid content depending on the production system (Karaosmanoglu & Ustun 2021; Karaosmanoğlu 2022). Moreover, it was determined that the production system had no significant impact on the amount of oleic acid in sunflower seed oils (Perretti et al. 2004).

As can be seen from Table 4, the linoleic acid contents of OHO and CHO were observed in the range of 9.54–10.51% and 8.19-8.89%, respectively. Similar linoleic acid content (9.3-10.3% for organic hazelnuts and 8.1-10.3% for conventional hazelnuts from Çakıldak, Sivri, Foşa, Tombul, and Palaz varieties) were determined by Karaosmanoglu & Ustun (2021). However, it has been reported that organic and conventional Tombul hazelnuts had lower levels of linoleic acid than the results of this study (Karaosmanoğlu 2022). Compared to CHO, OHO exhibited higher linoleic acid at all storage periods (Table 4). Contrary to our results, Karaosmanoğlu (2022) reported that the organic Tombul hazelnuts contain lower linoleic acid (6.9%) than conventional Tombul hazelnuts (7.8%). On the other hand, it was previously reported that the amount of linoleic acid did not change depending on the production technique in hazelnuts (Karaosmanoglu & Ustun 2021) and sunflowers (Perretti et al. 2004).

Table 5- Primary volatile compounds were extracted from both non-stored and stored organic and conventional hazelnut oils, with their corresponding peak areas identified

		Area of peak x 10^3			
Retention index	*Volatile compounds*	*OHO day 0*	*OHO day 14*	*CHO day 0*	*CHO day 14*
634	Pentane	1371	5495	350	5149
648	Acetic acid	361	*	495	*
651	n-Hexane	2716	310	816	572
688	2,2-dimethyl- Hexane	893	*	132	*
696	Heptane	587	2296	277	973
797	Hexanal	2971	6150	512	6120
957	(Z)-2-Heptenal	*	11766	*	10219
980	1-Octen-3-ol	*	1316	*	1180
992	2-pentyl-furan	*	2722	*	2707
1003	Octanal	*	111	*	957
1068	(E)-2-Octenal	*	6345	*	6352
1070	6,7-Dodecanedione	*	749	*	895
1106	Nonanal	*	1378	*	1450
1166	(E)-2-Nonenal	*	1091	*	1157
1268	(E)-2-Decenal	*	114	*	97
1324	2,4-Decadienal	*	1399	*	1157
1371	2-Undecenal	*	969	*	989

Abbreviations: OHO, organic hazelnut oil; CHO, conventional hazelnut oil; *: not detectable

Table 5 shows primary volatile compounds identified in OHO and CHO samples, both non-stored and stored. The volatile compounds isolated from OHO samples were similar to the volatile compounds isolated from CHO samples both at the beginning and after storage. Six volatile compounds were identified in non-stored OHO and CHO, while 15 volatile compounds were detected in OHO and CHO at the end of storage (14.day). Among the 15 compounds found in stored OHO and CHO samples, 9 were identified as aldehydes, 3 as alkanes, 1 as ketones, 1 as alcohols and 1 as furans, which previously identified as lipid oxidation products (Petersen et al. (2012a). These results are in agreement with AVs, which indicate secondary oxidation products such as aldehydes. Indeed, AVs also increased after accelerated storage (Figure 2). (Z)-2-Heptenal, 1-octen-3-ol, 2-pentyl-furan, octanal, (E)-2-octenal, 6,7-dodecanedione, nonanal, (E)-2-nonenal, (E)-2-decenal, 2,4-decadienal and 2-undecenal were found only in autoxidized (stored) OHO and CHO samples, whereas hexanal was in both fresh (non-stored) and oxidized (stored) OHO and CHO samples. As expected, the content of hexanal in oxidized OHO and CHO samples was higher than that in non-stored OHO and CHO. Similarly, Petersen et al. (2012a) reported that non-stored sunflower and high-oleic sunflower oil samples had hexanal and that the amount of hexanal in sunflower and high-oleic sunflower oil samples increased with oxidation (storage at 80 °C for 9-day). Some of these compounds including pentanal, hexanal, octanal, 1-octen-3-ol, nonanal and (E)-2-heptenal were reported before as the important oxidative degradation products of vegetable oils (Xu et al. 2017, Mildner-Szkudlarz et al. 2003 and Petersen et al. 2012a). Mildner-Szkudlarz et al. (2003) evaluated rapeseed, sunflower, peanut, soybean, sunflower, and olive oil that stored at 60 °C for a duration of 5 days. They found that these stored oils contain more volatile compounds than non-stored oils due to oxidation. They also reported that the amount and type of volatile components detected vary depending on the type of stored oil. Some of these reported compounds were identified in this study as well. Petersen et al. (2012a) stored sunflower and high-oleic sunflower oils at 80 °C for 9 days in a drying cabinet. They identified in total 74 volatile components encompassing the volatile substances detected in our study. They also reported that these compounds are predominantly generated as secondary oxidation products through the autoxidation process of oleic and linoleic acids. Furthermore, Petersen et al. (2012b) measured the volatile compounds of rapeseed and high-oleic rapeseed oils which were stored at 40 °C for 26 days. They identified 55 volatile lipid oxidation compounds and described E, Z-2,4-decadienal, propanal, and E,E-2,4-heptadienal as the prevailing volatile compounds in both rapeseed oils.

4. Conclusions

This study evaluated effect of production system (conventional and organic) in hazelnut oil samples on quality parameters including peroxide and anisidine values, free fatty acid, fatty acid composition, antioxidant capacity, and volatile substances during of accelerated storage. Organic hazelnut oils showed similar antioxidant capacity (DPPH assay) to conventional hazelnut oil during storage despite its high initial antioxidant capacity. During accelerated storage, OHO exhibited more linoleic acid and less oleic acid than CHO. Although OHO had lower PV at the end of storage, it showed higher PVs and AVs during storage. In

conclusion, these results indicate that OHO has less oxidation stability compared to CHO. Therefore, OHO should be consumed as fresh as possible without prolonged exposure to oxidation.

Acknowledgements

The research conducted for this study received financial support under the B-2136 research projects from the Scientific Research Project Coordination Unit at Ordu University in Turkey.

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