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The Quality Characteristic and Fatty Acid Profile of Cold-Pressed Hazelnut Oils during Nine Months of Storage

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Abstract: Poland is one of the largest producers of hazelnuts in Europe; however, information regarding the storage of cold-pressed hazelnut oil is limited. Thus, the aim of this study was to determine the oxidative indices and fatty acid composition of oils from six hazelnut cultivars during 9 months of storage. At the beginning of storage, the hazelnut oils showed zero or very low oxidation values, which indicated the absence of initial triglyceride hydrolysis and fatty acid oxidation. Acid values increased with storage time, which was statistically significant, ranging from 0.17 to 0.34 mg KOH/g oil. The peroxide value in the first 5 months of storage was undetectable, whereas after 9 months the oils showed a slight increase in oils obtained from the 'Olbrzym z Halle' cultivar, followed by the 'Barcelonski' cultivar, at 3.39 and 2.15 meq O_2/kg, respectively. The lipid content of the kernels was very stable under storage conditions. Total monounsaturated fatty acid content exhibited the highest proportion, while saturated fatty acids (SFAs) had the lowest content over the entire storage period. The percentage of polyunsaturated fatty acids showed a small decrease during storage, but was not statistically significant; therefore, polyunsaturated fatty acid remained stable. The percentage of monounsaturated fatty acids decreased by approx. 1.6%, thus the percentage of SFA increased by approx. 13.7% during 9 months of storage. The oil yield ranged from 69% for nuts from the 'Nottinghsamski' cultivar to 75% from the 'Webba Cenny' and 'Barcelonski' cultivars.

Keywords: shelf-life; oil yield; hazelnut oil; peroxide value; acid value; oxidative indices; fatty acid composition

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1. Introduction

In Poland, the cultivation of only large-fruited hazelnuts, so-called table cultivars, has been developed on approx. 3750 ha, and annual production with shell is 5440 tons. Over 70% of the world's production of hazelnuts is produced and exported by Turkey, followed by Italy, Azerbaijan, USA and Chile. In 2019, total hazelnut production surpassed 1 million tons, which highlights hazelnuts' worldwide popularity [1].

Hazelnut is a healthy food that plays an important role in human nutrition and health due to its nutrient profile and bioactive compounds [2,3]. Hazelnut composition consists of over 60% fat, the quality of which largely determines both their nutritional value and technological suitability. Additionally, they are a valuable source of unsaturated fatty acids, in particular C18:1 oleic acid, iron, magnesium and phosphorus. Their strong antioxidant effect stems from the high vitamin E content of 33.1 mg/100 g of oil, in the form of α-tocopherol (α-TE) equivalent [4–6]. The daily recommended consumption of hazelnuts by the Food and Drug Administration (FDA) (1.5 oz or $\sim$42.5 g/day) provides up to 72.7% of vitamin E for adult males and females [7,8]. Additionally, hazelnuts are used in cosmetics and pharmaceutical industries, and above all in the food industry as an ingredient in confectionery, creams and chocolates, and for direct consumption [9–13].

Cold-pressed oils are continuously gaining in popularity among consumers, the food industry, cosmetics and pharmaceutical products. The cosmetic industry applies the nondrying oil to formulations because of its excellent shelf stability. Unsaturated fatty acids, sterols and tocopherols in hazelnut oil play important roles in preventive medicine [14]. Additionally, hazelnut oil can be consumed crude or refined. Virgin hazelnut oil is obtained directly from hazelnuts without any refinement, which is known to provide high nutrition due to its comprehensive monounsaturated fatty acids (MUFA) and rich minor compounds, such as bioactive substances recovered in the pressing [15]. The cold pressing technique involves gentle pressure on the crude material, but due to the low processing, this technique is usually expensive. The most important factor during the pressing operation is maintaining low temperature. The superior nutty flavor and fresh taste are a result of non-chemical process and limited temperature [14]. To maintain the freshness of hazelnuts or their oil, it is of paramount importance to study their susceptibility to lipid oxidation in order to optimize the processing and storage conditions. The importance of diet and health in modern society has contributed to greater intake of unprocessed and natural food. Cold-pressed oils belong to this category. Despite the constantly growing area of hazelnut farming in Poland, unfortunately, to-date, there are no studies that examine the efficiency of pressing and quality of the products obtained from hazelnut cultivars which are grown in Poland. Moreover, studies that focus on the characteristics of cold-pressed hazelnut oil are limited, where the majority of reports describe the stability of the kernel during storage [16]. Therefore, the aim of the present study was to determine the quality parameters of cold-pressed oils from six cultivars of hazelnuts grown in Poland and examine changes that occur during storage.

2. Materials and Methods

2.1. Plant Material

Six hazelnut cultivars (‘Barcelonski’, ‘Katalonski’, ‘Webba Cenny’, ‘Cosford’, ‘Olbrzym z Halle’, and ‘Nottinghamski’) were cultivated and collected in an orchard located in Poland (Końskowola, 51°25′ N 22°03′ E). Nuts were collected at physiological maturity during September 2017. The fallen nut samples totaling 5 kg per cultivar were collected from the soil manually (collected two times). After harvest the hazelnuts were sorted, and the mouldy, dark, rotten and mechanically damaged hazelnuts were removed. Moreover, the moisture control was conducted, and the hazelnuts were dried to 6% kernel humidity applied in commercial production and then stored at 20 °C for 30 days. The hazelnuts were cracked by hand, and the kernels were stored in plastic bags in a dark, cool, dry place at 4 ± 1 °C and 55% relative humidity until they were cold-pressed and analyzed.

2.2. Oil Cold-Pressing and Extraction Yield

Cold pressing was performed by directly pressing hazelnuts in a continuous screw press. In this study, a screw press with a capacity of 40 kg/h of nuts, equipped with a 460 W engine (Oleum, Yoda, KT-OPM, Hazgzhou, Zhejiang, China) was used. A total of 200 g of hazelnut were chopped and transferred to the press to obtain the oil. The temperature of the obtained oil was measured with a handheld digital thermometer (Bioterm/Biowin, Łódź, Poland), with 0.01 °C resolution and error ± 0.07 °C), which remained below 40 ± 5 °C. The obtained hazelnut oil was centrifugated in an MPW 352R centrifuge (MPW, Warsaw, Poland) at 18 °C for 10 min at 10,000 rpm to remove solid particles. Then, the oil was decanted from the sediment and the process’s efficiency was determined for each studied cultivar. Moreover, each oil sample was analyzed in triplicate. Oil was pressed after 30 days of storage and all chemical properties were determined immediately after pressing, and after 3, 5 and 9 months of storage. During the study, the oil samples (30 g) were stored in dark glass bottles, tightly capped in the dark, at 7 ± 1 °C for further analysis.

The nut oil pressing efficiency was calculated from the weight of the oil obtained after the purification process; the weight of the processed nuts and kernel fat was measured in the nuts using Equation (1) [17]:

$$\text{Extraction yield (\%)} = M_{oil} \times 100 \times 100 / M_{nuts} \times C_{fat} \quad (1)$$

where:

M_{oil} is the mass of the oil after decanting (g);

M_{nuts} is the mass of the nuts from which oil was extruded (g);

C_{fat} is the fat content (the information was obtained from previously conducted research on the same hazelnut cultivars [18]).

2.3. Oxidation Indices

The acid value (AV) was determined according to PN-EN ISO 660:2010 [19] and expressed in mg KOH per g of oil. The peroxide value (PV) was determined according to PN-ISO 3960:2010 [20] and expressed in milliequivalents of active oxygen per kg of oil (meq O_2/kg). The anisidine value (AnV) was determined according to EN-ISO 6885:2008 [21], where TOTOX value (TV) was calculated from PV and AnV using Equation (2):

$$TV = (2 \times PV) + AnV \tag{2}$$

2.4. Fatty Acids Composition

Fatty acid composition of the hazelnut oil was analyzed using gas liquid chromatographic method of fatty acids methyl esters (FAME) according to American Oil Chemists' Society (AOCS) [22]. A total of 0.09 g of oil samples from six hazelnut cultivars were analyzed. Firstly, 0.5 mL of tridecanoic acid solution 0.5 g/L (as internal standard) was added to the vials and sealed with a screw cap. Then, 2 mL of 0.5 M methanolic KOH was added, and the sample was heated at 60 °C for 30 min. After cooling, 2 mL of 10% methanolic BF_3 was added, and the sample was again heated at 60 °C for 30 min. After the mixture was cooled to the ambient temperature, 2 mL of hexane was added, and the mixture was shaken on laboratory vortex for 60 s, then 2 mL of NaCl was added, followed by mixing. After centrifugation, the hexane layer was transferred to GC vials. FAME composition was analyzed using a Shimadzu GC-2010 gas chromatograph (Tokyo, Kanto, Japan) with a flame-ionization detector (FID) and equipped with a RT-2560 column (100 m × 0.25 mm ID and 0.2 µm film thickness) (RESTEK, Bellefonte, PA, USA). Oven temperature started at 140 °C for 5 min, and was programmed to reach 240 °C. Injector and detector temperatures were 240 °C and 260 °C, respectively. Split ratio was 70:1 and the volume of injection was 1 µL. Carrier gas was helium with a flow rate of 1.0 mL/ min. Each sample was measured in triplicate. The relative content (%) of each fatty acid was calculated by dividing the peak area of each fatty acid by the total peak area of all the fatty acids identified.

2.5. Statistical Analysis

The obtained results were statistically analyzed with XLSTATS by Addinsoft 2019.3.2. version software (Boston, MAs, USA). Values were expressed as means ± standard deviations (SD), and measurements were obtained in triplicate (n = 3). The statistical differences were determined by one-way ANOVA (factor being storage time and hazelnut cultivar). A lack of significant differences ($p \geq 0.05$) is indicated in the tables as not significant (N.S). Different letters within a row or column indicate significant differences at $p < 0.05$ level.

3. Results and Discussion

3.1. Lipid Oxidation

Storage time significantly affected the indices of the lipid fractions. As expected, AV, AnV and PV increased with storage time in all tested oils and hazelnut cultivars (Table 1). According to Codex Alimentarius Commission Standard [23], AV set value is 0.6 for refined oils, 4.0 mg KOH/g oil for cold pressed and virgin oils, and is an indicator of the total free fatty acids. In general, the higher AV, the more intense lipid hydrolysis, and higher free fatty acid content. Moreover, higher AV may contribute a soapy flavor or off-flavors in nuts. At the beginning of storage, the hazelnut oils showed zero or very low oxidation values, which indicated the absence of initial triglyceride hydrolysis and fatty acids oxidation. Hence, the results of all hazelnut oil samples were in agreement with the recommendations for unrefined oil. Before storage, AV values were similar among cultivars, with an average of 0.18 mg KOH/g oil. AV increased with storage time, which was statistically significant ($p < 0.05$), and ranged from 0.17 to 0.34 mg KOH/g oil.

Table 1. Extraction yield and oxidation indices of cold-pressed hazelnut oil from six hazelnut cultivars during 9 months of storage.

Cultivar	Storage Period (Months)	AV (mg KOH/g)	PV (meq O_2/kg)	AnV	TV	Extraction Yield (%)
'Barcelonsk'i	0	0.17 ± 0.00 b	nd	0.12 ± 0.02 a	0.12 ± 0.02 b	75.33 ± 2.12
	3	0.17 ± 0.00 b	nd	0.20 ± 0.02 b	0.20 ± 0.02 b	
	5	0.23 ± 0.01 a	nd	0.22 ± 0.12 b	0.22 ± 0.12 b	
	9	0.26 ± 0.03 a	2.15 ± 0.12	0.35 ± 0.12 a	4.65 ± 0.12 a	
p-value time		$p < 0.0001$		$p < 0.0001$	$p < 0.0001$	
'Olbrzym z Halle'	0	0.19 ± 0.01 b	nd	0.02 ± 0.02 b	0.08 ± 0.02 b	71.61 ± 1.32
	3	0.20 ± 0.02 b	nd	0.08 ± 0.01 b	0.02 ± 0.01 b	
	5	0.21 ± 0.01 b	nd	nd	nd	
	9	0.30 ± 0.02 a	3.39 ± 0.18	0.14 ± 0.07 a	6.92 ± 0.007 a	
p-value time		$p < 0.0001$		0.0065	$p < 0.0001$	
'Cosford'	0	0.19 ± 0.01 b	nd	0.16 ± 0.03 b	0.32 ± 0.005 b	72.87 ± 1.95
	3	0.24 ± 0.00 a	nd	nd	nd	
	5	0.26 ± 0.06 a	nd	0.24 ± 0.01 ab	0.24 ± 0.01 c	
	9	0.34 ± 0.04 a	0.25 ± 0.06	0.32 ± 0.03 a	0.57 ± 0.02 a	
p-value time		0.0032		$p < 0.0001$	$p < 0.0001$	
'Webba Cenny'	0	0.21 ± 0.02 b	nd	0.08 ± 0.01 b	0.08 ± 0.001 b	75.49 ± 2.25
	3	0.19 ± 0.02 b	nd	nd	nd	
	5	0.21 ± 0.02 b	nd	0.18 ± 0.00 a	0.18 ± 0.00 b	
	9	0.25 ± 0.02 a	0.45 ± 0.07	nd	0.90 ± 0.07 a	
p-value time		$p < 0.0001$		$p < 0.0001$	$p < 0.0001$	
'Katalonski'	0	0.18 ± 0.00 c	nd	nd	nd	73.21 ± 3.21
	3	0.23 ± 0.02 b	nd	nd	nd	
	5	0.26 ± 0.02 b	nd	nd	nd	
	9	0.32 ± 0.05 a	0.60 ± 0.10	nd	1.22 ± 0.14	
p-value time		$p < 0.0001$				
'Nottinghamski'	0	0.14 ± 0.02 b	nd	nd	nd	69.37 ± 3.57
	3	0.10 ± 0.03 c	nd	nd	nd	
	5	0.21 ± 0.02 a	nd	nd	nd	
	9	0.28 ± 0.04 a	nd	nd	nd	
p-value time		$p < 0.0001$				
p-value cultivar		$p < 0.0001$	0.0012	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$

AV–acid value, PV–peroxide value, AnV-anisidine value, TV–totox value, nd—not detected, means with different letter (a–c) in the same column were significantly different ($p < 0.05$).

PV is one of the most commonly used tests for the evaluation of oxidative rancidity in oils and fats. It measures the content of peroxides and hydroperoxides, and is often used as an indicator of initial stage of lipid oxidation of unsaturated fatty acids (UFA) [24]. The effects of hazelnut cultivar and storage time impact oil quality parameters. As shown in Table 1, PV after 5 months of storage was undetectable in each oil sample from different hazelnuts. After 9 months, oils showed higher PV, except for oil obtained from the 'Nottinghamski' cultivar. The highest PV was observed for oil obtained from 'Olbrzym z Halle' (3.39 meq O_2/kg), followed by the 'Barcelonski' cultivar (2.15 meq O_2/kg). In the case of other cultivars, PV ranged from 0.25 to 0.60 meq O_2/kg, although all stored hazelnut oil samples did not exceed 15 meq O_2/kg of oil for virgin oils and cold-pressed fats and oils, as stated in the Codex Alimentarius Commission Standard [24]. Moreover, fresh oils usually have PV below 10 meq/kg, and a rancid taste becomes noticeable above PV of 20 meq O_2/kg. Other studies have reported an increase in AV and PV after storage of cold pressed oils from nuts and seeds [15,25–28]. AnV is an indicator of secondary oxidation products and measures non-volatile aldehydes, the larger the value, the more severe the oxidative deterioration [29]. As shown in Table 1, the increased rate of AnV was slow during all months of storage and varied from 0.08 to 0.35, or undetectable in oils from 'Katalonski' and 'Nottinghamski'. Therefore, the results show that oils had not entered the high oxidative stage, and a sharp increase in oxidation indices were not observed. Moreover, values of oxidation indices clearly showed that the hazelnut oil's lipid fraction maintained its characteristics and stability, due to refrigeration and darkness conditions of storage. Rabadan et al. [29] indicated that PVs increased faster at room temperature than at lower temperatures during storage, and a greater increase was observed for oil stored at room temperature and exposed to daylight. However, reports have stated [30,31] that stability depends strongly on storage temperature, and light is a major factor; however, the significance of light diminishes with the increasing temperature of storage.

Furthermore, low oxidation indices are due to the presence of natural antioxidants, including polyphenols (mostly phenolic acids) and tocopherols (mostly α–tocopherol) [32,33]. Moreover, cold-pressed hazelnut oil contains the highest amount of tocopherols among all tree nuts, which are health-beneficial active compounds and protects the oil from oxidation. Arranz et al. [34] showed that tocopherols are responsible for most of the radical scavenging capacity in tree nut oils. Total oxidation value, Totox value (TV), is another useful indicator of measuring the onset of progressive deterioration in oil and provides information regarding progression of the formation of primary and secondary oxidation products and TV below 10 characterize fresh and high-quality oil [35,36]. TV shows similar changes in PV and AnV, and, as expected, the highest was observed in the last month of storage in oil from 'Barcelonski' (4.65). Similar results were reported for oxidative indices of hazelnut oils during storage [15,37]. In our study, the oil yield ranged from 69% for nuts from 'Nottinghsamski' to 75% from 'Webba Cenny' and 'Barcelonski'. Due to the lack of studies concerning the cold-pressing of hazelnut oil, it was difficult to compare the results obtained due to different extraction methods (hydraulic or screw press) as well as the origin and cultivar of the hazelnuts being employed.

3.2. Fatty Acid Composition

The fatty acid composition is the most popular characteristic of oils as it is related to nutritional value and oil quality. The major fatty acid profile of cold-pressed hazelnut oils from six cultivars during storage are shown in Figure 1. In this study changes in the fatty acid profile relates to the lipid composition as a function of storage time. The lipid content of the kernels was very stable under storage conditions. MUFA exhibited the highest proportion, while saturated fatty acids (SFAs) showed the lowest content over the entire storage period. The percentage of polyunsaturated fatty acids (PUFA) slightly decreased during storage, and the change was not statistically significant, therefore, polyunsaturated fatty acids were considered stable during storage. The percentage of MUFA in the examined hazelnut oil samples decreased by approx. 1.6%, thus the percentage of SFA increased by approx. 13.7% during the last month of storage. These findings were in agreement with those reported by Belviso et al. [37]. The observed increase was probably due to oxidation of the unsaturated fatty acids.

As expected, oleic acid (C18:1) was the dominant fatty acid found in hazelnut oil, followed by linoleic (C18:2), palmitic (C16:0) and stearic (C18:0) acid. Similar results were obtained by Turan [38]. In the case of saturated fatty acids, palmitic and stearic acid content increased from 5.15% to 5.46% and 1.89% to 2.20%, respectively. These results were in agreement with those in the literature [15,39,40]. In our study, during storage, oleic and linoleic acid content decreased, which was in accordance with other reports. The sum of minor fatty acids (myristic, palmitoleic, margaric, heptadecenoic, arachidonic, eicosanoid, alfa-linoleic acid) was less than 1% after the first and last day of storage, which was comparable to results described by Turan [38]. The effect of storage time was not found to be significant for myristic (C14:0), heptadecenoic (C17:1*cis*) acid ($p > 0.05$). Oleic to linoleic acid ratio (O/L) is a useful criterion to measure the quality of oils, where a higher O/L ratio indicates greater oxidative stability [2,39]. In our study, the O/L ratio showed a slight decrease during the storage period, hence the lipid fraction of the hazelnut oils maintained their freshness and stability.

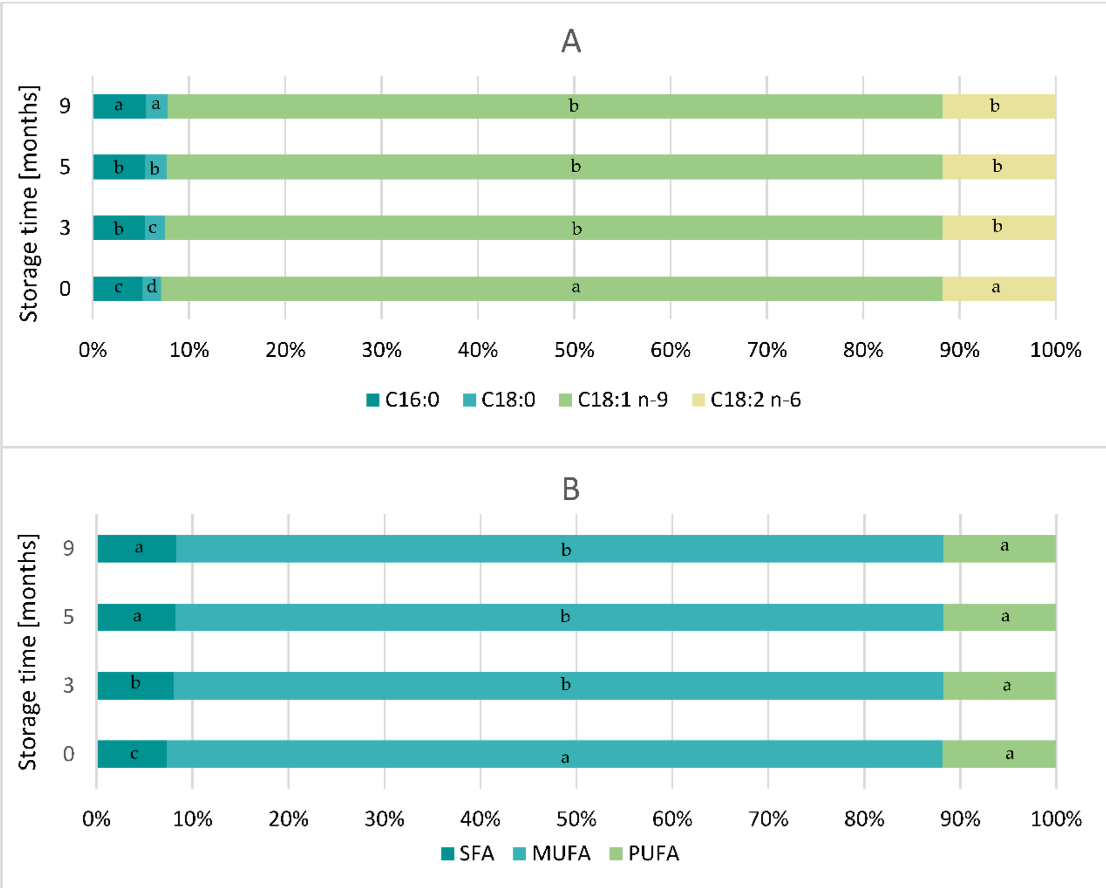

Figure 1. Percentage of main fatty acids (**A**) and total SFA, MUFA, and PUFA (**B**) of lipid fractions of hazelnut oil during 9 months of storage (%). Means with different letter (a–d) in the same row were significantly different ($p < 0.05$). SFA—saturated fatty acids; MUFA—monounsaturated fatty acid; PUFA—polyunsaturated fatty acid.

Table 2 lists a detailed description of fatty acid composition of six hazelnut cultivars during storage. Oleic acid was the major compound in hazelnut cultivars, in which the highest percentage was observed for the 'Barcelonski' and 'Katalonski' cultivars, at 82.01% and 81.91%, respectively, and the 'Nottinghamski' cultivar (78.61%) was the lowest. Before storage, the 'Nottinghamski' cultivars were also characterized with the highest content of C16:0 and C18:2, at 6.01% and 12.67%, respectively. Stearic acid (C18:0) was the highest in 'Cosford' and 'Nottinghamski' cultivars. Minor fatty acids, such as heptadecenoic acid (C17:1), did not vary among cultivars, and were not detectable in 'Barcelonski' and 'Nottinghamski' cultivars. Moreover, by comparing O/L ratios from cultivars, the highest proportion was observed in 'Cosford' cultivar (7.96), while the lowest in 'Nottinghamski' cultivar (6.20). This suggested that 'Nottinghamski' cultivar was more susceptible to lipid oxidation. However, the comparison of oxidation indices revealed that 'Nottinghamski' cultivar had the lowest oxidation values during storage, which was probably due to high tocopherol isomer content [32].

Table 2. Percentage of fatty acids, total SFA, MUFA, PUFA of lipid fractions of oils from six hazelnut cultivars during storage (%, mean value ± SD).

Fatty Acid (%)	'Katalonski'	'Barcelonski'	'Olbrzym z Halle'	'Nottinghamski'	'Webba Cenny'	'Cosford'	p-Value Cultivar
Storage time: initial							
C14:0	0.04 ± 0.01 b	0.05 ± 0.02 ab	0.07 ± 0.01 a	0.06 ± 0.06 a	0.01 ± 0.01 c	0.02 ± 0.02 c	<0.0001
C16:0	4.77 ± 0.13 c	4.66 ± 0.17 c	5.31 ± 0.05 b	6.01 ± 0.69 a	5.47 ± 0.06 b	4.70 ± 0.22 c	0.0001
C16:1 $n-7$	0.20 ± 0.01 a	0.21 ± 0.03 a	0.03 ± 0.00 c	0.13 ± 0.03 b	0.21 ± 0.03 a	0.15 ± 0.01 b	<0.0001
C17:0	0.01 ± 0.00 c	nd	0.21 ± 0.01 a	nd	0.06 ± 0.02 b	0.11 ± 0.01 b	<0.0001
C17:1 $n-7$	0.07 ± 0.00 a	0.08 ± 0.01 a	0.08 ± 0.00 a	0.08 ± 0.01 a	0.08 ± 0.01 a	0.07 ± 0.01 a	N.S.
C18:0	1.77 ± 0.08 b	1.75 ± 0.09 b	1.86 ± 0.06 b	2.01 ± 0.14 a	1.65 ± 0.03 b	2.27 ± 0.01 a	0.0034
C18:1 $n-9$	81.45 ± 0.13 a	82.01 ± 0.38 a	79.23 ± 0.24 b	78.61 ± 0.83 c	79.47 ± 0.11 b	81.91 ± 0.27 a	<0.0001
C18:2 $n-6$	11.07 ± 0.07 ab	10.65 ± 0.07 b	12.63 ± 0.09 a	12.67 ± 0.05 a	12.44 ± 0.01 a	10.29 ± 0.09 c	0.0009
C20:0	0.10 ± 0.01 b	0.10 ± 0.00 b	0.10 ± 0.01 b	0.10 ± 0.01 b	0.18 ± 0.01 a	0.17 ± 0.00 a	0.0028
C20:1 $n-9$	0.09 ± 0.01 b	0.09 ± 0.01 b	0.12 ± 0.02 a	0.14 ± 0.03 a	0.10 ± 0.02 a	0.09 ± 0.00 b	<0.0001
C18:3 $n-3$	0.17 ± 0.00 b	0.18 ± 0.00 a	0.19 ± 0.01 a	0.14 ± 0.02 c	0.18 ± 0.01 a	0.14 ± 0.01 c	<0.0001
∑SFA	6.69 ± 0.05 c	6.69 ± 0.07 c	7.55 ± 0.03 b	8.18 ± 0.23 a	7.37 ± 0.03 b	7.27 ± 0.05 b	0.0001
∑MUFA	81.81 ± 0.04 a	81.81 ± 0.11 a	79.43 ± 0.07 b	78.96 ± 0.23 c	79.86 ± 0.04 b	82.22 ± 0.07 a	0.0001
∑PUFA	11.24 ± 0.04 b	11.24 ± 0.04 b	12.82 ± 0.05 a	12.81 ± 0.04 a	12.62 ± 0.01 a	10.43 ± 0.05 c	<0.0001
Storage time: 3 months							
C14:0	0.01 ± 0.00 a	0.03 ± 0.01 a	0.04 ± 0.01 a	nd	0.02 ± 0.00 a	0.03 ± 0.01 a	N.S.
C16:0	4.89 ± 0.01 c	4.76 ± 0.10 c	5.14 ± 0.17 ab	6.74 ± 0.06 a	5.70 ± 0.03 a	5.00 ± 0.03 b	0.0001
C16:1 $n-7$	0.10 ± 0.02 a	0.02 ± 0.01 c	0.03 ± 0.01 c	nd	0.06 ± 0.01 b	nd	<0.0001
C17:0	0.23 ± 0.01 ab	0.22 ± 0.00 b	0.23 ± 0.01 ab	0.29 ± 0.01 a	0.26 ± 0.01 a	0.20 ± 0.00 c	<0.0001
C17:1 n−7	0.07 ± 0.00 a	0.08 ± 0.01 a	0.07 ± 0.00 a	0.07 ± 0.00 a	0.08 ± 0.01 a	0.06 ± 0.01 a	N.S.
C18:0	1.86 ± 0.03 c	1.82 ± 0.10 c	1.88 ± 0.02 c	2.14 ± 0.01 b	1.95 ± 0.04 c	2.44 ± 0.02 a	<0.0001
C18:1 $n-9$	81.33 ± 0.04 a	81.81 ± 0.25 a	79.70 ± 0.11 b	76.98 ± 0.06 c	78.72 ± 0.06 b	80.34 ± 0.05 a	<0.0001
C18:2 $n-6$	11.06 ± 0.07 a	10.76 ± 0.08 b	12.49 ± 0.08 a	12.65 ± 0.04 a	12.22 ± 0.04 a	10.28 ± 0.03 c	0.0001
C20:0	0.15 ± 0.01 b	0.15 ± 0.01 b	0.16 ± 0.01 b	0.14 ± 0.00 b	0.15 ± 0.00 b	1.29 ± 0.03 a	<0.0001
C20:1 $n-9$	0.07 ± 0.00 b	0.08 ± 0.01 bc	0.09 ± 0.00 b	0.13 ± 0.01 a	0.09 ± 0.01 b	0.10 ± 0.01 b	0.0037
C18:3 $n-3$	0.08 ± 0.00 b	0.11 ± 0.06 a	0.09 ± 0.00 a	0.10 ± 0.01 a	0.09 ± 0.01 a	0.06 ± 0.01 c	<0.0001
∑SFA	7.14 ± 0.01 c	6.98 ± 0.04 d	7.45 ± 0.04 c	9.31 ± 0.02 a	8.08 ± 0.02 b	8.96 ± 0.02 ab	<0.0001
∑MUFA	81.50 ± 0.02 a	81.91 ± 0.07 a	79.8 ± 0.03 bc	77.05 ± 0.02 d	78.86 ± 0.02 c	80.4 ± 0.02 b	0.0001
∑PUFA	11.14 ± 0.04 b	10.87 ± 0.07 c	12.58 ± 0.04 a	12.75 ± 0.01 a	12.31 ± 0.03 a	10.34 ± 0.02 c	0.0001
Storage time: 5 months							
C14:0	0.01 ± 0.00 a	0.02 ± 0.01 a	0.03 ± 0.01 a	nd	nd	0.05 ± 0.02 a	0.0034
C16:0	4.97 ± 0.03 b	4.97 ± 0.02 b	5.27 ± 0.05 b	6.37 ± 0.08 a	5.67 ± 0.09 b	5.10 ± 0.15 b	<0.0001
C16:1 $n-7$	0.06 ± 0.01 a	nd	nd	nd	nd	nd	N.S.
C17:0	0.22 ± 0.02 c	0.23 ± 0.01 c	0.23 ± 0.01 c	0.30 ± 0.01 a	0.27 ± 0.01 b	0.25 ± 0.03 bc	<0.0001
C17:1 $n-7$	0.07 ± 0.01 a	0.07 ± 0.01 a	0.07 ± 0.00 a	0.07 ± 0.01 a	0.07 ± 0.00 a	0.06 ± 0.01 a	N.S.
C18:0	1.95 ± 0.03 b	1.98 ± 0.01 b	2.13 ± 0.06 a	2.18 ± 0.05 ab	1.86 ± 0.03 b	2.76 ± 0.09 a	<0.0001
C18:1 $n-9$	81.15 ± 0.08 a	81.30 ± 0.05 a	79.12 ± 0.05 b	76.99 ± 0.03 c	78.17 ± 0.03 bc	79.79 ± 0.11 b	<0.0001
C18:2 $n-6$	11.03 ± 0.02 b	10.70 ± 0.00 c	12.58 ± 0.13 a	12.54 ± 0.05 a	12.25 ± 0.08 a	10.22 ± 0.06 c	<0.0001
C20:0	0.14 ± 0.01 b	0.15 ± 0.01 b	0.16 ± 0.01 b	0.14 ± 0.00 b	0.15 ± 0.01 b	1.25 ± 0.01 a	<0.0001
C20:1 $n-9$	0.05 ± 0.01 b	0.07 ± 0.01 b	0.08 ± 0.01 a	0.08 ± 0.01 a	0.09 ± 0.01 a	0.09 ± 0.01 a	0.0021
C18:3 $n-3$	0.08 ± 0.01 a	0.08 ± 0.01 a	0.08 ± 0.01 a	0.09 ± 0.00 a	0.10 ± 0.01 a	0.04 ± 0.01 b	<0.0001
∑SFA	7.29 ± 0.02	7.35 ± 0.01	7.82 ± 0.03	8.99 ± 0.04	7.95 ± 0.04	9.41 ± 0.06	<0.0001
∑MUFA	81.28 ± 0.03	81.37 ± 0.02	79.19 ± 0.02	77.06 ± 0.02	78.24 ± 0.01	79.85 ± 0.04	<0.0001
∑PUFA	11.11 ± 0.02	10.78 ± 0.01	12.66 ± 0.07	12.63 ± 0.00	12.35 ± 0.05	10.26 ± 0.04	0.0001
Storage time: 9 months							
C14:0	0.03 ± 0.00 b	0.04 ± 0.01 b	0.03 ± 0.00 b	0.03 ± 0.00 b	0.03 ± 0.01 b	0.07 ± 0.01 a	0.001
C16:0	4.95 ± 0.02 c	5.09 ± 0.01 b	5.30 ± 0.01 a	6.54 ± 0.02 s	5.82 ± 0.02 a	5.07 ± 0.05 b	<0.0001
C16:1 $n-7$	0.03 ± 0.00 a	nd	nd	nd	0.03 ± 0.00 a	nd	N.S.
C17:0	0.04 ± 0.01 c	0.21 ± 0.01 b	0.25 ± 0.01 b	0.37 ± 0.03 a	0.36 ± 0.03 a	0.25 ± 0.01 b	<0.0001
C17:1 $n-7$	0.07 ± 0.02 a	0.07 ± 0.01 a	0.08 ± 0.01 a	0.08 ± 0.00 a	0.09 ± 0.01 a	0.06 ± 0.01 c	<0.0001
C18:0	1.91 ± 0.02 c	2.00 ± 0.01 b	2.03 ± 0.01 b	2.45 ± 0.01 a	1.95 ± 0.05 c	2.83 ± 0.03 a	<0.0001
C18:1 $n-9$	81.05 ± 0.04 a	81.30 ± 0.01 a	79.10 ± 0.03 b	77.02 ± 0.01 d	78.24 ± 0.03 c	79.91 ± 0.16 b	<0.0001
C18:2 $n-6$	11.04 ± 0.02 b	10.60 ± 0.02 c	12.56 ± 0.02 a	12.60 ± 0.01 a	12.37 ± 0.06 a	10.36 ± 0.13 c	0.0012
C20:0	0.18 ± 0.01 b	0.17 ± 0.01 b	0.16 ± 0.01 b	0.15 ± 0.01 b	0.31 ± 0.06 b	1.01 ± 0.11 a	<0.0001
C20:1 $n-9$	0.15 ± 0.00 a	0.06 ± 0.01 b	0.09 ± 0.01 b	0.14 ± 0.01 a	0.16 ± 0.00 a	0.09 ± 0.01 b	<0.0001
C18:3 $n-3$	0.07 ± 0.01 a	0.06 ± 0.02 ab	0.09 ± 0.00 a	0.10 ± 0.00 a	0.10 ± 0.01 a	0.04 ± 0.00 b	<0.0001
∑SFA	7.11 ± 0.01 c	7.51 ± 0.01 c	7.77 ± 0.01 c	9.54 ± 0.01 a	8.47 ± 0.03 b	9.23 ± 0.04 a	<0.0001
∑MUFA	81.15 ± 0.02 a	81.37 ± 0.01 a	79.18 ± 0.02 b	77.10 ± 0.01 c	78.36 ± 0.01 c	79.97 ± 0.06 b	<0.0001
∑PUFA	11.11 ± 0.02 b	10.66 ± 0.02 c	12.65 ± 0.01 a	12.70 ± 0.01a	12.47 ± 0.03 a	10.40 ± 0.07 c	<0.0001

Means with different letter (a–d) in the same row were significantly different ($p < 0.05$). N.S.–not significant, nd—not detected; SFA—saturated fatty acids; MUFA—monounsaturated fatty acid; PUFA—polyunsaturated fatty acid.

According to the minor fatty acid content, C14:0 and C16:1 decreased during storage in all investigated cultivars; however, C16:1 was detectable after 9 months of storage only in 'Katalonski' and 'Webba Cenny' cultivars. During storage, heptadecanoic acid (C17:1) was stable and the differences between cultivars were significant; however, after 9 months of storage, these differences were very small, ranging between 0.06–0.08%. Additionally, storage increased margaric acid content (C17:0) in all oil samples, where the highest peak was observed after 3 months of storage, and decreased after 9 months. Similarly, storage time increased; the content of C20:0 also increased after 3 and 5 months of storage. The most intense process was observed in the 'Cosford' cultivar, where the content increased by 6–7 times compared with the beginning of storage. C18:3 content during storage changed significantly and varied between cultivars; however, the differences were very small. Compared with other reports [40], changes in fatty acid profiles were similar but a consistent decrease in polyunsaturated profiles was observed among cultivars when stored under standard commercial conditions. Overall, our study showed that storage time and cultivar impact minor fatty acid content in hazelnut cold-pressed oil.

In the case of major fatty acids, such as C16:0 and C18:0, an increase was observed during storage, in which the highest was found in Nottinghasmki and 'Cosford' cultivars, and the 'Olbrzym z Halle' cultivar was quite stable during storage period. After 9 months of storage, oleic acid (C18:1) content decreased, and the 'Cosford' cultivar showed the greatest loss and 'Olbrzym z Halle' the lowest by 2.5% and 0.10%, respectively. The second main fatty acid, linoleic acid (C18:2), was also stable during storage with no significant reduction being detected in the studied cultivars. However, differences between cultivars were observed, and varied from 10.29 ('Cosford') to 12.67 ('Olbrzym z Halle') at the beginning of the storage, and 10.36 ('Cosford') to 12.56 ('Olbrzym z Halle') after 9 months. The obtained results were comparable to those described in the literature data for different hazelnut cultivars [41–43]. Similarly, total MUFA and PUFA levels measured were in agreement with those reproted; however, slight differences were observed in the total SFA content, in which lower values were previously reported [2,44–46]. Furthermore, the fatty acid composition of oils was strongly influenced by cultivar, ecological conditions, latitude and agricultural practices.

According to previously published studies [18,32,47], important factors in choosing cultivars for oil production include their oil content and sphericity. Spherical nuts are highly desirable for industrial processing and are more easily cracked, blanched and roasted. Non-spherical hazelnut cultivars are processed for edible oil production, and are considered to be of lower quality nuts. In the case of the six studied cultivars, three cultivars ('Nottinghamski', 'Webba Cenny', 'Cosford') were non-spherical, and could be used in the oil industry. Based on the obtained results, the 'Katalonski' cultivar displayed the best quality indices during the 9 months of storage.

4. Conclusions

Over a 9-month storage period, the lowest oxidation indices (PV, AnV and AV) were observed in oils obtained from 'Katalonski' and 'Nottinghamski', in which all hazelnut oil samples did not exceed the recommendations stated in the Codex Alimentarius Commission Standard for cold-pressed and unrefined oil. Obtained oxidation indices results revealed that the oils maintained their characteristics and stability. Moreover, the effectiveness of low temperature in delaying the quality loss of hazelnut cold-pressed oil was confirmed. In general, before and after storage, the content of major and minor fatty acids in hazelnut cold-pressed oil was observed. The O/L ratio slightly decreased during storage, hence the lipid fraction of the hazelnuts maintained freshness and stability. Based on this comprehensive approach, it is possible to select the best cultivars grown in Poland for industrial use and oil cold-pressing, where the 'Nottinghamski' and 'Katalonski' cultivars are recommended for cold-pressing. Despite this fact, 'Nottinghamski' showed the lowest oil yield, but the lowest oxidation values during storage, which makes this cultivar suitable for the oil industry.

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