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Morphological Traits, Kernel Composition and Sensory Evaluation of Hazelnut (*Corylus avellana* L.) Cultivars Grown in Poland

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Abstract: In the present study, the nut and kernel traits of six hazelnut cultivars ('Barceloński', 'Kataloński', 'Webba Cenny', 'Olbrzym z Halle', 'Cosford', and 'Nottinghamski') grown in Poland were investigated. Results showed that significant differences estimated among all six cultivars with all selected morphological traits and compositional properties. During statistical analysis the year of the study was not found to affect most of the investigated traits. The investigated cultivars showed a lower protein content (11.27–13.44%), higher carbohydrate content (16.40–21.79%) and similar fat content (58.91–63.83%) to nuts grown in a warmer climate like Turkey, Italy or Spain. The studied hazelnut varieties were large-sized with diameters greater than 20 mm. The nuts of the 'Barceloński', 'Kataloński' and 'Olbrzym z Halle' cultivars were characterized by the smallest diameters of nut and kernel, were the most spherical (0.85–0.95) and exhibited the largest average nut volume (4.26–4.46). Significant differences were found between the cultivars for oil content and the ratios of major fatty acids. The QDA results, estimated that other than shape, the evaluated nuts significantly differed only in the intensity of nutty flavor (4.88–5.92). The highest intensity of this attribute was found in three cultivars, 'Nottinghamski', 'Cosford', 'Olbrzym z Halle', whereas the lowest estimate was found in the 'Barceloński' cultivar, which was also slightly less sweet and more bitter. As a result, the present study showed that the investigated hazelnut kernels can be divided into two groups: 'Nottinghamski', 'Cosford', and 'Webba Cenny' are suitable for table consumption, while 'Barceloński', 'Kataloński', and 'Olbrzym z Halle' are suitable for the processing industry. The current experimental results may help to growers and breeders when choosing the cultivars for new plantations and possibilities of destinations of the produced nuts, for confectionery use or table consumption.

Keywords: filbert; fatty acid composition; geometric properties; sensory analysis

1. Introduction

Hazelnut (*Corylus avellana* L.) is one of the most important tree nut crops in worldwide production. Poland ranks as the 11th largest producer of hazelnuts in the world, with total production of 4635 tons and harvested area 3740 ha in 2017 [1]. Turkey is the main producer and exporter of hazelnuts with 569,162 tons/year, followed by Italy and USA with 108,428 and 33,783 tons/year, respectively. The world market for hazelnuts is divided into two groups: nuts with intact shells for direct consumption (10%) and shelled nuts transferred for further technological purposes (90%). Poland has developed the cultivation of only large-sized, so-called table cultivars, with large, oval nuts, almost all of which are sold as a raw product for fresh consumption [2–5]. Furthermore, most of hazelnut grown in Poland are originated from *C. avellane* var. *pontica*, *Corylus maxima*, *Corylus lamberti* or are derived from their hybrids [6].

Knowledge of nut and kernel physical characteristics (such as volume, sphericity, etc.) are necessary to project the processing lines of hazelnuts because many types of machines are influenced by the size and shape of the food. The size of hazelnuts is used in the separation of foreign materials and separation into size categories. Sphericity is one of the most important quality traits among hazelnut properties because it is mostly spherical nuts that most preferred in the food industry, whereas the surface area is used to estimate the amount of packaging material required and is important in roasting and cooling operations. The rupture force required for the whole nut and kernel is important during the mechanical shelling process because the application of too great a force can cause damage to the hazelnuts and nut losses in production [7–9].

In recent years, some studies have been carried out on the physicochemical properties of hazelnuts grown in Poland [2–4,10]. However, research on the morphological and physical characteristics of hazelnuts grown in Poland is limited compared to that on nuts from Turkey [11,12], Italy [13–15] Iran [7], Portugal [9] and Serbia [16]. Furthermore, high-quality hazelnut cultivars to be used for processing purposes have not been identified in Poland and the cultivated kernels often do not meet market standards determined by the confectionery industry. The first objective of this research was to determine the genetic variability between all six hazelnut cultivars in relation to the nut and kernel genetic variability physical characteristics as well as major physio-quality traits. The second objective was to select the most suitable hazelnut cultivar with the highest processing value for confectionery use and table consumption for Poland.

2. Materials and Methods

2.1. Plant Materials and Weather Condition

The experiment was carried out in Department of Functional and Organic Food in Institute of Human Nutrition. Six hazelnuts cultivars, 'Barceloński', 'Cosford', 'Kataloński', 'Nottinghamski', 'Olbrzym z Halle' and 'Webba Cenny', were collected at an orchard located in the Lubelskie region (Końskowola, 51°25′ N 22°03′ E) in Poland. Plantation was under integrated pest management. All the chosen cultivars are listed in the Polish National List of Fruit Plant Varieties 2019 [17]. Nuts were collected at physiological maturity during September 2016 and 2017. The fallen nut samples totaling 5 kg per cultivar (10 trees for each cultivar) were collected from the ground. After harvest, they were dried to 6% kernel humidity according to the current postharvest treatments applied in commercial production and then stored at 20 °C. The nuts were cracked by hand, and the kernels were stored in closed plastic bags in the dark at ±4 °C until analysis. Detailed information on the climate conditions in 2016 and 2017 (minimum and maximum temperature, sun exposure and rainfall) is presented in Supplementary Figure S1. In 2016, the vegetation period was taken into account in the second decade of April, when average daily temperatures above +5 °C were recorded. The next spring months were warm, reaching a temperature exceeding 20 °C at the end of May and in the first half of June. Temperatures above 30 °C were recorded in warm summer data (July and August). In 2017, the temperature distribution was similar to 2016. Both in one and the second year of flowering hazel fell in February. Meteorological conditions vary in years in terms of monthly rainfall and the 2017 was drier than the previous year. The lowest monthly rainfall was recorded in June, July, and September.

2.2. Morphological Traits

To determine the average size of the nut (N) and kernel (K), 90 nuts of each cultivar were randomly selected. The three main dimensions (mm) for each nut and kernel of length (L), width (W) and thickness (T) were measured by using a digital caliper with a sensitivity of 0.01 mm. Among these three linear dimensions, that with the greatest value was considered to be the diameter (mm). Kernel mass (M) was measured by using a digital balance with a sensitivity of 0.001 g. The kernel ratio (RK) was calculated from the measurement of kernel mass and nut mass. The volume (V), geometric mean diameter (Dg), sphericity (φ) and surface area (S) were calculated by using the following equations [7,9]:

$$V = \pi LTW/6\ (cm^3),\ Dg = (LTW)1/3\ (mm),\ \varphi = Dg/L\ (\text{-}),\ S = \pi Dg2\ (cm^2). \quad (1)$$

The frequency of two major defects including moldy kernels and these damaged by hazelnut weevil *Curculio nucum* L. (Beatles, Curculionidae) was evaluated for all six cultivars. Ninety total nuts for each cultivar (30 nuts from each of three trees) were selected, cracked and inspected with each type of defect recorded.

2.3. Nut Oil Extraction

Oil was extracted from the sampled nuts by cold pressing. Cold pressing was performed by directly pressing raw/dried nuts in a continuous screw press at low temperature. In this research, a screw press with a capacity of 40 kg/h of nuts, equipped with an engine of 460 W (Oleum, Yoda, KT-OPM, Hazgzhou, Zhejiang, China) was used. The temperature of the extracted oil was measured with a digital thermometer and remained below 45 °C. The extracted nut oil was purified by centrifugation in an MPW 352R centrifuge at 18 °C for 10 min at 10,000 rpm. The next step was to decant the oil from the sediment and determine the efficiency of the process for each of the studied cultivars. The nut oil extraction efficiency was calculated from the weight of the oil obtained after the purification process, the weight of the processed nuts and the kernel fat measured in the nuts [18].

$$\text{Oil yield } [\%] = M_{oil} \times 100 \times 100 / M_{nuts} \times C_{fat} \quad (2)$$

where M_{oil} is the mass of oil after the decanting process (g); M_{nuts} is the mass of nuts from which oil was extruded [g]; and C_{fat} is the fat content (Soxhlet method) of the nuts subjected to oil extrusion (%).

2.4. Kernel Composition

The kernel moisture content was determined by drying crushed kernels at 100 ± 5 °C (5.0 g per sample) until they reached a constant weight [19]. The kernel fat content was determined using the Soxhlet extraction method in hexane [20]. The protein content was determined via the Kjeldahl method, and the conversion factor used to calculate the protein content was 6.25 [19]. To determine the total ash content, preweighted samples were placed in an oven at 525 °C until they had completely turned to ash, which was then weighed [19]. The carbohydrate content was estimated by subtracting the sum of the other components using the following formula [16]:

$$\text{carbohydrate content } (\%) = 100\% - (\%\text{ moisture} + \%\text{ protein} + \%\text{ fat} + \%\text{ ash}) \quad (3)$$

Total calories per sample were calculated based on the physiologic caloric values of protein, fat and carbohydrates.

$$\text{energy (kcal)} = 4 \times (\text{g protein} + \text{g carbohydrate}) + 9 \times (\text{g fat}). \quad (4)$$

2.5. Fatty Acid Analysis

The fatty acid composition of the hazelnut oil was analyzed according to American Oil Chemists' Society (AOCS) Ce 1b-89 with some modification [21]. Samples of 0.09 g of oil from six varieties of nuts were analyzed. First, 0.5 mL of tridecanoic acid solution 0.5 g/L (as internal standard) was added to vials with a screw cap. Then, 2 mL of 0.5 M methanolic potassium hydroxide was added, and the sample was heated at 60 °C for 30 min. After cooling, 2 mL of 10% boron trifluoride in methanol was added, and the sample was again held at 60 °C for 30 min. Thereafter, the mixture was cooled; 2 mL of hexane was added, and the mixture was shaken for approximately one minute. Next, 2 mL of a saturated solution of aqueous sodium chloride was added, followed by mixing. After centrifugation, the hexane layer was transferred to a gas chromatography vial. The fatty acid methyl ester composition was analyzed using a Shimadzu GC-2010 gas chromatograph(Tokyo, Kanto, Japan) with a flame ionization detector according to the method described by Wojtasik-Kalinowska et al. [22].

2.6. Texture Measurements

To measure textural properties, an Instron universal testing machine (Model 5965, Instron, Canton, MA, USA) with Bluehill®2 software was used. The compression test was carried out using a flat probe (Canton, MS, USA). Sample deformation was limited to 50% for all the determined parameters. This deformation percentage was found to be sufficient to break the nut or kernel. The test was conducted 90 times for each cultivar, where one speed test (10 mm/min) was applied. The force curve (N) versus distance (mm) allows the hardness to be calculated. The hardness of the hazelnut was designated as the maximum compression force (N).

2.7. Sensory Analysis

The sensory characteristics of the hazelnut samples were assessed using the quantitative descriptive analysis profiling method, following the procedure described in the International Organization for Standardization (ISO) standard 13299:2016 [23]. Sixteen attributes were chosen and defined according to the quantitative descriptive analysis (QDA) protocol. The intensity of the attributes was measured on a linear unstructured scale (0–10 cm; anchored): "round" to "elongated" for shape; "light cream" to "dark cream" for color; "none" to "very intensive" for odor, flavor (nutty, sweet, fatty, rancid) and taste (sweet, bitter); and "low" to "high" for the visually perceived peel presence, peel uniformity, textural features (hardness, crispness) and overall sensory quality of the samples. Sensory assessment was performed by trained panelists (ten members). The panelists fulfilled the requirements of the ISO standard 8586:2012 [24]. Individual samples of hazelnuts (two whole nuts and one cut in half) were placed in plastic containers and covered with lids. The samples were coded differently for each panelist, and presented to them in a random order. Each sample was analyzed in two independent replications, so the mean values are based on 20 individual results used for statistical analysis. The evaluation was conducted in a sensory laboratory fulfilling all requirements of ISO standard 8589:2014 [25].

2.8. Statistical Analysis

The results of experiments were expressed as the mean ± standard deviation. Statistical calculations were carried out using two-way analysis of variance with Tukey's test with Statgraphics 5.1 software (StatPoint Technologies, Inc., Warrenton, VA, USA). Principal component analysis was applied to assess the similarities and differences in the sensory profiling characteristics of the evaluated nuts (ANALSENS software).

3. Results

3.1. Nut and Kernel Physical Properties

During the two years of investigation, damage caused by *Monilia coryli* Schellenb ranged from 0.62 to 23.60%, whereas by hazelnut weevil (*Curculio nucum* L). from 0 to 9.42%. In 2017 the quality of hazelnuts was higher than in 2016 and damage caused by *M. coryli* and *C. nucum* were on average 7.73% and 1.53%, while in 2016 were 16.61% and 3.33%, respectively (Table 1). 'Webba Cenny' and 'Nottinghamski' were the most susceptible to the pathogen (23.60% and 15.60% respectively) and 'Cosford' was the most resistance cultivar (0.62%). On the other hand, the most damaged nuts by hazelnut weevil were found in 'Cosford' and 'Nottinghamski' cultivar (9.42% and 3.55%, respectively). No damaged kernels by hazelnut weevil were observed in samples collected from 'Barceloński', 'Kataloński' and 'Olbrzym z Halle'.

Table 1. Frequency of two types of kernel defects in 6 cultivars in 2016 and 2017 (n = 90).

Cultivar	Mouldy Kernels (%)			Kernels Damaged by Hazelnut Weevil (%)		
	Year			Year		
	2016	2017	Average	2016	2017	Average
Barceloński	14.10 ± 0.02 ^{b}	10.52 ± 0.02 ^{c}	12.35 ± 0.21 ^{c}	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{a}
Cosford	1.32 ± 0.01 ^{a}	0.00 ± 0.00 ^{a}	0.62 ± 0.01 ^{a}	11.32 ± 0.23 ^{d}	7.52 ± 0.27 ^{c}	9.42 ± 0.0 d
Kataloński	13.80 ± 0.01 ^{b}	11.12 ± 0.06 ^{d}	12.46 ± 0.14 ^{c}	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{a}	0.00 ± 0.00^{a}
Nottinghamski	25.41 ± 0.02 ^{c}	5.72 ± 0.10 ^{b}	15.6 ± 0.43 ^{d}	6.95 ± 0.48 ^{c}	0.00 ± 0.00 ^{a}	3.55 ± 0.33 ^{c}
Olbrzym z Halle	12.52 ± 0.01 ^{b}	4.33 ± 0.09 ^{b}	8.42 ± 0.39 ^{b}	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{a}
Webba cenny	32.90 ± 0.02 ^{d}	14.32 ± 0.21 ^{d}	23.60 ± 1.02 ^{e}	1.5 ± 0.04 ^{b}	1.32 ± 0.03 ^{b}	1.41 ± 0.43 ^{b}
Average	16.61 ± 0.04	7.73 ± 0.13	12.22 ± 1.05	3.33 ± 0.32	1.53 ± 0.00	2.42 ± 0.46

Means with different small letters (a–d) in the same raw were significantly different ($p < 0.05$).

The morphological traits of the six hazelnut cultivars during the two years of the study are presented in Table 2. Significant variabilities ($p < 0.05$) among the cultivars were observed for all the examined traits and properties of the nuts and kernels. An impact of the year on the morphological traits of nuts was observed only for width (18.54–18.88 mm) and rupture force (198.29–211.70 N), while the kernel traits that significantly differed included the length (18.72–19.83 mm), volume (1.38–1.48 cm^3), geometric diameter (13.76–13.93 mm) andsurface area (5.97–6.10 cm^2). Nuts of the 'Webba Cenny' and 'Olbrzym Halle' cultivars were characterized by the greatest average nut masses of 3.21 g and 2.98 g, respectively. In contrast, the 'Nottinghamski' and 'Cosford' cultivars exhibited the lowest average nut masses of 2.24 g and 2.41 g, respectively. The average kernel mass ranged from 0.93 g for 'Nottinghamski' to 1.38 g for 'Webba Cenny' cultivars. Among the three recorded (length, width, thickness) dimensions, that with the greatest value (length) was considered the diameter. The largest diameter was observed in nuts of 'Webba Cenny' (27.61 mm) and the lowest in those of 'Barceloński' (21.40 mm) and 'Kataloński' (21.52 mm). The average nut width ranged from 15.88 mm ('Notthingamski') to 20.97 mm ('Barceloński' and 'Kataloński'). Thickness ranged from 14.32 mm ('Cosford') to 18.97 mm ('Barceloński'). In current study, kernels of the 'Barceloński', 'Kataloński' and 'Olbrzym z Halle' cultivars were characterized by the smallest diameter (21.40 mm, 21.52 mm, 21.86 mm, respectively) and the nuts of these cultivars were also the most spherical and presented the largest average nut volume, with values of 0.85 cm^3, 0.95 cm^3, and 0.92 cm^3 and 1.46 cm^3, 1.40 cm^3, and 1.53 cm^3, respectively. The average kernel sphericity ranged between 0.62 and 0.85, and the nuts could be divided into two groups based on this traits: round ('Barceloński', 'Kataloński' and 'Olbrzym z Halle') and elongated ('Cosford', 'Nottinghamski' and 'Webba Cenny'). The surface area of the nuts was between 9.84 cm^2 for 'Nottinghamski' and 13.10 cm^2 for 'Kataloński'. The average kernel percentage was significantly different for the six cultivars, and ranged from 39.95% to 45.68% for 'Olbrzym z Halle' and 'Cosford', respectively. The average value of the rupture force for the nut varied from 163.01 N to 220.29 N for 'Barceloński' and 'Webba Cenny', respectively, while that for the kernel ranged from 39.95 N to 45.68 N for 'Olbrzym z Halle' and 'Cosford', respectively.

Table 2. Physical properties and geometric measurements of nuts and kernels (n = 90).

	Barceloński	Cosford	Kataloński	Nottinghamski	Olbrzym z Halle	Webba Cenny	Year 2016	Year 2017
Nut								
Mass (g)	2.70 ± 0.32 ^{b}	2.41 ± 0.32 ^{a}	2.70 ± 0.47 ^{b}	2.24 ± 0.31 ^{a}	2.98 ± 0.46 ^{c}	3.21 ± 0.36 ^{d}	2.70 ± 0.30 ^{A}	2.81 ± 0.37 ^{A}
Length (mm)	21.40 ± 0.80 ^{a}	24.17 ± 0.86 ^{b}	21.52 ± 0.89 ^{a}	24.22 ± 1.06 ^{b}	21.86 ± 1.08 ^{a}	27.61 ± 0.92 ^{c}	23.46 ± 0.92 ^{A}	23.59 ± 1.08 ^{A}
Width (mm)	20.97 ± 1.03 ^{c}	16.07 ± 0.83 ^{a}	20.97 ± 0.92 ^{c}	15.88 ± 0.98 ^{a}	19.60 ± 0.88 ^{b}	17.78 ± 0.85 ^{ab}	18.54 ± 0.85 ^{A}	18.88 ± 0.90 ^{B}
Thickness (mm)	18.97 ± 0.84 ^{c}	14.32 ± 0.78 ^{a}	18.88 ± 0.86 ^{c}	14.43 ± 0.72 ^{a}	18.94 ± 0.94 ^{c}	15.86 ± 0.77 ^{b}	16.90 ± 0.77 ^{A}	16.92 ± 0.90 ^{A}
Volume (cm^3)	4.46 ± 0.03 ^{b}	2.91 ± 0.02 ^{a}	4.46 ± 0.12 ^{b}	2.91 ± 0.03 ^{a}	4.26 ± 0.05 ^{b}	4.08 ± 0.09 ^{b}	3.85 ± 0.04 ^{A}	3.88 ± 0.03 ^{A}
Geometric mean diameter (mm)	20.41 ± 0.12 ^{b}	17.71 ± 0.61 ^{a}	20.42 ± 0.12 ^{b}	17.70 ± 0.68 ^{a}	20.09 ± 0.02 ^{b}	19.81 ± 0.65 ^{ab}	19.35 ± 0.65 ^{A}	19.49 ± 0.73 ^{A}
Sphericity (-)	0.85 ± 0.03 ^{ab}	0.73 ± 0.02 ^{a}	0.95 ± 0.00 ^{b}	0.73 ± 0.002 ^{a}	0.92 ± 0.002 $^{\mathbf{b}}$	0.72 ± 0.02 ^{a}	0.84 ± 0.01 ^{A}	0.83 ± 0.02 ^{A}
Surface area (cm^2)	13.08 ± 0.86 ^{b}	9.85 ± 0.68 ^{a}	13.10 ± 0.87 ^{b}	9.84 ± 0.75 ^{a}	12.69 ± 1.05 ^{b}	12.33 ± 0.81 ^{b}	11.82 ± 0.81 ^{A}	11.88 ± 0.91 ^{A}
Rupture force (N)	163.01 ± 3.46 ^{b}	212.49 ± 8.21 ^{c}	154.93 ± 5.93 ^{a}	219.39 ± 7.76 ^{c}	218.55 ± 7.87 ^{c}	220.29 ± 7.52 ^{c}	198.29 ± 7.50 ^{A}	211.70 ± 4.81 ^{B}
Kernel								
Mass (g)	1.22 ± 0.18 ^{b}	1.09 ± 0.20 ^{b}	1.17 ± 0.27 ^{b}	0.93 ± 0.23 ^{a}	1.18 ± 0.17 ^{b}	1.38 ± 0.15 ^{c}	1.17 ± 0.15 ^{A}	1.17 ± 0.20 ^{A}
Length (mm)	16.64 ± 0.87 ^{a}	19.68 ± 3.08 ^{b}	16.46 ± 2.6 ^{a}	18.29 ± 0.14 ^{b}	17.12 ± 1.07 ^{ab}	22.88 ± 1.03 ^{c}	18.72 ± 0.03 ^{A}	19.83 ± 0.94 ^{B}
Width (mm)	13.99 ± 1.09 ^{b}	11.42 ± 1.95 ^{a}	13.34 ± 2.37 ^{b}	10.84 ± 1.89 ^{a}	13.77 ± 1.22 ^{b}	12.32 ± 0.85 ^{ab}	12.75 ± 0.85 ^{A}	12.53 ± 1.04 ^{A}
Thickness (mm)	12.11 ± 1.5 ^{c}	10.08 ± 1.79 ^{ab}	11.36 ± 2.19 ^{b}	9.58 ± 1.73 ^{a}	12.42 ± 1.07 ^{c}	10.38 ± 0.91 ^{b}	11.10 ± 00.91 ^{A}	11.08 ± 1.75 ^{A}
Volume (cm^3)	1.48 ± 0.07 ^{c}	1.24 ± 0.08 ^{b}	1.40 ± 0.25 ^{c}	1.07 ± 0.02 ^{a}	1.54 ± 0.02 ^{d}	1.50 ± 0.02 ^{cd}	1.38 ± 0.02 ^{A}	1.48 ± 0.08 ^{B}
Geometric mean diameter (mm)	14.10 ± 0.08 ^{b}	17.71 ± 0.015 ^{c}	13.53 ± 0.08 ^{ab}	12.67 ± 0.84 ^{a}	14.29 ± 0.18 ^{b}	14.28 ± 0.14 ^{b}	13.76 ± 0.63 ^{A}	13.93 ± 0.85 ^{B}
Sphericity (-)	0.85 ± 0.01 ^{b}	0.65 ± 0.01 ^{a}	0.81 ± 0.00 ^{b}	0.66 ± 0.021 ^{a}	0.84 ± 0.047 ^{b}	0.62 ± 0.03 ^{a}	0.75 ± 0.63 ^{A}	0.78 ± 0.10 ^{A}
Surface area (cm^2)	6.24 ± 0.65 ^{b}	5.67 ± 0.22 ^{a}	5.96 ± 0.98 ^{a}	5.06 ± 0.68 ^{a}	6.43 ± 0.79 ^{b}	6.41 ± 0.56 ^{b}	5.97 ± 0.56 ^{A}	6.10 ± 0.81 ^{B}
Rupture force (N)	63.90 ± 0.71 ^{c}	51.84 ± 3.71 ^{b}	57.03 ± 1.72 ^{b}	49.46 ± 1.04 ^{a}	62.99 ± 1.34 ^{c}	62.58 ± 1.01^{c}	69.51 ± 2.07 ^{B}	60.33 ± 3.37 ^{A}
Kernel (%)	44.94 ± 4.01 $^{c\backslash b}$	45.68 ± 3.46 ^{c}	43.91 ± 9.0 ^{b}	41.45 ± 6.71 ^{a}	39.95 ± 3.65 ^{a}	43.14 ± 3.30 ^{b}	42.85 ± 3.31 ^{A}	42.89 ± 7.53 ^{A}

All data represent the mean ninety determinations. Means with different small letters (a–d) in the same raw were significantly different ($p < 0.05$). Means with different capital letters (A–B) in the same raw were significantly different ($p < 0.05$).

The physical properties and geometric measurements of all six cultivars were presented in Supplementary Table S1. Significant variabilities ($p < 0.05$), among the year of cultivation, were observed mainly for the masses of nut and kernel, as well as the rupture force. The percentage of kernel was not significantly influenced by year of cultivation only in 'Katanoński' cultivar.

3.2. Kernel Composition

The chemical compositions of the six cultivars of hazelnuts are given in Table 3. The influence of the cultivar on the kernel composition was found to be significant ($p < 0.05$), while an impact of the year was observed only for carbohydrates for all six cultivars. The kernel moisture content ranged from 3.45% for 'Cosford' to 6.54% for 'Olbrzym z Halle'. Carbohydrates constituted 18% of the kernel on average, while proteins constituted 12%. The content of fat in the studied cultivars varied from 58.91% for 'Webba Cenny' to 63.83% for 'Nottinghamski'.

The principal fatty acids identified in hazelnut oil were oleic acid (C18:1n9), followed by linoleic acid (C18:2n6), palmitic acid (C16:0), and stearic acid (C18:0). The content of oleic acid ranged from 78.61% in 'Nottinghamski' to 82.01% in 'Barceloński', while that of linoleic acid ranged from 10.29% in 'Cosford' to 12.67% in 'Nottinghamski'. Total monounsaturated fatty acids (MUFAs) exhibited the highest proportion (78.82–82.15%), while polyunsaturated fatty acids (PUFAs) (10.42–13.83%) presented the lowest content among the total fatty acids of the hazelnuts. Total saturated fatty acids (SFAs) ranged between 6.79% and 8.37%, and palmitic acid and stearic acids were the dominant saturated fatty acids (4.66–6.01% and 1.75–2.27%, respectively) in all samples. The highest ratio of unsaturated fatty acid (UFA)/SFA was obtained in 'Olbrzym z Halle' (13.73), while the lowest was obtained in 'Nottinghamski' (10.95). In our study, the oil yield ranged from 70% for nuts of the 'Webba Cenny' cultivar to 73% for the 'Barceloński' and 'Katanoński' cultivars.

Table 3. Kernel composition of six hazelnut cultivars grown in Poland.

	Barceloński	Cosford	Kataloński	Nottinghamski	Olbrzym z Halle	Webba Cenny	Year 2016	Year 2017
Energy (kcal)	676.3 ± 0.76 ^{b}	676.5 ± 0.34 ^{b}	683.6 ± 0.56 ^{c}	688.9 ± 0.34 ^{c}	671.9 ± 0.32 ^{b}	661.0 ± 0.56 ^{a}	676.0 ± 0.39 ^{A}	677.1 ± 0.30 ^{A}
Fat (%)	62.43 ± 1.12 ^{b}	59.92 ± 0.23 ^{a}	62.54 ± 0.81 ^{b}	63.83 ± 0.03 ^{c}	61.78 ± 0.04 ^{b}	58.91 ± 0.36 ^{a}	61.55 ± 0.80 ^{A}	62.29 ± 0.49 ^{A}
Protein (%)	12.15 ± 0.20 ^{b}	12.52 ± 0.17 ^{b}	11.50 ± 0.07 ^{a}	13.44 ± 0.07 ^{c}	12.57 ± 0.07 ^{b}	11.27 ± 0.08 ^{a}	12.26 ± 0.20 ^{A}	12.52 ± 0.41 ^{A}
Carbohydrate (%)	16.45 ± 0.46 ^{a}	21.79 ± 0.24 ^{c}	18.69 ± 0.94 ^{b}	15.14 ± 0.02 ^{a}	16.40 ± 1.02 ^{a}	21.45 ± 0.12 ^{c}	18.20 ± 0.68 ^{A}	19.34 ± 0.59 ^{B}
Ash (%)	2.79 ± 0.02 ^{c}	2.32 ± 0.00 ^{a}	2.81 ± 0.01 ^{c}	2.39 ± 0.01 ^{a}	2.71 ± 0.03 ^{c}	2.56 ± 0.02 ^{b}	2.54 ± 0.02 ^{A}	2.50 ± 0.03 ^{A}
Moisture (%)	6.18 ± 0.09 ^{d}	3.45 ± 0.61 ^{a}	4.46 ± 0.38 ^{b}	5.20 ± 0.63 ^{c}	6.54 ± 0.19 ^{d}	5.81 ± 0.14 ^{c}	5.19 ± 0.54 ^{A}	5.26 ± 0.67 ^{A}
Oil yield (%)	73.24 ± 1.35 ^{c}	71.10 ± 0.90 ^{ab}	73.14 ± 1.35 ^{c}	73.19 ± 0.53 ^{c}	72.21 ± 0.23 ^{b}	70.16 ± 0.49 ^{a}	72.10 ± 0.14 ^{A}	71.54 ± 0.26 ^{A}
Palmitic acid C16:0	4.66 ± 0.17 ^{a}	4.70 ± 0.22 ^{a}	4.77 ± 0.13 ^{a}	6.01 ± 0.09 ^{c}	5.31 ± 0.05 ^{b}	5.47 ± 0.06 ^{b}	5.16 ± 0.13 ^{A}	5.14 ± 0.12 ^{A}
Stearic acid C18:0	1.75 ± 0.09 ^{a}	2.27 ± 0.01 ^{b}	1.77 ± 0.08 ^{a}	2.01 ± 0.14 ^{b}	1.86 ± 0.06 ^{a}	1.65 ± 0.03 ^{a}	2.43 ± 0.18 ^{A}	2.44 ± 0.16 ^{A}
Oleic acid C18:1	82.01 ± 0.38 ^{b}	81.91 ± 0.27 ^{b}	81.45 ± 0.13 ^{b}	78.61 ± 0.03 ^{a}	79.23 ± 0.24 ^{a}	79.47 ± 0.11 ^{a}	79.76 ± 1.40 ^{A}	79.80 ± 0.99 ^{A}
Linoleic acid C18:2	10.65 ± 0.07 ^{a}	10.29 ± 0.09 ^{a}	11.07 ± 0.07 ^{a}	12.67 ± 0.06 ^{b}	12.63 ± 0.09 ^{b}	12.44 ± 0.01 ^{b}	11.97 ± 1.22 ^{A}	11.95 ± 1.25 ^{A}
α-llinolenic acid C18:3	0.18 ± 0.00 ^{a}	0.14 ± 0.01 ^{a}	0.17 ± 0.00 ^{a}	0.14 ± 0.02 ^{a}	0.19 ± 0.01 ^{a}	0.18 ± 0.01 ^{a}	0.15 ± 0.00 ^{A}	0.16 ± 0.01 ^{A}
Total SFA	7.67 ± 0.01 ^{bc}	7.43 ± 0.01 ^{b}	7.02 ± 0.06 ^{a}	8.37 ± 0.04 ^{c}	6.79 ± 0.06 ^{a}	7.62 ± 0.02 ^{bc}	7.48 ± 0.02 ^{A}	7.50 ± 0.01 ^{A}
Total MUFA	81.89 ± 0.05 ^{b}	82.15 ± 0.03 ^{b}	81.74 ± 0.09 ^{b}	78.82 ± 0.11 ^{a}	79.38 ± 0.15 ^{a}	79.76 ± 0.18 ^{a}	81.15 ± 0.19 ^{A}	80.92 ± 0.04 ^{A}
Total PUFA	10.44 ± 0.03 ^{a}	10.42 ± 0.05 ^{a}	11.24 ± 0.04 ^{b}	12.81 ± 0.05 ^{b}	13.83 ± 0.01 ^{c}	12.63 ± 0.13 ^{b}	12.03 ± 0.03 ^{A}	12.08 ± 0.01 ^{A}
UFA/SFA	12.04 ± 0.02 ^{a}	12.46 ± 0.12 ^{a}	13.22 ± 0.54 ^{b}	10.95 ± 0.32 ^{a}	13.73 ± 0.45 ^{b}	12.13 ± 0.14 ^{a}	11.90 ± 0.32 ^{A}	11.54 ± 0.19 ^{A}

Three independent samples ($n = 3$) were analyzed from each hazelnut varieties and all analytical measurements were performed in duplicate. Means with different letter (a–d) in the same row were significantly different ($p < 0.05$). Means with different (A-B) in the same raw were significantly different ($p < 0.05$). SFA—saturated fatty acids; MUFA—monounsaturated fatty acid; PUFA—polyunsaturated fatty acid; UFA—unsaturated fatty acid.

3.3. Sensory Evaluation

The results of sensory profiling are presented as the mean values in Table 4. Considering the attributes of appearance, it can be stated that the evaluated samples of hazelnuts differed substantially in shape. Three tested varieties ('Barceloński', 'Kataloński', 'Olbrzym z Halle') were characterized by a round shape, while the remaining varieties ('Cosford', 'Nottinghamski', 'Webba Cenny') were elongated. The kernels of all tested nuts were surrounded by a peel. The uniformity of the peel was slightly lower in the 'Barceloński' and 'Kataloński' varieties, but these differences were not statistically significant. The color of the hazelnuts was described as light cream with a slightly lower intensity in 'Kataloński'. All tested nuts exhibited a slightly perceptible smell with nearly the same intensity of aromatic descriptors. Their odor was described as nutty (2.43–2.8 c.u.), slightly sweet 0.74–1.12 c.u. and fatty 0.55–0.89 c.u. The intensity of the rancid odor was very low, not exceeding 0.5 c.u. on the scale. The hazelnuts showed quite similar texture profiles, and no statistically significant differences in the intensity of these attributes were found. The average nut hardness ranged from 5.53 c.u. in 'Barceloński' to 6.83 c.u. in 'Webba Cenny' and crispness from 5.43 c.u. in 'Webba Cenny' to 6.37 c.u. in 'Cosford'. Regarding the flavor characteristics, it was found that evaluated nuts significantly differed only in the intensity of nutty flavor. The highest intensity of this attribute was found in three varieties ('Nottinghamski', 'Cosford', 'Olbrzym z Halle') and the lowest in 'Barceloński', which was also slightly less sweet and more bitter. The intensity of fatty flavor ranged from 1.27 c.u. in 'Barceloński' to 1.63 c.u. in 'Olbrzym z Halle'. The rancid flavor remained at a similar level with a low intensity in all samples. The overall sensory quality was significantly lower in 'Barceloński' than in 'Nottinghamski'.

Table 4. Sensory characteristics of row nuts —the mean values, two sessions (n = 20).

	Barceloński	Cosford	Kataloński	Notthingamski	Olbrzym z Halle	Webba Cenny
Visual Attributes/Appearance						
shape	2.68 ^{a}	7.69 ^{b}	2.96 ^{a}	7.20 ^{b}	2.60 ^{a}	7.92 ^{b}
peel presence	7.29 ^{a}	7.79 ^{a}	7.77 ^{a}	7.93 ^{a}	7.92 ^{a}	7.94 ^{a}
peel uniformity	6.64 ^{a}	7.71 ^{a}	6.85 ^{a}	7.75 ^{a}	7.31 ^{a}	7.62 ^{a}
colour	2.12 ^{a}	2.80 ^{a}	1.78 ^{a}	2.58 ^{a}	2.65 ^{a}	2.88 ^{a}
Odour (o.)						
o. nutty	2.49 ^{a}	2.66 ^{a}	2.43 ^{a}	2.54 ^{a}	2.80 ^{a}	2.58 ^{a}
o. sweet	0.74 ^{a}	1.11 ^{a}	0.93 ^{a}	1.12 ^{a}	0.94 ^{a}	1.08 ^{a}
o. fatty	0.80 ^{a}	0.89 ^{a}	0.80 ^{a}	0.55 ^{a}	0.71 ^{a}	0.77 ^{a}
o. rancid	0.42 ^{a}	0.33 ^{a}	0.26 ^{a}	0.14 ^{a}	0.24 ^{a}	0.20 ^{a}
Texture						
hardness	5.53 ^{a}	6.57 ^{a}	6.28 ^{a}	5.91 ^{a}	6.62 ^{a}	6.83 ^{a}
crispness	5.67 ^{a}	6.37 ^{a}	5.70 ^{a}	6.00 ^{a}	6.09 ^{a}	5.43 ^{a}
Taste (t.), flavor (f.)						
f. nutty	4.88 ^{a}	5.91 ^{b}	5.48 ^{ab}	5.92 ^{b}	5.88 ^{b}	5.47 ^{ab}
t. sweet	2.67 ^{a}	3.18 ^{a}	3.06 ^{a}	3.66 ^{a}	3.63 ^{a}	3.63 ^{a}
t. bitter	1.90 ^{a}	1.58 ^{a}	1.28 ^{a}	0.89 ^{a}	1.63 ^{a}	0.85 ^{a}
f. fatty	1.27 ^{a}	1.56 ^{a}	1.30 ^{a}	1.44 ^{a}	1.63 ^{a}	1.47 ^{a}
f. rancid	0.79 ^{a}	0.43 ^{a}	0.44 ^{a}	0.35 ^{a}	0.28 ^{a}	0.40 ^{a}
overall quality	5.66 ^{a}	6.20 ^{ab}	6.13 ^{ab}	6.74 ^{b}	6.55 ^{ab}	6.56 ^{ab}

All data represent the mean twenty determinations. Means with different small letters (a–b) in the same raw were significantly different ($p < 0.05$).

The results of PCA performed on the sensory data are presented in Figure 1. The first two components (PC1 and PC2) accounted for 94.56% of the total variability, with 88.03% contributed by PC1 (horizontal axis) and only 6.53% by PC2 (vertical axis). According to the PCA results, it can be stated that the main sensory attribute that differentiates the evaluated samples is shape. The samples can also be observed to form two distinctive clusters: the first consisting of nuts with elongated shapes ('Cosford', 'Nottinghamski', 'Webba Cenny') and the second consisting of round nuts ('Barceloński', 'Kataloński', 'Olbrzym z Halle'). The close position of elongated nuts in the PCA space indicates their quite similar sensory profiles. The round nuts showed greater variation. 'Olbrzym z Halle' is located at a shorter distance from the overall sensory quality vector and attributes positively correlated with it, while 'Barceloński' is located at the greatest distance.

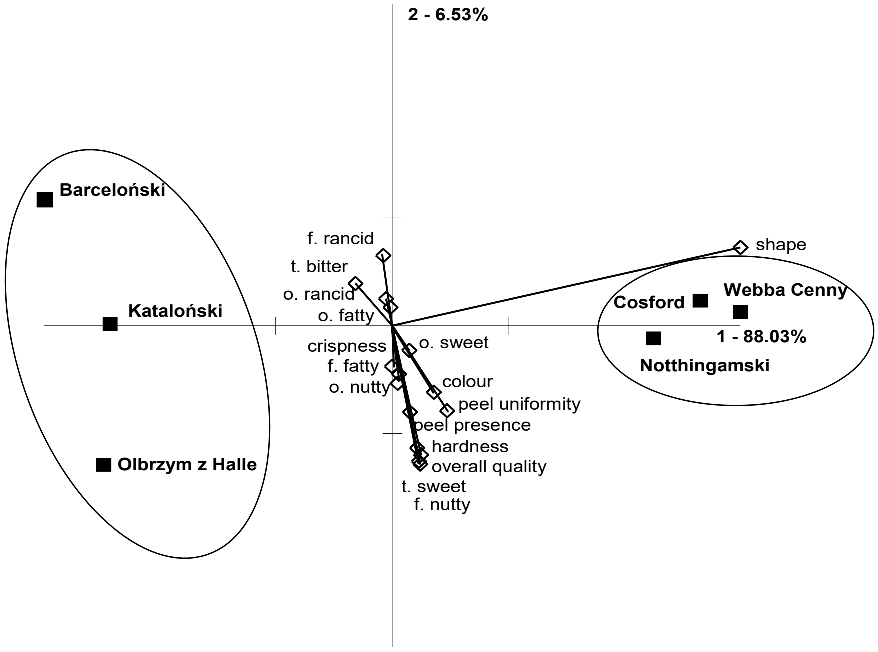

Figure 1. Principal component analysis plot of the similarities and differences in the sensory profiling characteristics of the nuts (o. is odour, f. is flavour, t. is taste).

4. Discussion

Factors affecting crop quality in Poland are weather conditions and cultivar characteristics. According to current research the occurrence of damaged nuts by hazelnut weevil is mainly shaped by cultivar factors [26]. The incidence of moldy kernels is moderately heritable and mainly depend on the weather conditions, which is in agreement with research published by Mechlenbacher et al. [27] and Gantner [4]. Probably the changes in kernel and nut mass in investigated cultivars were caused by different amounts of rainfall during the vegetation period, which is in close agreement with the results obtained by Solar and Stampar [28].

Morphological traits are often used for cultivars identification. For traits to be useful, they must be consistent from year to year and tree to tree. Solar and Stampar [28] showed that the nut masses of sixteen cultivars of hazelnut of different origins ranged from 2.36 g to 4.30 g, the current study results were also ranged same. Nuts of small and medium sizes with a nut weight of up to 3.2 g and crisp kernels are preferred for the kernel market, while for the in-shell market, larger, attractive nuts are considered the most favorable [27]. Although the investigated hazelnut cultivars were characterized by a greater average nut mass, the average kernel mass was quite similar to results obtained by Ozdemir and Akinci [28], where this trait in Turkish hazelnut cultivars was varied from 0.89 g to 1.33 g. All six hazelnut cultivars showed diameters greater than 20 mm, which may be considered suitable for market use, indicated per previously conducted studies [16]. The current study is consistent with Solar and Stampar [29] who noted that cultivars with nut diameters between 15.66 mm and 20.25 mm may be considered suitable for table consumption. In present study, the 'Barceloński', 'Kataloński' and 'Olbrzym z Halle' cultivars were characterized by the smallest diameters, which makes them useful for the processing industry. Furthermore, these cultivars ('Barceloński', 'Kataloński' and 'Olbrzym z Halle') were the most spherical, and according to Ozdemir and Akinci [28], spherical nuts are more easily cracked, blanched and roasted, so they are highly desired by the processing industry. In reference to the surface area, it was clear that a greater number of 'Nottinghamski' and 'Cosford' nuts could be packed in a predetermined volume compared to the larger nuts of other cultivars [16]. The surface area of the nuts of different cultivars was recorded at between 8.34 cm^2 and 10.32 cm^2 by Ozdemir and Akinci [28] which were smaller than the results obtained in the current research. The analysis of morphological traits of hazelnut reported by Solar and Stampar [29] showed that the year of cultivation had a smaller impact on morphological traits than the cultivar of hazelnut, although this was not confirmed by Xu and Hanna [30]. Larger differences concern the rupture force for the whole nut versus that for the kernel, where the average rupture force was aligned. The current study results were similar to those obtained by Ozdemir and Akinci [28] where the rupture force for nuts growing in Turkey varied from 93.40 N to 232.70 N and that for kernels from 50.10 N to 64.19 N. The differences between the rupture forces of the hazelnut cultivars should be considered in the design of specific machines for nut cracking, cleaning, separation and conveyance [31]. Furthermore, softer and thinner nut and food processor shells are more desirable to growers and food processors because these nuts require less time for drying and, thus, processing, which contributes to decreasing production costs [11]. Kernel moisture of all six hazelnut cultivars is in line with the marketing standards established by Commission Regulation (EU) 1284/2002 [32], where moisture content not exceeding 7% for the kernels. Furthermore, is desirable for the preservation of hazelnuts to extend protection from rancidification processes and mold contamination [7]. One of the most important factors is moisture, since water activity influences quality parameters, including mold if moisture is too high, shrivel if too low, color changes, and rancidity. Consequently, to ensure a long shelf-life and to extend protection from rancidification processes, the nuts have to be dried, immediately after harvest, to 3.5–5% kernel moisture content.

The obtained results showed that cultivars grown in Poland exhibited higher average carbohydrate contents and a lower average protein content compared to origin from countries like Turkey, Spain or Italy [7,28,31,33–35]. A higher content of carbohydrates may positively affect the sensory profile of the nuts by giving them a sweet taste. Hazelnuts are a good source of energy, and the obtained results are in line with other results for nuts growing in warmer climates, such as Turkey (55.01%–64.85%), Italy (60.8%), Slovenia (59.3%), Portugal (58.2%), Greece (56.8%), Spain (55.9%) or Iran (43.22%–65.5%) [7,28,31,33]. The fatty acid composition is the most popular characteristic of oils and is related to nutritional value and oil quality. The obtained results are comparable to those reported in the literature for different hazelnut cultivars [3,36–38]. Ciemniewska-Żytkiewicz et al. [39] reported lower contents of alfa-linoleic acid in the cultivars 'Kataloński' (0.12%) and 'Webba Cenny' (0.11%), whereas in the present study, the same cultivars showed higher contents of alfa-linoleic acid 0.17% and 0.18%, respectively. The total MUFA and PUFA levels measured are in close agreement with the results obtained by other researchers [7,29,31,33,40]. However, in the case of total SFAs, the obtained ranges were lower than those reported by other authors [29,31,40–43]. The UFA/SFA ratio is lower in hazelnuts from Spain, Italy, France, Greece and Turkey compared to hazelnuts from Poland [7,40]. High UFA/SFA ratios improve nutritional quality and are more desirable. However, high levels of UFAs, especially PUFAs, in oil contribute to reducing the shelf life of nuts/oils [31,42,44]. Due to the lack of studies concerning the cold pressing of hazelnut oil, it is difficult to compare the results obtained in studies since different extraction methods (hydraulic or screw press) as well as origin and cultivar of the hazelnuts were used. Comparison of the obtained results to data in the literature shows that a relatively poor sensory profile, light color and moderate crispness is typical of raw nuts.

5. Conclusions

The hazelnuts grown under Polish climatic conditions are large-sized varieties, typically with large nuts, and their morphological traits are not a barrier to the commercial use of these hazelnuts by food processors. The obtained results provide a valuable supplement to previously reported observations regarding hazelnut yields and resistance to the most important pests in the 'Katalоński' and 'Olbrzym z Halle' hazelnut cultivars This comprehensive approach to the subject will allow the selection of the best cultivars for cultivation in Poland for direct consumption and industrial use. Based on the presented results, it is possible to select the cultivars with the highest-quality properties (nut mass, sphericity, diameter, rupture force) desired by the processing industry (mainly found in 'Barceloński', 'Kataloński', 'Olbrzym z Halle' cultivars) as well as for table consumption ('Nottinghamski', 'Cosford', 'Webba Cenny') based on high scores in sensory analysis and a larger diameter of nuts, which should be considered when choosing cultivars for new plantations. Further investigation regarding hazelnut grown in Poland and the nut roasting process is required.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/9/11/703/s1, Figure S1: Weather conditions in orchard 2016–2017 in time of hazelnut kernels development, Table S1: Physical properties and geometric measurements of all six cultivars (n = 90).

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