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Hazelnut Kernel Size and Industrial Aptitude

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Abstract: Kernel size is the main hazelnut quality parameter for the consumption market. However, industrial purposes are the main destination for the main hazelnut cultivars. This work aims to identify industrial aptitude relationships to kernel size, and qualitative nut and kernel traits eligible to enhance hazelnut's commercial value. The qualitative hazelnut traits of cv "Negret" and "Pauetet" were assessed via in-shell and shelled nut sizes for two years. In-shell hazelnuts were tested for weight, shape, percent kernel, yield and shell thickness. Kernels were measured for shape, weight, roasting aptitude, skin color, moisture content and water activity, free acidity, fat content, crude protein, total sugars, minerals, fatty acid composition, α-tocopherol and oil stability. In-shell hazelnut traits significantly differed between cultivars, sizes and storage period. Shell thickness and nut roundness increased almost linearly with nut caliber, whereas kernel percentage decreased. Kernel roundness increased linearly with caliber. The blanching and roasting aptitude of "Negret" increased linearly with caliber, whereas no significant trend was observed for "Pauetet". Significant differences between cultivars were confirmed for water activity, oil acidity and skin color. Regarding chemical composition, fat content increased linearly with caliber in both cultivars, and α-tocopherol followed the same trend in "Negret". The sugar content tended to decrease with caliber, whereas crude protein, fiber and minerals did not show any significant relationship with kernel size. Unsaturated and polyunsaturated fatty acids fitted to linear models related to caliber, showing differences between cultivars. Unsaturated fatty acids increased with caliber, whereas polyunsaturated fatty acids decreased, and the oil stability increased linearly with kernel size. These results show that some hazelnut key traits change significantly with kernel size. The linear models presented could be a powerful tool for the confectionery industry to modulate the industrial value of given hazelnut batches.

Keywords: fruit caliber; fruit quality; industrial aptitude; fatty acids; fat content; nut shape

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1. Introduction

Hazelnuts are considered a typical food of the Mediterranean diet, and their acceptance is growing in the international market [1]. Raw consumption is less than 10%, whereas industrial uses account for 90%. The aim is to provide the confectionery industries, cooperatives and first transformers with process kernels to produce slices, sticks, dices, flour, paste or whole kernels, among other specialties. The chocolate industry is the main hazelnut user (60–70%), though other confectioneries are relevant as well, such as nougat, marzipan, ice cream, cakes, beverages, praline and spreadable creams [2,3].

The industrial requirements of the supplied batches of hazelnuts are becoming increasingly exigent. The kernel size and homogeneity as industrial traits have been very important during the last forty years [4,5]. Since many confectionery applications use roasted hazelnuts, this process is one of the most studied. Liepe [6] described the taste changes that happen in an energy bar filled with different kinds of nuts and cereals. Voight et al. [7] concluded that a group of globular proteins from both cocoa beans and roasted nuts defined the final aroma of the chocolate. Ebrahem et al. [8] reported that the hazelnut storage temperature and the health status of the nuts affect their roasting aptitude and the final shelf-life of the product, while the importance of the roasting temperature was studied by Perren and Escher [9] and Richardson and Ebrahem [10], among others. The relationship among hazelnut cultivar, roasting intensity and consumer acceptability was analyzed by Romero et al. [11], while the kinetics of color change during the roasting process was described by Demir et al. [12]. Finally, the microstructural changes that happen during roasting were studied by Saklar et al. [13]. All these studies describe the interaction between processing conditions and some chemical compounds of hazelnuts. Thus, cultivar physical and chemical traits are a main factor to consider. There is available information about hazelnut characteristics and composition from many countries, such as Italy [14–16], Spain [2,17], USA [18], Turkey [19], Poland [20–23] and other European countries [24,25].

In Spain, the main hazelnut cultivars are "Negret" and "Pauetet" [26]. The selected clone "N-9" from cv "Negret" is the most planted in the Tarragona area, which is highly valued by the confectionery industry and has a very high roasting and blanching aptitude. "Pauetet" is important in the Tarragona area and in Southwest France [27], and is often mixed with "Negret", because both cultivars have a similar kernel shape [2], but "Pauetet" has a worse blanching aptitude [26]. However, both cultivars have a slightly different chemical composition [2,28,29].

Kernel size is a main hazelnut quality parameter for the consumption market. However, most hazelnut cultivars are used for industrial purposes. For industrial applications that use whole kernels, caliber has paramount relevance. Nevertheless, there is no information about the relationship between kernel size, within the same cultivar, and industrial aptitude when the kernel is sliced, diced, or grounded. Though inter-batch variations in the physical and chemical traits of a given cultivar have been explained as a function of geographical origin, irrigation conditions and environmental factors in a given year [30], little is known about intra-batch variations. In this regard, kernel size could be a source of variation that is assumed by the industry to a certain extent, but few studies have focused on this.

Xenia has been proposed as a mechanism affecting hazelnut kernel traits and nutritional composition [31], as it was observed in other nuts, such as almond [32–35], chestnut [36], pistachio [37] and macadamia [38]. All these studies suggest that xenia showed a qualitative effect, where cross-pollinated nuts grew and changed in some chemical components (i.e., oil content, fatty acids and tocopherol. Furthermore, these studies suggest that some cultivars affect kernel traits more than others. However, industrial experience suggest that more mechanisms could be involved, since it is suspected that differences are not exclusive to bigger calibers.

This work aimed to study if industrial aptitude is related to kernel size, which parameters are the most variable and how to improve grading strategies to enhance the commercial value of hazelnut.

2. Materials and Methods

2.1. Plant Material

Two hazelnut varieties were studied, "Negret" and "Pauetet", which are the most common in Spain. Samples (10 kg), both in-shell and shelled, were taken from COSELVA, a cooperative in La Selva del Camp (Spain), after calibration. The study was conducted in two consecutive years (2008–2009).

Six in-shell hazelnut sizes were considered: 12.5–14 mm, 14–14.5 mm, 14.5–15 mm, 15.5–16 mm, 16–17 mm and over 17 mm. Additionally, seven shelled hazelnut sizes were considered: below 9 mm, 9–10 mm, 10–11 mm, 11–12 mm, 12–13 mm and over 13 mm. Finally, for both in-shell and shelled samples, the average width was measured for 50 nuts and considered as the mean size (caliber) for that sample.

2.2. Physical Traits of In-Shell Nut

From each sample, up to 50 nuts were randomly taken, and several measurements were performed. Fruit dimensions (length, width and thickness) were measured (Figure 1) with a caliper (Mitutoyo, Model Absolute AOS Digimatic, San Francisco Bay Area, CA, USA). Fruit roundness was computed from the following expression:

$$\text{Roundness} = \frac{\text{width} + \text{thickness}}{2 \times \text{length}}$$

Figure 1. Hazelnut samples of cv "Negret" for its nut and kernel technological characterization.

Kernel yield (%) was computed as follows:

$$\text{Kernel yield } (\%) = \left(\frac{\text{weight of 50 shelled kernels}}{\text{weight of 50 nuts in shell}} \right) \times 100$$

The thickness of the shell was measured on the convex side of each half using a digital caliper. Finally, the shell water content was expressed as the loss of weight (%) in an oven at 105 ± 1 °C to constant weight.

2.3. Physical Traits of Shelled Nut

Physical measurements were carried out on 50 kernels from each sample. Dimensions and roundness were measured as described above. Roasting indexes R1 (% of nuts peeled in more than 95%) and R2 (% of nuts peeled in more than 50%) were measured after keeping them in an oven (JP-SELECTA "dry big" model, using forced air) at 175 ± 1 °C for 30 min. Blanching indexes B1 (% of nuts peeled in more than 95%) and B2 (% of nuts peeled in more than 50%) were measured after keeping them in an oven at 115 ± 1 °C for 20 min.

Skin color components, lightness (L*), reddish (*a**) and yellowish (*b**), were measured using a spectrophotometer (MINOLTA Model M3500) on fifty nuts for each variety and size. From these data, Chroma and Hue angles were determined using the following expressions:

$$\boldsymbol{Chroma} = \sqrt{\boldsymbol{a}^{*2} + \boldsymbol{b}^{*2}} Hue\ angle\ (^\circ) = \mathbf{tan}^{-1}\left(\frac{\boldsymbol{b}*}{\boldsymbol{a}*}\right)$$

2.4. Chemical Composition

Fat content was analyzed by the Soxhlet method, using 5–6 g of crushed kernels (with skin) and petroleum ether (boiling point 40 to 60 °C) for 7 h in the Soxhlet apparatus. Crude protein was analyzed by Dumas' combustion procedure using a Leco FP-528 analyzer [39]. Briefly, 0.2 g of grounded sample was weighed in a porcelain sample holder (boat) for introduction into the combustion chamber (850 ± 1 °C) utilizing an automated sample loader. The combustion process converts covalently bound nitrogen into nitrogen gas (N_2), which is quantified by passing the gas through a conductivity cell. The protein content was computed using a 6.25 factor. Crude fiber was measured using 1 g of ground sample by adding boiling 0.26 N sulfuric acid (30 min) followed by boiling 0.23 N potassium hydroxide (30 min). The extracted residue was dried at 103 ± 1 °C (3 h) and the dried sample weighed and placed into a furnace (550 ± 1 °C for 3 h); finally, the ashes were weighed. The mineral fraction was determined by burning 4 g of sample in a furnace at 550 ± 1 °C for 4 h [40].

The total sugar content was analyzed using the Luff–Schoorl method. For this, 2.5 g of crushed sample was extracted with ethanol (1 h), and then 5 mL of Carrez I and 5 mL of Carrez II solutions were added (1 min each). After ethanol evaporation, the extract was diluted in 200 mL of warm water to obtain a solution in which the total sugars after inversion were analyzed by the Luff–Schoorl method. Briefly, this consists of boiling 25 mL of solution for 10 min, adding 10 mL of potassium iodide and 25 mL of 6 N sulfuric acid, and then titrating with 0.1 N sodium thiosulfate solution for neutralization. This value was compared with an equivalent solution, but not boiled.

Fatty acids were analyzed by gas-chromatography with a flame ionization detector (GC-FID) using a capillary column. The fatty acid methyl esters (FAMEs) were prepared by trans-esterification with 0.5 M potassium hydroxide, following the official method UNE-EN ISO 5509:2000. FAMEs (1 mL) were separated using a gas-chromatograph (HP 6890; Agilent Technologies, Barcelona, Spain) equipped with an FID detector and a capillary column (30 m × 0.25 mm i.d. (HP-Innowax, Agilent Technologies, Santa Clara, CA, USA)). The carrier gas was helium, and the flow rate was 1 $\text{mL}\cdot\text{min}^{-1}$. The injector and detector temperatures were 220 and 275 °C, respectively. The FAME identification was based on the retention time relative to that of a standard FAME mixture (Sigma-Aldrich, Madrid, Spain).

α-tocopherol was measured by HPLC using a fluorescence detector (FLD), following the method Ce8–89 from AOCS. We used a PerkinElmer Series 200 HPLC-FLD (Shelton, CT, USA). Oil-free acidity was measured according to the AOAC method 16,239 [41]. Finally, oil stability was measured by the Rancimat method, using a Rancimat 617 series 09 Methrom, with a working temperature of 120 °C and 20 L/h of air flow. Oil was previously extracted from raw kernels using a manual press, filtered through a paper filter and stored in the freezer (−20 °C) until the analysis. All analyses were repeated twice.

2.5. Statistical Analysis

In the first approach, an analysis of covariance (ANCOVA) was performed considering both cultivar and time as the main factors, whereas nut size was used as a covariate. A linear model analysis was performed since, in all the cases, the covariate was highly significant (data not shown).

General Linear Model analysis was carried out to study if there was a significant linear relationship between nut size and each studied parameter and to determine if such linear model was equivalent for both cultivars. The GLM procedure from SAS software was used (version 9.4; SAS Institute, Cary, NC, USA).

3. Results

3.1. In-Shell Hazelnuts

The in-shell nut roundness index decreased with fruit caliber (Table S1), ranging from 1.29 to 1.19 for "Negret" and from 1.32 to 1.16 for "Pauetet" (Figure 2). Thus, it can be stated that bigger fruits have a more spherical shape for the same cultivar, which is a desirable characteristic for industrial shell-removing operations. Both cultivars showed the same trend, which fits very well to a linear model ($R^2 > 0.87$; $p < 0.002$), without statistical differences between cultivars regarding the slope of the model (Table 1). As expected, the mean roundness indexes for both cultivars were not significantly different.

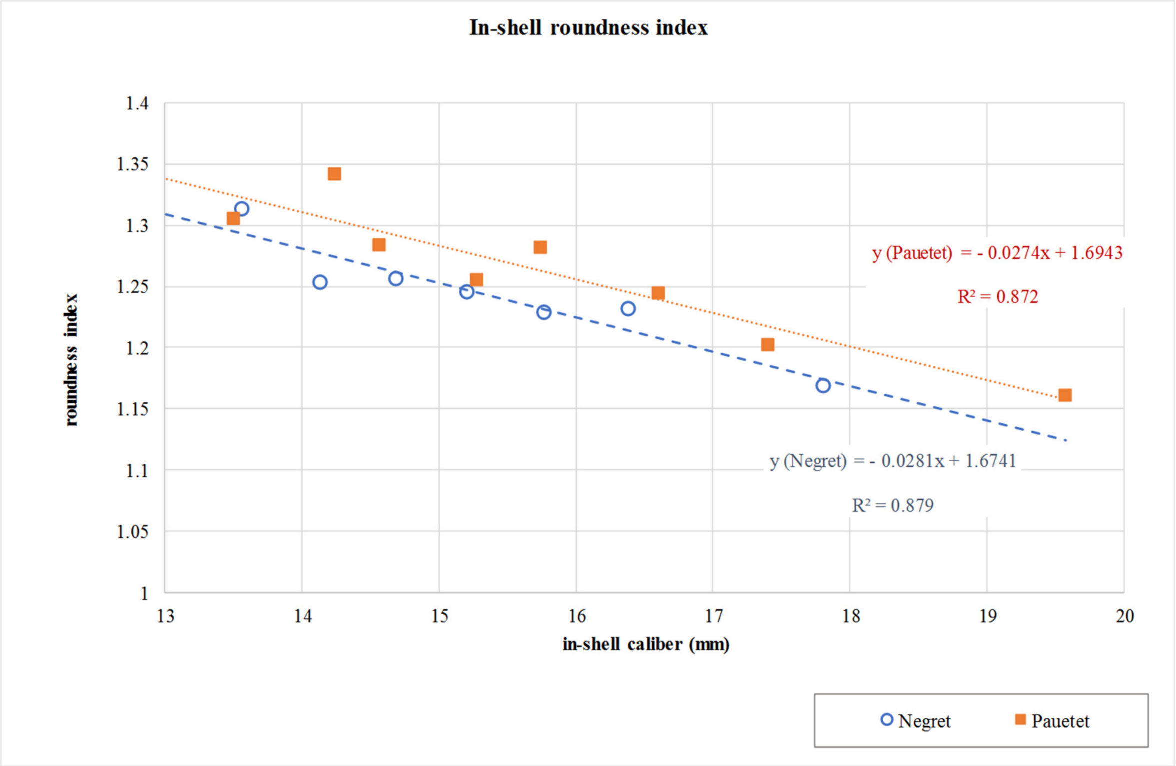

Figure 2. Roundness index linear models for in-shell hazelnuts of cv “Negret” and “Pauetet”.

Table 1. Hazelnut in-shell nut traits of cv “Negret” and “Pauetet”. Interpolated linear models and statistical tests for slope and cultivar homogeneity.

Nut Trait	Cultivar	Linear Models					Test for Slope		Test for Cultivar	
		Intercept	Slope	R^2	F Model	P Model	F Slope	P Slope	F Cultivar	P Cultivar
Kernel yield (%)	Negret	57.17 ± 1.53	−0.6466 ± 0.0993	0.895	42.44	0.0013	2.70	0.1283	41.07	<0.0001
	Pauetet	54.85 ± 1.69	−0.3815 ± 0.1062	0.683	12.92	0.0114				
Thickness of the shell (mm)	Negret	−0.043 ± 0.118	0.0622 ± 0.0077	0.929	65.08	0.0005	2.17	0.1684	0.23	0.6387
	Pauetet	0.186 ± 0.117	0.0452 ± 0.0074	0.862	37.49	0.0009				
Shell moisture (%)	Negret	14.32 ± 1.04	−0.0297 ± 0.0678	0.037	0.19	0.6799	3.69	0.0808	16.91	0.0017
	Pauetet	11.04 ± 1.50	0.2310 ± 0.0942	0.500	6.01	0.0497				
In-shell length (mm)	Negret	6.899 ± 0.820	0.6984 ± 0.0533	0.972	171	<0.0001	0.49	0.4977	30.58	0.0002
	Pauetet	8.334 ± 0.982	0.6340 ± 0.0615	0.947	106	<0.0001				
In-shell thickness (mm)	Negret	0.910 ± 0.514	0.7930 ± 0.0334	0.991	565	<0.0001	2.03	0.1821	44.51	<0.0001
	Pauetet	1.191 ± 0.403	0.7319 ± 0.0253	0.993	840	<0.0001				
In-shell roundness (mm)	Negret	1.674 ± 0.071	−0.0281 ± 0.0047	0.879	36.36	0.0018	0.01	0.9254	0.04	0.8520
	Pauetet	1.694 ± 0.068	−0.0274 ± 0.0043	0.873	41.19	0.0007				

Concerning in-shell nut dimensions, both length and thickness increased linearly with nut caliber (width). These results fit very well to a linear model (Table 1) for both dimension traits ($R^2 > 0.94$ for length and $R^2 > 0.99$ for thickness). However, thickness increases faster than length. This can explain the trend of nuts being more spherical at a higher nut size. Even though nuts of cv “Pauetet” were significantly longer and thicker than those of the cv “Negret”, no significant differences for linear model slopes were observed.

The thickness of the shell measured at the equatorial cross section was wider at higher calibers. A significant linear trend was observed between both traits ($R^2 > 0.86$; $p < 0.0001$), without any significant difference between cultivars either for slope or mean values (Table 1 and Figure 3).

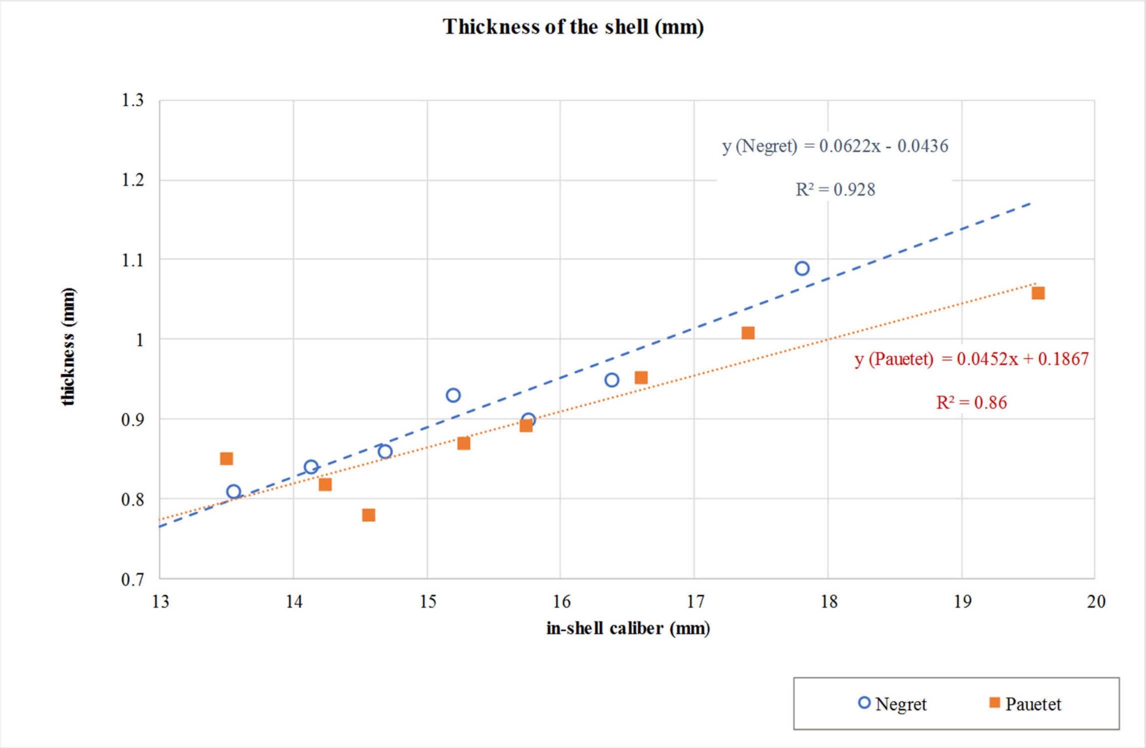

Figure 3. Linear models for central shell thickness of cv "Negret" and "Pauetet".

Significant differences between cultivars were observed for shell moisture, with a slightly higher water content in cv "Pauetet" (14.7% in average) than for "Negret" (13.9%), as shown in Table S2. However, shell moisture was not related to fruit size (Table 1).

Finally, kernel yield was higher for cv "Pauetet" (48.6% in average) than for cv "Negret" (46.9%), as shown in Table S2. This trait decreased with nut size following a linear trend without significant differences between cultivars (Table 1 and Figure 4).

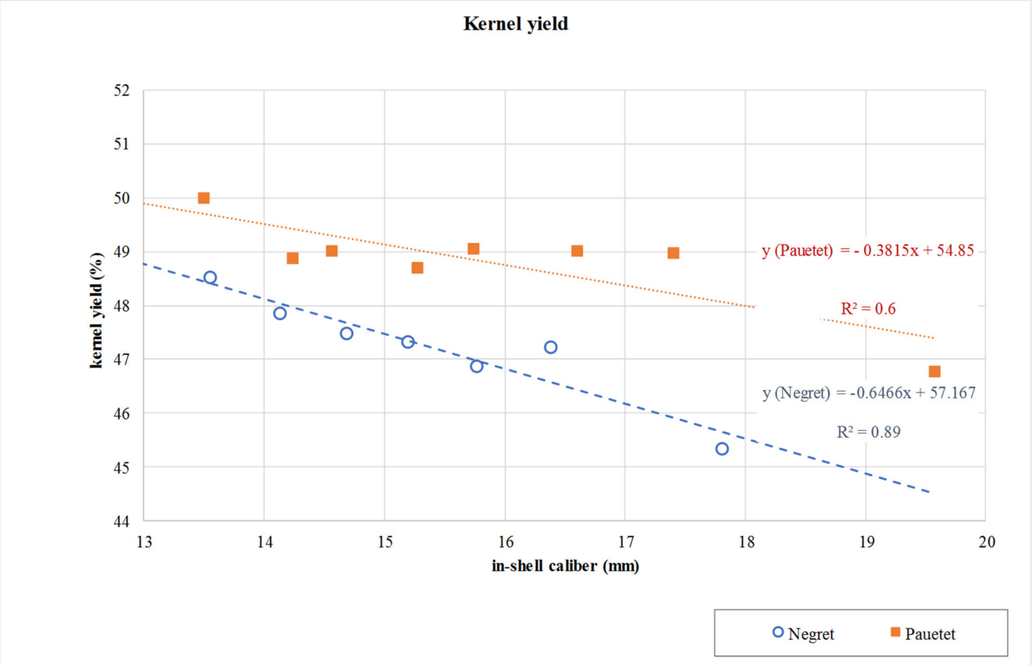

Figure 4. Linear models for kernel yield (%) of cv "Negret" and "Pauetet".

3.2. *Shelled Hazelnuts*

As occurred with in-shell nuts, the kernel roundness index decreased with caliber (Table S3), without any relation to hazelnut cultivar (Table 2 and Figure 5). The decreasing trend fits very well to a linear model ($R^2 > 0.80$; $p < 0.0001$). Furthermore, kernel thickness increases faster than length with caliber. As a result, the roundness index tended to one for bigger kernels of the same cultivar.

Table 2. Hazelnut shelled nut traits of cv "Negret" and "Pauetet". Interpolated linear models and statistical tests for slope and cultivar homogeneity (Lightness: L*; reddish: *a**; and yellowish: *b**).

Nut Trait	Cultivar	Linear Models					Test for Slope		Test for Cultivar	
		Intercept	Slope	R^2	F Model	P Model	F Slope	P Slope	F Cultivar	P Cultivar
Kernel length (mm)	Negret	8.5987 ± 0.6457	0.4231 ± 0.0618	0.824	46.82	<0.0001	0.98	0.3348	0.07	0.7917
	Pauetet	7.3151 ± 1.0799	0.5386 ± 0.1013	0.739	28.28	0.0003				
Kernel thickness (mm)	Negret	1.9348 ± 0.5645	0.7402 ± 0.0540	0.949	187	<0.0001	2.99	0.0991	2.31	0.1442
	Pauetet	0.3774 ± 0.3848	0.8546 ± 0.0361	0.982	560	<0.0001				
Kernel roundness	Negret	2.0824 ± 0.076	−0.0730 ± 0.0073	0.909	100	<0.0001	0.07	0.8007	0.38	0.5427
	Pauetet	2.0521 ± 0.1151	−0.0697 ± 0.0107	0.807	41.75	<0.0001				
L*	Negret	26.07 ± 2.67	0.1124 ± 0.2554	0.019	0.19	0.6692	0.03	0.8652	5.08	0.0356
	Pauetet	24.56 ± 7.67	−0.0151 ± 0.7191	0.000	0.00	0.9836				
*a**	Negret	6.9783 ± 0.7856	0.0997 ± 0.0752	0.149	1.76	0.2147	0.08	0.7821	2.80	0.1098
	Pauetet	6.9774 ± 2.0004	0.0444 ± 0.1876	0.006	0.06	0.8125				
*b**	Negret	13.86 ± 1.45	−0.0841 ± 0.1396	0.035	0.36	0.5602	0.05	0.8228	2.79	0.1104
	Pauetet	13.69 ± 4.69	−0.1859 ± 0.4404	0.017	0.18	0.6829				
Hue angle (°)	Negret	1.1065 ± 0.0441	−0.0086 ± 0.0042	0.291	4.11	0.0700	0.00	0.9500	1.75	0.2023
	Pauetet	1.0953 ± 0.08	−0.0090 ± 0.0075	0.128	1.47	0.2536				
Chroma	Negret	15.48 ± 1.51	−0.0208 ± 0.1447	0.002	0.02	0.8886	0.06	0.8127	2.89	0.1048
	Pauetet	15.33 ± 4.98	−0.1346 ± 0.4670	0.008	0.08	0.7790				

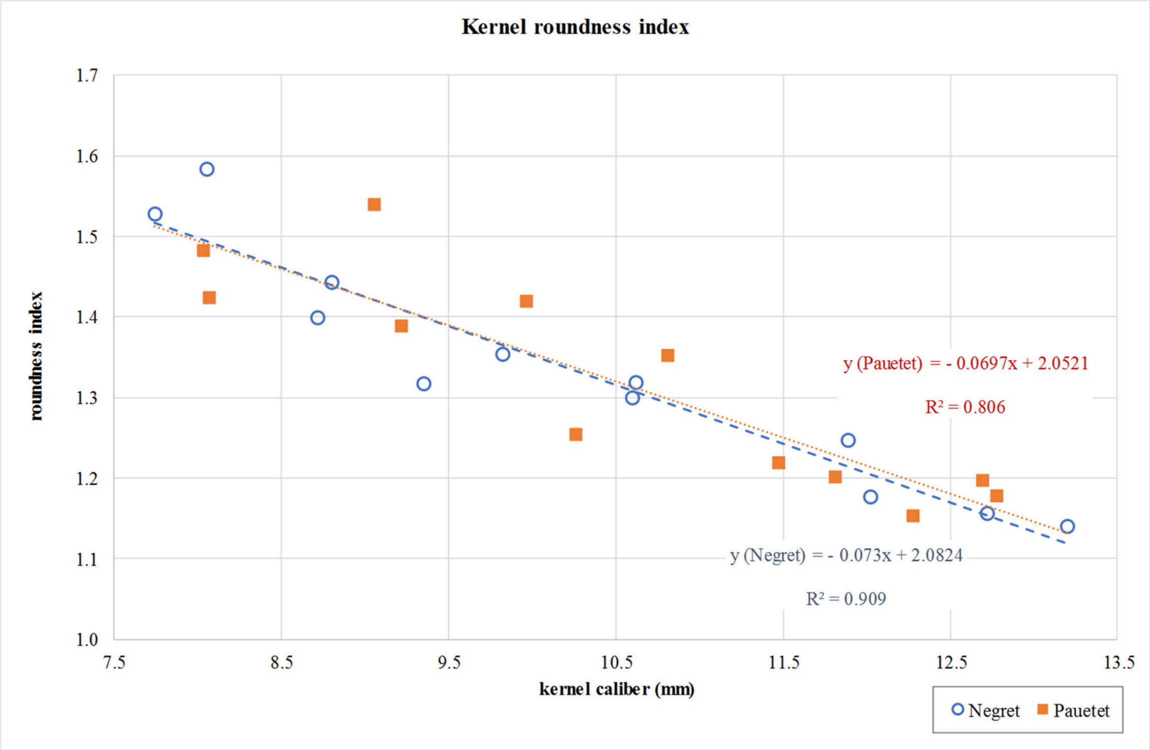

Figure 5. Linear models for kernel roundness index of cv "Negret" and "Pauetet".

Regarding kernel skin color, no significant trend with respect to caliber was observed for either “Negret” or “Pauetet”. Apart from a small difference in lightness (L*), which was higher in “Negret”, the other color components (*a**, *b**, Hue angle and Chroma) were equivalent for both cultivars (Table 2).

Roasting (R1) and blanching (B1) indexes (Table 3) were significantly different for each cultivar (R1 = 66.2% and B1 = 40.0% for “Negret”, whereas R1 = 56.1% and B1 = 21.0% for “Pauetet”). Additionally, “Negret” fit to a linear trend with caliber ($R^2 = 0.58$; $p = 0.0041$ for R1 index and $R^2 = 0.87$; $p < 0.0001$ for B1 index), whereas “Pauetet” did not change with caliber. Figure 6 shows the different behavior of each cultivar for the B1 index.

Table 3. Hazelnut shelled nut industrial properties of cv “Negret” and “Pauetet”. Interpolated linear models and statistical tests for slope and cultivar homogeneity. Roasting index R1 (% of nuts peeled in more than 95%); roasting index R2 (% of nuts peeled in more than 50%); blanching index B1 (% of nuts peeled in more than 95%); blanching index B2 (% of nuts peeled in more than 50%).

Nut Trait	Cultivar	Linear Models					Test for Slope		Test for Cultivar	
		Intercept	Slope	R^2	F Model	P Model	F Slope	P Slope	F Cultivar	P Cultivar
Roasting aptitude R1 (%)	Negret	0.0241 ± 0.1747	0.0619 ± 0.0167	0.578	13.71	0.0041	5.25	0.0342	7.88	0.0117
	Pauetet	0.4953 ± 0.1397	0.0059 ± 0.0126	0.027	0.22	0.6486				
Roasting aptitude R2 (%)	Negret	0.9317 ± 0.0582	0.0027 ± 0.0056	0.022	0.23	0.6424	0.11	0.7470	22.69	0.0002
	Pauetet	0.8233 ± 0.0934	0.0059 ± 0.0084	0.059	0.50	0.4986				
Blanching aptitude B1 (%)	Negret	−0.5632 ± 0.1206	0.0936 ± 0.0115	0.868	65.64	<0.0001	22.07	0.0002	46.54	<0.0001
	Pauetet	0.1612 ± 0.1538	0.0044 ± 0.0138	0.013	0.10	0.7574				
Blanching aptitude B2 (%)	Negret	0.1168 ± 0.2376	0.0648 ± 0.0227	0.448	8.11	0.0173	0.03	0.8620	48.41	<0.0001
	Pauetet	−0.2084 ± 0.1944	0.0589 ± 0.0179	0.574	10.76	0.0112				
Oil acidity (% ocelic acid)	Negret	0.3219 ± 0.1109	−0.0094 ± 0.0106	0.073	0.79	0.3961	1.56	0.2291	1.18	0.2918
	Pauetet	0.7559 ± 0.3366	−0.0436 ± 0.0297	0.234	2.14	0.1865				
Water activity (a_w)	Negret	0.6695 ± 0.0297	−0.0033 ± 0.0028	0.117	1.33	0.2764	0.61	0.4433	4.97	0.0374
	Pauetet	0.0441 ± 0.0561	0.0013 ± 0.0053	0.006	0.06	0.8078				

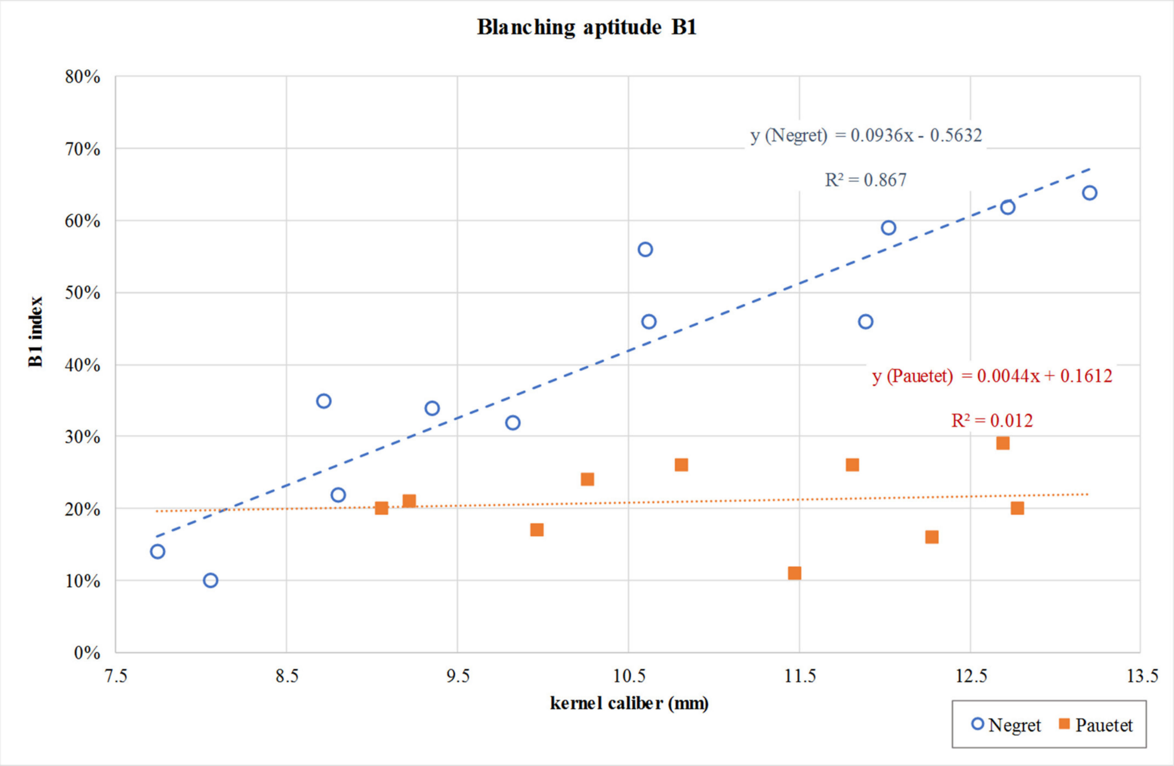

Figure 6. Linear models for kernel blanching (B1 index) of cv “Negret” and “Pauetet”.

Water activity (Tables 3 and S4) was slightly higher in cv "Pauetet" (0.658) than cv "Negret" (0.636), in accordance with the observed drift in moisture. Water activity did not show a linear trend with caliber, suggesting that differences in moisture were not due to external water absorption but to tissue water content. As stated above, kernel moisture was significantly higher for "Pauetet" (5.0% in average) than for "Negret" (4.7%). Furthermore, moisture decreased with caliber without significant differences between cultivars (Table 4 and Table S4). Though the linear model was significant, the adjustment was not very high, as shown in Figure 7 (R^2 = 0.66 for "Negret" and R^2 = 0.40 for "Pauetet").

Table 4. Hazelnut shelled nut chemical composition of cv "Negret" and "Pauetet". Interpolated linear models and statistical tests for slope and cultivar homogeneity.

Nut Trait	Cultivar	Linear Models					Test for Slope		Test for Cultivar	
		Intercept	Slope	R^2	F Model	P Model	F Slope	P Slope	F Cultivar	P Cultivar
Moisture content (%)	Negret	6.7179 ± 0.4626	−0.1949 ± 0.0443	0.659	19.36	0.0013	0.30	0.5905	5.72	0.0267
	Pauetet	6.639 ± 0.6408	−0.1544 ± 0.0600	0.398	6.60	0.0279				
Fat content (%)	Negret	38.05 ± 6.72	2.4105 ± 0.6308	0.619	14.60	0.0041	0.00	0.9673	1.70	0.2086
	Pauetet	40.67 ± 6.06	2.3747 ± 0.5795	0.651	16.79	0.0027				
Protein (%)	Negret	16.06 ± 0.97	−0.1059 ± 0.0903	0.314	1.38	0.3254	3.28	0.1202	0.24	0.6439
	Pauetet	20.29 ± 1.74	−0.4268 ± 0.1588	0.707	7.22	0.0746				
Crude fiber (%)	Negret	14.6116 ± 2.6437	−0.2714 ± 0.2419	0.290	1.23	0.3488	4.99	0.0669	0.01	0.9360
	Pauetet	5.0274 ± 3.4554	0.6109 ± 0.3130	0.559	3.81	0.1460				
Sugars (%)	Negret	5.2274 ± 0.7489	−0.2109 ± 0.0694	0.755	9.24	0.0559	0.51	0.5027	3.34	0.1173
	Pauetet	5.6912 ± 1.2988	−0.3061 ± 0.1187	0.689	6.65	0.0818				
Minerals (%)	Negret	2.2106 ± 0.4259	−0.0135 ± 0.0395	0.038	0.12	0.7543	0.86	0.3903	0.12	0.7424
	Pauetet	1.4651 ± 0.6650	0.0522 ± 0.0607	0.197	0.74	0.4538				

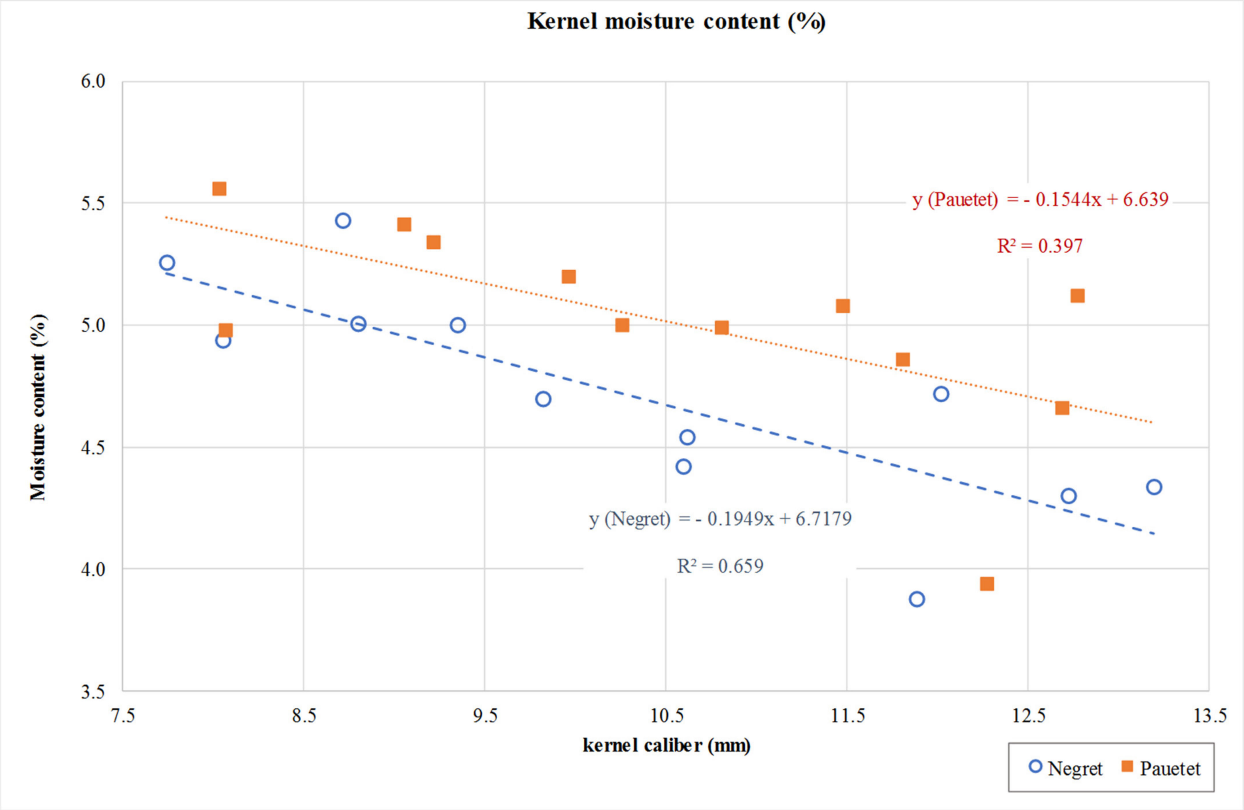

Figure 7. Linear models for kernel moisture content of cv "Negret" and "Pauetet".

Regarding kernel chemical composition (Tables 4 and S4), no significant differences were observed between cultivars. However, the fat content fitted relatively well to a linear model related to caliber with a positive slope (R^2 = 0.63; $p < 0.0041$ for "Negret" and R^2 = 0.65; $p = 0.0027$ for "Pauetet") without any differences in trend between cultivars (Figure 8).

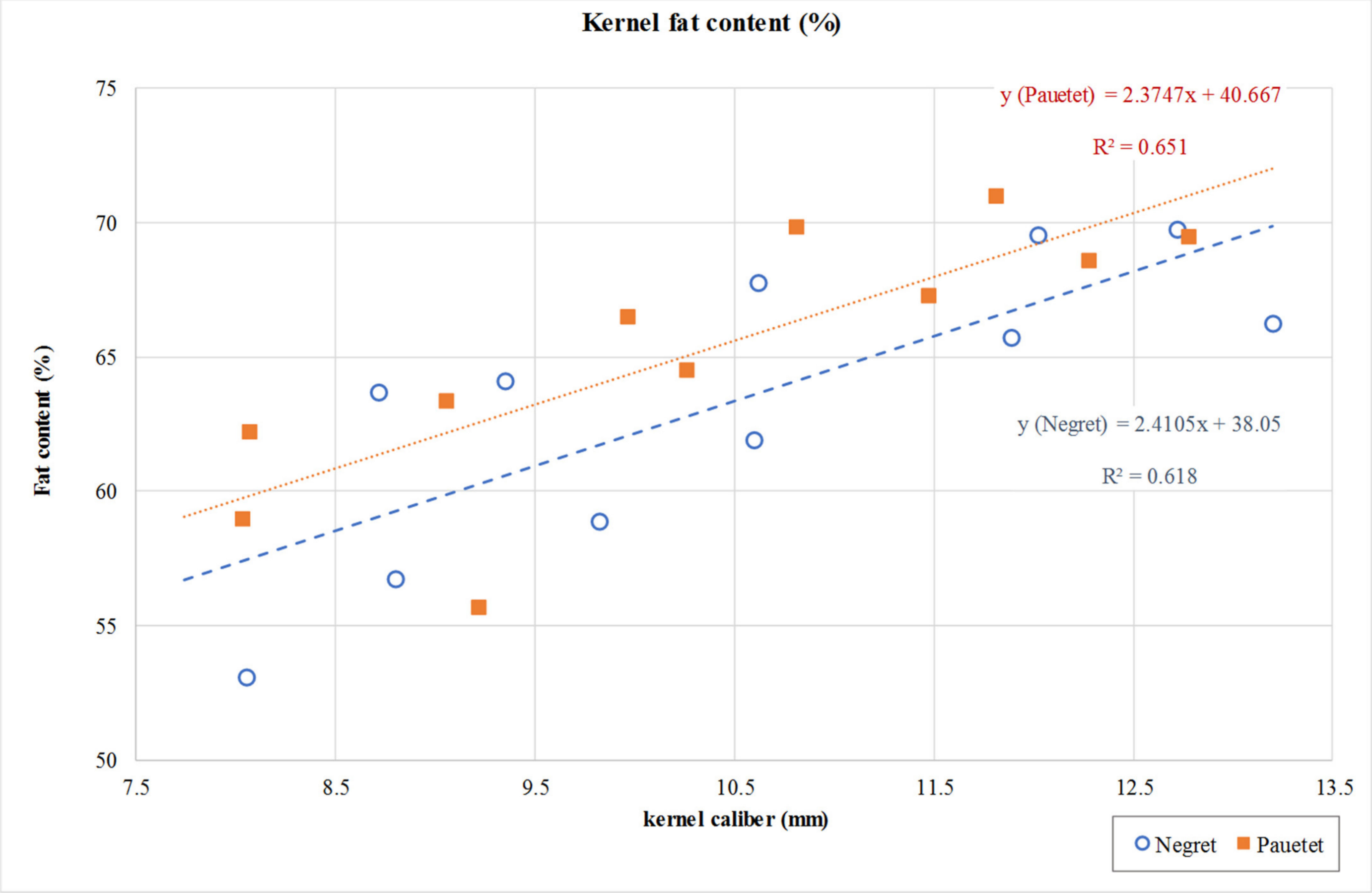

Figure 8. Linear models for kernel fat content of cv "Negret" and "Pauetet".

On the other hand, the total sugar content showed a significant linear trend with a negative slope (R^2 = 0.76; $p < 0.0559$ for "Negret" and R^2 = 0.69; $p < 0.0818$ for "Pauetet") and no significant differences in trend between cultivars (Figure 9). α-tocopherol fit to a linear model with a positive slope for "Negret" (R^2 = 0.91; $p < 0.0112$) but not for "Pauetet". However, the slope was positive in both cultivars (Figure 10). Finally, protein, crude fiber and mineral content did not show any significant relationship with kernel caliber.

The fatty acid composition, especially unsaturated and polyunsaturated fatty acids, fitted very well to linear models, with significant differences between cultivars concerning mean values but not for slopes (Table 5 and Table S4). In fact, the mean oleic acid content was higher in "Pauetet" (79.6% in average) than "Negret" (75.8%), and both cultivars showed a significant direct relationship with caliber, as shown in Figure 11 ($R^2 > 0.96$; $p < 0.0001$). Linoleic acid content was significantly lower in "Pauetet" (11.9%) than in "Negret" (16.2%), and both cultivars followed a decreasing linear model with caliber ($R^2 > 0.97$; $p < 0.0001$). Then, linolenic acid was significantly higher in "Negret" (0.09%) than "Pauetet" (0.08%), and both cultivars followed a decreasing linear model with caliber ($R^2 > 0.85$; $p < 0.0003$). On the other hand, palmitic acid was significantly higher in "Pauetet" (5.9%) than in "Negret" (5.7%), but only "Pauetet" showed a significant increasing linear trend with caliber (R^2 = 0.64; $p < 0.0099$), whereas "Negret" seemed to follow a similar trend, but the adjustment was poor (R^2 = 0.07; $p < 0.4291$).

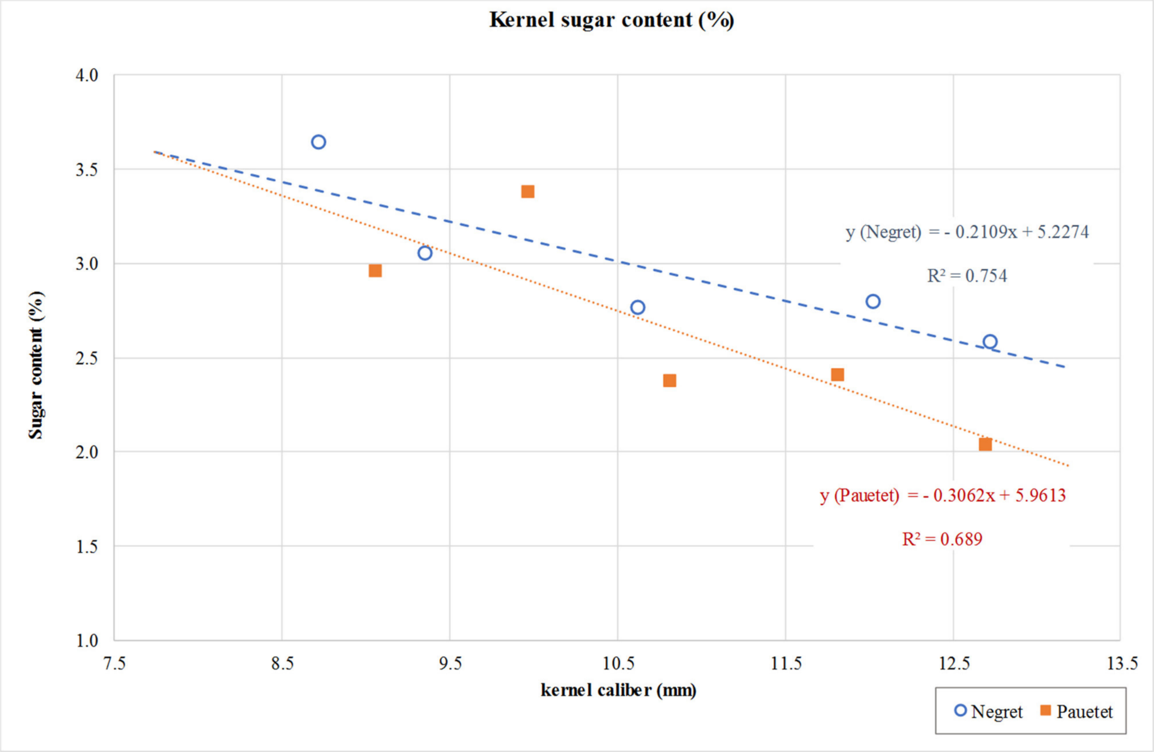

Figure 9. Linear models for kernel sugar content of cv "Negret" and "Pauetet".

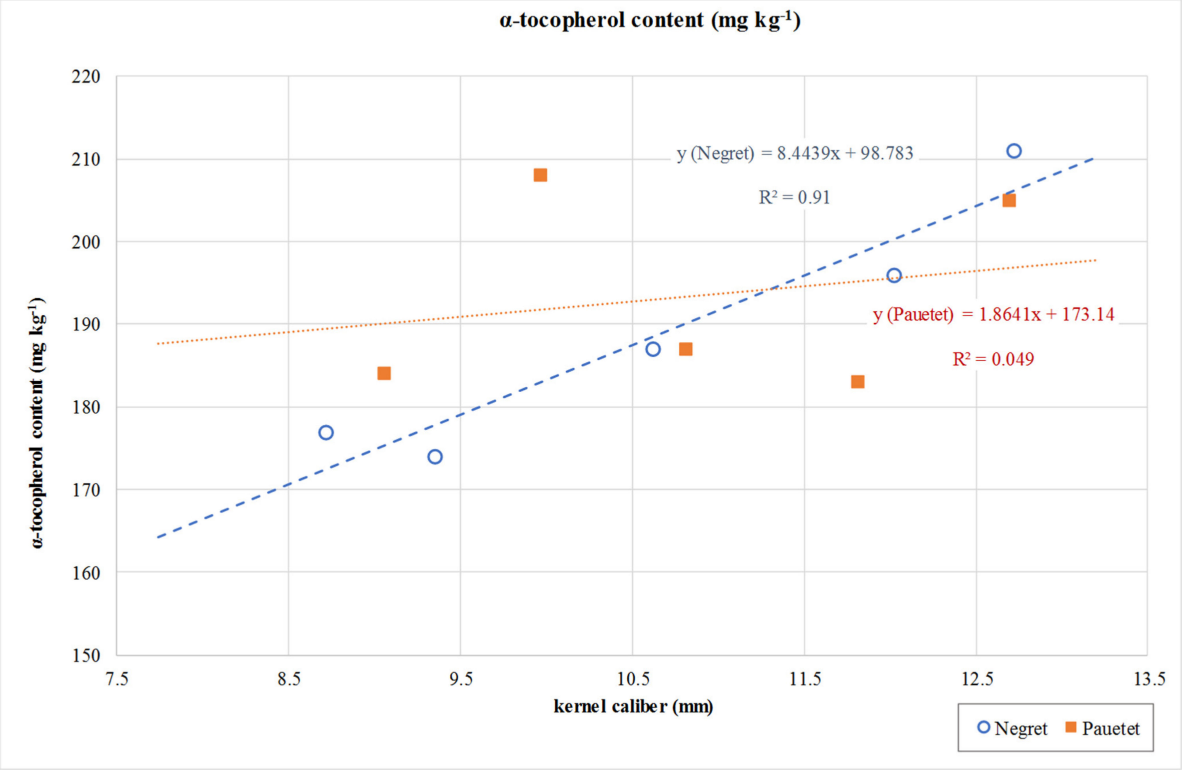

Figure 10. Linear models for α-tocopherol content of cv "Negret" and "Pauetet".

Table 5. Fatty acid composition, oil stability and α-tocopherol content of cv "Negret" and "Pauetet". Interpolated linear models and statistical tests for slope and cultivar homogeneity.

Nut Trait	Cultivar	Linear Models					Test for Slope		Test for Cultivar	
		Intercept	Slope	R^2	F Model	P Model	F Slope	P Slope	F Cultivar	P Cultivar
Palmitic acid (C16:0 %)	Negret	5.5462 ± 0.1404	0.0109 ± 0.0132	0.071	0.69	0.4291	4.16	0.0582	70.57	<0.0001
	Pauetet	5.2791 ± 0.1826	0.0566 ± 0.0161	0.638	12.32	0.0099				
Oleic acid (C18:1 %)	Negret	52.51 ± 1.26	2.2169 ± 0.1186	0.975	349	<0.0001	0.12	0.7375	172	<0.0001
	Pauetet	53.86 ± 1.99	2.2906 ± 0.1763	0.960	168	<0.0001				
Linoleic acid (C18:2 %)	Negret	40.54 ± 1.31	−2.3228 ± 0.1129	0.975	356	<0.0001	0.28	0.6048	205	<0.0001
	Pauetet	39.33 ± 1.96	−2.4385 ± 0.1729	0.966	198	<0.0001				
Linolenic acid (C18:3 %)	Negret	0.1787 ± 0.0112	−0.0085 ± 0.0011	0.878	64.67	<0.0001	0.18	0.6789	14.10	0.0017
	Pauetet	0.1679 ± 0.0134	−0.0077 ± 0.0012	0.858	42.30	0.0003				
Stability (h at 120 °C)	Negret	−0.0214 ± 0.8942	0.6109 ± 0.0841	0.854	52.80	<0.0001	1.02	0.3269	28.01	<0.0001
	Pauetet	−1.1723 ± 1.6516	0.7770 ± 0.1459	0.802	28.35	0.0011				
α-tocopherol (mg/kg)	Negret	98.78 ± 16.24	8.4429 ± 1.5048	0.913	31.49	0.0112	1.98	0.2090	0.46	0.5241
	Pauetet	173.14 ± 51.69	1.8664 ± 4.7236	0.049	0.16	0.7195				

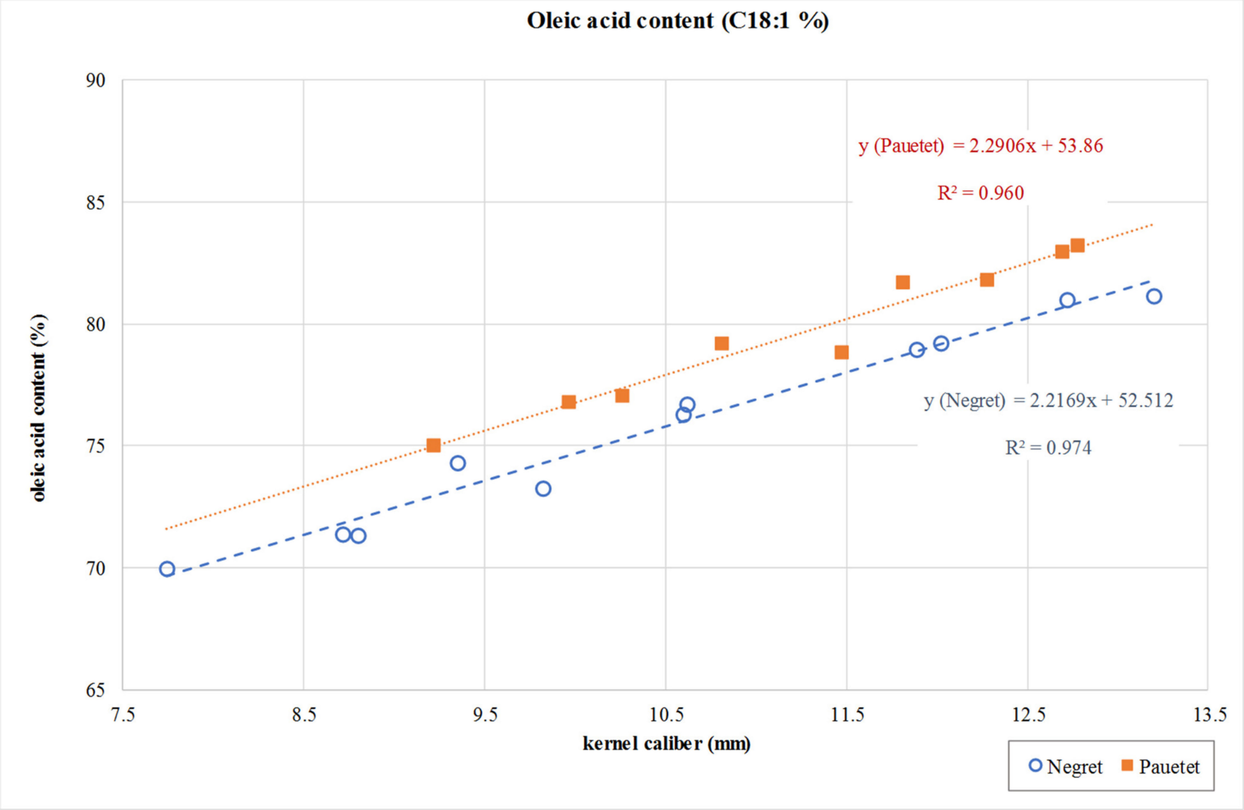

Figure 11. Linear models for oleic acid content of cv "Negret" and "Pauetet".

In agreement with the observed trends in polyunsaturated fatty acids, the mean oil stability was higher in "Pauetet" (7.57 h at 120 °C) than in "Negret" (6.39 h at 120 °C), and it fit to a linear increasing trend with caliber (Table 5 and Figure 12), which is equivalent for both cultivars ($R^2 > 0.80$; $p < 0.0011$).

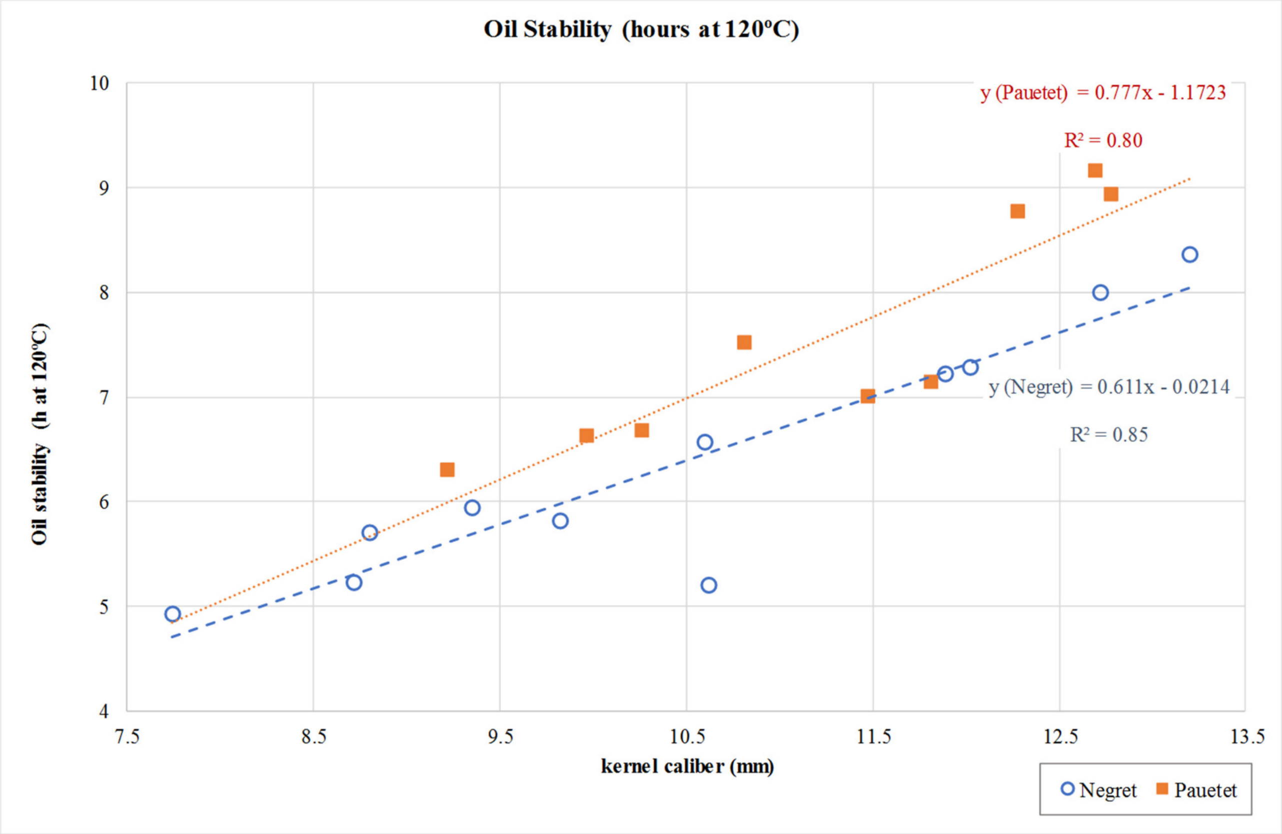

Figure 12. Linear models for oil stability of cv "Negret" and "Pauetet".

4. Discussion and Conclusions

The fact that the in-shell roundness index is closer to one for bigger nuts and that bigger fruits have a thicker shell, regardless of the cultivar, could be useful information for shelling machine builders. Cristofori et al. [16] also reported significant differences for nut roundness concerning years, but did not report any relationship with kernel caliber. In addition, the reported result that bigger kernels are more spherical is interesting for the chocolate industry, mainly for specialties in which a whole kernel is placed in the center, such as in the case of bonbons.

Concerning the roasting and blanching aptitude of both hazelnut cultivars, the results of this study agree with those reported by Rovira et al. [26] that "Negret" has a significantly better roasting aptitude than "Pauetet". Interestingly, in the present study, results show that if one cultivar (i.e., "Negret") is suitable for such processes, this property is enhanced with kernel caliber, whereas if the cultivar is unsuitable (i.e., "Pauetet"), this property negatively affects all the calibers.

Romero et al. [2] reported that "Negret" and "Pauetet" have similar chemical compositions, at least for major components, which agrees with the presented results for fat content, protein, fiber, sugar, minerals and tocopherol. However, significant differences were found for fatty acid composition. Rovira et al. [25,26] reported the industrial traits and chemical composition of several hazelnut cultivars planted in Tarragona (Spain), including "Negret" and "Pauetet". These researchers observed significant differences among cultivars and years, mainly for fat and total sugar contents, but not for "Negret" and "Pauetet", which showed a very similar composition, in accordance with the results obtained in the present study. Similar results were reported in Italy by Cristofori et al. [16] for a different group of cultivars. Bacchetta et al. [41], in a study of 75 accessions of European hazelnut germplasm, also reported similar values of fat content and fatty acid composition for both cultivars, "Negret" and "Pauetet", over two years of study. On the other hand, Percerisa et al. [29]

observed significant differences in chemical composition due to environmental factors for both cultivars over a three-year period. In the same vein, Klockmann et al. [42] developed classification models to decipher geographical origin using metabolomics approaches; however, they did not compare the same cultivar growing in different countries but only mixed samples from different countries.

To the best of our knowledge, the finding that chemical composition changes almost linearly with kernel caliber has not been previously reported. Xenia has positive effects on the quality of fruit concerning both nut size and chemical composition via cross-pollination [31]. However, this does not explain the linearity with kernel size since xenia seems to have a qualitative effect. Furthermore, the results were the same for two years and two cultivars. This is more difficult to explain through the cross-pollination effect, which can change every year, especially in the Tarragona area where several cultivars are used as pollinizers. Finally, it must be stated that hazelnut is a self-incompatible species [43]; thus, cross-pollination happens in most fruit crops every year, and differences due to xenia are expected to be low.

Fat content variation in relation to kernel size can be very useful for the confectionery industry, which is concerned with this property. In fact, some technological food properties, such as final taste and consumer acceptability, improve with fat content [44,45]. For this purpose, choosing higher calibers for a given cultivar could be an interesting direction when there is a demand for better quality at a higher price. In some cases, fat migration is a problem [46,47]; thus, selecting kernels with lower fat content could be an option. On the other hand, the total energy of a product is sometimes a handicap, mainly when it includes sugar and fat from the hazelnut; in these cases, choosing kernels with a smaller caliber could help, since this reduces the fat content. The fact that the total sugar content of hazelnut increases at lower calibers should not be a big problem, since fat energy is more than two-fold higher than that of sugar, and our results show that the slope is ten-fold lower for the relationship of sugar with caliber than for fat content.

The positive increasing linear trend in oleic acid and stability with kernel size is a very interesting point, which has not been reported to date. In fact, differences among varieties were previously reported [16,17]. In addition, these researchers highlighted the influence of environmental conditions from either the yearly climate or geographical origin. However, no reports could be found relating fatty acid composition to kernel size. This is a very useful tool, because it enables the improvement of the final stability or monounsaturated fatty acid content through calibration.

Finally, these results demonstrate that hazelnut grading, considering both cultivars, ‘Negret and “Pauetet”, and nut size, can help to improve the total commercial value of the harvest, because the industry can benefit from different industrial properties.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/agriculture11111115/s1, Table S1: In-shell fruit physical traits according to nut caliber; Table S2: In-shell fruit physical traits according to hazelnut cultivar; Table S3: Kernel characteristics according to caliber; Table S4: Kernel characteristics according to hazelnut cultivar.

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