Research Article

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Influence of different parameters on the characteristics of hazelnut (var. Grada de Viseu) grown in Portugal

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Abstract: "Grada de Viseu" is an indigenous hazelnut variety from Portugal, and it is considered by the producers as the most important variety in terms of production and productivity. Therefore, the aim of this study was to assess the influence of harvest year (2017/2018/2019) and location of production (Viseu/Faia) on some physical and chemical properties of the variety "Grada de Viseu," namely biometric parameters, colour, true and bulk densities, texture parameters (hardness and friability), and chemical composition. The results showed that the fruits of the samples harvested in 2019 had higher values of height, width, and thickness. Hazelnuts from 2018 had a clearer shell, independently of the location of production, but only the samples from Faia harvested in 2018 had a clearer kernel. As for the texture, the fruits grown in Viseu harvested in 2018 had a harder shell and was more resistant to fracture, whereas the sample from 2019 had a harder kernel. In all cases, fat was the major chemical component. The sample from 2019 had a water activity greater than 0.62, meaning that its stability was not guaranteed. "Grada de Viseu" from Faia in 2018 presented a higher induction period and, therefore, was the one with the highest oxidation stability. The year of production showed to be the best predictor for almost every chemical and biometric characteristics. In general, it was possible to verify that harvesting year and geographical location influence hazelnut characteristics.

Keywords: chemical properties, Grada de Viseu, harvest year, location, physical properties

1 Introduction

European hazelnut (*Corylus avellana* L.) belongs to the *Betulaceae* family, and it is characterised for having a low tolerance to heat, humidity, and wind stress. However, it presents a high tolerance to extreme cold conditions, such as snow and winter frost [1,2]. Worldwide, hazelnut cultivation occupies more than 660,000 ha, with Turkey being the most significant producer [3]. Hazelnut is an important crop in Portugal, mainly in the north of the country, due to the more favourable edaphoclimatic conditions [4]. In Portugal, in 2018, hazelnut production was equal to 240 tons [5], being this dried fruit the one with the lowest area of production. Nevertheless, the country has good environmental conditions for its production [6]. The worldwide demand for hazelnuts has been increasing due to their health benefits and to their increasing usage by, for example, chocolate and pharmaceutical companies [7]. Hazelnuts can be consumed in nature, as a nut, or as an ingredient in many types of foods and deserts [8].

There are different hazelnut varieties, but only 30 currently represent the basis of the worldwide hazelnut production [9]. Hazelnut characteristics vary according to different factors, namely the variety, genotype, environmental conditions, and also agricultural techniques [10]. The main varieties used by the Portuguese producers are "Grada de Viseu" and Segorbe, with Grada being the most important variety in terms of production and productivity [11]. It is important to highlight that the variety "Grada de Viseu" is an indigenous variety [12,13]. There are many studies about hazelnuts' physical and chemical properties, especially about those cultivated in Turkey [14–16] and Italy [17–20]. However, the studies about the hazelnut physio-

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chemical properties cultivated in Portugal are still limited. Therefore, the aim of this study was to evaluate the physical and chemical properties of hazelnut variety "Grada de Viseu" cultivated in Portugal, as well as to compare the properties of that variety through different harvesting years and production locations.

2 Materials and methods

2.1 Hazelnut samples

To perform this study, only one hazelnut variety, "Grada de Viseu," was harvested in different years and collected from different producers, from different geographic origins, Viseu (Municipality of Viseu in the centre of Portugal), and Faia (Municipality of Sernancelhe situated in the interior north of the country; Figure 1), according to Table 1. The criteria used to obtain the samples were availability by the producer, industrial and commercial importance and location of the orchard, as well as the representativeness of production. The hazelnuts harvested at the appropriate stage of maturity, during 2017–2019, were being used for each year/variety/produced sets of 1 kg of hazelnut fruits. Subsequently, the hazelnuts were stored at 5°C until the experiments began.

Table 1: Location of the different samples used in the study

Year	Location	Producer*	Sample name
2017	Viseu	P1	GV-Viseu-17
	Faia	P2	GV-Faia-17
2018	Viseu	P1	GV-Viseu-18
	Faia	P2	GV-Faia-18
2019	Viseu	P1	GV-Viseu-19

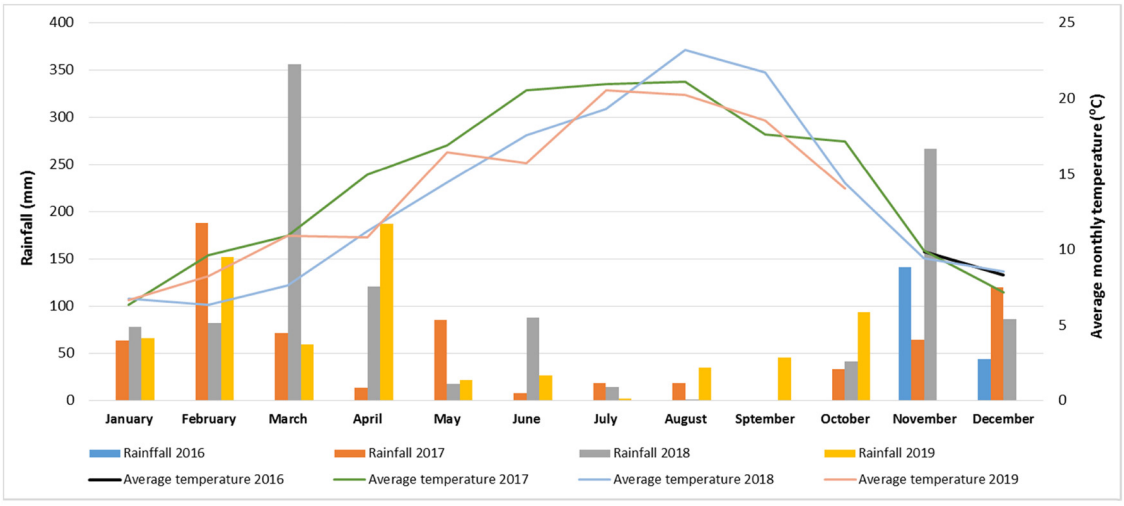
*For confidentiality reasons, the names of the producers are not provided.

The meteorological conditions that occurred in the three agricultural years in which the fruit analyses were carried out are shown in Figure 2. The meteorological variables were obtained from the information made available by the Agriculture and Fisheries Departments of the Centre and North of Portugal.

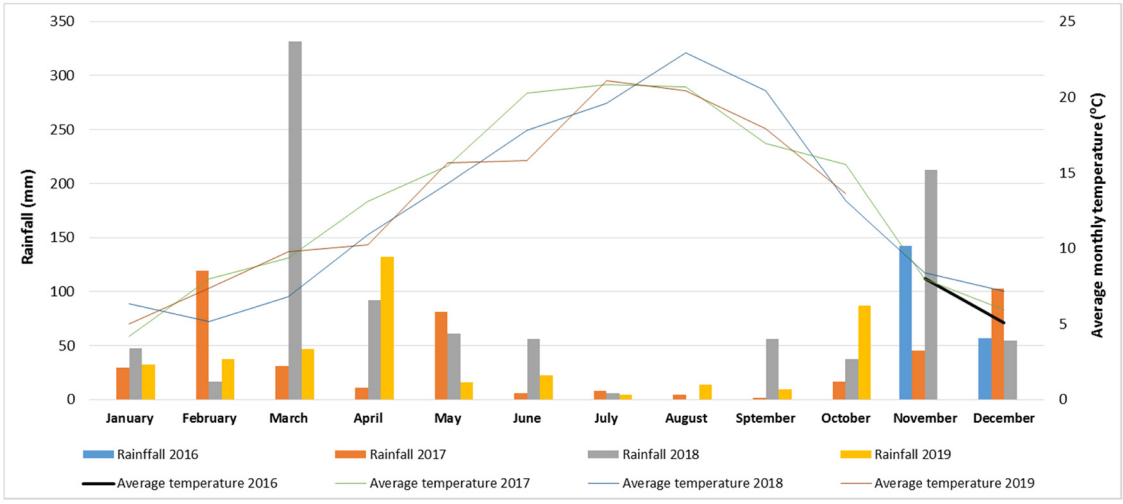
2.2 Colour evaluation

The colour was assessed by the Cartesian coordinates CIE L^*, a^*, and b^* using a colorimeter Konica Minolta CR-400. The L^* coordinate represents the lightness, varying from 0 (black) to 100 (white). The a^* and b^* represent chromaticity coordinates ranging from −60 to +60. The

Figure 1: Geographic origins of the samples used in the study.



(a)



(b)

Figure 2: Average monthly temperature (°C) and rainfall (mm) in the three agricultural years for (a) Viseu, Centre of Portugal and (b) Sernancelhe, North of Portugal.

coordinate a^* goes from red ($+a$) to green ($-a$), whereas the coordinate b^* varies from yellow ($+b$) to blue ($-b$) [8,21,22]. All colour measurements were made on different parts of the fruits, namely two on the brown shell, two on the hilum, two on the skin, and also two on the inner kernel. For that purpose, 30 randomly selected hazelnuts from each sample were used.

2.3 Analysis of texture

A texturometer TA.XT.Plus (Stable Micro Systems, Godalming, Surrey UK) was used to measure the texture parameters (shell crushing and kernel cutting) of 30 hazelnuts fruits from each sample. Moreover, it was used a 500 N load cell in both tests. The compression test, used for shell crushing, was performed using a flat P75 probe (diameter of 75 mm) that compressed the sample against the base of the texturometer. In all cases (pre-test, test, and post-test), the speeds were equal to 1.0 mm/s, the distance was 6 mm, and the trigger force considered was 0.2 N. Based on this test, it was possible to obtain a curve of force (N) versus distance (mm), which allowed calculating the value of the force that corresponded to the crushing of the shell, known as hardness.

A probe Blade Set HDP/BS (Warner-Bratzler) was used to perform the test of kernel cutting. The trigger force was 0.15 N and the distance was 30 mm. The pre-test and test speeds were 1.0 mm/s, and the post-test

speed was 10.0 mm/s. The obtained curve of force vs distance allowed calculating the hardness (the force at first peak) and friability (the distance of first peak).

2.4 Density evaluation

Both the true and apparent (or bulk) densities were assessed according to the procedure described by Guiné et al. [8]. In order to determine the bulk density, two samples of 100 g of hazelnuts (one with shell and one without shell) were weighted. Then, they were placed in two separate beakers, one with a capacity of 500 mL to determine the bulk density of whole hazelnut and the other with a capacity of 250 mL for the hazelnut kernels. The bulk density was calculated as the ratio between the mass of the sample and the volume measured. The true density was measured by placing 250 mL of water in two 500 mL beakers. Then, 100 g of shelled hazelnuts was added to one of the beakers, and 100 g of hazelnuts without the shell was added to the other. In both cases, the initial and the final volumes were registered. The true density was calculated as the mass divided by the differences observed in the volume. All the measurements were performed in triplicate for each sample.

2.5 Biometric evaluation

A sample of 50 hazelnuts of each variety was analysed on different biometric parameters: width (wider equatorial zone), height (distance between centres), and thickness (narrow equatorial zone perpendicular to the latter). These parameters were evaluated for the whole fruits and also for the corresponding kernels [23]. For that purpose, a calliper rule with a precision scale was used. The shape and compression ratios were calculated according to the following equations [22]:

$$\text{Shape ratio} = \frac{\text{Width} + \text{Thickness}}{2 \times \text{Height}}, \quad (1)$$

$$\text{Compression ratio} = \frac{\text{Width}}{\text{Thickness}}. \quad (2)$$

Kernel percentage was calculated according to Ozturk et al. [24]:

$$\text{Kernel percentage (\%)} = \frac{\text{Kernel weight}}{\text{Nut weight}} \times 100. \quad (3)$$

2.6 Chemical analyses

For the chemical analysis, only the kernels were used, and the experimental procedures were done after each sample was milled and homogenised. The moisture, ash, fibre, protein (%$N \times 5.30$), and fat contents were determined using standard methods of the Association of Official Analytical Chemist [25]. Moreover, the water activity (a_w) was determined at a constant temperature using a Hygroscope Rotronic. The Rancimat test for oils and fats was used to evaluate the oxidation stability of the hazelnuts' fat, and it was performed with a Rancimat equipment model 743, Metrohm from Herisau/Switzerland. All analyses were done in triplicate.

2.7 Statistical analysis

Results were analysed using the Statistical Software for Social Sciences (SPSS) software from IBM Inc. (version 25), and for all tests, a 5% level of significance ($p < 0.05$) was considered. All of the data were reported as the mean value and standard deviation of a set of replication measurements. The data collected were subjected to one-way analysis of variance (ANOVA), and in order to identify which means are significantly different from the others, the *post hoc* test Tukey honestly significant difference was used. In order to analyse the relative importance of the variables year and local of production on the hazelnuts' chemical and biometric properties, a tree classification was performed using the Classification and Regression Trees algorithm with cross-validation, and the minimum number of cases considered for parent or child nodes was 5 and 3, respectively [26,27]. This statistical method is used to determine the influence of one or more descriptive variables on the dependent variable [28].

3 Results and discussion

3.1 Physical properties

3.1.1 Biometric characteristics

The weight of the shelled hazelnuts and the kernels are shown in Table 2. The sample GV-Viseu-18 presented the heaviest shelled fruits (4.05 ± 0.66 g) on average, whereas

Table 2: Weight of the hazelnut fruits and kernels (mean ± standard deviation)

Sample	Fruit weight[1] (g)	Kernel weight[1] (g)	Kernel percentage (%)
GV-Viseu-17	2.81 ± 0.57^{a}	1.18 ± 0.40^{a}	39.41 ± 7.33^{ab}
GV-Faia-17	3.41 ± 0.54^{b}	1.37 ± 0.40^{b}	42.00 ± 5.92^{ab}
GV-Viseu-18	4.05 ± 0.66^{c}	1.58 ± 0.28^{cd}	43.17 ± 17.03^{ab}
GV-Faia-18	3.46 ± 0.60^{b}	1.44 ± 0.25^{bc}	39.04 ± 9.57^{a}
GV-Viseu-19	3.82 ± 0.65^{c}	1.70 ± 0.31^{d}	44.62 ± 3.73^{b}
p-value	<0.0005	<0.0005	0.021

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

GV-Viseu-17 showed the lightest hazelnuts (2.81 ± 0.57 g). Considering the kernels, GV-Viseu-19 was the sample with the heaviest fruits (1.70 ± 0.31 g), whereas GV-Viseu-17 (1.18 ± 0.40 g) showed the lightest kernels.

It was observed that the differences encountered between the samples were statistically significant ($p < 0.0005$). These differences report on harvest years and also geographical locations. The fruits from the sample GV-Viseu-17 were much smaller than the fruits harvested in 2018 and 2019 in the same location. This tendency was also observed for the kernels. With respect to location, differences were noticed, namely the fruits of the year 2017 were smaller in Viseu than in Faia (2.81 ± 0.57 and 3.41 ± 0.54 g, respectively). However, in 2018, the fruits from Faia were smaller than in Viseu (3.46 ± 0.60 and 4.05 ± 0.66 g, respectively). The same tendency was observed for the kernels.

In food industry, kernel percentage is one of the most important parameters for nut processing [23,29]. Kernel percentage ranged from 39.04 ± 9.57% (sample GV-Faia-18) to 44.62 ± 3.73% (sample GV-Viseu-19). The only statistically significant differences encountered were between the samples GV-Faia-18 and GV-Viseu-19. In the study performed by Correia et al. [23], a lower kernel percentage for the variety Grada de Viseu (37.5 ± 12.1%) was found. This difference may be explained by the fact that the samples are from different harvesting years and also from different location of production. Weather conditions, especially temperature and rainfall, affect the fruit production and, consequently, the hazelnut characteristics [1]. Comparing the average temperatures in Viseu and Faia, for the three agriculture years analysed (Figure 2), it was observed that the average annual temperature was higher in Viseu than in Faia. Moreover, in Viseu, the average monthly precipitation was higher in 2018 compared to the other years, predominantly in March, June, and November. For Faia, the average monthly precipitation was also higher in 2018, especially in March, September, and November. According to Cabo et al. [1], these differences in temperature and also precipitation may have an influence in blossom, pollination, and fruit setting.

Table 3 shows that the hazelnuts of GV-Viseu-19 had higher height, width, and thickness. As for the shape ratio, GV-Viseu-17 has presented the highest value (0.94 ± 0.18), whereas GV-Faia-17 has shown the lowest shape ratio (0.85 ± 0.13), which means that the fruits from GV-Viseu-17 were less elongated. In all the cases, the compression ratio values were higher than 1; the GV-Viseu samples harvested in the years of 2017 and 2018 were the ones with the highest compression ratio (1.15 ± 0.19 and 1.15 ± 0.15, respectively). When the values of compression ratio are close to 1, it means that those fruits are more rounded in the equatorial zone. However, a higher compression ratio corresponds to more asymmetric fruits [22]. The ANOVA test results showed that the differences encountered between the varieties for the shape ratio were statistically significant ($p < 0.0005$) but not for compression ratio ($p = 0.334$).

Table 3: Biometric measures of the kernels (mean ± standard deviation)

Sample	Height[1] (cm)	Width[1] (cm)	Thickness[1] (cm)	Shape ratio[1]	Compression ratio[1]
GV-Viseu-17	1.34 ± 0.38^{a}	1.33 ± 0.42^{a}	1.19 ± 0.42^{a}	0.94 ± 0.18^{ab}	1.15 ± 0.19^{a}
GV-Faia-17	1.53 ± 0.35^{bc}	1.36 ± 0.37^{a}	1.25 ± 0.34^{a}	0.85 ± 0.13^{a}	1.09 ± 0.12^{a}
GV-Viseu-18	1.52 ± 0.10^{bc}	1.41 ± 0.17^{a}	1.24 ± 0.16^{a}	0.88 ± 0.11^{b}	1.15 ± 0.15^{a}
GV-Faia-18	1.44 ± 0.10^{ab}	1.37 ± 0.16^{a}	1.22 ± 0.17^{a}	0.90 ± 0.10^{ab}	1.13 ± 0.14^{a}
GV-Viseu-19	1.65 ± 0.11^{c}	1.60 ± 0.12^{b}	1.42 ± 0.15^{b}	0.92 ± 0.09^{ab}	1.13 ± 0.12^{a}
p-value	<0.0005	<0.0005	<0.0005	0.007	0.334

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

When the results were analysed according to the year of harvest, it was observed that, as with the exception of the compression ratio, statistically significant differences were found among the samples. The hazelnuts from Viseu harvested in 2017 were smaller than the fruits harvested in 2018 and 2019. This difference may be explained by the fact that in the agriculture year of 2016/2017 the average annual temperature was higher and also rained less than in the following years, as shown in Table 2. In the case of the fruits from Faia, it was observed that the hazelnuts harvested in 2017 had a higher height, but a smaller width than those harvested in 2018. As for the thickness, the hazelnuts from Viseu harvested in 2019 were statistically different from the other samples.

Considering the geographical location, significant differences were also encountered, specifically for the year of 2017, in which the fruits were different in terms of height, depending on the location (Viseu or Faia). According to Figure 2, climatic conditions of the two places in study were different, and for that reason, fruits are different. These results are in accordance with an earlier research, where it was found that the morphological characteristics and quality of a cultivar is dependent on the genotype and also the environment conditions [30].

3.1.2 Density

Table 4 shows the mean values of the bulk and true densities with and without the shell. In general, the values of the fruits without the shell were higher than those with the shell, with the exception of GV-Viseu-19 for real density. In all the cases, the true density was higher than the bulk density, both for shelled and unshelled hazelnuts. These results are in accordance with those obtained in the study performed by Guiné et al. [8]. Moreover, the results of the ANOVA test showed that there were statistically significant differences between the values of densities among the samples under study ($p < 0.05$). According to the year of harvest, it was found that the true and bulk densities without shell were higher for the samples of 2019; these samples were statistically different from the samples of other years. In Viseu, agriculture year of 2018/2019 was characterised by a higher average annual rainfall (86.6 mm) when compared to the other years. Considering the variability according to location, no significant differences were found, in general, in the densities of fruits from Viseu or Faia in 2017, and a similar observation can be made for the year of 2018, whose fruits had similar densities in Viseu and Faia.

3.1.3 Colour

Tables 5–8 show the colour coordinates for the shell, the hilum, the skin, and the kernel of the hazelnuts studied, respectively. Regarding lightness of the shell (L^* value), the samples of 2018 showed to be lighter when compared to the samples of the other years. As for the values of a^* on the shell, it was observed that the sample with higher value was GV-Viseu-17 (20.33 ± 2.04), meaning that those fruits showed a more intense red tone, which corresponds to a stronger brown coloration of the shell. In this case, the samples with the lowest values were the ones harvested in 2018. The yellowness of the shell (b^*) was higher for the sample GV-Viseu-19 (22.61 ± 3.78). Furthermore, the differences between the samples were statistically different ($p < 0.0005$) for the three colour coordinates of the shell. Regarding the year of harvest, for the coordinate L^*, there were significant differences between the samples GV-Viseu harvested in 2018 and the ones harvested in 2017 and 2019. The same trend was observed for the samples from Faia. As for the a^* coordinate, there were significant differences for the samples from Viseu harvested in different years but not for the samples from Faia. Additionally, no significant differences

Table 4: Hazelnuts' density (mean ± standard deviation)

Sample	True density (g/mL)		Bulk density (g/mL)	
	With shell[1]	Without shell[1]	With shell[1]	Without shell[1]
GV-Viseu-17	0.86 ± 0.02^{a}	0.94 ± 0.02^{ab}	0.44 ± 0.01^{c}	0.49 ± 0.01^{b}
GV-Faia-17	0.85 ± 0.02^{a}	0.93 ± 0.02^{a}	0.44 ± 0.03^{c}	0.47 ± 0.02^{b}
GV-Viseu-18	0.86 ± 0.05^{a}	0.96 ± 0.03^{ab}	0.42 ± 0.02^{bc}	0.49 ± 0.01^{b}
GV-Faia-18	0.92 ± 006^{a}	1.07 ± 0.04^{b}	0.39 ± 0.00^{ab}	0.50 ± 0.01^{b}
GV-Viseu-19	1.39 ± 0.05^{b}	1.35 ± 0.09^{c}	0.35 ± 0.01^{a}	0.42 ± 0.01^{a}
p-value	<0.0005	<0.0005	<0.0005	<0.0005

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

Table 5: Colour coordinates in the shell (mean ± standard deviation)

Sample	L^{*1}	a^{*1}	b^{*1}
GV-Viseu-17	43.58 ± 2.32^{b}	20.33 ± 2.04^{c}	27.50 ± 3.78^{bc}
GV-Faia-17	42.49 ± 1.80^{b}	20.08 ± 3.93^{b}	23.74 ± 3.63^{a}
GV-Viseu-18	44.63 ± 1.51^{a}	16.65 ± 2.59^{a}	20.66 ± 2.65^{c}
GV-Faia-18	44.38 ± 2.64^{a}	17.07 ± 3.09^{b}	23.73 ± 4.42^{c}
GV-Viseu-19	42.56 ± 3.05^{b}	19.11 ± 2.49^{b}	22.61 ± 3.78^{ab}
p-value	<0.0005	<0.0005	<0.0005

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

Table 6: Colour coordinates in the hilum (mean ± standard deviation)

Sample	L^{*1}	a^{*1}	b^{*1}
GV-Viseu-17	54.24 ± 3.74^{d}	9.69 ± 1.46^{c}	22.89 ± 1.88^{ab}
GV-Faia-17	52.35 ± 3.66^{c}	10.98 ± 1.50^{a}	24.03 ± 1.51^{c}
GV-Viseu-18	48.09 ± 4.03^{a}	10.41 ± 1.43^{bc}	22.13 ± 1.81^{a}
GV-Faia-18	47.69 ± 3.93^{a}	10.28 ± 1.15^{ab}	22.47 ± 2.19^{ab}
GV-Viseu-19	49.79 ± 2.97^{b}	10.60 ± 1.35^{bc}	23.02 ± 1.71^{b}
p-value	<0.0005	<0.0005	<0.0005

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

Table 7: Colour coordinates in the skin (mean ± standard deviation)

Sample	L^{*1}	a^{*1}	b^{*1}
GV-Viseu-17	43.47 ± 4.32^{a}	19.82 ± 2.46^{d}	24.19 ± 3.06^{a}
GV-Faia-17	46.64 ± 5.83^{b}	18.14 ± 1.74^{bc}	25.47 ± 2.95^{b}
GV-Viseu-18	42.40 ± 3.78^{a}	17.52 ± 1.79^{b}	23.74 ± 2.43^{a}
GV-Faia-18	43.93 ± 4.16^{a}	18.88 ± 1.75^{c}	25.81 ± 2.56^{b}
GV-Viseu-19	43.75 ± 4.08^{a}	15.56 ± 1.33^{a}	23.65 ± 2.17^{a}
p-value	<0.0005	<0.0005	<0.0005

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

were found for the samples from Viseu in relation to b^*. Analysing the location where the fruits were cultivated, no significant differences were found for L^*, but differences were found for a^* and b^*. For the a^* coordinate, it was found that for the samples of 2017, the fruits from Viseu had a higher value than those from Faia, but in 2018, the situation was the reverse. As for b^*, significant differences were found only for the samples of 2017; GV-Viseu-17 presented a higher value of b^* when compared to the samples from Faia (GV-Faia-17), as shown in Table 5.

Table 8: Colour coordinates in the kernel (mean ± standard deviation)

Sample	L^{*1}	a^{*1}	b^{*1}
GV-Viseu-17	78.94 ± 2.25^{c}	1.95 ± 0.62^{b}	22.73 ± 2.20^{a}
GV-Faia-17	76.98 ± 2.86^{b}	2.25 ± 0.73^{bc}	24.25 ± 2.44^{b}
GV-Viseu-18	78.20 ± 4.60^{bc}	1.50 ± 0.77^{a}	27.49 ± 2.76^{c}
GV-Faia-18	79.26 ± 3.25^{c}	1.86 ± 0.76^{ab}	27.95 ± 3.10^{c}
GV-Viseu-19	72.35 ± 4.27^{a}	2.45 ± 0.94^{c}	25.24 ± 2.28^{b}
p-value	<0.0005	<0.0005	<0.0005

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

The hilum showed higher values for the coordinates L^* and b^* when compared to the rest of the shell but showed lower values of a^* (Table 6), which means that the hilum is lighter and more yellow but less red than the rest of the shell. The sample with the highest value of L^* was GV-Viseu-17, the sample with the highest value of a^* was GV-Viseu-19, and the sample with the highest value of b^* was GV-Faia-17. In all three cases the differences between samples were statistically significant ($p < 0.0005$). Some differences were identified also according to year of harvest or geographical location of production.

As for the skin (Table 7), L^* varied between 42.40 ± 3.78 (GV-Viseu-18) and 46.64 ± 5.83 (GV-Faia-17), a^* varied between 15.56 ± 1.33 (GV-Viseu-18) and 19.82 ± 2.46 (GV-Viseu-17), and b^* varied between 23.65 ± 2.17 (GV-Viseu-19) and 25.81 ± 2.56 (GV-Faia-18). Again, there were statistically significant differences between the samples for the three coordinates. Furthermore, some significant differences were found according to the year, specifically in coordinate L^* in the samples from Faia, also in the coordinate a^* in the samples GV-Viseu in years 2017–2019. Moreover, the place of harvest also showed significant differences among the samples. For the year of 2017, there were statistically significant differences between the samples from Viseu and Faia for all the coordinates. In the year of 2018, the differences encountered between the samples from Viseu and Faia only existed for the coordinates a^* and b^*.

The experimental values of the colour coordinates for the hazelnut kernels are given in Table 8, and as it can be observed, the values of the coordinates L^* and a^* of the kernel are quite different from the colour of the shell and the skin (Tables 5 and 7, respectively), with L^* values much higher (ranging from 72.35 ± 4.27 to 79.26 ± 3.25, respectively, for the samples GV-Viseu-19 and GV-Faia-18) and values of the coordinate a^* very close to zero. These results indicate that the kernels are brighter and

also that the red colour is practically absent in the kernel, when compared to the colour of other hazelnut parts. As for the coordinate b^*, the values were positive for all samples, meaning that the yellow colour is present in the kernels. Similar results were obtained in an earlier study [22]. Moreover, the results in Table 8 revealed significant differences among the samples studied. When the results are seen by the year of harvesting, it was observed that for the coordinate L^*, the samples GV-Viseu in the years 2017 and 2018 were not significantly different from each other, but they were significantly different from the GV-Viseu-19 sample. There were also significant differences in the GV-Faia samples harvested in 2017 and 2018. Regarding the coordinate a^*, significant differences were found in the GV-Viseu samples harvested in different years (2017–2019). As for the coordinate b^*, significant differences were also found for the GV-Faia samples harvested in 2017 and 2018. Analysing the location where the fruits were produced, there were significant differences for the coordinates L^* and b^* but only for the fruits harvested in Viseu or Faia in the year 2017.

3.1.4 Texture characteristics

Texture evaluation plays a major role in food analysis as food texture can greatly influence consumer acceptance [31]. In this study, two textural parameters were evaluated, namely hardness and friability. Hardness is defined as the force that is necessary to cause the crashing of a product [32], which in the case of hazelnuts is related to the force required to break the shell or the kernel. This parameter is very important because it guarantees the physical integrity of the product [32]. However, friability evaluates the tendency for the fracture to occur in the products [33,34].

As it can be observed in Table 9, the sample with the harder shell was GV-Viseu-18 (494.24 ± 80.08 N), and GV-Faia-19 was the one with the harder kernel (68.15 ± 15.23 N). The results obtained are similar to those obtained in the study by Lopes et al. [22], where it was found that the hardness of the shell of the variety "Grada de Viseu" was approximately 379 N. Furthermore, significant differences were found between the varieties regarding the hardness of the shell ($p < 0.0005$); the sample GV-Viseu-18 was statistically different from the other samples.

As for the friability of the kernel (Table 8), GV-Faia-18 presented the lowest value and, therefore, can be fractured more easily (5.01 ± 2.75 mm), whereas the sample GV-Viseu-18 was less susceptible to fracture (8.75 ± 5.62 mm). Again there were statistically significant differences among the samples under study ($p < 0.0005$).

According to the year of harvest, there were significant differences among the samples from Viseu, regarding the hardness of the shell and the friability of the kernel. When the results were analysed according to the location where the fruits were produced, there were statistically significant differences between the samples of 2018 from Viseu and Faia, regarding the hardness of the shell and the friability of the kernel.

3.2 Chemical properties

The results obtained for the chemical analyses of the samples under study are presented in Table 10. As it can be seen, the moisture of the samples analysed varied between 4.72 ± 0.09% (GV-Viseu-17) and 7.18 ± 0.38% (GV-Viseu-19), meaning that only the sample GV-Viseu-19 had values higher than the limit mentioned. According to the results obtained in the study performed by Silva et al. (2003), in the natural state, hazelnut moisture content ranges between 4 and 6%. ANOVA test results showed that there were significant differences among the samples ($p < 0.0005$), with GV-Viseu-19 being different from all the other samples. The differences found

Table 9: Hazelnuts' textural properties (mean ± standard deviation)

Sample	Hardness of the shell[1] (N)	Hardness of the kernel[1] (N)	Friability of the kernel[1] (mm)
GV-Viseu-17	361.00 ± 76.9^{a}	58.51 ± 13.60^{a}	7.95 ± 2.77^{b}
GV-Faia-17	397.35 ± 82.80^{a}	62.45 ± 11.31^{a}	7.05 ± 2.57^{ab}
GV-Viseu-18	494.24 ± 80.08^{b}	67.38 ± 22.93^{a}	8.75 ± 5.62^{b}
GV-Faia-18	398.92 ± 99.49^{a}	67.03 ± 18.98^{a}	5.01 ± 2.75^{a}
GV-Viseu-19	389.91 ± 94.31^{a}	68.15 ± 15.23^{a}	5.15 ± 1.45^{a}
p-value	<0.0005	0.135	<0.0005

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

Table 10: Hazelnuts' chemical properties (determined on the kernel)

Sample	Moisture[1] (g/100 g)	Water activity[1]	Fat[1] (g/100 g)	Ash[1] (g/100 g)	Fibre[1] (g/100 g)	Protein[1] (g/100 g)	Induction period (h)[1]
GV-Viseu-17	4.72 ± 0.09^{a}	0.62 ± 0.01^{a}	65.39 ± 0.36^{b}	2.52 ± 0.14^{a}	8.40 ± 0.17^{b}	14.15 ± 0.25^{b}	22.45 ± 2.04^{a}
GV-Faia-17	5.53 ± 0.09^{b}	0.58 ± 0.05^{a}	65.72 ± 0.14^{b}	2.57 ± 0.13^{a}	8.51 ± 0.17^{b}	12.30 ± 0.12^{a}	19.54 ± 0.80^{a}
GV-Viseu-18	5.17 ± 0.19^{ab}	0.57 ± 0.00^{a}	75.62 ± 2.91^{c}	2.92 ± 0.14^{b}	6.58 ± 0.50^{a}	15.10 ± 0.41^{c}	21.58 ± 2.25^{a}
GV-Faia-18	5.28 ± 0.05^{b}	0.61 ± 0.01^{a}	63.14 ± 0.17^{b}	2.64 ± 0.03^{ab}	7.32 ± 0.42^{ab}	12.35 ± 0.35^{a}	28.51 ± 2.74^{b}
GV-Viseu-19	7.18 ± 0.38^{c}	0.73 ± 0.01^{b}	42.73 ± 1.42^{a}	2.41 ± 0.13^{a}	9.82 ± 0.71^{c}	16.30 ± 0.38^{d}	23.76 ± 2.16^{ab}
p-value	<0.0005	<0.0005	<0.0005	0.005	<0.0005	<0.0005	0.004

[1]Mean values in the same column with the same letter are not statistically different ($p > 0.05$).

for the year of 2019 can be explained by the fact that in that year the rainfall was higher in the months when the fruits are harvested and dried, September and October, when compared to the similar months of previous years (Figure 2).

The a_w values varied between 0.57 (GV-Viseu-18) and 0.73 ± 0.01 (GV-Viseu-19). According to Guiné [35], the limit for fungal activity corresponds to a value of a_w equal to 0.62. In the evaluated samples, the a_w of GV-Viseu-19 passed that upper limit, and therefore, it was more susceptible to microbial or mould deterioration. Again, this can be justified by the precipitation in that year, especially in September and October. These results are not in accordance with those obtained by Lopes et al. [22], in which it was found that the variety "Grada de Viseu" had an a_w equal to 0.47 ± 0.01.

In an earlier study by Oliveira et al. [36], it was observed that fat is the major chemical component present in hazelnuts, which was also observed in the present study. Again, there were significant differences in the fat content among the samples under study ($p < 0.0005$); more specifically, there were significant differences between the samples from Viseu according to the year of harvest and also between the samples from Viseu and Faia in the year of 2018.

Ash content varied between 2.52 ± 0.14 g/100 g and 2.92 ± 0.14 g/100 g, respectively, for the samples, GV-Viseu-17 and GV-Viseu-18. In the study of Oliveira et al. [36], higher values of ash content ranging from 4.2 to 5.2 g/100 g were found. Fibre content was highest for the sample GV-Viseu-19 (10.58 ± 0.77 g/100 g) and lowest for sample GV-Viseu-18 (6.58 ± 0.50 g/100 g). Protein ranged from 12.30 ± 0.12 g/100 g (GV-Faia-17) to 17.56 ± 0.40 g/100 g (GV-Viseu-19). Ramalhosa et al. [37] reported that hazelnuts' protein content varies between 10 and 20%, meaning that the values obtained in the present study are in accordance with the values mentioned. In all the cases, ANOVA test results showed significant differences among the samples.

The oxidation stability of oils and fats is an important parameter in the food industry because it accesses the quality of oils and fats [38]. The Rancimat method is commonly used to evaluate the oxidation stability under heating conditions, and it measures the induction time. Moreover, a longer induction time corresponds to a higher oxidation stability [39,40]. The induction time varied between 19.54 ± 0.80 h for the sample GV-Faia-17 and 28.51 ± 2.74 h for the sample GV-Faia-18, meaning that the fruits of GV-Faia-18 showed a higher oxidation stability (Table 9).

Table 11: Classification tree for chemical properties

Variable	First level		Second level	
	Predictor	Groups	Predictor	Groups
Moisture	Year of production	G1: 2017, 2018	Producer	G1: Viseu G2: Faia
		G2: 2019	(Terminal)	—
Ash	Year of production	G1: 2018	Producer	G1: Viseu G2: Faia
		G2: 2017, 2019	Year of production	G1: 2017 G2: 2019
Fat	Year of production	G1: 2017, 2018	Producer	G1: Viseu G2: Faia
		G2: 2019	(Terminal)	—
Fibre	Year of production	G1: 2018	Producer	G1: Viseu G2: Faia
		G2: 2017, 2019	Year of production	G1: 2017 G2: 2019
Protein	Producer	G1: Viseu	Year of production	G1: 2017, 2018 G2: 2019
		G2: Faia	Year of production	G1: 2018 G2: 2017
Water activity	Year of production	G1: 2017, 2018	(Terminal)	—
		G2: 2019	(Terminal)	—

When the results were analysed according to harvest year or place of production, it was found that, in some cases, there were also significant differences in the chemical properties depending on the year or the place of cultivation. These results are consistent with the results of an earlier research; it was found that the nutritional and chemical composition of hazelnut is affected by factors such as cultivar, ecology, irrigation, soil, cultivation method, climate, and harvest year [41].

3.3 Classification of predicting factors affecting hazelnuts' chemical and biometric properties

The relative importance of the factors year and location on the chemical and biometric properties of hazelnuts was evaluated through classification of trees, and the results are shown in Tables 11 and 12, respectively. As it can be observed in Table 11, the best predictor for almost every hazelnuts' chemical properties was the year of production, just with the exception of protein content, for which the best predictor was the producer. In the case of moisture, fat, and a_w, the best predictor was the year of production that differentiated the years of production of 2017 and 2018 from the year 2019. In the case of the groups from the years 2017 and 2018, for the variables moisture and fat, the next predictor was the producer. For a_w, the differentiation did not continue for the next level. As for the variables ash and fibre contents, the best predictor was also the year of production, but in this case, the differentiation was between 2018 (G1) and 2017, 2019 (G2). For protein, the best predictor was the producer, which was differentiating the locations Viseu and Faia, and in both cases, the next predictor was the year of production.

The result in Table 12 shows that, again, the year of production was the better predictor for almost every variable, with the exception of the variable kernel weight. For the variables fruit weight, kernel weight, kernel width, and kernel thickness, the year of production was differentiating 2017 and 2018 from the year 2019, and the next predictor for both groups was the producer (G1: Viseu

Table 12: Classification tree for biometric characteristics

Variable	First level		Second level	
	Predictor	Groups	Predictor	Groups
Fruit weight	Year of production	G1: 2017	Producer	G1: Viseu G2: Faia
		G2: 2018, 2019	Producer	G1: Viseu G2: Faia
Kernel weight	Producer	G1: Viseu	Year of production	G1: 2017 G2: 2018, 2019
		G2: Faia	Year of production	G1: 2018 G2: 2017
Kernel height	Year of production	G1: 2017	Producer	G1: Viseu G2: Faia
		G2: 2018, 2019	Producer	G1: Viseu G2: Faia
Kernel width	Year of production	G1: 2017	Producer	G1: Viseu G2: Faia
		G2: 2018, 2019	Producer	G1: Viseu G2: Faia
Kernel thickness	Year of production	G1: 2017	Producer	G1: Viseu G2: Faia
		G2: 2018, 2019	Producer	G1: Viseu G2: Faia
Shape ratio	Year of production	G1: 2017, 2018	Year of production	G1: 2018 G2: 2017
		G2: 2019	(Terminal)	—
Compression ratio	Year of production	G1: 2017, 2018	Year of production	G1: 2018 G2: 2017
		G2: 2019	(Terminal)	—

and G2: Faia). In the case of the variables shape and compression ratios, the year of production was differentiating the years 2017 and 2018 from the year of 2019. The next predictor was the year of production, but only for the group G1 (2017, 2018). For the variable kernel weight, the best predictor was the producer, that was differentiating the locations of Viseu and Faia, and the next predictor, for both cases, was the year of production.

4 Conclusion

This study provided results that allowed to compare the differences between the hazelnut variety "Grada de Viseu" according to the year of harvest and place of cultivation. The results showed that, in general, there were statistically significant differences among the varieties under study. Climate conditions in the three agriculture years studied and also between Faia and Viseu locations were different, which can explain some of the differences encountered. In Viseu in 2016/2017 there was a higher average annual temperature and a lower average annual precipitation, which originated smaller fruits than those harvested in the other years. According to the location, the fruits from Faia harvested in 2017 had a higher height when compared to the fruits from Viseu.

The hazelnuts' samples of 2018 revealed a lighter shell, independently of the location, whereas the sample GV-Faia-18 had the lightest kernel. For all the samples, the hilum was lighter and yellower when compared to the rest of the shell. Regarding texture, GV-Viseu-18 had a harder shell and was more resistant to fracture. However, GV-Viseu-19 had a harder kernel. As for the chemical properties, fat was the major component for all varieties, followed by protein and fibre. The sample GV-Viseu-19 had values of moisture and a_w above the recommended limits, meaning that this sample was more susceptible to fungal activity. This can possibly be attributed to the fact that in 2019 it rained more in September and October when compared to the similar months of the two previous agricultural years. The sample with the highest induction period was GV-Viseu-18, revealing higher oxidation stability.

It is important to highlight that for almost every chemical and biometric parameter, the best predictor was the year of production, which means that the differences encountered between the samples are more justified by this factor.

The results of this study allowed to corroborate some findings of earlier studies, where it was described that the properties of hazelnut are dependent on the harvest year and also the geographical location, among other factors. These findings are important for all Portuguese producers in the hazelnut sector.

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References

[1] Cabo S, Morais MC, Aires A, Carvalho R, Pascual-Seva N, Silva AP, et al. Kaolin and seaweed-based extracts can be used as middle and long-term strategy to mitigate negative effects of climate change in physiological performance of hazelnut tree. J Agron Crop Sci. 2020;206:28–42. doi: 10.1111/jac.12369.

[2] Karaosmanoglu H, Ustun NS. Fatty acids, tocopherol and phenolic contents of organic and conventional grown hazelnuts. J Agric Sci Technol. 2021;23:167–77.

[3] Silvestri C, Bacchetta L, Bellincontro A, Cristofori V. Advances in cultivar choice, hazelnut orchard management, and nut storage to enhance product quality and safety: an overview. J Sci Food Agric. 2021;101:27–43. doi: 10.1002/jsfa.10557.

[4] Martins S, Simões F, Mendonça D, Matos J, Silva AP, Carnide V. Western European wild and landraces hazelnuts evaluated by SSR markers. Plant Mol Biol Rep. 2015;33:1712–20. doi: 10.1007/s11105-015-0867-9.

[5] Instituto Nacional de Estatística. Estatísticas agrícolas: 2018. Lisboa: INE; 2019.
[6] Cabo S, Aires A, Carvalho R, Pascual-Seva N, Silva AP, Gonçalves B. Corylus avellana L. Husks an underutilised waste but a valuable source of polyphenols. Waste Biomass Valor. 2020;101:459–75. doi: 10.1007/s12649-020-01246-4.
[7] Taghavi T, Dale A, Kelly JM, Galic D, Rahemi A. Performance of hazelnut cultivars and selections in southern Ontario. Can J Plant Sci. 2020;100:537–48. doi: 10.1139/cjps-2019-0161.
[8] Guiné R, Rodrigues C, Correia P, Ramalhosa E. Evaluation of some physical and chemical properties of hazelnuts. FABE 2019: Food and Biosystems Engineering Conference; 2019.
[9] Mehlenbacher SA. Genetic resources for hazelnut: state of the art and future perspectives. Acta Horticul. 2009;845:33–8.
[10] Król K, Gantner M. Morphological traits and chemical composition of hazelnut from different geographical origins: a review. Agriculture. 2020;10:375. doi: 10.3390/agriculture10090375.
[11] Ferrão AC, Guiné R, Rodrigues M, Droga R, Correia P. Post-harvest characterisation of the hazelnut sector. Rev Mill. 2020;2(ed espec nº6):11–20. doi: 10.29352/mill0206e.01.00344.
[12] Correia PMR, da Costa CA, Teixeira D, Gaião D, Correia HE, Rodrigues P. Aveleira: estado da produção. CNCFS; 2017.
[13] Silva AP, Santos FA, Santos AS, Sousa V, Lopes A, Mota BS, et al. Variedades de Aveleira. Vol. 162, Projecto AGRO; 2004.
[14] Köksal Aİ, Artik N, Şimşek A, Güneş N. Nutrient composition of hazelnut (Corylus avellana L.) varieties cultivated in Turkey. Food Chem. 2006;99:509–15. doi: 10.1016/j.foodchem.2005.08.013.
[15] Pelvan E, Olgun EÖ, Karadağ A, Alasalvar C. Phenolic profiles and antioxidant activity of Turkish Tombul hazelnut samples (natural, roasted, and roasted hazelnut skin). Food Chem. 2018;244:102–8. doi: 10.1016/j.foodchem.2017.10.011.
[16] Taş NG, Gökmen V. Phenolic compounds in natural and roasted nuts and their skins: a brief review. Curr OpFood Sci. 2017;14:103–9. doi: 10.1016/j.cofs.2017.03.001.
[17] Cristofori V, Bertazza G, Bignami C. Changes in kernel chemical composition during nut development of three Italian hazelnut cultivars. Fruits. 2015;70:311–22. doi: 10.1051/fruits/2015025.
[18] Ghirardello D, Contessa C, Valentini N, Zeppa G, Rolle L, Gerbi V, et al. Effect of storage conditions on chemical and physical characteristics of hazelnut (Corylus avellana L.). Postharvest Biology and Technology. 2013;81:37–43. doi: 10.1016/J.POSTHARVBIO.2013.02.014.
[19] Lucchetti S, Ambra R, Pastore G. Effects of peeling and/or toasting on the presence of tocopherols and phenolic compounds in four Italian hazelnut cultivars. Eur Food Res Technol. 2018;244:1057–64. doi: 10.1007/s00217-017-3028-6.
[20] Oddone M, Aceto M, Baldizzone M, Musso D, Osella D. Authentication and Traceability Study of Hazelnuts from Piedmont, Italy. J Agric Food Chem. 2009;57:3404–8. doi: 10.1021/jf900312p.
[21] Gómez-Polo C, Muñoz MP, Lorenzo Luengo MC, Vicente P, Galindo P, Martín Casado AM. Comparison of the CIELab and CIEDE2000 color difference formulas. J Prosthet Dent. 2016;115:65–70. doi: 10.1016/j.prosdent.2015.07.001.
[22] Lopes A, Matos A, Guiné R. Evaluation of morphological and physical characteristics of hazelnut varieties. Millenium – J Educ Technol Health. 2016;2(1):13–24. doi: 10.29352/mill0201.01.00035.
[23] Correia P, Rodrigues C, Filipe A, Guiné R. Evaluation of biometric characteristics of hazelnuts. FABE 2019: food and biosystems engineering conference; 2019.
[24] Ozturk SC, Ozturk SE, Celik I, Stampar F, Veberic R, Doganlar S, et al. Molecular genetic diversity and association mapping of nut and kernel traits in Slovenian hazelnut (Corylus avellana) germplasm. Tree Genet Genomes. 2017;13:16. doi: 10.1007/s11295-016-1098-4.
[25] AOAC. Official methods of analysis of AOAC international. Rockville, Maryland, USA: Association of Official Analytical Chemists; 2019.
[26] Guiné R, Correia P, Fernandes S, Ramalhosa E. Consumption of nuts and similar dried foods in portugal and level of knowledge about their chemical composition and health effects. J Nuts. 2021;12:171–200. doi: 10.22034/jon.2021.1928049.1112.
[27] Macena M, Carvalho R, Cruz-Lopes LP, Guiné RPF. Plastic food packaging: perceptions and attitudes of Portuguese consumers about environmental impact and recycling. Sustainability. 2021;13:9953. doi: 10.3390/su13179953.
[28] Strzelecka A, Zawadzka D. Application of classification and regression tree (CRT) analysis to identify the agricultural households at risk of financial exclusion. Proc Comput Sci. 2021;192:4532–41. doi: 10.1016/j.procs.2021.09.231.
[29] Petriccione M, Ciarmiello LF, Boccacci P, De Luca A, Piccirillo P. Evaluation of 'Tonda di Giffoni' hazelnut (Corylus avellana L.) clones. Sci Horticul. 2010;124:153–8. doi: 10.1016/j.scienta.2009.12.019.
[30] Silvanini A, Dall'Asta C, Morrone L, Cirlini M, Beghè D, Fabbri A, et al. Altitude effects on fruit morphology and flour composition of two chestnut cultivars. Sci Horticul. 2014;176:311–8. doi: 10.1016/j.scienta.2014.07.008.
[31] Chen J, Rosenthal A. 1 – Food texture and structure. In: Chen J, Rosenthal A, editors. Modifying food texture. Woodhead Publishing; 2015. p. 3–24. doi: 10.1016/B978-1-78242-333-1.00001-2.
[32] Guiné RPF, Almeida CFF, Correia PMR, Mendes M. Modelling the influence of origin, packing and storage on water activity, colour and texture of almonds, hazelnuts and walnuts using artificial neural networks. Food Bioprocess Technol. 2015;8:1113–25. doi: 10.1007/s11947-015-1474-3.
[33] Almeida C. Efeitos das condições de conservação nas características de frutos secos. Portugal: Escola Superior Agrária de Viseu; 2013.
[34] Gharibzahedi SMT, Mousavi SM, Hamedi M, Khodaiyan F. Comparative analysis of new Persian walnut cultivars: nut/kernel geometrical, gravimetrical, frictional and mechanical attributes and kernel chemical composition. Sci Horticul. 2012;135:202–9. doi: 10.1016/j.scienta.2011.11.030.
[35] Guiné R. Unit operations for the food industry: thermal processing & nonconventional technologies. Germany: LAP Lambert Academic Publishing GmbH & Co; 2013.
[36] Oliveira I, Sousa A, Morais JS, Ferreira IC, Bento A, Estevinho L, et al. Chemical composition, and antioxidant and antimicrobial activities of three hazelnut (Corylus avellana L.) cultivars. Food Chem Toxicol. 2008;46:1801–7. doi: 10.1016/j.fct.2008.01.026.

[37] Ramalhosa E, Delgado T, Estevinho L, Pereira JA. Chapter 73 – Hazelnut (Corylus avellana L.) cultivars and antimicrobial activity. In: Preedy VR, Watson RR, Patel VB, editors. Nuts and seeds in health and disease prevention. San Diego: Academic Press; 2011. p. 627–36. doi: 10.1016/B978-0-12-375688-6.10073-8.

[38] Ciemniewska-Żytkiewicz H, Ratusz K, Bryś J, Reder M, Koczoń P. Determination of the oxidative stability of hazelnut oils by PDSC and Rancimat methods. J Therm Anal Calorim. 2014;118:875–81. doi: 10.1007/s10973-014-3861-9.

[39] Casal S, Malheiro R, Sendas A, Oliveira BPP, Pereira JA. Olive oil stability under deep-frying conditions. Food Chem Toxicol. 2010;48:2972–9. doi: 10.1016/j.fct.2010.07.036.

[40] Ouarouer Y. Determination of kinetic parameters using Rancimat analysis. Bragança: Instituto Politécnico de Bragança; 2017.

[41] Rezaei F, Bakhshi D, Fotouhi Ghazvini R, Javadi D, Pourghayoumi M. Evaluation of fatty acid content and nutritional properties of selected native and imported hazelnut (Corylus avellana L.) varieties grown in Iran. J Appl Botany Food Qual. 2014;87:104–7. doi: 10.5073/JABFQ.2014.087.016.