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AVALIAÇÃO DE CARACTERÍSTICAS MORFOLÓGICAS E FÍSICAS DE VARIEDADES DE AVELÃ

EVALUATION OF MORPHOLOGICAL AND PHYSICAL CHARACTERISTICS OF HAZELNUT VARIETIES

EVALUACIÓN DE CARACTERÍSTICAS MORFOLÓGICAS Y FÍSICAS DE VARIEDADES DE AVELLANAS

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RESUMO

Introdução: As avelãs são culturas importantes em Portugal, cujos os frutos podem ser usados para consumo direto ou introduzidos numa gama alargada de alimentos.

Objetivos: Neste estudo foram avaliadas 15 variedades de aveleira existentes numa coleção na Estação Agrária de Viseu.

Métodos: As avelãs foram estudadas no que respeita a características morfológicas, como peso do fruto, peso do miolo, índices de forma e de compressão e espessura da casca. O estudo foi complementado com análises de propriedades físicas como a cor e a textura, e ainda com a determinação da humidade e da atividade da água, uma vez que estes últimos parâmetros assumem bastante importância na capacidade de conservação dos frutos. Todas as determinações seguiram métodos estandardizados, tendo ainda sido usados os seguintes equipamentos: texturómetro, colorímetro e higrómetro.

Resultados: Os resultados obtidos permitiram conhecer os intervalos espectáveis para cada um dos parâmetros cromáticos na casca, película e miolo: L*, a*, b* croma e tonalidade, havendo entre as cultivares em estudo diferenças estatisticamente significativas. No que respeita aos parâmetros de textura avaliados pelos testes de britagem da casta e corte do miolo (dureza, fraturabilidade e resiliência) verificaram-se também diferenças significativas. A avaliação da humidade revestiu-se de grande importância pois permitiu confirmar que a secagem solar, utilizada para extrair o excesso de humidade dos frutos, foi suficiente para que estes atingissem valores compatíveis com uma boa conservabilidade (entre 1,66% e 4,52%).

Conclusões: Este trabalho permitiu identificar as carateristicas de algumas variedades de avelã no que respeita às suas propriedades morfológicas e físicas.

Palavras-chave: *Corylus avellana* L.; dimensões; cor; textura; humidade.

ABSTRACT

Introduction: Hazelnut are an important crop in Portugal, wich fruits can be used for direct consumption or introduced in a large range of food products.

Objectives: In this study 15 hazelnut varieties existing in a collection of Viseu Agricultural Station were evaluated.

Methods: The nuts were studied in respect of their morphological characteristics, such as fruit and kernel weight, index of compression and of shape and shell thickness. The study was complemented with analysis of physical properties such as colour and texture, and the determination of moisture content and water activity, given the importance that these parameters take in the conservation capacity of the fruits. All experiments followed standard methods, being also used the following equipment: texturometer, colorimeter and hygrometer.

Results: The results obtained allowed to know the expectable ranges for each color parameters in the shell, film and kernels: L*, a*, b* chroma and hue, having been found statistically significant differences among the cultivars studied. As regards the textural parameters evaluated by crust crushing and crumb cutting tests (hardness, friability and resilience) there were also significant differences. Evaluation of moisture was of great importance because confirmed that the solar drying, used to extract the excess of moisture from the fruits, was sufficient to reach low values, between 1.66% and 4.52%, being so a guarantee of preservation.

Conclusions: This work allowed identifying the characteristics of several hazelnut varieties concerning the morphological and physical properties.

Keywords: *Corylus avellan*a L.; dimensions, color; texture; moisture.

RESUMEN

Introducción: Las avellanas son una cultura importante en Portugal, que se puede utilisar para el consumo directo o introduzido en una amplia gama de alimentos

Objetivos: Este estudio incluyó 15 variedades de avellana existentes en una colección en la Estación Agraria de Viseu.

Métodos: Las avellanas se estudiaron con respecto a las características morfológicas, tales como el peso del fruto, peso del grano, forma y índice de compresión y la grosor de la cáscara. El estudio se completó con el análisis de las propiedades físicas tales como el color y la textura, y con la determinación de la actividad de la agua y la humedad, ya que los últimos parámetros asumen gran importancia en la capacidade de conservación de la fruta. Todas las determinaciones siguieron métodos estándar, todavía hay sido utilizado el siguiente equipo: texturometro, colorímetro y el higrómetro.

Resultados: Los resultados obtenidos permitieron conocer los rangos esperables para cada uno de los parámetros de color de la cáscara, el cine y lo grano: L*, a *, b* croma y tonalidad, existiendo entre los cultivares estudiados diferencias estadísticamente significativas. En cuanto a los parámetros de textura evaluados por pruebas de trituración de la cáscara e corte del grano (dureza, friabilidad y resistencia) también hubo diferencias significativas. La evaluación de humedad es de gran importancia, ya que se confirmó que el secado solar, utilizado para extraer el exceso de humedad de los frutos, fue suficiente para que se alcanzaron valores compatibles con una buena conservación (entre 1,66% y 4,52 %).

Conclusiones: Las avellanas son una cultura importante en Portugal, que se puede utilizar para el consumo directo o introduzido en uma ampla gama de alimentos.

Palabras clave: *Corylus avellana* L.; tamaño; color; textura; humedad.

INTRODUCTION

The hazelnut is the fruit of the hazel tree (*Corylus avellana* L.), a shrub of the family Betulaceae that grows naturally in most European countries, Asia Minor and part of North America. This species is well adapted to different climatic conditions, but prefers cool areas and moderate altitudes (Ekinci *et al.*, 2014).

Besides its use for direct consumption, the hazelnut crumb is widely used in bakery and confectionery. The toasted hazelnuts are used in snacks and also used as ingredients in many products such as cookies, ice cream, breakfast cereals, spreadable creams or chocolates (Caligiani *et al.*, 2014).

The nutritional and nutraceutical properties of hazelnut are widely documented, taking this fruit an important role in nutrition and human health due to its composition. It is rich in monounsaturated fatty acids, proteins, carbohydrates, fibre, vitamins (A, C and E), minerals (such as magnesium), phytosterols and phenolic antioxidants (Oliveira *et al*., 2008; Guiné *et al.*, 2015b). The antioxidant activity of the phenolic compounds is based on their ability to scavenge free radicals, and thus plays a crucial role in preventing certain diseases such as cancer, atherosclerosis or diabetes (Guiné *et al.*, 2015a).

The quality of food is a concept that has unquestionable interest to industries and consumers, hence the concern to preserve the products in appropriate conditions, avoiding physical and chemical changes that endanger the integrity. The quality of hazelnuts is evaluated according to the chemical and nutritional properties, but also depends on the appearance aspects, such as absence of broken cores and presentation of a clear and uniform colour. Other types of problems may be associated with pests or diseases (Delprete & Sesana, 2014).

According to Ghirardello *et al*. (2013) storage conditions influence the quality hazelnut, therefore, it is a concern for both the food industry and the consumer. However, the final quality of these fruits is influenced by a number of other factors, such as the appearance, texture, flavour, chemical composition, nutritional value, and other food safety issues.

The aim of this work was to study 15 cultivars of hazelnut, with respect to morphology and physical properties like colour and texture, which are of great importance in terms of quality, and also the determination of moisture and water activity , by the importance that the latter parameters take on the fruits conservation capacity.

1. METHODS

The plantation from where the samples were collected was installed in March 1989, in Agricultural Station of Viseu (Estação Agrária de Viseu- DRABL), and comprises a total of 270 plants of 15 varieties (Butler, Dawton, Ennis, Fertile of Coutard, Gentle of Viterbo, Gironela, Grada of Viseu, Grosse of Spain, Gunslebert, Empress Eugénie, Merveille de Bollwiller, Negreta, Provence, Segorbe and Tonda of Giffoni). Each variety is represented by 18 trees, 6 in each of the three repetitions, with a plant spacing of 5 m x 3 m.

The fruits were harvested in 2013 and the weight was measured for each variety in 50 whole fruits and respective core in a precision scale (±0,0002 g). The shell thickness was measured with calipers on 20 fruits.

The shape and compression ratios were calculated from measurements of the height (distance between centres), width (wider equatorial zone) and depth (narrow equatorial zone perpendicular to the latter) in 50 fruits. The rates were calculated by equations (Yao & Mehlenbacher, 2001):

$$\text{(1)} \qquad Shape\ ratio = \frac{(Width + Depth)}{2\ x\ Height}$$

(2) $$Compression\ ratio = \frac{Width}{Depth}$$

The moisture content was determined by drying at 105 ºC to constant weight and the water activity by a hygrometer BT-RS1 (Rotronic) at 25ºC.

The colour was measured immediately after harvest on 25 fruits, with a colorimeter Konica Minolta CR-400 which evaluates the Cartesian coordinates CIE L*, a* e b *. The L* is the lightness, which is light reflected by the fruit and ranges from 0 to 100, corresponding respectively to black and white. The a* and b* are chromaticity coordinates, which vary between -60 e +60, the first going from green to red and the second from blue to yellow. These coordinates allow the calculation of the cylindrical coordinates Hue angle (ºH) and chroma (C), according to the equations:

(3) $$C = \sqrt{(a\,*)^2 + (b\,*)^2}$$

(4) $$ºH = tan^{-1}\left(\frac{b*}{a*}\right)$$

The coordinate ºH assumes the values 0º (red), 90º (yellow), 180º (green) and 270º (blue). The chroma defines the purity or intensity of colour, and takes a value between zero (washed out) and 60 (vivid colour) (Guiné & Barroca, 2012).

For determining the texture properties was used a texturometer TA.XT.Plus (Stable Micro Systems) and 25 repetitions were made. For evaluation of the crushing strength was used the compression test with a flat probe P/75 and for the cutting force of the core, was used a cutting test with a probe Warner-Bratzler (Blade Set HDP/BS). The obtained graphs were used to determine the textural properties: hardness, friability and resilience, according to the illustrated in Figure 1.

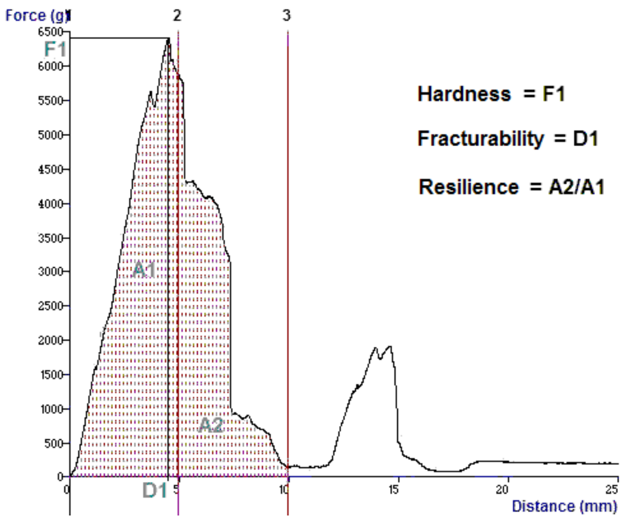

Figure 1. Example of a texture analysis - cutting test of the kernels.

The results were subjected to a one factor analysis of variance (ANOVA) to compare the means between the different cultivars. ANOVA is used in order to assess whether the sample differences are real or casual. In cases where statistically significant differences were detected, Tukey's test for multiple comparisons was used to verify which samples were different. Statistical analysis was performed using SPSS (IBM, Inc.) version 23, and was considered a 5% significance level for all tests.

2. RESULTS AND DISCUSSION

Table 1 shows the values obtained from the measurements of weight of the fruits with shell, the kernel and also the thickness of the shell. The fruits of the variety Ennis are heavier on average (4.42 ± 0.42 mm) and also with greater kernel weight (1.79±0.27 mm) being the fruits of the variety Empress those who, on average, are lighter, both in shell as only considering the kernel (1.72±0.28 mm e 0.86±0.19 mm, respectively), and that the differences encountered are statistically significant (p = 0.000). Among the lighter varieties still appear the varieties Negreta and Dowton. As regards the thickness of the shell, the fruits of the variety Dawton have a thinner skin (0.93±0.07 mm) being those who presented the thicker shell those of the variety Provence (1.54±0.21 mm) and again the differences are significant (p = 0.000). Also with a thick skin appear the fruits of the variety Fertile.

Table 1 – Fruit weight, kernel weight and thickness of the shell (mean ± standard deviation, n = 50 for the weights and 20 to the thickness).

Variety	Fruit weight[1] (g)	Kernel weight[1] (g)	Shell thickness[1] (mm)
Butler	3.68±0.41^{bc}	1.65±0.26^{ab}	1.38±0.24^{abc}
Dawton	1.84±0.26^{g}	0.98±0.20^{f}	0.93±0.07^{e}
Empress	1.72±0.28^{g}	0.86±0.19^{f}	1.05±0.14^{de}
Ennis	4.42±0.42^{a}	1.79±0.27^{a}	1.35±0.17^{abc}
Fertile	3.63±0.40^{c}	1.48±0.22^{c}	1.52±0.19^{a}
Gentil	2.49±0.42^{ef}	0.98±0.17^{f}	1.47±0.25^{ab}
Gironela	2.33±0.35^{f}	0.98±0.21^{f}	1.29±0.20^{bc}
Grada	3.67±0.45^{c}	1.47±0.23^{cd}	1.45±0.19^{ab}
Grosse	3.65±0.51^{c}	1.46±0.25^{cd}	1.45±0.23^{ab}
Gunslebert	3.01±0.56^{d}	1.31±0.37^{de}	1.20±0.14^{cd}
Merveille	3.97±0.53^{b}	1.40±0.21^{cd}	1.37±0.17^{abc}
Negreta	1.94±0.27^{g}	0.96±0.14^{f}	1.07±0.14^{de}
Provence	3.60±0.48	1.50±0.28^{bc}	1.54±0.21^{a}
Segorbe	2.76±0.28^{de}	1.21±0.12^{e}	1.39±0.15^{abc}
Tonda	3.16±0.48^{c}	1.39±0.26^{cd}	1.45±0.27^{ab}

[1]Values in the same column with the same letter are not statistically different, p < 0.05.

Table 2 shows the values for the height, width, and depth, as well as the shape and compression ratios. As regards the height, this varies from 17.58±0.89 mm and 24.97±0.89 mm, respectively for the varieties Gentil and Ennis, with significant differences between the varieties (p = 0.000). The width has values between 14.73±0.64 mm and 22.84±0.93 mm, found for the varieties of hazelnuts Dawton and Ennis, respectively, and the differences are statistically significant (p = 0.000). The depth of the fruit also shows significant differences between the varieties (p = 0.000) assuming values between 13.17±0.56 mm (var. Dawton) and 21.67±1.03 mm (var. Ennis). It is observed that the variety with lower value for width is also has that with lower depth, corresponding to small fruits (var. Dawton) and contrarily the variety Ennis has larger fruits (greater width, greater height and greater depth). Moreover, these results are consistent with the previously observed relative to the weight of the fruit kernels and, since the variety Ennis presented the highest values of these measures.

Table 2 – Height, width, depth, shape ratio and compression ratio (mean ± standard deviation, n = 50).

Variety	Hight[1] (mm)	Width[1] (mm)	Depth[1] (mm)	Shape ratio[1]	Compression ratio[1]
Butler	21.93±1.08^{d}	20.72±1.12^{c}	18.56±0.89^{de}	0.90±0.05^{e}	1.12±0.05^{cd}
Dawton	22.61±1.15^{cd}	**14.73±0.64^{g}**	**13.17±0.56^{i}**	**0.62±0.03^{g}**	1.12±0.05^{c}
Empress	19.39±0.95^{e}	16.27±0.91^{f}	14.47±0.79^{h}	0.79±0.04^{f}	1.12±0.04^{bc}
Ennis	**24.97±0.89^{a}**	**22.84±0.93^{a}**	**21.67±1.03^{a}**	0.89±0.04^{e}	**1.05±0.03^{f}**
Fertile	20.72±1.00^{d}	22.12±0.94^{b}	19.44±1.03^{b}	1.00±0.04^{ab}	1.14±0.06^{bc}
Gentil	**17.58±0.89^{f}**	19.27±0.87^{d}	16.39±0.78^{g}	1.02±0.06^{a}	**1.18±0.04^{a}**
Gironela	17.75±0.96^{f}	17.94±0.99^{e}	15.89±0.77^{g}	0.96±0.06^{d}	1.13±0.05^{bc}
Grada	20.87±0.90^{d}	22.01±0.90^{b}	19.68±0.91^{b}	1.00±0.04^{abc}	1.12±0.0^{bc}
Grosse	20.37±0.75^{d}	22.19±1.18^{ab}	19.29±0.81^{bc}	**1.02±0.05^{a}**	1.15±0.04^{ab}
Gunslebert	24.21±0.89^{b}	19.60±1.08^{d}	18.05±0.74^{e}	0.78±0.04^{f}	1.09±0.05^{de}
Merveille	22.62±1.23^{c}	22.56±1.30^{ab}	21.27±1.29^{a}	0.97±0.04^{cd}	1.06±0.03^{ef}
Negreta	19.48±0.94^{e}	16.80±0.70^{f}	14.77±0.62^{h}	0.81±0.05^{f}	1.14±0.04^{bc}
Provence	20.33±1.14^{d}	20.91±1.08^{c}	18.70±0.96^{cd}	0.98±0.04^{bcd}	1.12±0.04^{c}
Segorbe	18.86±1.00^{e}	19.37±0.99^{d}	17.19±0.84^{f}	0.97±0.05^{cd}	1.13±0.05^{bc}
Tonda	19.48±1.37^{e}	20.81±1.05^{c}	18.29±0.89^{de}	1.01±0.05^{ab}	1.14±0.05^{bc}

[1]Values in the same column with the same letter are not statistically different, $p < 0.05$.

As for the shape and compression ratios (Table 2), varieties with lower shape ratio, which correspond to longer hazelnuts, are Dawton, Gunslebert and Empress (<0.8), while the varieties Fertile, Gentil, Grada, Grosse and Tonda have the highest values of the shape ratio (≥1). The values of compression ratio close to 1, shown by Ennis and Merveille varieties (with values 1.05±0.03 and 1.06±0.03, respectively) indicate that these fruits are more rounded in the equatorial zone. In contrast, the variety Gentil has the highest compression ratio, indicating that these are more asymmetric hazelnuts (1.18±0.04). In the case of both ratios, shape and compression, statistically significant differences were observed between the varieties under study (p = 0.000 in both cases).

The moisture content of the fruits is one of the parameters that most influence their conservation capacity, and 6% is the maximum limit recommended by the EU for international trade of peeled hazelnuts (Silva *et al* 2005). The percentage of moisture present in all varieties studied, is less than the limit values (Table 3), which gives a good indication of the storage capacity of these fruits. Still, there are varieties with much lower moisture concentration than the recommended limit, such as the variety Dawton (1.66±0.43%) compared to Gunslebert variety, which has the largest value (4.52±0.94%), being the differences between varieties statistically significant (p = 0.000).

Table 3 – Moisture and water activity (mean ± standard deviation, n = 10 and 5, respectively).

Variety	Moisture[1] (%)	Water activity[1,2]
Butler	2.42±0.56^{de}	0.52±0.01^{ab}
Dawton	**1.66±0.43^{e}**	n.d.
Empress	1.85±0.73^{e}	n.d.
Ennis	4.40±0.61^{ab}	0.52±0.01^{a}
Fertile	3.71±0.61^{abc}	n.d.
Gentil	1.77±0.48^{e}	n.d.
Gironela	1.81±0.38^{e}	n.d.
Grada	3.68±0.75^{abc}	0.47±0.01^{c}
Grosse	3.67±1.04^{abc}	n.d.
Gunslebert	**4.52±0.94^{a}**	n.d.
Merveille	3.59±0.81^{abc}	n.d.
Negreta	1.92±0.62^{e}	0.51±0.01^{b}
Provence	3.19±0.37^{cd}	n.d.
Segorbe	3.32±0.40^{cd}	n.d.
Tonda	3.52±0.50^{bc}	0.47±0.00^{c}

[1]Values in the same column with the same letter are not statistically different, $p < 0.05$.

[2]n.d. = not determined

The water activity (a_w) in a food is the fraction of water which is in the free form and hence available for reactions from microbial, enzymatic or chemical nature. The a_w is thus one of the best ways to predict and control food deterioration. The development of microorganisms is strictly linked to this parameter, so that to less than 0.62, mentioned as the limit for fungal activity, ceases all microbial activity (Guiné, 2011). In the present study it was not possible to determine the a_w for all samples studied, but those in which this has been reported, it appears that all have values that ensure stability in terms of prevention of microbial growth, since the largest recorded value is 0.52 (for var. Butler and Ennis). The Grada and Tonda varieties have an even lower value (0.47), which is statistically different from the others ($p = 0.000$).

In Tables 4, 5 and 6 are presented, respectively, the chromatic parameters for the shell, the film and the kernel of the fruits studied. The values of L* for the shell vary significantly ($p = 0.000$) 42.58±1.57 (ver. Dawton) and 51.07±1.91 (var. Empress), situated at approximately the middle of the scale, indicating that they are only slightly darker (Table 4). The chromatic coordinates a* and b* are positive in all cases, with higher values indicating a prevalence of the red colour with yellow, resulting in a brown hue as expected for hazelnut shells. While the a* varied between 14.74±2.01 (var. Gentil) and 21.96±1.89 (var. Merveille) the b* varied in the range from 19.82±4.25 (var. Fertile) to 29.93±2.24 (var. Ennis), being the encountered differences statistically significant ($p = 0.000$ in both cases). The chroma values range from 25.95±5.21 and 35.66±2.30, corresponding to a strong colour purity, being registered for the varieties with correspondingly lower and higher intensity of yellow (b*). The hue angle varies from 48.25±1.60º (var. Negreta) to 58.73 ± 2.44º (var. Empress), corresponding to a red colour. In both cases the differences are significant ($p = 0.000$).

Table 4 – Chromatic parameters in the shell: L*, a*, b*, chroma and hue (mean ± standard deviation, n=25).

Variety	Cartesian coordinates			Cylindrical coordinates	
	L*[1]	a*[1]	b*[1]	Croma[1]	Hue angle[1]
Butler	46.39±2.48^{cd}	20.22±1.82^{ab}	29.25±2.82^{a}	35.61±2.72^{a}	55.26±3.21^{bcd}
Dawton	**42.58±1.57^{h}**	18.86±1.85^{bcd}	21.56±2.65^{de}	28.66±3.11^{cd}	48.74±1.83^{h}
Empress	**51.07±1.91^{a}**	17.94±1.68^{cd}	29.55±2.26^{a}	34.60±2.40^{a}	**58.73±2.44^{a}**
Ennis	48.38±2.18^{b}	19.32±1.68^{bc}	**29.93±2.24^{a}**	**35.66±2.30^{a}**	57.13±2.59^{ab}
Fertile	43.66±1.57^{gh}	16.73±3.14^{d}	**19.82±4.25^{e}**	**25.95±5.21^{d}**	49.70±1.97^{gh}
Gentil	47.77±1.90^{bc}	**14.74±2.01^{e}**	22.66±3.62^{cde}	26.91±4.04^{d}	57.31±2.06^{ab}
Gironela	44.44±2.03^{efgh}	17.12±2.24^{cd}	21.63±4.35^{de}	27.62±4.67^{cd}	51.31±3.06^{efg}
Grada	42.61±1.88^{h}	17.16±3.25^{cd}	20.08±4.18^{e}	26.43±5.21^{d}	49.38±2.08^{gh}
Grosse	43.22±2.05^{gh}	17.70±2.51^{cd}	20.07±3.25^{e}	26.79±3.91^{d}	48.52±2.72^{h}
Gunslebert	45.75±1.32^{def}	17.35±1.66^{cd}	23.35±2.85^{cd}	29.10±3.18^{cd}	53.30±1.77^{de}
Merveille	44.18±1.25^{fgh}	**21.96±1.89^{a}**	27.60±2.84^{ab}	35.29±3.24^{a}	51.44±1.76^{efg}
Negreta	43.12±1.64^{h}	18.43±1.96^{bcd}	20.64±2.11^{de}	27.68±2.78^{cd}	**48.25±1.60^{h}**
Provence	45.13±2.81^{defg}	17.56±3.06^{cd}	22.05±3.13^{cde}	28.21±4.17^{cd}	51.56±2.75^{efg}
Segorbe	46.22±1.69^{cde}	18.03±2.31^{bcd}	24.98±3.15^{bc}	30.83±3.73^{bc}	54.19±2.25^{cd}
Tonda	47.79±2.68^{bc}	18.63±2.53^{bcd}	28.19±3.46^{a}	33.87±3.62^{ab}	56.46±3.99^{abc}

[1]Values in the same column with the same letter are not statistically different, $p < 0.05$.

The film shows values of the chromatic parameters very similar to the shell, with L* varying between 43.87±4.26 (var. Grosse) and 52.42±2.91 (var. Butler), a* between 14.61±1.65 (var. Gunslebert) and 18.41±1.21 (var. Butler) and b* between 23.62±2.61 (var. Gentil) and 28.64±1.85 (var. Butler) (Table 5). In all three cases the differences between varieties are statistically significant ($p = 0.000$). With regard to chroma that varies within a narrow range between 29.08±2.48 (var. Gentil) and 33.81±1.68 (var. Ennis) and the hue angle between 53.43±1.86º and 60.21±3.20º, respectively for Grada and Gentil varieties, so it is slightly brown. Also in this case the observed differences are significant ($p = 0.000$).

Table 5 – Chromatic parameters on the film: L*, a*, b*, chroma and hue (mean ± standard deviation, n=25).

Variety	Cartesian coordinates			Cylindrical coordinates	
	L*[1]	a*[1]	b*[1]	Croma[1]	Tonalidade[1]
Butler	**52.42±2.91^{a}**	17.22±1.07^{abcd}	**28.64±1.85^{a}**	33.46±1.41^{a}	59.91±2.70^{abc}
Dawton	46.47±4.45^{bcd}	**18.41±1.21^{a}**	25.85±3.63^{b}	31.83±2.93^{ab}	54.20±4.65^{ef}
Empress	51.53±3.28^{a}	17.34±1.07^{abcd}	28.55±1.16^{a}	33.42±1.04^{a}	58.73±2.02^{abc}
Ennis	49.71±2.89^{ab}	18.15±1.39^{a}	28.48±1.94^{a}	**33.81±1.68^{a}**	57.44±2.83^{bc}
Fertile	45.41±4.47^{cd}	17.96±1.06^{ab}	24.72±2.50^{bc}	30.59±2.32^{bc}	53.88±2.58^{f}
Gentil	51.54±4.87^{a}	14.37±1.36^{f}	25.23±2.60^{bc}	**29.08±2.48^{c}**	**60.21±3.20^{a}**
Gironela	49.13±4.40^{ab}	16.41±1.21^{de}	25.32±2.49^{bc}	30.21±2.22^{bc}	56.93±3.16^{cd}

Grada	44.04±4.16[d]	17.84±1.35[abc]	24.12±2.55[bc]	30.01±2.71[bc]	**53.43±1.86[f]**
Grosse	**43.87±4.26[d]**	17.35±1.47[abcd]	**23.62±2.61[c]**	29.33±2.77[c]	53.60±2.27[f]
Gunslebert	49.10±3.98[abc]	**14.61±1.65[f]**	25.23±1.66[bc]	29.20±1.76[c]	59.94±3.10[ab]
Merveille	46.91±2.76[bcd]	16.72±1.00[bcd]	25.49±1.40[bc]	30.49±1.61[bc]	56.74±1.09[cde]
Negreta	46.72±3.54[bcd]	16.54±1.11[cd]	25.58±2.45[bc]	30.50±1.89[bc]	57.00±3.05[cd]
Provence	45.09±3.98[d]	17.76±1.84[abc]	24.80±1.86[bc]	30.52±2.42[bc]	54.46±2.00[def]
Segorbe	49.89±3.00[ab]	16.38±1.20[de]	26.12±2.25[b]	30.85±2.32[bc]	57.86±2.03[abc]
Tonda	52.10±3.96[a]	15.24±1.85[ef]	25.04±1.33[bc]	29.36±1.48[c]	58.73±3.44[abc]

[1]Values in the same column with the same letter are not statistically different, $p < 0.05$.

The values in Table 6 show that the colour of the kernel is quite different from the colour of the shell and the film, with L* values much higher (between 73.48±6.08 and 80.01±3.15, respectively for var. Fertile and Gunslebert) corresponding to higher brightness, i.e., a colour more or near the white. The values of a* are very close to zero (less than 3), indicating that the red colour is practically not present, but the b* values are high (from 21.15±1.54 to 26.73±3.17, respectively for var. Grosse and Ennis), though slightly smaller than the shell and the film, which indicates the presence of yellow colour in the kernel. Moreover, this parameter dominates on the definition of the colour, since virtually the a* dos not contribute to the setting of the kernel colour. In this case the range for the chroma is lower (from 21.19±1.53 to 26.81± .16, for var. Grosse and Ennis) indicating lower colour purity. But the tone is higher, approaching more the value of 90º, corresponding to yellow (with values varying between 84.03±3.25 and 87.68±0.79, respectively for the var. Gunslebert and Gironela). For all chromatic parameters evaluated in the kernell the differences observed between the studied varieties are statistically significant (p = 0.000).

Table 6 – Chromatic parameters in the kernel: L*, a*, b*, chroma and hue (mean ± standard deviation, n=25).

Variety	Cartesian coordinates			Cylindrical coordinates	
	L*[1]	a*[1]	b*[1]	Croma[1]	Tonalidade[1]
Butler	74.29±3.54[de]	**2.69±0.87[a]**	26.11±2.14[ab]	26.26±2.18[ab]	84.16±1.63[e]
Dawton	78.62±4.32[ab]	1.62±1.12[bcd]	25.52±2.30[abc]	25.59±2.36[abc]	86.42±2.05[abc]
Empress	77.72±3.16[abcd]	2.07±0.83[abc]	26.71±3.01[a]	26.80±3.03[a]	85.61±1.61[bcde]
Ennis	74.35±4.65[de]	1.86±1.04[abcd]	26.73±3.17[a]	26.81±3.16[a]	85.92±2.19[abcde]
Fertile	**80.01±3.15[a]**	1.47±0.96[bcd]	22.28±2.29[de]	22.34±2.33[de]	86.29±2.09[abcd]
Gentil	80.00±2.53[a]	1.18±0.49[cd]	23.15±2.82[cde]	23.18±2.83[cde]	87.11±0.99[ab]
Gironela	79.53±2.01[ab]	**0.91±0.32[d]**	22.35±2.15[de]	22.37±2.15[de]	**87.68±0.79[a]**
Grada	77.18±4.49[abcd]	1.93±1.89[abc]	22.48±1.98[de]	22.62±2.20[de]	85.32±3.75[bcde]
Grosse	79.41±2.26[ab]	1.23±0.38[cd]	21.15±1.54[e]	**21.19±1.53[e]**	86.65±1.04[abc]
Gunslebert	**73.48±6.08[e]**	**2.69±1.89[a]**	25.06±3.01[abc]	25.20±3.18[abc]	**84.03±3.25[e]**
Merveille	76.21±2.62[bcde]	1.67±0.47[bcd]	23.61±2.08[cd]	23.67±2.08[cd]	85.95±1.05[abcde]
Negreta	76.17±4.13[bcde]	2.09±0.79[abc]	22.24±2.50[de]	22.35±2.52[de]	84.69±1.80[cde]
Provence	79.25±2.91[ab]	1.69±0.60[bcd]	21.96±2.70[de]	22.03±2.71[de]	85.60±1.41[bcde]
Segorbe	74.77±5.39[cde]	2.37±1.21[ab]	23.92±2.32[bcd]	24.07±2.37[bcd]	84.41±2.67[de]
Tonda	78.24±2.89[abc]	2.09±0.91[abc]	22.26±2.69[de]	22.37±2.74[de]	84.73±1.94[cde]

[1]Values in the same column with the same letter are not statistically different, $p < 0.05$.

The texture of the fruits was assessed using two tests: crushing the shell and cutting the kernel, whose results are shown in Tables 7 and 8, respectively. The first test proves very important to determine how the nuts are separated from their outer shell by breaking the latter. It provides information on the force required to produce the breaking of the shell, being associated to the needs and conditions of operation of the crushing equipment. On the other hand, the cutting test of the kernel has relevance whether the hazelnut is intended to be swallowed whole or subjected to various cutting operations to produce for example grated hazelnuts, chips or other forms intended for direct sale or for incorporation into other food products.

The Fertile variety has a harder shell (46.21±7.13 kg) also being one of the varieties with greater skin thickness, which may explain the greater force required for crushing (Table 7). The Empress and Gunslebert varieties are those which have showed a softer skin (with values close to 20 kg). As regards friability of the shell, the variety Ennis is less susceptible to fracture (being necessary to go 2.51 mm before rupture occurs) while the variety Tonda has the lowest value of the friability and therefore more easily fractures (1.69 mm only to occur break). Resilience is considerably variable between the samples analysed, ranging from 4% (var. Ennis) to 130% (var. Negreta). For the different texture properties assessed in shell statistically significant differences were found between varieties (p = 0.000 in all three cases).

Table 7 – Texture parameters in the test of crushing the shell (mean ± standard deviation, n=25).

Variety	**Hardness[1] (kg)**	**Fracturability[1] (mm)**	**Resilience[1]**
Butler	31.47±8.07^{fg}	2.03±0.44^{bcde}	0.05±0.74^{bcdef}
Dawton	22.18±4.91^{hi}	1.80±0.44^{de}	0.91±0.60^{abcde}
Empress	**20.03±3.51^{i}**	1.75±0.25^{e}	0.38±0.18^{efg}
Ennis	39.77±5.47^{bcd}	**2.51±0.28^{a}**	**0.04±0.07^{g}**
Fertile	**46.21±7.13^{a}**	2.33±0.38^{ab}	0.15±0.22^{fg}
Gentil	33.18±7.14^{efg}	1.93±0.35^{cde}	1.03±1.01^{abc}
Gironela	44.59±6.13^{ab}	2.35±0.35^{ab}	0.24±0.32^{fg}
Grada	38.63±7.39^{bcde}	2.13±0.40^{bcd}	0.55±0.66^{cdefg}
Grosse	38.30±9.56^{cde}	2.19±0.40^{abc}	0.38±0.48^{efg}
Gunslebert	20.68±4.10^{i}	1.81±0.21^{de}	1.19±0.65^{ab}
Merveille	42.20±7.24^{abc}	2.33±0.30^{ab}	0.18±0.20^{fg}
Negreta	22.88±5.43^{hi}	1.86±0.50^{cde}	**1.26±1.00^{a}**
Provence	34.84±5.59^{def}	2.16±0.32^{bc}	0.41±0.31^{defg}
Segorbe	27.69±4.35^{gh}	1.97±0.32^{cde}	0.94±0.57^{abcd}
Tonda	27.98±4.62^{gh}	**1.69±0.35^{e}**	1.24±0.54^{a}

[1]Values in the same column with the same letter are not statistically different, $p < 0.05$.

Regarding the kernel it was found that the hardness ranges between 2.70±1.70 kg (in var. Dawton) and 5.52±2.36 kg (in var. Merveille), and therefore, and as expected, values are considerably lower than those found for the hardness of the skin (Table 8). As regards friability, the range of variation is slightly wider than that of the shell, between 1.39±0.79 mm and 3.11±1.55 mm (for var. Dawton and Tonda), whereby the ability of the fruits to resist fracture is higher, i.e., they resist more before rupture occurs. This is due to the fact that the shell has a much more rigid structure, which does not absorb the strain caused by force in the same way that the kernel does, for being more deformable. Finally, and similarly to what was observed for the test of crushing the shell, resilience also showed to be very variable (from 0% to 114%). Also in this case the differences are statistically significant, with p values of 0.000 for the hardness and resilience of the crumb, and 0.001 for the case of friability.

Table 8 – Texture parameters in the test of crushing the shell (mean ± standard deviation, n=25).

Variety	Hardeness[1] (kg)	Fraturability[1] (mm)	Resilience[1]
Butler	4.76±2.64[abc]	2.38±1.32[ab]	0.23±0.19[ef]
Dawton	**2.70±1.70[c]**	**1.39±0.79[b]**	**0.17±0.28[f]**
Ennis	5.34±2.84[a]	2.48±1.29[ab]	0.65±0.46[bcd]
Fertile	4.45±2.25[abc]	1.93±0.88[ab]	0.54±0.35[cdef]
Gentil	3.29±1.95[abc]	1.83±0.97[b]	0.47±0.40[cdef]
Gironela	2.83±2.22[c]	1.63±1.08[b]	0.85±0.71[abc]
Grada	4.25±2.60[abc]	2.11±1.41[ab]	0.52±0.38[cdef]
Grosse	4.93±1.74[abc]	2.35±0.80[ab]	0.76±0.46[abcd]
Gunslebert	3.88±2.41[abc]	2.46±1.75[ab]	**1.14±0.53[a]**
Imperatriz	3.07±1.96[bc]	1.68±1.01[b]	0.30±0.29[ef]
Merveille	**5.52±2.36[a]**	**3.11±1.55[a]**	1.07±0.39[ab]
Negreta	3.54±1.52[abc]	1.93±0.84[ab]	0.29±0.34[ef]
Provence	4.50±2.35[abc]	1.91±0.95[ab]	0.58±0.34[cdef]
Segorbe	3.26±2.06[abc]	1.71±1.05[b]	0.49±0.37[cdef]
Tonda	5.05±2.12[abc]	2.07±0.86[ab]	0.39±0.33[def]

[1]Values in the same column with the same letter are not statistically different, $p < 0.05$.

CONCLUSIONS

The results obtained in this study for moisture and water activity revealed of great importance because they allowed to confirm that solar drying used to extract the excess of moisture from the fruits was enough for them to reach a moisture content compatible with good conservation during the storage.

It was also possible to characterize the samples analysed in relation to different biometric parameters evaluated, emphasizing the variety Ennis as larger, heavier and more rounded.

The results also allowed to know the expectable ranges for each colour parameters in the shell, film and the core, which may serve as a reference, since they correspond to close to the harvested, and therefore also not subject to storage or processing. The fruits have strongly brown shell and films, while the core is strongly yellow.

Finally, we evaluated the texture characteristics for the shell, which are extremely important for conservation and transportation, and also at the technological level when there is need for its crushing. While the variety Fertile has a high hardness of the shell, the Empress presents a softer shell and therefore is easier to break. The Ennis variety emerges as the most resistant to fracture in the shell, which coupled with its larger size, makes it an interesting variety. Also the kernel has been studied in relation to the texture, which is of great importance at economic level, since it can determine losses by breaking or flaking, or even at the organoleptic level, when during consumption. In this regard, it was concluded that the Dawton variety presents itself softer, making it pleasant to chew, but perhaps less resistant to stresses originating from the processing and/or transportation, offering a lesser resistance to rupture.

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