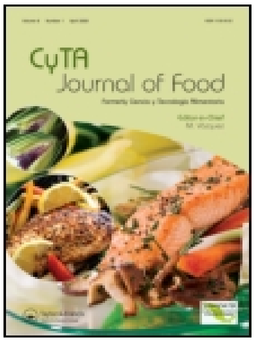

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Effects of roasting and boiling on the physical and mechanical properties of 11 Portuguese chestnut cultivars (Castanea sativa Mill.) Efectos de asado y hervido en las propiedades físicas y mecánicas de once cultivares de castaña porgueses (Castanea sativa Mill.)

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Effects of roasting and boiling on the physical and mechanical properties of 11 Portuguese chestnut cultivars (*Castanea sativa* Mill.)

Efectos de asado y hervido en las propiedades físicas y mecánicas de once cultivares de castaña porgueses (*Castanea sativa* Mill.)

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In order to characterise the changes produced by boiling and roasting on the mechanical properties of 11 Portuguese chestnut cultivars (cvs.), the moisture, mass, force and energy required as well as shell and kernel stiffness of raw, boiled and roasted chestnuts were evaluated. In comparison to raw chestnuts, boiling increased the moisture content about 4% and roasting decreased the moisture content about 20%. Lamela and Judia cvs. required more energy to rupture the shell, while Negra and Boaventura kernels offered higher resistance to penetration. Colour was also evaluated because it is a parameter that influences the consumers' choice. Thus, processed chestnuts showed lower brightness than the raw fruits. After boiling, the most attractive chestnuts with higher brightness were cvs. Judia and Lamela, and after roasting, cvs. Lada and Lamela. These results provide important information about the cultivars most suitable for processing, resistant to mechanical harvest and most attractive to consumers.

Keywords: processing; chestnuts; texture

Con el fin de caracterizar los cambios producidos por el hervido y asado en las propiedades de once cultivares de castaña portugueses (cvs.), se evaluó la humedad, masa, fuerza y enegía requeridas, así como la cáscara y dureza de a semilla de castañas crudas, hervidas y asadas. Comparado con las castañas crudas, el hervido aumentó el contenido de humedad en un 4% y el asado lo disminuyó en un 20%. Lamela y Judia cvs. neesitaron más energía para el rasgado de la cáscara, mientras los frutos de Negra y Boaventura ofrecieron una mayor resistencia a penetración. Tambien se evaluó el color, ya que es un parámetro que influye en la elección del consumidor. Así, las castañas procesadas mostraron un menor brillo que los frutos crudos. Tras el hervido, las castañas más atractivas con un mayor brillo resultaron cvs. Juadia y Lamela, y tras el asado, cvs. Lada y Lamela. Estos resltados aportan información importante sobre los cultivos más adecuados para procesado, resistente a cosecha mecánica y más atractivos al consumidor.

Palabras clave: procesamiento; castaño; textura

Introduction

Chestnut (*Castanea* sp.) is an important nut crop worldwide with a global production of approximately 1.2 million tones. China is the main producer of chestnuts, accounting around 76% of the world's total production, while Europe accounts for 12% of total production, especially in Italy and Portugal (4% and 3%, respectively). This fruit was a basic foodstuff for many local populations, and in the past, chestnuts were widely consumed raw, boiled, roasted or dehydrated until potatoes and cereals became available (Pérez González, Hernández Suárez, Díaz Romero, & Rodríguez Rodríguez, 2006).

In Portugal, there has been a significant increase in the area of sweet chestnut (*Castanea sativa* Mill) over the past 25 years, especially in the Trás-os-Montes e Alto Douro region, where about 85% of the total Portuguese chestnut production is concentrated and it is one of the few regions with a largely positive trade balance (GPP, 2007). The increase in area of chestnut orchards can be attributed to factors such as of consumers' knowledge on the nutritional qualities of this fruit and potential health benefits, the existence of programmes that encourage planting new areas, the favourable climatic, edaphic and ecological conditions of this region and the existence of excellent plant material. In order to protect the specificity and the standing of this fruit, preserve and improve the genetic material of native Portuguese cultivars and eliminate unfair competition, three Protected Designation of

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Origin (PDO) were created in the Northeast of Portugal: Terra Fria, Padrela and Soutos da Lapa. Each PDO has a distinct ecology and geographical parameters, with well-adapted native cultivars that are commercially important and a nutritionally indispensable food commodity for the populations of these regions. About approximately 80% of chestnut produced in the PDO is exported (in fresh and processed forms) mainly to European Union countries (65%) or to other countries (15%); only 20%–30% of regional production is destined for the national market. Small chestnuts (width <30 mm) are usually industrially frozen, while medium and larger fruits are consumed as a fresh product or destined for the confectionery industry (GPP, 2007). Size, shape, colour and texture are important quality attributes that affect consumers' preference and have a decisive significance for industry (Korel & Balaban, 2006).

Local populations usually know about the morphological and physical characteristics of the different cultivars and can distinguish which is most appropriate to industry or for to roasting or boiling. However, few studies had been conducted on this subject.

Chestnut shell cracking does not share the same importance of other nuts, like almond, hazelnut, walnut, macadamia, pistachio, because the shelling method using compression force is not usually applied in this fruit (Braga, Couto, Hara, & Neto, 1999; Galedar, Jafari, & Tabatabaeefar, 2008; Ozdemir, 1999). A study of this parameter can provide important information on the hardness of the shell and kernel, which influences mechanical harvesting techniques and the industrial processes.

Texture is considered as a manifestation of the rheological properties of food (Pomeranz & Meloan, 1994), is an important attribute that affects processing and handling (Charm, 1962), shelf-life and consumers' acceptance (Matz, 1962). Texture is important in order to obtain the optimal processing of food (Bourne, 2002). Colour characteristics are also important quality attributes that increase acceptability and is considered to be a highly appreciated property by consumers (Moreira, Chenlo, Chaguri, & Fernandes, 2008). Colour determination can also be used to improve the specification for the PDO which already exists.

According to several authors (Borges & Peleg, 1997; Güner, Dursun, & Dursun, 2003; Liang, Chin, & Mitchell, 1984; Navarrete & Chiralt, 1999; Oloso & Clarke, 1993), the physical quality of the kernel is highly influenced by the nut's moisture content. Aydin (2002) found that rupture force of shell and kernel of hazelnut decreased with increasing moisture content. Moreover, Güner et al. (2003) found that the rupture deformation and rupture energy increased while rupture force decreased with increasing moisture content. After harvesting, the chestnuts are subject to significant water loss, which can cause serious damage for industry and trade.

Boiled or roasted chestnuts are preferred preparations for most consumers; candied chestnuts must be light brown with texture that is neither too soft nor too hard (Korel & Balaban, 2006). According to Attanasio, Cinquanta, Albanese and Matteo (2004), foods suffer volume changes during the roasting or boiling process, due to moisture loss, gas generation or pore formation. Processing also affects texture, determined by sensorial analysis (Künsch et al., 2001), and colour attributes (Correia, Leitão, & Beirão-da-Costa, 2009; Künsch et al., 2001). The aim of this study was to characterise the changes produced by boiling and roasting on physical and mechanical properties of 11 cultivars of sweet chestnut fruits, grown in the three PDO from Northeast of Portugal. The parameters analysed in this study were moisture, unit mass, minimum force, average force, energy required to rupture the shell and to penetrate the kernel with a needle probe until 5 mm, stiffness and colour of shell and kernel.

Materials and methods

Samples

Eleven of the most important chestnut native cultivars were grown in the three PDO areas: Terra Fria, Padrela and Soutos da Lapa (Borges, Carvalho, Correia, & Silva, 2007). In 2006, three representative trees of all cultivars were selected, and three replications of mature chestnuts (1 kg of fruits per sample) from each selected tree were randomly collected and kept in a refrigerator until analyses were carried out. This lapse of time was the shortest possible because, as stated by Pérez González et al. (2006), changes in physicochemical properties may occur after 60 days of refrigerated storage.

Supplementary Table 1 summarises some key parameters that characterise the samples of each cultivar.

Traditional methods used by consumers were adopted to process the chestnuts. For the boiling process, 500 g of raw chestnuts from each cultivar, previously cross-cut on the top, were boiled for 20 min in 2 L of water and 5 g of salt. For the roasting process, 500 g of raw nuts from each cultivar, also slit with a knife, were sprinkled with 7 g of salt and then placed in a preheated electric oven with air circulation (Nabertherm Mod. – L9R), at 200°C for 40 min. The same conditions for fruits of all cultivars were used. The boiling and roasting processes were carried out in three replicates.

Physical and mechanical properties

To determine the unit mass of raw, boiled and roasted chestnuts, 15 fruits from each sample were individually weighed, and moisture content was determined by the Association of Official Analytical Chemists (AOAC) method (AOAC, 2000).

Tests on texture with a texture analyser (TA.XT Plus; Stable Micro Systems, UK) were carried out on

15 chestnuts from each cultivar and treatment, for shelled and unshelled fruits. The samples were penetrated with a needle probe (P/2N) for puncture tests. Penetration was made to a depth of 5 mm, and the maximum force (N) was measured with a 30 kg load cell, and 0.05 mm s^{-1} load cell speed, at room temperature (20°C–22°C). Each sample was placed on the analyser plate and was penetrated perpendicular to the embryonic axis. The force-deformation profile registered during the puncture test produces a function (Supplementary Figure 1) that allows the determination of the following: (i) energy (the area under the curve between the initial point and the yield point); (ii) rupture force (minimum force required to penetrate the sample) and (iii) stiffness (force needed to achieve a certain deformation of a structure). The function also calculates the average of the data values from the curve between two selected points (the beginning and end of compression). All determinations were made for shell and kernel.

Colour parameters were determined on three different zones of the surface on 25 chestnuts from each cultivar and treatment using a tristimulus colorimeter (Minolta CR-200 Chroma Meter; Minolta, Japan) having an 8-mm diameter measuring area. Chromatic analyses were carried out following the Commission International de l'Eclairage (CIE) system of 1986.

Values of L^*, a^* and b^* were measured to describe a three-dimensional colour space and interpreted as follows: L^* (luminosity) is representative of the vertical axis of a colour solid with percentage values ranging from 0 (completely opaque or black) to 100 (completely transparent or white), a^* (+ red, − green) and b^* (+ yellow, − blue) (Hutchings, 1994; Voss, 1992). The chroma (C^*) obtained as ($C^* = a^{*2} + b^{*2})^{1/2}$ is a measurement of chromaticity, which denotes the purity or saturation of the colour (Voss, 1992). The hue angle ($h° = \text{arctg}\,(b^*/a^*)$) expresses the colour nuance (red–purple: 0°, yellow: 90°, bluish-green: 180°, and blue: 270°) (McGuire, 1992).

Total colour difference (TCD) between the colour of processed chestnuts (L_f^*, a_f^*, b_f^*) and raw chestnuts (L^*, a^*, b^*) were calculated from the following formula (Commission International de l'Eclairage [CIE], 1986):

$$TCD = ((L_f^* - L^*)^2 + (a_f^* - a^*)^2 + (b_f^* - b^*)^2)^{1/2}$$

Statistical analysis

Data analyses were performed using Super ANOVA software (1.1, Abacus Concepts Inc., USA, 1991) and the Stat View 4.0 package. Mean separations were made using Duncan's test ($P < 0.05$). A Fisher correlation analysis including all the parameters was also performed.

Results and discussion

Mass and moisture content

There were significant differences on fruit mass and moisture among all the cultivars, treatments and cultivar × treatment interaction (Supplementary Table 2). Roasted chestnuts presented lower mass, due to lower moisture content, compared to boiled or raw fruits (Supplementary Table 3). The average moisture content increased 4% with boiling but decreased 20% with roasting compared to raw chestnuts.

Variation of mass and moisture of raw, boiled and roasted chestnuts of 11 cultivars (Supplementary Table 3) showed that Boaventura and Lamela chestnuts, both from PDO "Terra Fria", presented the highest mass, whereas Trigueira and Longal P had the lowest values. These results agree with previous studies from our research team (Borges, Gonçalves, Soeiro, Correia, & Silva, 2008; Borges et al., 2007; Silva et al., 2007), and it is commonly accepted and recognised in Northeast of Portugal region. Cv. Judia frequently produces the heaviest fruits, but in this study and, probably due to the atypical environmental conditions, it was classified in third place. Fruit mass decreased significantly after roasting and ranged from 6% (cv. Aveleira) to 43% (cv. Martaínha).

Moisture content of raw chestnuts varied between 42% (Trigueira – PDO "Terra Fria") and 56% (Lada – PDO "Padrela") with an average of 49% (Supplementary Table 3), lower than the mean value (51%) referred by Borges et al. (2007) for the same region and by Chenlo, Moreira, Torres and Ferra (2008) for Galicia, Spain (55%). Both Borges et al. (2007) and Ferreira-Cardoso (2007) concluded that the water content depends significantly on genetic factors, geographical origins and also soil genesis of local production. High levels of precipitation and low levels of sunlight during the maturation period negatively affected the photosynthetic process, and consequently, the fruit size and the water content of chestnuts. Indeed, raw fruits of cv. Longal found in both PDO Padrela and PDO Soutos da Lapa presented different moisture content values. Pereira-Lorenzo, Ramos-Cabrer, Díaz-Hernández, Ciordia-Ara and Ríos-Mesa (2006) found significant correlations between summer rainfall levels and fruit moisture content. Knowledge of this parameter could be useful to predict postharvest storage suitable of each cultivar, since chestnuts with high water content present lower storage suitability and are more susceptible to mould growth. Moreover, these cultivars are essential for supplying the Portuguese and international fresh markets. According to Sacchetti, Pittia, Mastrocola and Pinnavaia (2005), the limited shelf-life of many chestnuts is due to the high metabolic activity of the nuts and porous, non-lignified epicarp characteristics.

Lamela and Trigueira fruits gained more water during boiling, and Trigueira, Lada and Judia chestnuts lost more water during roasting. This fundamental information is important to industry since it allows the evaluation of water losses during processing.

Rheological properties

All the texture parameters varied significantly between cultivars, treatments and cultivar × treatment interaction (Supplementary Table 2). Supplementary Tables 4 and 5 show the variation in texture of raw, boiled and roasted chestnuts. The minimum force (F_1), the average force (Fm_1) and the energy needed (E_1) to rupture the shells of the roasted chestnuts were 20%, 21% and 52% higher than the raw ones, respectively (Supplementary Table 4). Moreover, the shells of raw chestnuts of cvs. Lada and Longal P had the lowest F_1, while cvs. Judia, Lamela and Côta had the highest value (about 1.5 times; Supplementary Table 5). Cvs. Judia and Lamela also needed the highest E_1 to rupture the shells, which differed significantly from all other cultivars. The stiffness S_1 ranged between 4.3 (cv. Longal P) and 7.6 N mm^{-1} (cv. Negra). These results provide relevant information for chestnut handling during harvest and postharvest periods, since chestnuts with softer shells require more careful handling to avoid fruit damage.

Braga et al. (1999) and Aydin (2002) found significant negative correlations between the minimum force to break the shells and the moisture content on hazelnut and macadamia fruits, respectively. Galedar et al. (2008) concluded that some physical properties of pistachio shell and kernel are a function of moisture content. Results from our study did not produce any correlation (data not shown), indicating that the moisture content values of the kernel of these cultivars were not directly dependent upon shell moisture content, similar to Braga et al.' s study (1999), where some macadamia samples presented a similar moisture content between shell and kernel, and others did not show any correlation. Other studies about the shell/kernel moisture content ratios should be carried out.

After 20 min of boiling, the shell of the cv. Judia showed the highest F_1 (5.4 N) and cvs. Trigueira and Martaínha presented the lowest (3.2 and 3.0 N, respectively). The Fm_1, E_1 and S_1 presented the same tendency (Supplementary Table 5). The correlations between F_1 and Fm_1, E_1 and S_1 of boiled chestnuts were highly significant ($P < 0.0001$) ($R^2 = 0.958$, $R^2 = 0.838$ and $R^2 = 0.845$, respectively). The shells of roasted chestnuts of cv. Lamela had the highest F_1 (5.9 N) as opposed to cvs. Trigueira (3.1 N), Longal P (3.3 N) and Longal SL (3.4 N). Results showed that the raw chestnuts of cv. Judia had the hardest shells and maintained this attribute after boiling or roasting, whereas the cvs. Longal P and Trigueira presented the softest shells and kept the same characteristic after processing. Conversely, cv. Côta chestnuts with hard shells became softer after boiling and roasting.

Results on kernel analysis showed that the minimum force (F_2) needed to penetrate raw chestnuts was 12.5 N, value 2.8 and 2.2 times higher than the force necessary to penetrate boiled and roasted fruits, respectively (Supplementary Table 4). The average force (Fm_2), energy (E_2) and stiffness (S_2) were also higher in raw chestnuts than in processed ones. The F_2, Fm_2 and E_2 of raw chestnuts were lowest on cvs. Trigueira and Longal P, and cv. Negra showed the highest value (1.6 times higher) (Supplementary Table 5). The S_2 value ranged between 1.6 (cv. Trigueira) and 2.8 N mm^{-1} (cv. Boaventura); however, differences between cv. Boaventura and cvs. Negra, Aveleira, Longal SL, Martaínha and Judia were not statistically significant.

Boiled kernels of cv. Lamela showed the highest F_2 value, while values of cvs. Trigueira, Aveleira, Martaínha and Longal SL were about 50% lower. Roasted kernels of cv. Martaínha had the maximum F_2, Fm_2, E_2 and S_2, while cv. Côta had the minimum F_2 and E_2, cv. Aveleira had the minimum Fm_2, and cv. Negra had the minimum S_2 (Supplementary Table 5).

Statistical results for coefficient of determination (R^2) (Supplementary Figure 2) showed a strong positive correlation between stiffness and F_2 ($R^2 = 0.864$), but only for the kernel of raw chestnuts. These parameters are probably interchangeable since both refer to the same physical characteristic.

Results indicate that fruits from cvs. Trigueira and Aveleira were the most suitable for both types of processing since they had the lowest hardness values but both before and after boiling and roasting, indicating that texture characteristics remained unchanged even after processing.

Colour analysis

The colour parameters of fresh, boiled and roasted chestnuts (Supplementary Tables 6 and 7) varied significantly between cultivars, treatments and cultivar × treatment interaction (Supplementary Table 2). Luminosity (L*), chroma (C*) and hue angle ($h°$) values of boiled chestnut shells were 14%, 12% and 9% lower than of the raw chestnuts, respectively, indicating loss of shell purity and lightness after cooked (Supplementary Table 6). Differences in chromatic parameters between the fresh and roasted chestnuts were far less evident except for fruit tonality, which increased with roasting. Values of $h°$ and C* were highest on raw kernels compared to processed ones, meaning that the colour of fresh kernels was more pastel yellow, while boiled chestnuts were yellow-brownish and roasted chestnuts were more brownish. The highest L* value indicated that raw chestnuts ($L^* = 86.5$) were lighter than the roasted or boiled kernels ($L^* = 66.6$). These results could be attributed to changes in porosity and *Maillard* reaction or other chemical reactions during the processing (Gowen et al., 2006).

Analysis of the cultivar × treatment interaction showed that the h° value ranged between 57.5 (cv. Lada) and 33.9 (cv. Negra) in raw chestnut shells. Lada, Trigueira, Lamela and Aveleira chestnut cvs. had a lighter tonality, while Negra and Martaínha had a reddish-brown colour. Although, the cvs. Lamela and Boaventura had lighter shells, 37.4 and 36.4, respectively, cv. Negra presented 27% less lightness than Lamela and had a characteristically darker shell; nevertheless, the kernel showed the highest luminosity. These results are higher than the values reported by Künsch et al. (2001) for some native Swiss and commercial chestnuts. The tonality varied between 94.7 in cv. Lamela raw kernel and 98.4 in cvs. Trigueira and Martaínha. This last cultivar had the lightest kernel (90.4), followed by cvs. Trigueira and Aveleira, while the kernels of cvs. Boaventura, Lamela, Judia, Lada and Longal P were more opaque. The chroma was higher in the kernels of cvs. Lada, Judia and Boaventura (∼26) and lower in cvs. Lamela and Martaínha (∼20), with similar values reported by Correia et al. (2009) in fresh chestnuts flour measured immediately after milling. In summary, the chestnuts with the most attractive colour were from cvs. Judia, Lamela, Lada and Côta after boiling and from cvs. Lada, Lamela, Longal P and Côta after roasting.

The TCD determined with raw and processed kernels (Supplementary Figure 3A and B) varied significantly among the 11 cultivars (Supplementary Table 2). After roasting, the kernels from cvs. Longal P, Lada and Lamela exhibited higher colour stability than in the other eight cultivars (Supplementary Figure 3A). In contrast, Trigueira kernels had a strong variation in colour (with higher TCD), becoming darker (lowest tonality) and opaque (lowest lightness). With boiling, Judia, Lamela and Lada kernels maintained almost all colour attributes (Supplementary Figure 3B); however, processing by boiling strongly affected colour variation in Aveleira, Martaínha and Negra. It is important to emphasise the different behaviours presented by the kernels of cv. Judia, which appears to be suitable for boiling, while cvs. Lada and Lamela exhibited more colour stability after processing.

Supplementary material

The supplementary material for this article is available online at http://dx.doi.org/10.1080/19476337.2010.518249

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