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REVIEW ARTICLE

A Review of the Use of Chestnut in Traditional and Innovative Food Products

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A R T I C L E I N F O

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A B S T R A C T

Chestnuts have been consumed in Portugal for immemorial times. These fruits are highly appreciated, not only due to their organoleptic characteristics but also due to their nutritional and functional values. For the nutrients to be more accessible and for the chestnuts to have better flavour and digestibility, it is necessary to heat, cook or roast them, for example. Chestnuts are a very versatile food, in terms of preparation, and can be cooked, roasted, as an accompaniment to dishes, replacing rice, pasta or potatoes, in the base of soups or the preparation of appetizing desserts and cakes. In Portugal the use of chestnuts to produce differentiated food products is traditional, but also new and innovative products are appearing on the market, either made with chestnuts or even with some residues of their processing, in the context of a circular economy. Examples of traditional usages of chestnut in Portugal include chestnut soup, or roasted chestnuts, which are typically consumed in the colder months of autumn and winter. In what concerns more modern trends, the use of chestnut flour to incorporate into a variety of foods, like bread, cookies or pasta is highlighted. This article explores the value of the chestnut sector in Portugal and the use of these fruits to obtain either traditional or innovative foods, such as bread, biscuits, pasta and beverages.

Introduction

The current markets are in constant competition for supremacy, being crucial to constantly innovate to obtain some differentiation and, consequently, the conquest of new markets and optimization of profits (Guiné *et al*., 2020, 2021). The nut sector is relevant for many regions of the globe, and includes nuts such as almond (De Leijster *et al*. 2020; González-Gómez *et al*., 2022; Xu and Chen, 2022), Brazil nut (Brouwer *et al*., 2021; Lima *et al*., 2021), cashew (N. Chen *et al*., 2022; S. C. Pereira *et al*., 2022), chestnut (Kim *et al*., 2022; Li *et al*., 2022), hazelnut (Ayvaz *et al*., 2022; Paradinas *et al*., 2022; Sun *et al*., 2022), macadamia (Shabalala *et al*., 2022; Shuai *et al*., 2022), peanut (Yuan *et al*., 2022; Zhen *et al*., 2022), pecan (Feng and Kong 2022; McKay *et al*., 2022), pine nut (Jin *et al*., 2021; E. F. R. Silva *et al*. 2022), pistachio (Homayouni *et al*. 2022; Saeedi *et al*. 2022) or walnut (Akça *et al*., 2020; Chatrabnous *et al*. 2018; Sarikhani *et al*., 2021; Vahdati, 2014), all with a very marked influence on food markets al regional level and also for world trade. Most of these nuts are consumed after slight processing, like roasting, drying or frying (L. Chen *et al*., 2021; Civera *et al*., 2022; Darfour *et al*., 2021; Yan *et al*., 2021), but they are also incorporated into a very wide diversity of food products, like for example, chocolate (De Clercq *et al*., 2017; Paz *et al*., 2021). The food industry is an increasingly demanding industry, both in terms of

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quality and safety. Consumers seek to satisfy their needs and preferences, being bombarded with a wide variety of products, as a result of competition and attempts at innovation among companies in a given area. Therefore, companies must invest more and more in new production technologies, in the development of new products that can meet the growing needs, and in commercial strategies to captivate and retain captivate and retain potential new consumers (Guiné *et al*., 2016).

The chestnut tree constitutes a regional wealth that has an important sociological, ecological, forestry and agronomic role. The use of chestnut fruits in human food dates back to the beginnings of civilization in the North and Centre of Portugal, where the species was abundant (Ribeiro *et al*., 2020). European sweet chestnut (*Castanea sativa* Miller) is a tree species of the *Fagaceae* family that is important to humans from both nutritional and economic points of view.

Portugal is among the largest European chestnut producers, with the district of Bragança being the one with the largest quantities. This is because the region has good soil and climate conditions for chestnut trees. Additionally, this crop has historic economic importance for the rural populations of the district as well as for other intervenients in the chestnut sector (Carocho *et al*., 2012).

Traditional ways of consuming chestnuts include roasted, boiled, pounded and as ingredients in culinary preparations, in addition to "marron glacé", the noblest preparation of chestnuts, very common in France and Italy, but also already valued in the Portuguese markets. Hence, the objective of this work is to identify traditional chestnut products that are available in the Portuguese market, constituting an added value for both industrials and rural populations, as well as the identification of some innovative products developed, intending to praise certain regions. In this way, the specific objectives of this review include a literature revision focusing on the composition of Portuguese chestnut cultivars, the protection of the autochthone cultivars following European Regulations, the transformation of chestnut into food products and beverages, and sustainability aspects related with processing operations. In what refers to the specific products based on the chestnut found in Portugal, either traditional or innovative, are focused the chestnut flour and the bread and biscuits made with that flour, the dehydrated and candied chestnuts and the beverages.

The chestnut tree and fruits

The chestnut tree is a hardwood, which preferably grows in mountainous areas, either in an agroforestry system (as scattered trees or in orchards called in Portuguese “Soutos”) (Fig. 1) or in a forest system. It is a tree very sensitive to pollution, excessive soil moisture, summer droughts and severe frosts. This hardwood can reach 30 meters in height and exceed 1500 years of life. Its male flowers - yellow grouped in inflorescences, are arranged in erect clusters (“amentos” or “amentilhos”) - and the female ones, are gathered in a thorny dome (Fig. 2). The chestnut tree blooms from March to June and the fruit ripens in the fall. The fruit is born inside a hedgehog that opens when it ripens and falls from the tree in mid-September, the earliest species, to November, the latest (Esposito *et al*. 2019) (Fig. 3). The chestnut tree begins its fruition at 6 years after its cultivation, producing between 1 and 3 kilograms of chestnuts per year. Its productivity increases until the age of 10, when it reaches fullness, producing an average of between 30 and 50 kilograms per tree. Over time, at about 70 years of age, the chestnut productivity starts to declines once again (Cabo and Almeida, 2019; Laranjo *et al*., 2017).

Fig. 1. Chestnut orchards or "Soutos" (on the left) and centenary isolated chestnut trees (on the right).

Fig. 2. Chestnut male flowers (on the left) and female flowers (on the right).

Fig. 3. Chestnut hedgehogs.

Of the genus *Castanea ssp*, it belongs to the Fagales order of the Fagaceae family (the same as the oaks) of the *C. sativa* species, and taking the binomial name of *Castanea sativa* Miller, this indigenous European fruit is the name given to the sweet chestnut, European chestnut, chestnut or Portuguese chestnut. The chestnut tree can also be known as Portuguese chestnut in Brazil or "Castinheiro" or "Castiro" in Galicia – Spain. It is typically a large tree that reaches 30 meters and sometimes even larger, with ternary ages, a full crown and sharp, shiny green leaves. From this tree, it is still possible to obtain wood for the construction of much-appreciated furniture and also for the production of Shitake mushroom (Esposito *et al*., 2019).

Chestnut production

The chestnut tree can be installed with two types of exploration objectives: Candlesticks, called wild chestnut trees, essentially for the production of wood; Soutos or Orchards, called tame chestnut trees, mainly for fruit production. Different species of chestnut grow in specific areas of the globe, as shown in Fig. 4.

Fig. 4. Scattering of the chestnut species around the world.

The most used species and with the most recognized characteristics are • *Castanea sativa* (European) – can only be grown in areas free from late blight, the fruit has varieties that can be very good, but can also produce chestnuts bitter and difficult to peel; • *Castanea dentata* (American) – the fruits are usually small, sweet, and the species is very susceptible to chestnut blight; • *Castanea mollissima* (Chinese) – quite resistant to diseases, with some sweet varieties of very attractive size, which are also easy to peel; • *Castanea crenata* (Japanese) – disease resistant, producing quite large nuts but with little flavour. These chestnut trees are mainly used for hybridization, that is, to create clones resistant mainly to the ink disease.

There is an increase in demand for chestnut trees in Portugal, which leads to the onset of companies that dedicate themselves exclusively to the production of these trees, satisfying the market demand. Techniques such as *in vitro* micro propagation prove to be an asset for these companies, because despite the large initial investment in equipment, in the future there is a guarantee of the production of a large number of plants with high productive and phytosanitary quality in a short time. The InProPlant is such a company and works closely with academia to aggregate scientific knowledge with knowledge of the producers. In this way it is necessary to select in the field the trees with commercial interest, and to develop in the laboratory the protocols inherent to the effective production of plants, destined to large-scale propagation (Baltazar 2015). Clones of *Castanea Sativa* essayed by Baltazar (2015) include CX1, CX5, 633, among others, and the essays consisted in propagation and rooting, and they were tested against the *Phytophthora cinamomi*. The CX5 genotype showed better performance compared with others.

Each species of chestnut tree can produce different varieties of chestnut fruits. The chestnut tree species grown in Portugal, the *Castanea Sativa*, has several varieties such as those indicated in Table 1. In the northeastern corner of Portugal, the Trás-os-Montes region, the soil and climatic conditions are favourable to the vegetative development and fruiting of the sweet chestnut tree, with more than 80% of the total national production being from this area (Ribeiro *et al*. 2020). This is even more noteworthy since Portugal is among the 10 largest sweet chestnut producers in the world (Fig. 5), producing 42 thousand tonnes in 2020 (“FAOSTAT” 2020).

Table 1. Fruit varieties within the *Castanea Sativa* Species.

Variety	Calibre	Number of fruits/kg	Aroma / Sweetness
Aveleira	Medium	82 -98	Weak / Sweet
Martinha*	Medium to Large	69 -95	Weak / Sweet
Longal*	Medium to Large	67 -87	Weak / Sweet
Judia*	Large	49 -69	Weak / Sweet
Colarinha	Small to Medium	84-96	Weak / Sweet
Verdeal	Large	58-74	Weak / Sweet
Rebordã	Medium to Large	76-92	Weak / Sweet
Côta	Small	102	Weak / Low Sweet
Lada	Large	78	Weak / Low Sweet
Bária	Large	82	Weak / Very Sweet
Negral	Large	77	Weak / Low Sweet
Boa-Ventura*	Medium to Large	68-76	Weak / Sweet
Lamela	Large	71	Weak / Sweet
Zeive	Large	73	Weak / Sweet
Redonda	Medium	80	Weak / Very Sweet

*Varieties with higher production in Portugal

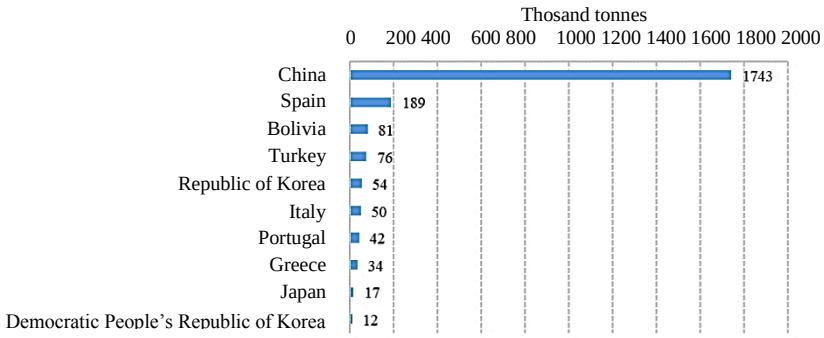

Fig. 5. World's top chestnut producers (data from 2020) ("FAOSTAT" 2020).

Because it is recognized the socio-economic importance of *C. sativa* there have been efforts to protect its diversity. However, the identification of the different varieties and the evaluation of genetic resources in Mediterranean countries has not been easy (Pereira-Lorenzo *et al*., 2010). As an example, in Portugal, the identification of varieties is problematic due to confusion between names, with some different varieties having the same popular name or the same variety having different names, respectively corresponding to homonymy and synonymy problems (Costa *et al*., 2005; M. J. P. Pereira *et al*., 1999).

Nutritional value

Chestnuts are mostly made up of carbohydrates, of which considerable amounts of amyloses and amylopectins stand out. These polysaccharides allow the development of intestinal flora and the production of short-chain fatty acids. In addition, indigestible substances (fibre) stimulate the presence of beneficial probiotic bacteria (*Bifidobacterium* and *Lactobacillus*) in the intestine, also contributing to the regulation of cholesterol levels and the insulin response. When compared to other nuts, chestnuts have lower calorie content, as they are low in fat (and the fat they contain is essentially polyunsaturated) and do not contain cholesterol. But its interest is not limited to these functional aspects. They are a source of nutrients, namely vitamins, minerals and chemical compounds that protect cells. Of the vitamins present in the chestnut, vitamin C, vitamin B6 and folic acid should be highlighted. As for minerals, chestnuts provide

calcium, iron, magnesium, potassium, phosphorus, zinc, copper, manganese and selenium. It also has different phytochemicals, namely lutein and zeaxanthin, and several phenolic compounds that are important antioxidants and cell protectors.

The natural components of the chestnut benefit human health and, therefore, the chestnut is increasingly becoming a food associated with healthy diets. From a nutritional point of view, this food can be a substitute for potatoes, rice and wheat. In addition to being rich in starch, the chestnut has a low percentage of fat and has a considerable fraction of fermentable carbohydrates (mono and disaccharides) and a large fraction of dietary fibre. About 50% of the nut consists of water, which makes it difficult to store *in natura* as the enzymatic activity continues to evolve, even when subjected to refrigeration (Rodrigues *et al*., 2006).

The amount of protein is moderate, making it a great addition to a vegetarian diet. Although the level of protein is considered low compared to other nuts, the chestnut is interesting because it does not contain gluten. The chestnut is essentially rich in insoluble fibre, and its intake is beneficial for the human body, reducing the speed of absorption of sugars, fats and some minerals such as sodium (Guiné *et al*., 2016).

Table 2 shows the composition of the dehydrated chestnut, also called "Castanea pilada", which is a very popular product in Portugal.

Table 2. Nutritional composition of dehydrated chestnut (INSA 2021).

Composition	Content (g(100 g)
Water	9.9
Protein	5.1
Total fat	2.0
Total carbohydrates	70.0
Starch	52.8
Dietary fibre	11.3
Energy (kcal Kj^{-1})	**324 / 1356**

Guiné *et al*., (2021) evaluated the consumption of nuts in Portugal as well as the level of knowledge about their chemical composition and health effects. In this study, which included chestnut as well as other nuts, revealed that, globally, the Portuguese were neither well informed about the chemical composition of nuts nor their positive effects on human health.

Official recognition and protection

Recognizing the importance of traditional products, the EU developed some mechanisms, which were important milestones in the European Quality Policy as they presuppose the protection of designations of agricultural products and foodstuffs. It's been more than 20 years ago that the European Union (EU) introduced measures to regulate certification schemes, particularly, through Regulations (EC) 2081/92 and 2082/92, and to promote them as a means of developing opportunities and preserving the traditional characteristics of certain foods and/or processes for food production. So it was not only created the European System of Protection and Quality of Agricultural Products and Foodstuffs: Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI), as was also established the European System of Appreciation of the Specificity of Certain Agricultural Products and Foodstuffs, taking into account the traditional way of production or the composition: the Traditional Specialty Guaranteed (TSG) (Conneely and Mahon 2015; EC 2004; Guiné 2016; Guiné 2016; Vales 2014).

The appreciation of the chestnut by consumers, its nutritional richness and its quality allow the chestnut to be considered a product with Protected Designation of Origin (PDO). The main objective of this

certification is to value and preserve traditional chestnut cultivars and preserve genetic heritage (Cruz, 2012). Since 1994, four protected designations of origin (PDO) have been recognized to preserve and honour Portugal's sweet chestnut biodiversity and identity, namely 'Castanha da Terra Fria', 'Castanha dos Soutos da Lapa', 'Castanha da Padrela' and 'Castanha do Marvão-Portalegre' (O. Borges *et al*., 2008):

• "Castanha da Terra Fria" – includes chestnuts of the European Chestnut (*Castanea sativa* Mill) cultivars Longal, Judia, Cota, Amarelal, Lamela, Aveleira, Boa-Ventura, Trigueira, Martaínha and Negral. More than 70% of the Portuguese production corresponds to the Longal cultivar, with the remaining 30% corresponding to the production of other cultivars. It is produced in the municipalities of the districts of Bragança and Vila Real.

• "Sotos da Lapa" – includes cultivars Martaínha and Longal. The geographical area of production covers some parishes in the municipalities of S. João da Pesqueira, Penedono, Sernancelhe, Moimenta da Beira, Aguiar da Beira, Armamar, Tarouca, Tabuaço, Trancoso and Lamego.

• "Castanha da Padrela"- chestnuts obtained from the Judia, Longal, Lada, Negral, Côta and Preta cultivars. The geographical area covers some parishes in the municipalities of Chaves, Murça, Valpaços and Vila Pouca de Aguiar.

• "Castanha de Marvão"- originates from the Bárea, Clarinha and Bravo cultivars. The geographical area covers the municipalities of Marvão, Castelo de Vide and Portalegre.

Chestnut transformation

The processing of chestnuts is divided into two distinct markets. The first is dedicated to the first transformation operations aimed at obtaining semi-processed chestnuts. These include the separation of varieties, sizing, taking off the shell, peeling and freezing. In addition to adding value to the product, this processing allows the chestnut to be available throughout the year, both for direct consumption, through the retail market, as well as for the agro-industry. The second market, corresponding to the second transformation, adds even more value to the chestnut by creating products such as jams, purées, marron glacé, flours, among others, from semi-processed chestnuts (Matos, 2003).

In Portugal, several companies produce and process chestnuts located essentially in the north of the country, with Sortegel being the one that stands out the most. It is one of the European reference units for processing and exporting chestnuts. Fig. 6 shows the operations involved in chestnut industrial transformation.

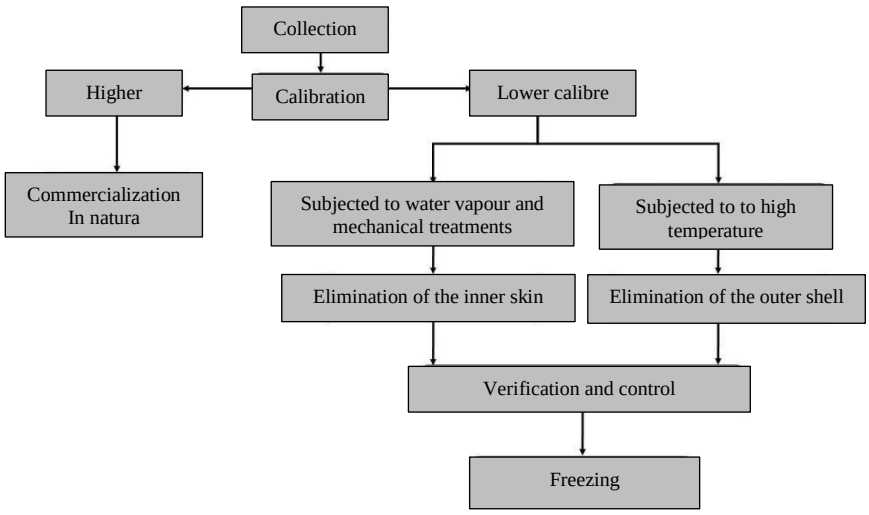

Fig. 6. Schematic representation of the processing operations of chestnut.

Sustainability of the chestnut processing industry

The chestnut processing industry involves several stages and a large number of people. The processing and transformation of the nut results in pieces, units of inferior quality that can be reused. The main objective is the reuse of units of lesser interest and/or considered by-products resulting from the processing of chestnuts, being these units of lower calibre and broken pieces. In addition, there are other by-products resulting from the processing of the chestnut that are also used in various applications (Braga, 2014).

During the entire process, a high amount of production waste is generated, with the shell alone corresponding to around 20% of the total weight of the chestnut. The chestnut processing industry mainly uses the fruit (nut) for food purposes, with other plant products (leaves, shells and hedgehogs) being considered waste. These by-products are either disposed and not assigned any other application or used as fuel. Valuing nut by-products can be achieved with the development of new products. Several studies have shown that nut by-products are a good source of phenolic compounds, with high biological activity, mainly antioxidant capacity (Barreira *et al*., 2008). In this sense, extracts from nut by-products can contribute to the sustainability of this industry, requiring the development of low-cost methods capable of extracting compounds with biological activity that can be used in different industries, thus reducing the negative impact of these residues on the environment. The industry will thus be able to achieve benefits through sustainable management, accompanied by better economic and environmental performance, based on the efficient use of resources, materials and energy (Husgafvel *et al*., 2013).

The hedgehog and the shell are generally used as biofuel, so their valorisation could lead to greater sustainability of the chestnut production process (Vázquez *et al*., 2009). The work by Lee *et al*., (2022) used chestnut shell from food processing as a feedstock for biorefinery, proposing a cheap process to minimize the loss of sugars during treatment with sodium hydroxide.

Besides energetic valorisation, chestnuts wastes can have other applicability. The work by Costa-Trigo *et al*. (Costa-Trigo *et al.*, 2019) describes a possible valorisation of chestnut (*Castanea sativa*) residues aiming at the elaboration of culture broths through the optimization of the acid-hydrolysis. Muneka *et al*. (2016) evaluated the phenolic composition of chestnut leaves for possible valorisation for the food, pharmaceutical, or cosmetic industries. Gulsunoglu - Konuskan (2021) proposed a bioprocess based on fermentation by *Aspergillus spp* to obtain ellagic acid, a polyphenol with health benefits, from chestnut shells.

More and more the concepts of eco-valorisation and circular economy are seen as a way to improve economic value while reducing the impact on the environment (Fig. 7).

Fig. 7. Valorisation of chestnut by-products and residues in a circular economy perspective.

Products made from chestnut

Chestnuts are available on the market in various forms, the most common being fresh chestnuts (very seasonal) and frozen or dehydrated chestnuts (available all year round). The chestnut is a versatile product that can be consumed raw, cooked, in the form of jams or sweets. Additionally, it has a high potential for the production of bread and cakes (Gonzaga, 2015; Paciulli *et al*., 2016; Rinaldi *et al*., 2015), being a gluten-free raw material, adequate for diets of celiac people (Paciulli *et al*., 2018).

Because the chestnuts and their residues can be used to obtain value-added products aimed at human consumption, some of these are addressed below.

Chestnut flour

Chestnut flour has been used for a long time by the rural people of Portugal, Spain, France and Italy, namely in porridge, crepes, or bread. Chestnut flour was of great importance in the diet of local populations, although being considered food for poorer families at the beginning of the 20th century (Cauvin and Young, 2008).

Obtained by grinding dehydrated chestnuts, the flour is thin, clear and with brownish spots. However, it is highly hygroscopic, which is an inconvenience due to its ability to absorb water easily, thus making its conservation difficult (A.P.Silva, 2007). Small-gauge or broken nuts can be separated and processed into flour as well (Cauvin and Young, 2008).

The process of production of chestnut flour includes several procedures, such as drying, peeling, sorting and grinding (Fig. 8). The result is characterized by a product of variable colour between white, yellowish and reddish. The drying process so that most of the water present in the fruit is evaporated, must be done carefully so that the flour has a longer shelf life and the degradation is as little as possible. Therefore, the drying of this fruit is tirelessly studied so that the nutritional properties are minimally deteriorated and increasingly better used (Correia *et al*., 2009; R. Guiné *et al*., 2004; Guiné and Fernandes, 2006; Moreira *et al*., 2013).

The milling process is also very important because care must be taken not to contaminate and alter the characteristics of the flours obtained. The nutritional properties and antioxidant activities must also be carefully preserved, as they easily deteriorate if they undergo very intense and long processing (Barreira *et al*., 2008; de Vasconcelos *et al*., 2010).

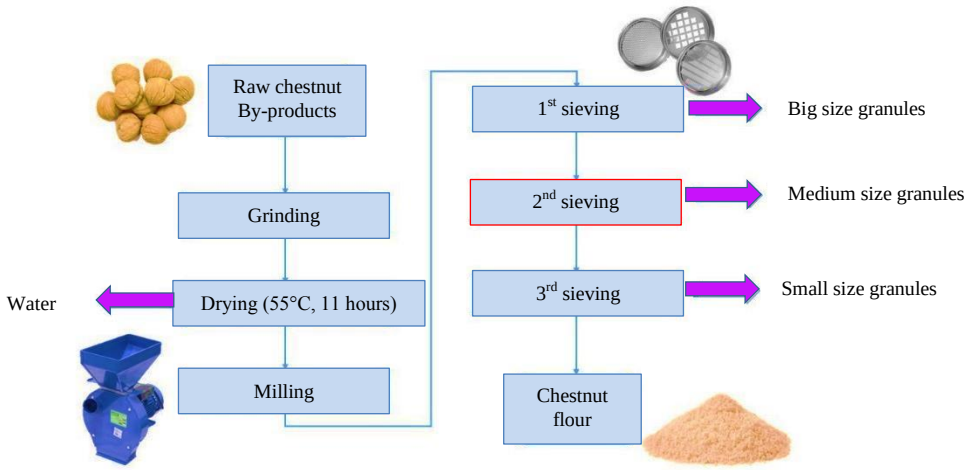

Fig. 8. Diagram for the processing of the chestnut flour.

Chestnut flour is considered a product from second processing, just like the dehydrated and frozen chestnuts (Fig. 9). It is a very versatile product due to its physical characteristics, its starch content very similar to that of corn, and can be used in sauces, soups and culinary thickeners (Borges, 2017). As it does not contain gluten, this flour has been widely used to replace wheat in bread (Gonzaga, 2015). Chestnut flour is used as a nutritional supplement in diets for celiacs, vegetarians and vegans, because it is a product with very high nutritional properties, has common use in pasta and cookies as it has a low density and gives the desirable crunchiness to cookies (Cauvin and Young, 2008; Dias, 2014; Fonseca, 2011).

Fig. 9. Chestnut flour is commercially available.

The chestnut flour possesses complex olfactory and gustatory aromas and tastes, predominantly a sweet taste and a moisture content not exceeding 10% (Souza *et al*., 2014).

Several authors recognize that chestnut flour has great potential for the implementation of new products in the food industry due to its physical and chemical characteristics, which bring great benefits to the consumer. The development of new products also leads to a greater demand for the product, which encouraged greater production (Cabo and Almeida, 2019).

Yang *et al*., (2022) reported that during the drying process, the digestibility of starch was influenced by temperature, and the presence of other compounds in the chestnut. Additional studies showed that chestnut flour can have improved functional properties when incorporated into food products such as bakery products (Zhou *et al*. 2021), sausages (Sirini *et al*., 2020) or pasta (Littardi *et al*., 2020).

Brochard *et al*., (2021) developed a pasta made with chestnut flour and bee pollen and their results revealed that the addition of chestnut flour over 40% to wheat-flour pasta shortened optimum cooking time and lowered cooking yield, and the addition to pasta prepared with wheat flour and eggs maintained, approximately constant, the cooking yield. Hence they found optimal properties for pasta with 50% chestnut

flour, allowing obtaining functional food products, valued by the consumer.

Chestnut bread and biscuits

The use of unconventional products has had a growing demand in the market, not only for their benefits but also for the search for innovation and market differentiation. In addition to this, market competition has been increasing and innovation in products with the incorporation of unconventional raw materials has been a very effective strategy. In this sense, the significant increase in the production of bread with unconventional flours has grown significantly, not only due to the aforementioned factors but also due to the increase in the number of people who develop gluten intolerances, as is the case with celiacs (Anjos *et al*., 2017; Gonzaga 2015). However, Pciulli *et al*., (2018) describe that chestnut flour affects the physicochemical properties of gluten-free doughs and biscuits, originating a darker colour, firmer texture and higher oxidative stability (Fig. 10).

Fig. 10. Chestnut bread and biscuits.

Dehydrated chestnut ("pilada")

The dehydrated chestnut is produced by a company located in Marvão, in the North of Portugal, from chestnuts cultivated, harvested and processed in an artisanal way, thus providing them with an authentic flavour. They can be used after hydrating the product in water for at least 12 hours. They can be consumed right after hydration or be prepared together with meats or simply accompany any type of dish, whole or in the form of puree. Once hydrated, they can also be used to make desserts and soups (Fig. 11).

Fig. 11. Dehydrated chestnut ("*Castanea pilada*").

Candied Chestnut (Marron Glacé) and jam

The first glazed chestnut would have appeared at the court of King Louis XIV, with Chef François Pierre de La Varenne, who cooked a chestnut with sugar. Others indicate that the glazed chestnut recipe appears for the first time in the 16th century, in Lyon. Others claim that candied chestnuts originated in Cuneo, Italy, back in the 16th century, due to the wide availability of chestnuts and an unprecedented spread of sugar. Marron Glacé is recognized worldwide as a refined and expensive candy (Fig. 12). A kilogram of Marron Glacé, in some stores in Paris, can cost more than 140 Euros.

This sweet requires chestnuts without any skinning, cutting, or hitting and which must be of

impeccable quality, both organoleptically and morphologically.

Fig. 12. Candied chestnuts - Marron glacé (top) and chestnut jam (bottom).

According to one of the renowned French manufacturers (Clément Faugier), the confection of this sweet must go through all the following stages: 1) Selection of chestnuts and removal of the husk and skin; 2) Group well together and every 4 chestnuts, wrapping them in "tulle" (gauze, mousseline), in a suitable stainless steel container (with holes); 3) Cooking at approximately 100ºC and subsequent removal of water. 4) Involve the chestnuts for 48 to 72 hours in vanilla-scented sugar syrup until the chestnuts are saturated in sugar. Then the chestnuts are separated from the tulle. 5) Brightening the chestnuts: this process gives that shiny appearance to the caramelized chestnuts; after this, they are separated one by one, placed on a conveyor belt that passes through a cascade of powdered sugar and then through a heat tunnel, so that the chestnuts acquire their final shine. 6) Packing: Finally, the nuts are packed one by one.

The jams incorporating chestnuts or fully made with chestnuts have been part of the Portuguese culinary culture for centuries (Coelho and Soares 2022), and one can find variable recipes throughout the country.

Conclusions

The work carried out a compilation of the information regarding the importance of the chestnut sector in Portugal and the use of chestnuts to produce traditional and also innovative food products, taking into account the main chestnut producing regions. In general, it was perceived that the valorisation of a Protected Designation of Origin product, endogenous of several regions of Portugal, can be achieved successfully. Besides, the excess of production that would be discarded by the producers and the industry, as well as the broken fruits or those of small calibre, which are not used either for fresh sale or in any other type of industry, can be used for the production of chestnut flour, increasing the income of producers.

It was also possible to approach and understand what innovations in terms of new products are based on chestnuts and see, in Portugal, what are some evolutions that have been made in this type of product, believing that there is still room for new types of products to appear into the market.

As for the by-products of the chestnut processing industry (shells and hedgehogs), they may form the basis of new products developed by the food or cosmetics industries, due to the high quality of the matrices. Their valorisation can contribute to the sustainability of the whole chestnut processing sector.

The chestnut processing industry in Portugal has primarily been limited to freezing the fruits, although other forms of processing are already beginning to take place, albeit at an early stage. Thus, it is to be expected that in the short term there will be other chestnut derivatives and new products, as a result of

the need and sustainability of the chestnut sector and processing industrial units.

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Conflict of interests

The authors have no conflicts of interest do declare.

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