Hazelnut: A Valuable Resource

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***Abstract*—Hazel (*Corylus avellana* L.) nutshell is one of the most consumed and most appreciated nut fruit all over the world. It is believed to have constituted a basic food in early prehistory, in temperate zones of the globe, such as for example Europe. Presently the hazelnut production is mainly concentrated on the Black Sea coast of Turkey, but other countries are also important producers, like for example Portugal, situated on the western Europe, in the Iberian Peninsula. The objective of this work is to make a review about the worldwide importance of hazelnut, their usages, including gastronomic and industrial applications, as well as some ways that allow adding value to this fruit, making it an even more valuable resource. The advantages include higher income for produces, lower environmental impacts and valorisation of residues improving sustainability and providing valuable products for consumers and/or ingredients to incorporate into those products.**

***Index Terms*—valorisation, added value, By-products, extraction**

I. Introduction

Hazelnut, scientifically known as *Corylus* species, is born of hazel, from the family Betulaceae. It is considered an exotic fruit, being original from North America, particularly the species *C. americana* and *C. cornuta*, and also from Asia Minor, particularly *C. avellana*, this last being the most common and coming mostly from the areas surrounding the Black Sea and East Mediterranean [1].

Hazelnuts are one of the most nutritive among nuts, and comprehend valuable nutrients, such as proteins, fibres, unsaturated fatty acids, sterols and phytochemicals, together with micronutrients such as tocopherols, polyphenols, essential minerals (potassium, calcium, magnesium, selenium), and B-complex vitamins. They are typically composed of fat, 62% fat, but they also contain protein, 16%, and carbohydrates, 11%. Nevertheless, its composition is significantly variable depending on variety, as well as other cultivation variables, like soil, climate and cultural interventions [2]–[6].

Owing to their nutritive value and exceptional flavour, they are widely used in dairy products, bakery, coffee, spreads and confectionery, being also applied directly into salads. Only a very small fraction of hazelnuts is commercialized as in-shell nuts, 10%, while the remaining 90% is used for industrial purposes as shelled nuts [7], [8].

Similarly, to other nuts, hazelnuts are included in the dietary guidelines of several countries, due to their high nutritional content and bioavailability of those nutrients. Furthermore, the bioactive molecules present in hazelnuts have been reported as having several benefits for the human health [9]–[11].

II. Consumption & Main Usages

From the Neolithic era, in the regions of Europe and the Caucasus, hazelnut has been used for human consumption. This fruit is an excellent food given its richness in lipids, dietary fibre, protein, minerals (especially calcium) and vitamins (in particular vitamin E), with the added advantages of low amounts of sodium and sugars. For those on a vegetarian diet, nuts can provide many of the nutrients commonly obtained from animal products, such as most B vitamins, phosphorus, iron, copper, potassium and protein [12], [13].

Hazelnuts can be consumed fresh or toasted in a variety of gastronomic and industrial applications. According to Sullivan *et al.* [14] hazelnuts are eaten raw, roasted or even blanched. Regarding the possible forma of application, they can be used whole, shredded ground our turned into paste.

The destination of most of the world's hazelnut production is industry, with about 70% for chocolate applications and 20% for ice cream and pastries, leaving only 10% of total production for direct consumption, whether fresh or in other applications [12], [13].

The adaptability of the hazelnuts to fresh consumption or to use in the food industry is related to their characteristics, especially when it comes to the manufacture of cocoa products. Thus, morphological characteristics and stability to lipid oxidation (rancification) have to be considered when evaluating the quality of hazelnuts. Among the morphological and physical characteristics of the peel and fruit stand out the volume, weight, appearance, uniformity, fibrosity and roughness [12], [13].

In the case of hazelnut destined to consumption *in natura*, this must have a core with a diameter larger than 20 mm, although not necessarily rounded in shape, while also possessing a thin shell and showing and attractive appearance. On the other hand, stand the fruits destined to the industrial applications, for which the physical characteristics that define the suitability for industry are: yield, rotundity, detachment of the pericarp, weight loss and the fragility of the core when submitted to roasting.

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These parameters allow the selection of varieties adapted for marketing and use in whole, fragmented, or in hazelnut paste, depending on the desired final product [12], [13].

Spherical hazelnuts are used in products that require whole fruits, while elongated ones (most likely to break in crushing) are primarily intended for the production of shredded hazelnuts or hazelnut paste. The most suitable varieties for industrial application are those that correspond to spheroidal fruits. In particular, the hazelnuts used in the confectionery industry must have a small, sub-spherical and uniform turgid core, excellent taste and aroma, adequate fat content, a thin and easily removable perisperm and must be free of fibres covering the tegument. In confectionery, hazelnuts are used to make pralines, chocolate truffles or Ferrero Rocher®, candies (Fig. 1) as well as many other products in the chocolate range [12]–[14].

Figure 1. Hazelnut praline, hazelnut stuffed truffles and chocolates.

Dacquoise is a cake made with layers of almond and hazelnut meringue and whipped cream or butter cream (Fig. 2). It is served in France, usually chilled and accompanied by fruit [13], [14].

Figure 2. French dacquoise cake.

In Turkey, hazelnuts are used in the production of baklavas (a Turkish sweet specialty) and Turkish delicacies (Fig. 3), in addition to cookies, puddings, pastries, cakes and waffles [13], [14].

Figure 3. Baklavas and Turkish delicacies.

Figure 4. Hazelnut chocolate, cake and ice cream.

The main use of hazelnuts is the confectionery industry, with approximately 300 thousand tons/year used in chocolate production. Hazelnuts are generally used after being roasted in snacks and confectionery, cakes and ice cream (Fig. 4) [14], [15].

III. Drying and Roasting of Hazelnuts

To ensure conservation of the hazelnuts, after harvesting, their moisture content must be decreased to reduce water activity and microbial spoilage as well as chemical degradation. Typically, after harvest the moisture content is between 25 and 30%, being necessary to bring it down to only about 6% for conservation purposes [16].

In most plantations, hazelnuts are dried outdoors because few farms have their own drying facilities. Nevertheless, some farms use private drying facilities or cooperatives. In Italy the harvest is highly mechanized with the use of large capacity machines, and the product is mainly dried by agricultural dryers available by producer cooperatives [17]. (Fig. 5)

Figure 5. Drier for hard shell nuts, including hazelnuts (Zaffrani).

Kaya *et al*. [16] studied the drying by artificial methods of hazelnut fruits in electric oven. Drying was done by convection with hot air at 30, 35 and 40 ℃ and natural conditions (ambient air) was used as control. The drying machine was designed with a horizontal roller working at 60 turns/hour. During the drying process the moisture content as well as the electrical consumption were monitored. One hour after removal, the humidity ratio was 0.26%, 0.35% and 0.30% and the energy consumption of 2.39, 3.33 and 4.02 kW/hour at temperatures of 30, 35 and 40 ℃, respectively.

After harvest, when the hazelnuts are dried they may be subject to shell-crack. If this happens, the fruits become more susceptible to accelerated quality deterioration and possible microbial contamination during storage. In this respect, Wang et al. [16] investigated the shell-cracking mechanisms and settled strategies to minimize cracking during hot-air drying of hazelnuts. Their findings showed that relative humidity (RH) was the factor that mostly contributed to reduce shell cracks, as compared to temperature or air velocity. They suggest that using gradual drying by increasing RH from 50 to 60% and reducing temperature from 38 to 32 °C when in-shells reached ∼16 g/100 g moisture content, resulted in a reduction of cracking ratio to lower than 30% and drying time less than 15 h.

Roasting in hazelnuts is performed to remove fruit peels, inactivate enzymes, destroy microorganisms and reduce water activity. In addition, roasting also allows to improve the colour, crispy texture and flavour of the product. Roasting increases amount of compounds with antioxidant activity, while at the same time inactivates undesirable enzymes and microorganisms. Nevertheless, it causes some loss of nutritional value and possible formation of undesirable compounds such as 5-hydroxymethylfurfural [18]–[20].

Industrial roasting is carried out at temperatures ranging from 100 to 160 ℃ for 10-60 minutes with dry air, depending on the desired colour and texture. However, it is usually held at 145 ℃ for 15 min. The chemical reactions that are responsible for the changes during roasting are mainly caramelization and Maillard reactions. The nature of the hazelnuts and the roasting conditions (temperature higher than 100 ℃ and time over 10 min) are favourable for these reactions to occur [20]–[22].

IV. Valorisation of Hazelnut

A. Hazelnut Components

Hazelnut contains bioactive molecules that act as potent antioxidants, such as vitamin E. These may be a preventative measure against chronic diseases, including cardiovascular disease, dementia (Alzheimer's) and alleviate the symptoms of aging. The bioactive component with the highest antioxidant potential is α-tocopherol (one of the most active forms of vitamin E), and has even been investigated for antioxidant activity and its beneficial association in the prevention of cancer and atherosclerosis. In pharmaceutical and cosmetic applications, these components play key roles in fighting free radicals, helping to minimize the effects of cell aging. Oxygen-derived free radicals are responsible for age-related damage to cells and tissues. In a normal situation, there is a balanced balance between oxidants, antioxidants and biomolecules. However, an excess in free radical generation can overwhelm natural antioxidant defences leading to oxidation and contributing to cellular function impairment [23], [24].

Phenolic compounds are a broad class of plant metabolites, comprising over 10 thousand compounds, of considerable importance in plant physiology and morphology. These compounds play an essential role in growth and reproduction and are also responsible for plant defense mechanisms against stressors. In addition, they contribute to the pigmentation and sensory characteristics of fruits and vegetables. Phenolic compounds can be divided into flavonoids or non-flavonoids. The flavonoid group comprises the flavanoids, flavonoids, isoflavones, flavones, flavanas, flavanones, proanthocyanidins and anthocyanins. Non-flavonoids include tocopherols, phenolic acids, hydrolysable tannins, stilbenes, coumarins and lignans [25]–[34]. The phenolic constituents in hazelnut extracts were studied by HPLC and the presence of twelve phenolic acids was observed, the main ones being gallic acid, caffeic acid, p-coumaric acid, ferulic acid and synapic acid. In all extracts, gallic acid was the most abundant, both in free and esterified forms [35].

B. Hazelnut Oil

Hazelnut oil, besides being edible, is widely used in cosmetics, in the preparation of creams, with special emphasis on products intended for dry skin, due to its emulsifying properties. This oil is astringent and closes the pores of the skin, being for that reason recommended for greasy skin and acne [12], [13].

Hazelnut oil is quite rich in components of interest for application in the pharmaceutical and cosmetic industries. The physical and chemical characteristics of hazelnut oil have potential applications in skin care, for restorative treatments (turgor, elasticity, cure) and as a UV radiation filter [36].

C. Food Ingredients and Technological Applications

The use of hazelnut as a food ingredient delivers different textures and provides well defined and very pleasant aromas, as well as improves the nutritional value of the product. Hazelnut's nutritional attributes have been harnessed to enhance a range of food products, such as pastries, dairy products, breakfast cereals, chocolate and appetizers [13].

Given the hazelnut high lipid content, it can be used to produce an edible oil of the highest quality, by means of a technology that allows the natural preservation of the chemical composition of the raw material. The oil can be used for frying, or alternatively in cooking and serving as an ingredient in food production [13], [14].

In addition to its contribution to human health, hazelnut oil has potential uses in the design of new margarine and butter formulations to improve the product's physical properties (like for example spreadability) due to its lower viscosities compared to saturated fats. Hazelnut oil can also be subjected to the hardening process to obtain a margarine that can replace animal fat or add aroma, nutritional richness and protein to bakery and confectionery foods such as candies, caramels, sauces and fillings [13], [14].

D. Extraction of Plastic Additives

Due to the high consumption of hazelnuts, agricultural and industrial processing generates a high amount of by-products rich in high value substances such as lipids, phospholipids, proteins, nucleic acids and fibrous components (cellulose, hemicellulose, lignin, etc.), which can be extracted and used as additives or fillers for polymeric matrices [37], [38].

The plasticization of poly (lactic acid) (PLA) as well as the improvement of photostability of poly(propylene) (PP) and its mechanical properties have been widely investigated [39]–[41]. Battegazzore *et al*. [38] studied a multistep extraction process to separate three hazelnut fractions consisting of PLA plasticizers, PP photo-stabilization enhancing antioxidants and reinforcing filler for both polymers. These fractions were further characterized as to chemical and thermal properties, and then fused with PLA or PP. Thus, the first fraction was used as a plasticizer in PLA, the second for UV protection of PP and the last to reinforce both matrices. The results obtained showed that the first fraction partially plasticized the PLA. The second fraction was found to consist of UV absorbers as well as thermal stabilizers which increased the oxidation induction time of PP by 30% in the case of hazelnut skin. The latter fraction was able to increase the storage modulus of PLA and PP by 30% and 20% (with 30% by weight of filler content) respectively.

E. Supercritical Extraction of Triglycerides

The United Nations Food and Agriculture Organization (FAO) estimates that globally about one third of food produced for human consumption is lost or wasted. In this context, the processing of food waste into fuels or the extraction of highly valuable products generates growing interest as opposed to conventional processing of food waste by incineration or composting [42], [43].

Oil extracted from hazelnut residues contains large amounts of triglycerides that can be used as a renewable source of high quality biodiesel [44]. In addition, these extracts may have other properties that contribute to their appreciation. The oil contained in hazelnuts consists mainly of unsaturated fatty acids, especially oleic and linoleic acids. High levels of mono- and polyunsaturated fatty acids as well as sterol and tocopherol have been reported to play a preventive role in many diseases, especially cardiovascular diseases, as they contribute to lower LDL (low-density lipoprotein) cholesterol [43], [45]. In a study by Manna *et al*. [43] triglycerides were extracted by supercritical CO_2 extraction from hazelnut residues (insect-damaged, rotten or roasting-damaged hazelnuts), with the aim of enhancing these food residues. The results showed that, compared to soxhlet extractions, they obtained satisfactory yields (55-100%), and hazelnut residues provided high amounts of triglycerides (0.3-0.4 g oil/g residue) [43].

V. Final Considerations

The hazelnut is a very ancient fruit with a global appreciation as a nut to be consumed *in natura* or for multiple applications in gastronomy and the food industry.

Hazelnut has important chemical constituents and bioactive components that give it many health beneficial properties, most especially having in consideration the high antioxidant capacity.

Besides the traditional applications, also the cosmetics and the pharmaceutical industries benefit from this multipurpose resource.

Finally, not only the fruit itself has been valued, but lately also attention has been given to the recovery of valuable components from hazelnut residues, with economic and environmental advantages.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Raquel Guiné wrote the article and supervised the work, Paula Correia helped in bibliographic search and got funding for project PDR2020-101-030759.

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