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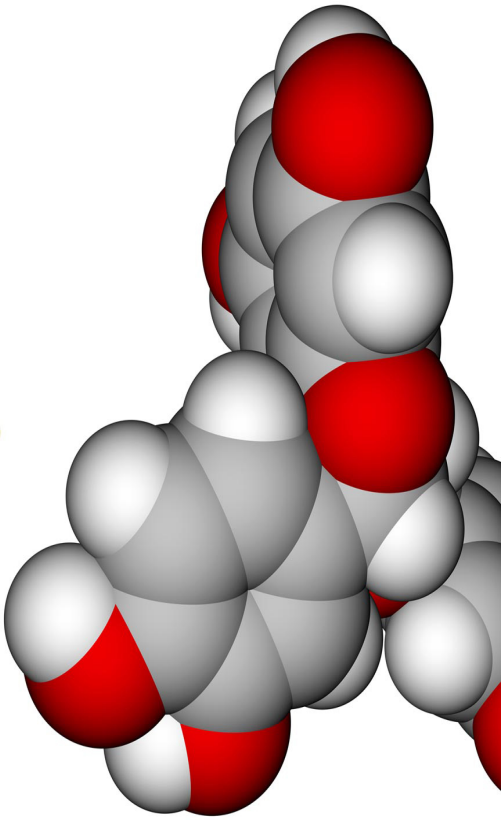
NATURAL BIOACTIVE COMPOUNDS FROM FRUITS AND VEGETABLES AS HEALTH PROMOTERS

PART 2



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CHAPTER 6

Bioactive Compounds of Chestnuts as Health Promoters

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Abstract: Different chestnut species can be cultivated for fruit production, the most valorised part for nutritional purposes. However *Castanea sativa* Mill., the "European chestnut", is one of the most valorised worldwide. Its fruits are consumed either raw or after processing, being boiling and roasting the most usual ones. The nutritional composition of fresh chestnut is variable, with interesting amounts of carbohydrates and fibre, together with low fat content, with differences between cultivars and producing regions. In respect to the presence of bioactive compounds, such as phenolic compounds, vitamins, fatty acids, among others, some studies had focused on the fruit benefits to human health but few reported the effect of processing in those compounds. In this context, this chapter intended to review the current knowledge on chestnut composition, together with the influence of diverse post-harvest technologies, such as refrigeration, flame peeling, freezing with CO_2, irradiation, boiling and roasting on the bioactive compounds of chestnut.

Keywords: Antioxidant activity, Bioactive compounds, Boiling, Carbohydrates, *Castanea sativa* Miller, Cold storage, Drying, Fatty acids, Fibre, Irradiation, Minerals, Nutritional composition, Organic acids, Osmotic dehydration, Phenolic compounds, Processing, Proteins, Roasting, Vitamin C, Vitamin E.

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INTRODUCTION

The genus *Castanea* belongs to the angiosperm family *Fagaceae*. Throughout the world, several different species of chestnut can be found, such as *Castanea creanata* Sieb. in Asia, *C. creanata* Zucc. in Japan, *C. mollissima* Bl. in China and Korea, *C. dentada* Borkh in North America, and *C. sativa* Mill. in Europe being, also called "European chestnut" [1, 2].

The specie *C. sativa* Mill. is one of the most valorised worldwide. However, to improve chestnut production and the resistance to certain common diseases of the tree, some hybrids have emerged over the years [3].

Chestnut production has a high importance in the world's primary economy. China is the main producer, with about 1650000 tonnes (t) in 2012, followed by Republic of Korea (70000 t), Turkey (59789 t), Boli*via* (57000 t), Italy (52000 t), Greece (28700 t), Japan (20900 t) and Portugal, the eighth largest world's producer (19100 t) [4]. Despite these figures, due to the small country size, chestnut production in Portugal still represents a high contribution for the trade balance. The greatest production area for this fruit is located in Trás-os-Montes region (northeast of Portugal). Being a natural product, chestnut production can be affected by several factors including climatic conditions such as temperature, sunlight and precipitation, and also cultivation inputs, for exemple nutrients, minerals, and diseases and pests [3].

From a botanical point of view, chestnut fruit is a starchy nut composed by a seed protected by a membrane called the pellicle (episperm) and followed by a brown peel called "shell". This last involves the nut that is shielded by a spiny bur. When the fruit begins to mature, the bur modifies its colour, from green to yellow-brown, and breaks in 2-4 lengthways lines liberating three nuts. Sometimes the bur releases the chestnut fruits from the tree; however, more often the bur falls and opens completely on the ground as a result of the high humidity, liberating the fruits [5] (Fig. **1**). Even though the shell and pellicle are difficult to remove, this nut presents interesting properties which will be presented throughout this chapter.

Fig. (1). *Castanea sativa*: **(a)** Tree, **(b)** Chestnut fruit in the bur, **(c)** Fruit.

There are some review studies that discuss the nutritional properties of chestnuts *in natura* [3, 6]; however, despite not being usual to consume it raw, there are few works reporting the effects of different types of processing on its physicochemical properties and bioactivity. Thus, in this chapter we intend to evidence the beneficial effects of chestnut on human health and in which way processing may affect the physicochemical properties of this fruit.

PHYSICOCHEMICAL PROPERTIES OF CHESTNUT

Numerous studies on the physicochemical characterization of different varieties of chestnuts from different countries have been published. From the nutritional point of view, chestnut has interesting properties. Chestnuts are a good source of fibres, starch, protein, aminoacids, minerals, lipids, vitamin E and phenolic compounds, being a naturally gluten-free product.

The proximate nutritional composition of raw chestnuts(*Castanea sativa* Mill.) is detailed in Table **1**. The major compound is water, with moisture ranging between 40 and 64 g/100 g fresh weight (FW). This high moisture content represents a strong disadvantage for long-term preservation purposes, due to the high probability of mould formation, together with a significant weight loss during storage. On dry basis (DM), carbohydrates are the main components of chestnuts (75-91%), particularly starch (39 and 82%). Several studies have been reported about the specific content of amylose and amylopectin [15, 19, 20], accounting approximately for 33% and 67% of the starch content, respectively. The starch can improve health by giving energy from the catabolism process of amylose and amylopectin into glucose, as well as it can have a positive role on gut functions

due to the presence of short-chain fatty acids (SCFA) that result from the bacterial catabolism of amylopectin-derived dextrins [19, 21]. Also, some researchers defend that starch is partially hydrolysed into glucose during storage, which gives increased sweetness to chestnuts [10, 15]. Indeed, this is one of the most important quality parameters, with recognized differences between varieties [22], being the sweetest fruits highly appreciated by the consumers. Sucrose is the main free sugar in chestnuts (Table **2**), followed by glucose and fructose. Other sugars such as maltose and xylose can also be present in chestnut fruits, but in reduced amounts.

Table 1. Proximate composition of raw chestnut fruits from several cultivars and origins (*Castanea sativa* Mill).

Moisture (g/100g FW)	Carbohydrates (g/100g DM)	Starch (g/100g DM)	Total minerals (g/100g DM)	Crude protein (g/100g DM)	Crude fat (g/100g DM)	Energetic value (kcal/100g DM)	References
40-64	-	39-67	1.5-8.0	3.9-10.9	0.9-4.4	-	[3]
52-55	-	-	1.5-1.9	5.0-6.5	1.6-1.8	401-402	[7]
53-54	89-91	-	1.7-2.4	5.2-6.4	1.5-1.7	400-402	[8]
46-53	-	39-48	1.5-2.2	4.9-7.4	1.7-3.1	-	[9]
-	75-86	54-70	1.0-3.2	4.9-10.9	0.5-2.0	-	[10]
46-51	-	64-65	1.9-2.3	3.9-5.1	1.6-1.9	-	[11]
41-54	-	49-54	2.0-2.7	-	1.9-4.4	413-427	[12]
-	-	-	-	4.1-5.8	-	-	[13]
48-59	-	57-82	1.8-3.1	6.0-8.6	1.3-3.0	-	[14]
40-60	-	42-66	1.8-3.2	4.5-9.6	1.7-4.0	-	[15]
48-57	-	49-52	2.1-2.4	4.2-7.0	2.2-4.5		[16]
50-60	-	-	1.7-2.6	4.5-9.9	1.9-4.7		[17]
42-53	-	-	1.2-2.4	4.2-5.6	3.0-4.6		[18]
40-64	75-91	39-82	1.0-8.0	3.9-10.9	0.5-4.7	400-427	Min-Max
Fibre (g/100g DM)							
NDF	**ADF**	**ADL**	**Celulose**				**References**
2.7-28.9	0.5-4.5	0.02-1.3	0.5-3.6				[3]
2.7-3.8	0.5-0.6	0.02	0.5-0.6				[7]
3.2-3.7	0.5-0.6	-	0.5				[8]
13.8-24.4	1.9-3.2	-	-				[9]
13.1-13.8	2.5-2.7	0.2-0.3	2.3-2.4				[11]
13.8-19.9	3.0-3.6	0.4-0.6	2.6-3.1				[12]
9.4-28.5	2.3-4.5						[15]
2.7-28.9	0.5-4.5	0.02-1.3	0.5-3.6				Min-Max

Fibre is also an important nutrient in chestnuts (Table **1**). Among fibre fractions neutral detergent fibre (NDF) represents 2.7 to 28.9% and acid detergent fibre (ADF) varies from 0.5 to 4.5%, while acid detergent lignin (ADL) only represents 0.02 to 1.3% and cellulose 0.5 to 3.6%, all on dry matter (DM) basis. Dietary fibre

has been described as the fragments of plant components which are not hydrolysed by human enzymes and it includes cellulose, hemicellulose and lignin, as well as other substances, namely waxes, cutin, and suberin [25].

Table 2. Free sugar contents of raw chestnut fruits (*Castanea sativa* Mill.) (g/100g DM).

Sucrose	Glucose	Fructose	Maltose	Xylose	References
6.6-29.7	<DL -2.3	0.04-2.3	0-1.8		[3]
8.9-21.3	-	-	-		[10]
6.6-19.5	<DL -0.3	0.04-0.3			[14]
5.1-9.8	0.1-0.3	0.05-0.2	-	-	[16]
10.9-22.1		0.44-2.22			[18]
29.7	1.4	1.9	1.5	0.4	[20]
3.7-24.2	1.0-6.8	0.6-5.3	-		[22]
6.6-19.5	<DL -0.3	0.04-0.3	-		[23]
10.2-13.7	0.07-0.3	0.11-0.4	0.4-0.6		[24]
3.7-29.7	0.07-6.8	0.04-5.3	0-1.8	0.4	Min-Max

DL –Detection limit

Dietary fibres are associated to positive health effects, including "stimulation of *Bifidobacterium* and *Lactobacillus* in the intestine, decrease in cholesterol levels, reduction of the risk of cardiovascular diseases, positive regulation of insulin response, increase in anticancer mechanisms and positive effects on metabolism of blood lipids" [26]. When the fermentation of dietary fibre occurs SCFA are produced. These compounds are very important to garantee the maintenance of colonic integrity and metabolism. They can also be considered therapeutic agents for the treatment of some illnesses such as colitis, antibiotic associated diarrhoea and colon cancer [27].

Few studies have been performed on proteins in chestnuts; however, proteins range from 3.9 to 10.9 g/100 g DM (Table **1**), being identified some essential amino acids such as arginine (Arg), isoleucine (Ile), leucine (Leu), phenylalanine (Phe), threonine (Thr), tryptophan (Trp) and valine (Val), and non-essential amino acids such as alanine (Ala), asparagine (Asn), aspartic acid (Asp), glutamine (Gln), glutamic acid (Glu), glycine (Gly), serine (Ser) and tyrosine (Tyr) [11, 13].

Concerning minerals (as total ashes), these vary from 1.0 to 8.0 g/100 g DM, being detected important macro-elements (K, P, Mg, Ca, S and Na). The most important in this group is potassium. Some interesting micro-elements (Fe, Mn,

Zn, Cu, B and Se) have also been identified (Table **3**). Mineral intake has an important role in human health. Calcium has important biological functions, namely giving rigidity to the skeleton [3]. Magnesium has an important enzymatic role (cofactor), is involved in the synthesis of some compounds (namely proteins, RNA and DNA), and keeps the electrical potential of nervous tissues and cell membranes [3]. Micro-elements also play important roles in health. For example, iron is related to the transport of oxygen through red blood cell haemoglobin. Moreover, iron and zinc are responsible by the synthesis and catabolism of some nutrients and xenobiotics, once are essential components of enzymes that participate in these processes [28].

Table 3. Mineral contents of raw chestnut fruits (*Castanea sativa* Mill.) (g/100g DM).

K	P	Mg	Ca	S	Na	Fe	Mn	Zn	Cu	B	Se	References
473-1476	68-305	47-100	26-72	26-133	0.8-30.9	1.4-10.9	1.5-12.5	0.6-3.1	0.4-2.7	3.0-3.1	0.4-0.8	[3]
473-974	104-148	63-93	41-51	-	0.8-3.9	5.3-10.9	3.1-8.0	1.4-3.1	1.3-2.7	-	-	[9]
761-1271	107-191	70-160	43-230	-	6-41	0.4-5.7	0.7-5.5	1.8-9.1	0.6-3.8	-	-	[10]
789-1130	68-305	49-100	26-72	-	3.0-26	1.4-2.4	1.7-12.5	1.0-1.9	0.6-1.0	-	-	[15]
740-940	106-159	54-66	55-70	-	-	2.1-6.1	1.3-4.1	0.9-1.7	0.3-2.3			[16]
633-811	110-142	49-58	31-46	35-46	21.4-28.3	3.0-7.1	1.5-5.1	0.8-1.1	0.6-0.9	3.0-3.1	0.5-0.7	[24]
473-1476	68-305	47-160	26-230	26-133	0.8-41	0.4-10.9	0.7-12.5	0.6-9.1	0.3-3.8	3.0-3.1	0.4-0.8	Min-Max

Some differences in protein and mineral contents can be found between varieties. These differences can be due to genetic differences, altitude and soil type, among others, as suggested by Pereira-Lorenzo *et al*. [15]. Míguelez *et al*. [14] refer that soils with a higher content of schist originate fruits with higher protein content than granite-based ones.

Although chestnuts present a low crude fat content (0.5-4.7 g/100 g DM) (Table **1**), its lipids are constituted by low saturated fatty acids (SFA) (14.1-27.7%) and high unsaturated fatty acids (USFA) contents, namely monounsaturated (MUFA) (17.9-40.8%) and polyunsaturated (PUFA) (41.5-60.1%) fatty acids. The main individual fatty acids in chestnuts are linoleic (C18:2) (37.6-51.4%), followed by oleic (C18:1) (17.4-38.2%), palmitic (C16:0) (12.0-17.3%), and α-linolenic acid (C18:3) (4-10.3%) (Table **4**). This fatty acids profile, low in saturated fatty acids and high in polyunsaturated ones, with the presence of omega 3 fatty acids, plays an important role in several physiological processes by regulating plasma lipid levels, neuronal development, and by having cardiovascular, immune and visual

functions, as well as insulin action [31].

Table 4. Fatty acid composition (g/100g fatty acids) of raw chestnut fruits (*Castanea sativa* Mill.).

SFA	C16:0	MUFA	C18:1	PUFA	C18:2	C18:3	References
14.1-27.7	-	17.9-39.3	17.4-37.6	42.0-60.1	37.6-50.9	-	[3]
16.2-19.4	14.2-17.3	30.9-38.7	29.6-37.4	42.0-51.9	37.9-45.5	4.0-6.4	[7]
16-19	16-17	36-38	35-37	43-48	38-40	4-5	[8]
14.1-18.6	12.5-16.8	22.5-39.3	20.7-37.6	42.0-60.1	37.6-50.9	4.4-10.0	[29]
15.9-24.6	12.0-16.8	21.7-40.8	21.3-38.2	41.5-56.7	37.9-51.4	3.56-10.3	[30]
14.1-27.7	12.0-17.3	17.9-40.8	17.4-38.2	41.5-60.1	37.6-51.4	4-10.3	Min-Max

Chestnut fruits also contain vitamins, such as, vitamin E and C (Table **5**). Vitamin E has an effect to protect the unsaturated fatty acids from oxidation, being γ-tocopherol the major vitamer (0.38-2.73 mg/100g FW). From the nutritional point of view, vitamin E has shown several benefits to human health, minimizing the harmful effects of inflammatory diseases (*e.g.* rheumatoid arthritis or hepatitis) [35], fortifying the immune system and decreasing the risk of cancer [36], as well as a probable contribution to decrease the viral load in HIV-infected patients [37], and aid in the treatment of Parkinson's syndrome [38].

Table 5. Vitamin C and E contents of raw chestnut fruits (*Castanea sativa* Mill.).

Vitamin E (mg/100 g FW)					
Tocopherol			Tocotrienols		References
α	γ	δ	γ	δ	
2×10^{-3}-1×10^{-2}	0.38-2.73	2×10^{-2}-10×10^{-2}	14×10^{-2}-39×10^{-2}	1×10^{-3}-4×10^{-3}	[3]
23×10^{-4}-100×10^{-4}	0.38-0.46	216×10^{-4}-285×10^{-4}	197×10^{-4}-399×10^{-4}	14×10^{-4}-32×10^{-4}	[8]
-	0.41-2.30	2×10^{-2}-10×10^{-2}	-	-	[24]
22×10^{-4}-100×10^{-4}	0.38-0.478	195×10^{-4}-332×10^{-4}	141×10^{-4}-418×10^{-4}	11×10^{-4}-41×10^{-4}	[32]
22×10^{-4}-1×10^{-2}	0.38-2.73	195×10^{-4}-10×10^{-2}	141×10^{-4}-39×10^{-2}	11×10^{-4}-41×10^{-4}	Min-Max
Vitamin C (mg/100 g DM)					
Ascorbic Acid		Dehydroascorbic acid			**References**
	30.8-40.2[a,b]				[3]
	0.77-1.64[a]				[3]
4.2-7.2		3.1-6.8			[3]
28-128					[18]
4.7-6.7[b]		4.04-6.13[b]			[24]
	40.0-69.3[a]				[33]
4.52-16.4		-			[34]

[a]Ascorbic + dehydroascorbic acids.
[b]Values are presented as mg 100 g^{-1} FW.

Vitamin C is a term that is used for all compounds with biological activity of *L*-ascorbic acid. *L*-Ascorbic and *L*-dehydroascorbic acids are the main sources of

vitamin C [39]. Both species are absorbed in the gastrointestinal tract [40]. Vitamin C is probably the most important hydrophilic antioxidant and it is believed to be of high importance for defence against diseases and degenerative processes produced by oxidative stress [41].

Besides ascorbic acid, other organic acids have been identified in chestnut fruits such as citric, malic, quinic, fumaric and oxalic acids (Table **6**). It was observed that the ranges of some organic acids were high probably due to the different extraction methods used. Organic acids might have a protective effect against multiple diseases as a result of their antioxidant activity [43]. Moreover, they can affect the organoleptic characteristics of fruits and vegetables such as the flavour [44].

Table 6. Organic acids contents of raw chestnut fruits (*Castanea sativa* Mill.) (mg/g DM).

Citric acid	Malic acid	Quinic acid	Fumaric acid	Oxalic acid	Oxalic acid + *cis*-aconitic acid	Malic acid + quinic acid	References
1.5-8.8	1.5-5.4	-	-	-	-	-	[17]
-	1.5-3.3	-	-	-	-	-	[18]
0.04-0.11	-	-	0.2×10^{-3}-1.4×10^{-3}	-	1.3×10^{-3}-7.1×10^{-3}	3.6×10^{-2}-11×10^{-2}	[34]
12	5	13	0.4	0.7	-	-	[42][a]
0.04-12	1.5-5.4	13	0.2×10^{-3}-0.4	0.7	1.3×10^{-3}-7.1×10^{-3}	3.6×10^{-2}-11×10^{-2}	Min-Max

[a]The values refer to chestnuts irradiated at 0, 0.5, 1, 3 and 6 kGy.

The antioxidants present in natural products are associated to the prevention of certain human diseases caused by oxidative stress such as inflammatory diseases, ischemic diseases, cancer, hemochromatosis, emphysema, gastric ulcers, hypertension and preeclampsia, neurological diseases, alcoholism, smoking-related diseases and others [45]. Several studies have been performed on the antioxidant activity of different parts of chestnuts, namely, seed, leaf, flower, bur, outer and inner skin, and fruit. As can be observed from Table **7** different methods have been applied that difficult data comparison. Nevertheless the methods applied have included the scavenging activity on ABTS and DPPH radicals (measured through the decrease in ABTS and DPPH radical absorption after exposure to radical scavengers), reducing power (measured by the conversion of a Fe^{3+}/ferricyanide complex to the ferrous form), β-carotene bleaching inhibition (by neutralizing the linoleate-free radical and other free radicals formed in the

system that attack the highly unsaturated β-carotene model), FRAP (measured by the capacity of reducing the Fe(III)/tripyridyltriazine complex to the ferrous form (blue colour) with an increase in absorbance at 593 nm), hemolysis inhibition (measured by the inhibition of erythrocyte hemolysis), hydroxyl radical scavenging activity (measured by inhibition of the hydroxyl radical generated by the Fenton reaction (Fe^{2+}/H_2O_2)), and TBARS inhibition (measured by the inhibition of the lipid peroxidation through the decrease of thiobarbituric acid reactive substances (TBARS)). For chestnuts, some studies reported that the antioxidant activity can vary between regions with different edaphoclimatic conditions [54, 55], being the coldest places those with the highest antioxidant activity. Indeed, severe climatic conditions might signalling for the plant defence mechanisms, including the production of important antioxidants, particularly phenolic compounds [54, 55]. Barreira *et al*. [47] reported that leaves, skins (outer and inner skins) and flowers presented the highest values of antioxidant activity comparing with chestnut fruits. When comparing chestnuts with other nuts it can be observed that the antioxidant activity of chestnut fruits [47] was of the same order of magnitude to those obtained for almond, peanut and pine nut [56, 57], while it was lower than those observed for hazelnut and walnut for the DPPH radical scavenging method. Nevertheless, the extraction methods were sometimes different. Similar results were also obtained for the reducing power method.

Due to their importance, the total phenol contents and some specific phenolic compounds determined in different chestnut parts, such as bur, flowers, leaves, outer shell, inner shell, and fruit are also presented in Table **8**. Gallic and ellagic acids are the main phenolic acids in fresh chestnut fruits; however, many other phenolic compounds have also been identified, such as vescalagin (0.06 to 0.10 mg/g FW), castalagin (0.41 to 0.82 mg/g FW), tannin T1 (0.06 to 0.09 mg/g FW), tannin T2 (0.05 to 0.09 mg/g FW), acutissimin A (0.05 to 0.08 mg/g FW) acutissimin B (0.41 to 0.51 mg/g FW) and ellagic acid derivatives (0.11 to 0.16 mg/g FW) in the outer shell of chestnuts [59]. In the inner shell of chestnuts these compounds are also detected at the following concentrations: vescalagin, 0.04 to 0.07 mg/g FW; castalagin, 0.07 to 0.21 mg/g FW; tannin T1, 0.03 to 0.07 mg/g FW; tannin T2, 0.03 to 0.04 mg/g FW; acutissimin A, 0.03 to 0.04 mg/g FW; acutissimin B, 0.04 to 0.09 mg/g FW; and ellagic acid derivatives, 0.0 to 0.01

mg/g fresh weight have also been detected [59]. Also Otles and Selek [55] have identified some phenolic compounds on chestnut fruits, namely, syringic+caffeic acids (0.002 to 0.02 mg/g FW), vanillic acid (0.15 to 0.92 mg/g FW), rutin (0.005 to 0.026 mg/g FW), catechin (0.024 to 0.13 mg/g FW), chlorogenic acid (0.004 to 0.12 mg/g Fw), *p*-coumaric acid (0.004 to 0.033 mg/g FW), ferulic acid (0.004 to 0.015 mg/g FW) and naringin (0.007 to 0.021 mg/g FW). These compounds have several positive effects on health, for example antioxidant properties, decrease of the risk of cardiovascular diseases, anticancer mechanisms and anti-inflammatory properties [60, 61]. The content of these compounds may vary due to several factors, such as climacteric conditions, soil type, precipitation and altitude. Dinis *et al*. [54] reported that the coldest ecotypes presented higher gallic and ellagic acid contents than the hottest ones for Judia cultivar, as already described for the antioxidant activity. Regarding flowers, Sapkota *et al*. [49] reported differences on phenolic content when comparing pre-bloom and full-bloom, showing higher phenolic content the flowers at pre-bloom than full-bloom.

Table 7. Antioxidant activity of different parts of chestnuts.

Tissue	ABTS radical	DPPH radical	Reducing power	β-Carotene bleaching inhibition	FRAP	Hemolysis inhibition	Hydroxyl radical	TBARS inhibition	Unity	Reference
Leaf	-	12.6-23.0	-	-	-	-	-	-	μg/mL (EC_{50})	[46]
Leaf	-	170	313	145	-	169	-	31.4	μg/mL (EC_{50})	[47]
Leaf	-	21.4	-	-	-	-	0	-	% (0.2 mg extract/mL solution)	[48]
Flower	-	74.9	87.3	161	-	196	-	9.93	μg/mL (EC_{50})	[47]
Flower	-	45.14-119.36	0.494-0.772[a]	-	-	-	-	-	μg/mL (EC_{50})	[49]
Catkin	-	38	-	-	-	-	43.6	-	% (0.2 mg extract/mL solution)	[48]
Bur	1.33-3.80	0.92-3.42	-	-	0.708-2.261[b]	-	-	-	mmol TRE/g extract	[50]
Outer skin	-	39.7	55.1	133	-	91.4	-	7.87	μg/mL (EC_{50})	[47]
Outer skin	-	21.4	-	-	-	-	21.8	-	% (0.2 mg extract/mL solution)	[48]
Inner skin	-	32.7	68.7	164	-	47.5	-	11.5	μg/mL (EC_{50})	[47]
Shell	-	-	-	-	475-3808	-	-	-	mmol AAE/mg extract	[51]
Fruit	4.77-8.15	-	-	-	-	-	-	-	μmoles TRE/g DM	[18]
Fruit	-	>10,000	9044	3632	-	3486	-	1117	μg/mL (EC_{50})	[47]
Fruit	-	0	-	-	-	-	5.5	-	% (0.2 mg extract/mL solution)	[48]
Fruit	0.564-1.046	-	-	-	-	-	-	-	mmol TRE/kg	[52]
Fruit	-	25.12-38.72	2.81-7.05	6.00-6.38	-	-	-	5.21-10.63	mg/mL (EC_{50})	[53]
Fruit	5.2-14.1	7.3-33.5	-	-	6.6-14.6	0.63-1.31	-	-	mg/g (EC_{50})	[54]
Fruit	-		-	-	9.08-14.15	-	-	-	mM $FeSO_4$/g DM	[55]

TRE - Trolox equivalent;AAE - Ascrobic acid equivalent;

[a]Absorbance at 700 nm of 1 mg/mL solution; [b]Value expressed in mmol AAE/g extract;

Table 8. Total phenols and individual phenolic compound contents present in different parts of chestnuts.

Tissue	Total phenols	Unity	Gallic acid	Ellagic acid	Unity	References
Leaves	103	mg CE/$g_{extract}$	-	-	-	[47]
Flowers	298	mg CE/$g_{extract}$	-	-	-	[47]
Flowers	251.6-467.9	mg GAE/$g_{extract}$	-	-	-	[49]
Bur	168.8-359.8	mg GAE/$g_{extract}$	-	-	-	[50]
Bark	-	-	-	0.71-21.6	mg/g DM	[58]
Shell	266-597	mg GAE/$g_{extract}$	-	-	-	[51]
Outer shell	510	mg CE/$g_{extract}$	-	-	-	[47]
Outer shell	61.9-84.9	mg GAE/g FW	0.14-0.33	0.14-0.18	mg/g FW	[59]
Inner shell	475	mg CE/$g_{extract}$	-	-	-	[47]
Inner shell	76.0-106.0	mg GAE/g FW	0.22-0.34	0.03-0.07	mg/g FW	[59]
Pericarp	-	-	-	0.04-0.19	mg/g DM	[58]
Pellicle	-	-	-	0.03-0.091	mg/g DM	[58]
Fruit	15.80-22.69	mg GAE/g FW	3.46-9.07	2.71-9.64	mg/g FW	[11]
Fruit	7.66-18.30	mg GAE/g FW	8.03-24.89	7.28-47.78	mg/g FW	[13]
Fruit	13.6-18.8	mg GAE/g DM	0.00376-0.0204	nd – 0.0249	mg/g DM	[17]
Fruit	0.0872-0.157	mg GAE/g DM	-	-	-	[18]
Fruit	3.73	mg CE/$g_{extract}$	-	-	-	[47]
Fruit	3.61-3.63	mg GAE/$g_{extract}$	-	-	-	[53]
Fruit	9.6-19.4	mg GAE/g DM	4.1-29.0	6.2-11.9	mg/g DM	[54]
Fruit	5.00-32.82	mg GAE/g DM	0.0859-0.277	0.0116-0.0487	mg/g DM	[55]
Fruit	-		-	tr-0.05	mg/g DM	[58]

PRINCIPAL POSTHARVEST TECHNOLOGIES

Cold Storage

Chestnut fruits are a seasonal product and several post-harvest techniques have been applied to preserve them, being cold storage one of the most commonly used. However, some studies reported modifications on some physicochemical properties of the fruits along cold storage. An increase of the dry matter content due to water loss and NDF fibre content has been observed when comparing chestnuts subjected to cold storage during three months with fresh chestnuts [12]. On the other hand, a decrease on starch content was observed, explained by the enzymatic catabolism of starch into soluble sugars. Some studies reported that sucrose content can increase along storage time [24, 62 - 64], while glucose and fructose remained almost constant during storage [24, 62]. Nevertheless, Chenlo *et al*. [64] reported that fructose depended on the moisture content because at low moisture contents fructose practically disappeared while it increased in samples stored at high moisture contents.

Regarding to vitamin E, a significant increase on δ-tocopherol and γ-tocopherol

contents in fresh weight was observed along cold storage [24]. On contrary, a decrease was verified on ascorbic acid concentration, while the dehydroascorbic acid content was not affected by the storage period. Also, an increase on the total phenols, gallic and ellagic acid contents was observed [13], but a decrease on the antioxidant activity determined by different methods was perceived after storage, with the exception of the β-carotene bleaching inhibition method for chestnut skins [65].

Drying

Hot air drying is another common technology applied to preserve chestnut fruits. Along the years, several studies using different dehydration methods have been performed, being hot air drying the most widely used. The aim of these studies was to evaluate several technological aspects, including drying kinetics [66, 67], drying characteristics and energy requirement for dehydration [68], the effect of drying temperatures on morphological, chemical, thermal and rheological properties of chestnut flours [69 - 71], and the effect of drying followed by rehydration on different chestnut properties [20, 72, 73].

Some of these studies reported a degradation on chestnut colour (browning) originated by the drying process, being more pronounced at higher temperatures [66, 72]. This can be a disadvantage because this characteristic is one of the most appreciated by the consumers of this nut. Moreover, Attanasio *et al*. [20] reported that sucrose content decreased significantly after drying at 60 °C, due to its thermal degradation. They also reported modifications on morphological characteristics after drying and rehydration as the products seemed more shapeless and the open pore volume of starch granules on dried samples increased. Correia *et al*. [69] observed that drying temperature affected chestnut flour properties, also depending on chestnut variety.

Regarding to the effect of hot air drying on other nutrients and bioactive compounds, no studies have been performed until now.

Osmotic Dehydration

Another dehydration method is osmotic dehydration. Along the years, some

studies have been performed using different osmotic agents such as sodium chloride, glycerol, glucose and sucrose [73 - 79], with the aim to evaluate mass transfer, dehydration kinetics of chestnut fruits and the effect of this treatment on chestnuts physical properties such as colour, size, shape, weight reduction (WR), water loss (WL), solid gain (SG), normalized moisture content (NMC). Again, no studies on the effect of osmotic dehydration on nutrients and bioactive compounds have been performed until now.

Irradiation

As previously mentioned, mould development is a particular concern in chestnut preservation due to its high moisture and carbohydrate contents. Chemical fumigation is one of the most effective disinfestation method but, due to the toxicity of the gases used for the operators and associated environmental problems, fumigation was banned in EU since 2010 [80, 81]. Thus, irradiation appears as an alternative technique, being nowadays considered a more environmentally friendly technology, meeting the food safety requirements [6]. Different types of irradiation have been tested along the years, being the most common the gamma irradiation and the electron beam irradiation.

Some studies on the effect of gamma irradiation on chestnut properties referred the existence of no differences on the nutritional composition [63], or on sugars and fatty acid compositions [82] of irradiated chestnuts. Moreover, irradiation may protect antioxidants such as tocopherols and phenolic compounds, as the antioxidant activity seemed to increase when compared with non-irradiated samples [65]. On the other hand, Carocho *et al*. [53] reported that irradiation dose had a significant role on the antioxidant activity, being 3kGy the dose that gave the best results with the highest phenolic content and the lowest EC_{50} values for DPPH scavenging activity, β-carotene bleaching and TBARS inhibition, suggesting a higher antioxidant activity.

Regarding to electron beam irradiation, Carocho *et al*. [53] reported that the irradiated samples presented also higher phenolic content and antioxidant activity than non-irradiated ones, except for flavonoids whose content decreased. In this study the irradiation dose that gave the best results was 1 kGy. However, Carocho

et al. [53] reported that the effect of electron beam irradiation on chemical and nutritional properties of chestnuts was very low.

Industrial Processing and Other Ways to Prepare Chestnuts for Consumption

Few studies have been performed with the aim to evaluate the effect of industrial processing on chestnut properties, such as flame peeling and freezing with CO_2. Regarding the proximate composition, small variations were observed when comparing fresh chestnuts with those submitted to industrial processing. These industrial processing methods had some positive effects, such as an increase on crude energy and fibre (NDF, ADF and cellulose) contents [12], as well as in free sugar contents [24]. On the other hand, a negative effect on starch and to a lesser extent in fat content [12] was observed with a decrease on these compounds. Concerning the bioactive compounds, industrial processing contributed positively by promoting a significant increase on total phenols, gallic and ellagic acids contents [13], and also on tocopherols amounts, while some negative effects, namely a decrease on some free amino acids [13] and vitamin C contents [24], were observed.

Another well-known chestnut processing is roasting. Some studies have been performed on the roasting effect on chestnuts physicochemical properties. Künsch *et al*. [83] observed that this process had a little effect on the chemical composition of different chestnut varieties, since the amount of starch, sucrose and fatty acids remained the same. Gonçalves *et al*. [17] observed that roasted chestnuts presented higher protein, fibre, citric acid, gallic acid and total phenolic contents than raw chestnuts. Regarding the effect of roasting on the bioactive compounds few studies have been performed until now. Barros *et al*. [52] observed that some cultivars were more affected by roasting than others concerning the hydrophilic antioxidant activity.

Boiling is also another cooking process very used by chestnut consumers. As expected, boiling promoted a decrease in dry matter content, as well as a decrease in chestnut colour such as brightness [84]. When comparing raw with cooked chestnuts (roasted and boiled) some studies reported differences between them.

Gonçalves *et al*. [17] observed that boiled chestnuts showed higher fat, soluble fibre, gallic and ellagic acids and total phenolic contents than raw chestnuts. Nevertheless, the last ones had significantly higher malic acid content than cooked nuts. Ribeiro *et al*. [34] observed a decrease on vitamin C (ascorbic acid) content indicating that this vitamin was degraded during the boiling process due to the high temperatures. Barros *et al*. [33] also detected a decrease in vitamin C content. Although vitamin C losses between 25 to 45% and 2 to 77% were observed for boiling and roasting processes, respectively, chestnuts subjected to both processes may be still a good source of this vitamin once it may represent 16.2% to 22.4% and 19.4% to 26.8% of the recommended dietary intake for adults, respectively.

CONCLUDING REMARKS

In conclusion, most of the studies until now performed had focused on physicochemical characteristics of raw chestnuts, being analysed different parts of this nut, namely flowers, leaves, outer and inner skins, bur, among others. The results point out that chestnut is a nut with important constituents such as antioxidants and vitamins, as well as with low fat and high starch contents, being also a gluten-free nut. However, generally this fruit is not consumed raw, being subjected to different types of processing, namely, roasting and boiling. There are some works that had studied the effect of processing on physicochemical properties, being some modifications observed. Nevertheless more studies should be done with the purpose to valorise and develop new products based on chestnuts.

CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest to declare for this publication.

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