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Nutritional values of edible chestnuts (*Castanea* species) – a short comparative review

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Abstract

Chestnuts are valuable nuts (fruits) of the trees from *Castanea* species, especially *C. sativa* (European chestnut), as well as *C. pumila* from North America, *C. mollissima* or *C. crenata* from Asia. In this short review a comparison on the main nutritional components of various edible chestnuts is presented. Thus, the chemical composition including lipids, proteins, carbohydrates/starch, ash, minerals and caloric contents are discussed for the main chestnut species, including the content of biologically active compounds (antioxidants or vitamins) in various parts of the fruit or tree. An important part of the review is focused on the fatty acid profile and triglyceride composition of the most consumed nuts from *Castanea* species, i.e. *C. sativa*, *C. mollissima*, *C. pumila* and *C. dentata*. The influence on various processing, handling and storage parameters on the composition of chestnuts was also discussed.

The review reveals the importance of the edible chestnuts as valuable foods. They have high content of starch, but also important contents of biologically active compounds such as polyphenols, antioxidant vitamins C and E, potassium and phosphorus. Moreover, the lipid fraction of chestnuts is rich in oleic acid, as well as α-linolenic acid, an omega-3 acid. These characteristics make chestnuts valuable, but also a healthy source of nutrition for the consumer, and more attention should be paid to their use as healthy foods.

Keywords: Chestnut, *Castanea* species, *Castanea sativa*, *Castanea mollissima*, *Castanea pumila*, *Castanea crenata*, *Castanea dentata*, healthy food, omega-3 fatty acid

1. Introduction

Chestnut is the generic name for trees of the *Castanea* species from the Fagaceae botanical family. The number of these species is relatively small, with only a few being identified, especially in the northern hemisphere, in temperate regions, including Europe (some species are hybrids). The nuts of this tree are called chestnuts and are edible from certain species (Figure 1). The most known species of *Castaneae* are [1-6]:

- *Castanea sativa* (European species, also called sweet chestnut, comes from southern Europe; edible nuts are used, but also the wood);
- *Castanea dentata* (a species from North America, in the eastern region, one of the most important afforestation trees due to its rapid growth; wood is used mainly for timber);
- *Chestnut pumila* (chestnut from Virginia, United States of America, small in size compared to other species; edible chestnuts are used for *C. pumila* and timber for *C. ozarkensis*);

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- *Castanea mollissima (*chestnut from the region of China, also known as Chinese chestnut; it is grown mainly in East Asia; edible nuts are used);
- *Castanea henryi* (chestnut from southeast China, up to 30 m, with smaller nuts; wood is used mainly for timber);
- *Chestnut seguinii* (chestnut with characteristics similar to the above; firewood in particular is used);
- *Chestnut crenata* (chestnut native to Japan and Korea, important for the production of edible chestnuts);
- *Chestnut davidii* (chestnut native to China; mainly used for firewood);
- *Chestnut floridana* (chestnut from the southeastern United States of America - Florida, used mainly as an ornamental tree);
- *Chestnut alnifolia* (chestnut from the southeastern United States of America, used mainly as an ornamental tree);
- *Chestnut paucispina* (chestnut from the southeastern United States of America).

Figure 1. European chestnut nuts (*Castanea sativa* L.)

Today, chestnuts are grown in many temperate regions of the Globe, especially for the edible nuts of *C. crenata*, *C. dentata*, *C. mollissima* and *C. sativa*, but also for wood or as ornamental trees. *C. sativa* has been naturalized even in temperate areas of the Himalayas [6]. There are also documents attesting to the cultivation of chestnuts as early as the year 2000 BC. The chestnut is mentioned in documents from the time of Alexander the Great, the Romans or the Greeks around 400 BC. Chestnuts have a high carbohydrate content and were currently replacing potatoes [5-7].

Regarding the production of *C. sativa*, it increased from ~300000 ha in 1996 to over double in 2016 (almost 603000 ha) [3]. This is also the trend of the production of edible chestnuts, with an increase from almost 678500 tons in 1996 to over 2261500 tons in 2016. The increase in productivity is more than double, which indicates an increasing consumption of such nuts with high nutritional value. The largest producer and consumer of chestnuts is China, followed by South Korea, Bolivia, Turkey, Italy, Japan, Greece, Portugal, France and Spain.

2. Use of chestnuts in food

2.1. General aspects regarding the use of chestnuts in the diet

By far, the most cultivated and used tree among these species is *C. sativa*, which is also called the "bread tree". Its nuts are valuable both nutritionally and for some pharmaceutical applications. In addition to their nutritional value, chestnuts have a specific, pleasant taste and smell, given the presence of carbohydrates, minerals, vitamins, proteins and fiber, but also lipids in smaller quantities. They also have an important tannin content, which gives them a slight bitter taste and astringency [2-6,9-12].

They are sold fresh, can be cooked at home or processed industrially. Processed chestnuts are sold in boiled, fried, frozen at -40 °C, dried or "crystallized". It is also sold in the "cooked" version, which involves immersion in cold water or hot water (hydrocooling or thermohydrotherapy), which increases their shelf life, but also changes their chemical composition [3].

Chestnuts can be used as an ingredient for various types of bread or cakes, soups or other foods, as well as for gluten-free products, in yoghurts and other dairy products [3].

2.2. Nutrient components specific to chestnuts

The use of chestnuts in the diet is closely linked to the replacement of other products with a high starch content. The starch content of chestnuts, over 50% of the total, depends on:

- Species / variety;
- Harvest year;
- Genetic factors;
- Fruit processing.

In addition to other sources of starch, chestnuts are gelatinized at ~56 °C. Also, its nutritional value and food use are due to its high sugar content, such as sucrose, which accounts for about a third of all simple saccharides. The water content of about 50% in fresh chestnuts makes them suitable for industrial processing. The lipid content is quite low (0.7-10 %), but it is of very good quality, including the presence of glycerides of unsaturated fatty acids (which includes omega-3 fatty acids, such as α-linolenic acid), but also tocols and phytosterols (part of which will be presented in detail below). Last but not least, chestnut protein and fiber are less influenced by the factors mentioned above, their content and type being similar to other nuts. Among the important amino acids, L-Asp, L-Glu and L-Arg are dominant in chestnut proteins / fibers. A special amino acid, rarely found in fruit, is γ-aminobutyric acid (GABA), at concentrations up to 0.2 mmol/g dry product. GABA is involved in reducing blood pressure and heartbeats, and is also an important neurotransmitter in the mammalian central nervous system [3].

Other important components in chestnuts, which make them valuable in food as well as pharmaceuticals, are antioxidants, especially polyphenols and enols (flavonoids, gallic and ellagic acids, their derivatives, vitamin C) (Figure 2). Last but not least, the bioactive compounds in chestnuts are supplemented with vitamins, with a significant content for vitamin C and thiamine in the case of European chestnuts, respectively vitamin A, riboflavin, pantothenic acid and pyridoxine for Chinese chestnuts. Minerals also play an important role in the human diet, and chestnuts make a contribution in this regard for Ca, Mg, Na, K, P, Zn, B, Fe, Cu and Mn [1,3,7,8].

2.3. The influence of processing on the quality of chestnuts

Chestnuts are used in food either fresh or processed. The processing is performed in the following ways [3,5,6,13]:

- Boiling
- Baking;
- Frying;
- Preservation.

As a result of these processes, changes may occur in the composition of the chestnuts and, therefore, in their quality (Table 1). Carbohydrates are usually affected, total fiber, insoluble or soluble fiber may increase in relative content in ripe chestnuts, boiling reduces the content of simple sugars (sucrose, glucose, fructose), and starch changes its properties by processing, most likely due to the fusion of the individual granules in baking and boiling. Therefore, the sensory and rheological properties, the digestibility, are influenced. Proteins are resistant to various types of processing, although some changes may occur due to partial degradation of peptides and proteins, as well as the occurrence of the Maillard reaction at higher temperatures. On the other hand, the content of the lipid fraction in chestnuts is reduced by boiling, baking or frying. Polyphenolic compounds and vitamins are affected in the processing of chestnuts. This is due to the oxidation of polyphenols at high temperatures, but the total antioxidant activity of chestnuts is not significantly affected (processing also releases compounds with antioxidant activity which, in fresh chestnuts, are chemically bound). The most affected in the processing of chestnuts is vitamin C, which most likely oxidizes to dehydroascorbic acid under higher temperature conditions. Organic acids are also affected by the processing of chestnuts (e.g., malic acid in cooking / boiling) [3,5,9].

Table 1. Influence of processing on chestnut characteristics (adapted from [3])

Species	Type of processing	Influence on characteristics
C. sativa	Boiling	Increases lipid, gallic and ellagic acid contents. The citric acid content increases and the malic acid content decreases. Variations in total amino acids, minerals and vitamins (especially vitamin C)
C. sativa	Baking	Increases protein and fiber content, gallic acid and total phenols, decreases lipid content. There are variations in the content (profile) of fatty acids, starches and sugars. Variations in total amino acids, minerals and vitamins (especially vitamin C)
C. sativa	Conservation	Variations in polyphenolic, mineral and trace element content
C. sativa	Microwave baking	Increasing carbohydrate content and antioxidant activity
C. mollissima	Boiling	Reducing the content of lipids, proteins, sugars, amino acids, total polyphenols, total flavonoids and organic acids
C. mollissima	Baking	Reducing the content of lipids, proteins, sugars, amino acids, total polyphenols, total flavonoids and organic acids

C. mollissima	Frying	Reduction of the content of lipids, proteins, sugars, amino acids, total polyphenols, total flavonoids and organic acids, respectively of the content of ascorbic acid

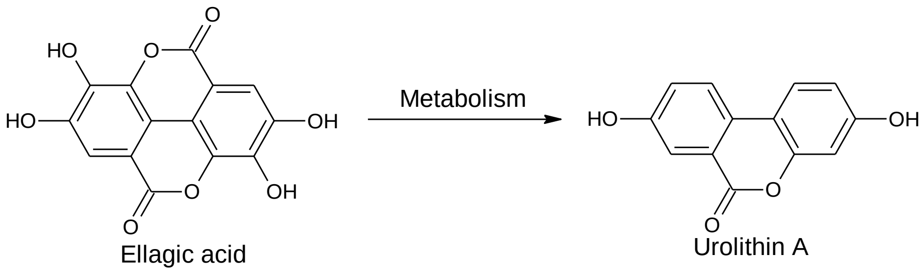

Figure 2. Metabolism of chestnut ellagic acid to urolithin

2.4. The influence of handling and storage on the quality of chestnuts

In principle, fresh chestnuts do not have a long shelf life due to their high moisture and saccharide contents. Moreover, peeled chestnuts are more prone to degradation. The following processes occur when handling and storing fresh chestnuts [3,5,6]:

- Weight loss (~1% after the first day of storage and ~26% after 3 months)
- Raising fungi.

In order to improve these aspects, the storage in controlled conditions of temperature and relative humidity was used, but also the use of techniques to inhibit the development of fungi. In the past, more fungicides were used, but the demand for quality, uncontaminated products, as well as the reduction of environmental and consumer health pollution risks led to the development of different conservation techniques, less polluting and not affecting the compositional and organoleptic quality of products. Thus, electron flux irradiation, natural film coating (e.g., soybean protein isolate), inert atmosphere packing (carbon dioxide) are used [1,3,5,6,10,11,14-18].

3. Use of chestnuts in human health

The components present in chestnuts make them an alternative remedy for various diseases of the human body, but also for maintaining its health.

Although they have a relatively low lipid content, they are a good alternative to other fruits in this class for their beneficial effects due to the presence of lipid components important for health. The profile of chestnut fatty acids is related to the components of biological processes (plasma lipid level, cardiovascular and immune functions, neurological development and visual function). It has been found that the use of chestnut extract reduces cholesterol and can prevent coronary heart disease. This is due to the reduced oxidation of low density lipoproteins (LDL), which are involved in cardiovascular disease. The same hypolipidemic and LDL-reducing effects occur with the consumption of phytosterols and chestnut fiber. Fiber is also linked to the beneficial effects against diabetes, some cancers, colitis and diarrhea associated with antibiotic use [2,3,5,6,9].

Consumption of chestnuts and chestnut-based pharmaceuticals is linked to protection against type 2 diabetes and the corresponding metabolic syndrome. It appears that certain components in chestnuts (fatty acids, fiber, protein and polyphenols) are involved in reducing oxidative degradation and inflammation of biomarkers in blood lipids. On the other hand, protection against some forms of cancer is related to the presence of omega-3 fatty acids and vitamins C, E, and gallic and ellagic acids, respectively (the latter in higher concentrations after boiling chestnuts). Elagic acid is metabolized to urolithine (A, B, D, etc.), a metabolic compound that plays an essential role in cardiovascular protection, having anti-inflammatory and anti-cancer properties (Figure 2). Vitamin C is involved in the formation of blood vessels, bone and even teeth, in the activation of B vitamins, folic acid, the conversion of cholesterol to bile acids and tryptophan to serotonin. Vitamin E has strong antioxidant activity, with an effect against the oxidation of unsaturated lipids, LDL and other membrane components, reducing the risk of cancer and cardiovascular disease. Chestnut B vitamins reduce the risk of abnormal body development, with favorable effects on cognitive impairment and anemia [2,3,5,6,9].

Chestnuts are a valuable source of macroelements such as Ca, P, K, Mg and S, but also of trace elements (Fe, Cu, Zn, Mn). All these elements have beneficial effects on the body, namely [3,5,6]:

- Calcium: reduction of osteoporosis, risk of colon cancer, hypercholesterolemia and high blood pressure;
- Potassium: involved in transmitting the nerve impulse, contraction of the heart muscle, in problems of the muscles and skin;
- Phosphorus: in the production of ATP, GTP, in phosphorylation reactions, in bone pain, fatigue, skin sensitivity;
- Magnesium: in aging processes and related diseases (diabetes, metabolic syndrome, hypertension);
- Iron: in hypochromic anemia, in the synthesis of hemoglobin and myoglobin;
- Copper: in the functioning of enzymes, in leukopenia and neuropenia, respectively bone disorders;
- Zinc: in the immune system, in the functioning of the senses of taste and smell, in alopecia and anemia;
- Manganese: in the control of cholesterol, red blood cells.

Because chestnuts do not contain gluten, they are valuable for products intended for consumers and patients with wheat / gluten allergies or celiac disease [3].

In addition, other parts of the chestnut are used for various pharmaceutical and medicinal benefits, namely [3]:

- Flowers, as a source of nectar and pollen for bees, with antioxidant and antimicrobial effects;
- Chestnut honey, considered to be of superior quality, used to treat wounds, diabetic ulcers, colds, gastric reflux or other respiratory and gastrointestinal disorders (including *Helicobacter pylori*) due to its high content of flavonoids and other phenolic compounds (caffeic, *p*-hydroxybenzoic and protocatechuic acids);
- Chestnut propolis, with antioxidant and antimicrobial effects, but also against hereditary spherocytosis (anemia characterized by the presence of abnormal red blood cells), depression and neurodegenerative diseases (Parkinson's and Alzheimer's diseases);
- Chestnut extracts, chestnut leaves, leaves and flowers – protective properties against liposome peroxidation, reducing oxidative stress, increasing cell viability by protecting DNA against degradative oxidation;
- Chestnut buds – chestnut bud extracts and preparations are used in homeopathy as well as in modern phytotherapy for the beneficial effects of the circulatory system or against recurrent cystitis.

4. Chemical composition of chestnuts

Chestnuts have a rich and valuable variety of nutrients and compounds with biological activity, namely [2,3,5-9,11,12,19]:

- Glycerides of unsaturated fatty acids in the lipid fraction;
- Vegetable proteins;
- Fibers;
- Starch / carbohydrates;
- Simple sugars;
- Organic acids;
- Minerals;
- Tocopherols;
- Phytosterols;
- Phenolic compounds;
- Vitamins etc.

A summary of the chemical composition of chestnuts of different species is presented in Tables 2-6 [3,6,14].

The moisture vary in a large range from 31.9 to 67.3 %. The highest content of nutritional components by classes was determined for carbohydrates (especially starch) with higher values for *C. mollissima*. Proteins were more concentrated in *C. sativa*, *C. mollissima* and *C. dentata* (up to 12.4 %), while *C. crenata* has a protein content less than a half. The lipid content is relatively low, but some *Castanea* species have important lipid fractions up to 10.2 % for *C. mollissima* and *C. dentata*. Due to the high content of carbohydrates, chestnuts have high energy values up to 410 kcal/100 g dry weight (Table 2) [3,14].

The most concentrated antioxidant compounds were determined in chestnut outer and inner shells (total phenol content up to 558 mg GAE/g dw, especially flavonoids), but also in *Castanea* flowers and leaves for all edible species (Table 3) [3,9]. Polyphenolic compounds are completed by antioxidant vitamins, such as vitamins C and E, with contents up to 134 mg/100 g dw for *C. mollissima* nuts (Table 4) [3,9,10,18].

Macro- and trace elements were important in various chestnut parts, especially in fruits. Thus, the maximum potassium and phosphorus contents were determined in chestnuts of *C. sativa* (up to 15871 and 3050 mg/kg dw, respectively) (Table 5) [3,20]. From the trace element class, manganese was the most important in chestnuts (Table 6) [3,20].

Table 2. The chemical composition (moisture: g/100 g fw; others: g/100 g dw; energy value: kcal/100 g dw) of chestnuts of different species; fw – fresh weight, dw – dry weight (adapted according to [3,6,14])

Parameter / Species	*C. sativa*	*C. mollissima*	*C. crenata*	*C. dentata*
Moisture	41.5-64.4	31.90-63.6	36.8-67.3	33.7-47.0
Lipid	0.70-5.37	0.90-10.2	0.10-1.70	1.32-10.2
Protein	2.20-12.4	3.88-12.20	2.0-5.30	4.83-10.2
Ash	0.80-4.39	1.44-2.20	0.80-2.60	1.10-1.90
Starch	40.99-66.18	40.80-71.08	36.09-56.32	-
Carbohydrates	41.60-94.2	49.07-81.6	28.7-88.43	32.4-48.57
Energy value	182.6-410.0	370.0-405.0	-	-

Table 3. Total phenol content (mg GAE/g dry product) and total flavonoids (mg GAE/g dry product) from various parts of *Castanea* species; GAE – gallic acid equivalent (adapted from [3,9])

Species / part	Total phenol content	Total flavonoid content
C. sativa/wood	40.8	-
C. sativa/bark	23.9-56.1	-
C. sativa/leaves	103-412.96	54.5-82.87
C. sativa/flower	251.62-327.17	27.93-160.0
C. sativa/pollen	64.02-103.8	-
C. sativa/brown outer shell	1.2	0.65
C. sativa/outer shell	510.0	503.0
C. sativa/inner shell	475.0	330.0
C. sativa/fruit skin	709.96	901.59
C. sativa/fruit	0.42-32.82	0.17-2.30
C. mollissima/fruit	2.24-27.7	1.13-2.62
C. mollissima/thorns	3.31-7.12	-
C. mollissima/shell	136.0-147.0	39.0-45.0
C. crenata/ leaves	256.98	-
C. crenata/brown outer shell	136.12-558.12	47.41-459.09
C. crenata/fruit peel	198.0-209.0	69.0-76.0

Table 4. Amino acid and vitamin contents of chestnuts from various *Castanea* species (mg/100 g dry product) (adapted from [3,6,9,10,18])

Species	Free amino acids	Vitamin E (as α-tocopherol)	Vitamin C (as ascorbic and dehydroascorbic acids)
C. sativa	374.6	0.74-16.53	40.0-69.3
C. mollissima	767.0	-	59.0-134.0

Table 5. Macroelement contents of different parts of chestnuts from various *Castanea* species (mg/kg dry product, except * - mg/kg fresh product) (adapted from [3,20])

Species / part	Ca	Mg	Na	K	P
C. sativa/fruit	260-2937	490-1852	27-526	4730-15871	680-3050
C. sativa/ buds	16600	3520	-	8100	1700
C. sativa/leaves	9300	2000	-	7000	1700
C. mollissima	287-1038	-	-	-	17-43
*C. crenata**	240	790	30	5040	960

Table 6. Trace element contents of different parts of chestnuts from various *Castanea* species (mg/kg dry product, except * - mg/kg fresh product) (adapted from [3,20])

Species/part	Zn	Fe	Cu	Mn

C. sativa/fruit	8.91-91	13.5-108.7	5.5-25.3	7.0-124.6
C. sativa/buds	66.0	28.0	10.0	1041
C. sativa/leaves	25.0	53.0	8.0	880
C. mollissima	15.0-36.0	6.0-23.0	7.0-15.0	-
*C. crenata**	11.6	15.2	3.9	21.6

5. Chestnut fatty acid profile

The lipid fraction of the chestnuts is less studied in terms of composition, it does not exceed 5.4 g/100 g dry product in *C. sativa*, 10.2 g/100 g in *C. mollissima* and *C. dentata*, respectively 1.70 g/100 g in *C. crenata* [3,6,12,13].

The most studied species in this respect is *C. sativa*, but there are some studies for other species such as *C. mollissima* [13]. Thus, peeled chestnuts of *C. sativa* and *C. mollissima* species were processed by boiling or baking at 92 °C and 182 °C, respectively, for various periods of time. The lipid fractions were then extracted into a solid-liquid system using petroleum ether as the organic solvent, and the fatty acid profile was determined by gas chromatography [13].

The main fatty acids identified by GC-FID after derivatization the corresponding glycerides from the lipid fractions of fresh or processed chestnuts to methyl esters were mainly oleic and linoleic acids, but also α-linolenic acid from the class of omega-3 acids, respectively palmitic acid from the class of saturated acids. The ratio between unsaturated and saturated acids was close to 10, but decreased significantly after processing, to ~5 even after 15 minutes of boiling, or to 6-7 in the case of baking [13]. Tables 7 and 8 show the relative concentrations of fatty acid methyl esters in the lipid fractions of unprocessed or boiled or baked chestnuts, while Figures 3-8 show their mass spectra from the NIST 2011 database used to identify them.

Table 7. Fatty acid profile (as methyl esters) of the lipid fractions of chestnuts of *C. sativa* species (extracted from fresh samples or after processing by boiling or baking) (adapted from [13])

Sample/ Fatty acid	**C16:0**	**C16:1**	**C18:0**	**C18:1**	**C18:2**	**C18:3**
Fresh	8.0	0.5	1.0	47.0	38.5	5.0
Boiled 15'	14.5	1.0	2.0	43.0	34.5	5.5
Boiled 30'	14.5	1.0	2.0	42.0	35.0	6.0
Boiled 45'	14.5	1.0	2.0	43.5	33.5	6.5
Boiled 60'	15.0	1.5	2.0	44.5	32.5	4.5
Baked 15'	13.0	0.7	0.9	45.5	34.5	5.5
Baked 30'	12.5	0.6	0.7	45.0	36.5	6.0
Baked 45'	13.5	0.6	0.8	44.0	36.0	6.0
Baked 60'	14.0	0.6	1.1	42.5	37.0	6.0

Table 8. Fatty acid profile (as methyl esters) of the lipid fractions of chestnuts of *C. mollissima* species (extracted from fresh samples or after processing by boiling or baking) (adapted from [13])

Sample/ Fatty acid	**C16:0**	**C16:1**	**C18:0**	**C18:1**	**C18:2**	**C18:3**
Fresh	8.5	0.5	1.0	46.5	39.0	5.0
Boiled 15'	14.5	0.6	1.2	42.5	36.5	5.5
Boiled 30'	14.0	0.8	1.1	42.0	36.5	6.0
Boiled 45'	14.5	0.8	1.2	41.5	36.5	6.0
Boiled 60'	15.0	0.9	1.3	43.0	35.0	4.5
Baked 15'	12.5	0.6	2.0	45.0	35.5	5.0
Baked 30'	13.5	0.5	1.5	42.0	36.0	6.5
Baked 45'	14.0	0.4	1.5	46.0	32.5	4.0
Baked 60'	14.5	0.3	2.0	45.0	33.0	4.0

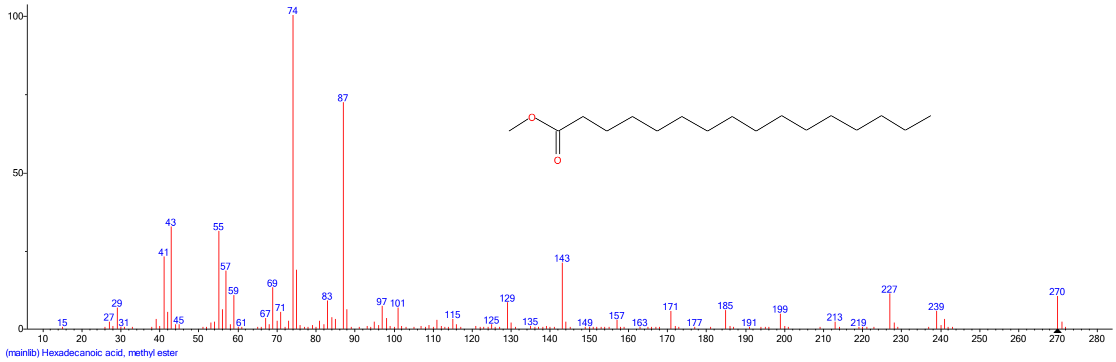

Figure 3. Chemical structure of the palmitic acid (methyl ester), C16:0, identified in chestnut lipids and its mass spectrum from the NIST 2011 database

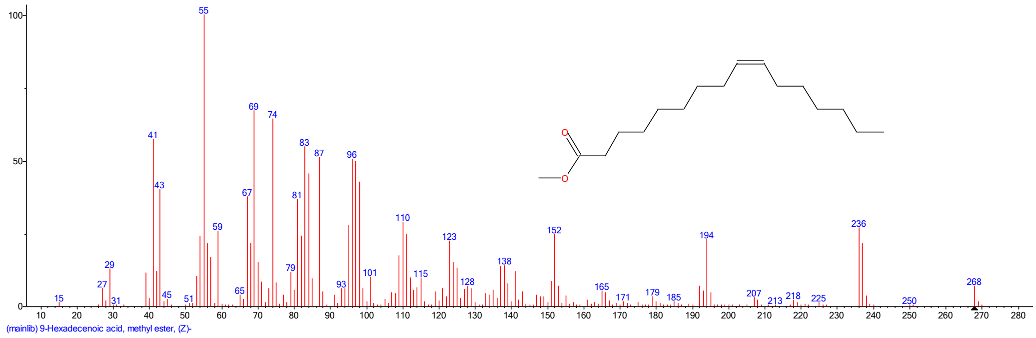

Figure 4. Chemical structure of the palmitoleic acid (methyl ester), C16:1, identified in chestnut lipids and its mass spectrum from the NIST 2011 database

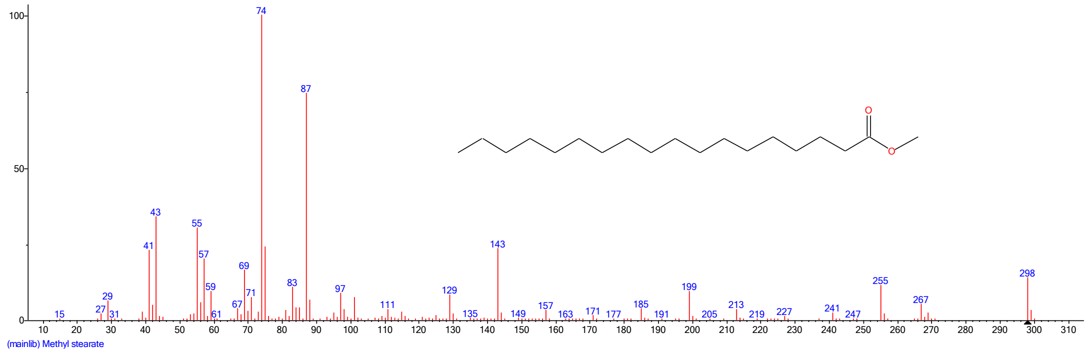

Figure 5. Chemical structure of the stearic acid (methyl ester), C18:0, identified in chestnut lipids and its mass spectrum from the NIST 2011 database

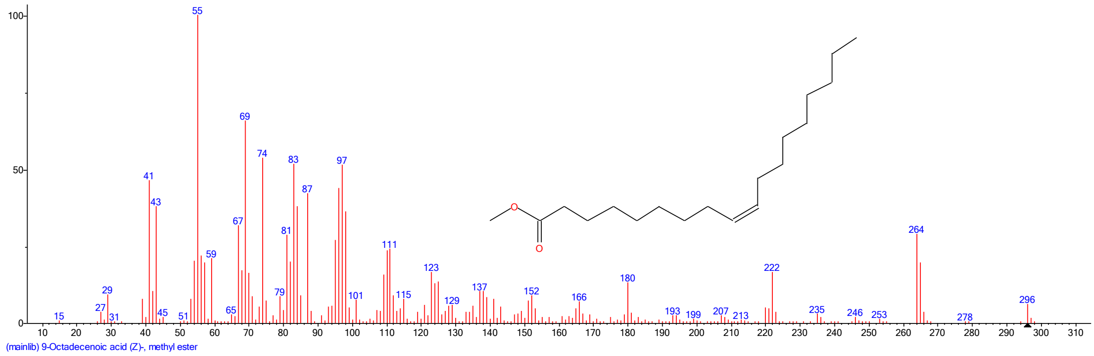

Figure 6. Chemical structure of the oleic acid (methyl ester), C18:1, identified in chestnut lipids and its mass spectrum from the NIST 2011 database

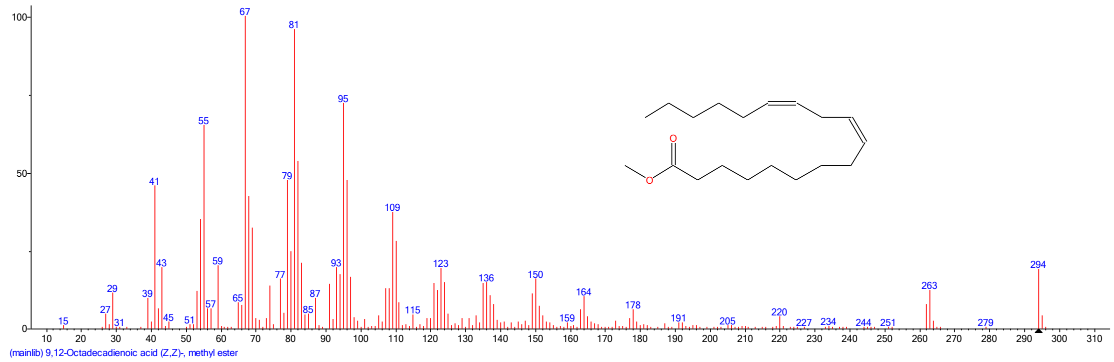

Figure 7. Chemical structure of the linoleic acid (methyl ester), C18:2, identified in chestnut lipids and its mass spectrum from the NIST 2011 database

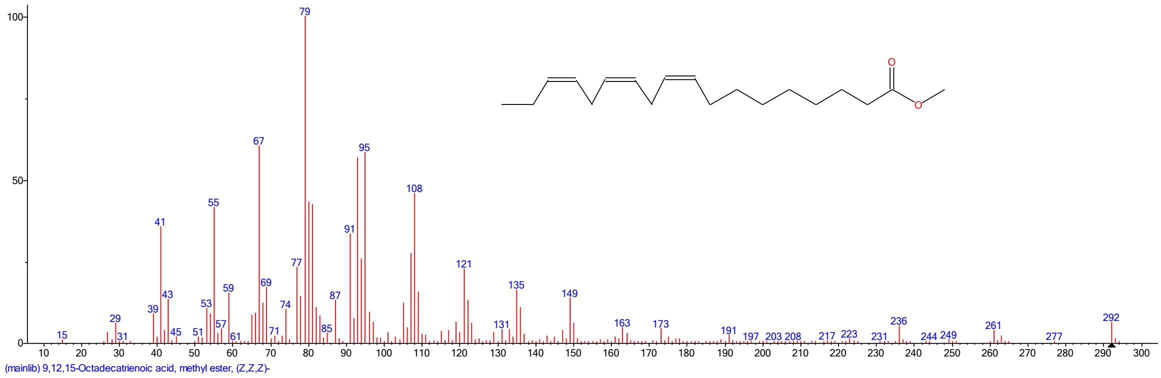

Figure 8. Chemical structure of the α-linolenic acid (methyl ester), C18:3, identified in chestnut lipids and its mass spectrum from the NIST 2011 database

In another study on the fatty acid profile of chestnut lipids, samples from four different species were studied, namely *C. sativa*, *C. mollissima*, *C. pumila* and *C. dentata* [12]. The results on the total lipid content of the chestnut kernels ranged from 2.17 % for *C. mollissima* to 9.50 % for *C. dentata*. The fatty acids identified and quantified in chestnut kernels were mainly oleic and linoleic acids among unsaturated fatty acids, but also palmitic and stearic acids for saturated acids. α-Linolenic acid, an omega-3 fatty acid that greatly increases the nutritional value and pharmaceutical applications of these fruits, has also been identified. Table 9 shows the absolute values of the fatty acid content (g/kg dry sample) of chestnuts obtained from the four species of *Castanea* [12].

Another study was conducted to determine the fatty acid profile of chestnuts from 17 producers in northern Portugal, which grow *C. sativa* species [19]. The lipid content of chestnuts varied between 1.67 and 3.50 %, and the highest concentrations were obtained for oleic and linoleic acids (20.66-37.60 %, respectively 37.57-50.62 %), while omega-3 fatty acid, α-linolenic acid was determined at 4.40-10.02 % [19].

When chestnuts were subjected to air drying in convection (50 °C, up to 10 hours), the relative concentration of fatty acids decreased significantly, by 19.4 % for oleic acid and by 14-15 % for stearic and arachidic saturated acids [18].

Barreira et al. [7] focused on evaluating the profile of triacylglycerols in *C. sativa* chestnuts. The following triglycerides (as well as other heterogeneous triglycerides) were quantified:

- PPP - 1,2,3-tripalmitoylglycerol
- SSS - 1,2,3-tristearoylglycerol
- LnLnLn - 1,2,3-trilinolenoylglycerol
- PoPoPo - 1,2,3-tripalmitoleoylglycerol
- OOO - 1,2,3-trioleoylglycerol
- LLL - 1,2,3-trilinoleoylglycerol
- LLP - 1,2-dilinoleoyl-3-palmitoyl-*rac*-glycerol
- LLO - 1,2-dilinoleoyl-3-oleoyl-*rac*-glycerol
- PPO - 1,2-dipalmitoyl-3-oleoyl-*rac*-glycerol
- OOS - 1,2-dioleoyl-3-stearoyl-*rac*-glycerol
- POL-1-palmitoyl-2-oleoyl-3-linoleoylglycerol
- OOP - 1,2-dioleoyl-3-palmitoyl-*rac*-glycerol

Table 9. Fatty acid composition of the chestnuts of four species of *Castanea* (g/kg dry sample) (adapted from [12])

Sample / Fatty acid	C16:0	C18:0	C18:1	C18:2	C18:3
C. sativa	4.32	0.39	8.82	12.57	1.66
C. mollissima	2.17±0.24	-	9.12±1.66	7.71±1.18	0.84±0.48
C. pumila	5.33±0.71	-	16.76±3.03	12.21±2.04	1.83±1.06
C. dentata	10.53±1.78	0.81±0.57	57.29±1.95	19.10±2.30	1.56±0.86

Table 10. Fatty acid profile (methyl esters, determined by GC-FID, % relative concentration), as well as triglyceride composition (determined by HPLC, % relative concentration) for the lipid fraction of chestnuts of *C. sativa* species (adapted from [7])

Fatty acid	Relative concentration (%)	Triglyceride	Relative concentration (%)
C14:0	0.11-0.16	LLnLn	0.20-0.26
C15:0	0.09-0.13	LLLn	0.69-3.70
C16:0	14.2-17.3	LLL	3.8-9.8
C16:1	0.28-0.34	OLLn	1.6-3.9
C17:0	0.13-0.33	PLLn	1.3-2.7
C17:1	0.12-0.17	OLL	18.9-24.5
C18:0	0.86-0.95	LLP	14.4-17.4
C18:1	29.6-37.4	OLO	13.2-18.4
C18:2	37.9-45.5	LOP	11.5-20.5
C18:3	4.0-6.4	PLP	0.79-1.80
C20:0	0.31-0.40	OOO	4.54-10.9
C20:1	0.83-0.83	OOP	3.0-8.1
C22:0	0.23-0.33	POP	0.08-0.36
C24:0	0.07-0.12		
SFA	16.2-19.4		
MUFA	30.9-38.7		
PUFA	42.0-51.9		

The lipid content for chestnut samples from four *C. sativa* growers ranged from 0.78-0.84 % fw. Table 10 shows the fatty acid profiles (relative percentage concentrations determined by GC-FID analysis of the corresponding methyl esters), as well as the percentage composition for the studied triglycerides (determined by high performance liquid chromatography – HPLC) [7].

Studies have been performed on the modification of the profile of fatty acids or triglycerides by irradiation using various methods [10,14-17]. Thus, irradiation with 10 MeV energy, at various absorption doses between 0.5-3.0 kGy, indicated an insignificant variation in the triglyceride composition even at a storage time of 30 days, while this composition was affected by irradiation at high absorption doses (1-3 kGy). In contrast, variations in triglyceride composition were less significant if these absorption dose values were lower (0.5 kGy). On the other hand, irradiation under the same conditions as above led to the conclusion that low absorption dose values <0.5 kGy are most suitable for such chestnut processing in order to increase their shelf life [14,16]. Only a slight increase in palmitic acid content and a decrease in oleic acid content were observed with an irradiation of 0.54 kGy and 60 days standard storage [10,15,17].

6. Conclusion and future perspectives

In this short review a comparison on the main nutritional components of various edible chestnuts, mainly *C. sativa* (European chestnut), as well as *C. pumila* from North America, *C. mollissima* or *C. crenata* from Asia, is presented. Chemical composition including lipids, proteins, carbohydrates/starch, minerals and energy values were discussed, as well as the content of biologically active compounds (antioxidants or vitamins) in various parts of the chestnuts. An important part of the review is focused on the fatty acid profile and triglyceride composition of the most consumed chestnuts from *Castanea* species, i.e. *C. sativa*, *C. mollissima*, *C. pumila* and *C. dentata*. The influence on various processing, handling and storage parameters on the composition of chestnuts was also discussed.

The review reveals the importance of the edible chestnuts as valuable foods. They have high content of starch, but also important contents of biologically active compounds such as polyphenols, antioxidant vitamins C and E, potassium and phosphorus. Moreover, the lipid fraction of chestnuts is rich in oleic acid, as well as α-linolenic acid, an omega-3 acid. These characteristics make chestnuts valuable, but also a healthy source of nutrition for the consumer, and more attention should be paid to their use as healthy foods.

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human or animal subjects (if exist) respect the specific regulation and standards.

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