



Characterizing the antioxidant activity and sensory profile of chestnuts (*Castanea sativa* Mill.) grown in the Cimino Mountains of central Italy

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ABSTRACT

For the first time, the antioxidant activity, sensory profile and fatty acid composition of an exceptional chestnut cultivar from the Cimino Mountains in central Italy have been studied in order to evaluate the possibility of adding value to this product, both for its excellent taste and as a source of bioactive compounds. Its main characteristic is its complex aroma. The chestnuts are characterized by the presence of almond (7.5) and floral (7) aromas. The high scores in the attributes of flavour (8), crispness (8) and sweetness (7) are worthy of note. The saturated fatty acid fraction was low in Vallerano chestnuts, both with and without pellicle (28% and 27.8% respectively). On the other hand, the percentage of unsaturated fatty acids was high (from 72% to 72.2%). The lipid fraction of chestnuts was mainly composed of linoleic, oleic and palmitic acids. The samples showed high antioxidant capacity values of 376.99 $\mu\text{mol TE/g}$ (ABST) and 0.64 $\text{mmol Fe}^{2+}\text{/g}$ (FRAP), making them nutritionally valuable. For their high quality and organoleptic features, chestnuts in the area of the Protected Denomination of Origin "Vallerano Chestnut" could be comparable to Marrone chestnuts.

1. Introduction

Chestnuts have been cultivated on a large scale for centuries and are one of the world's most valuable food crops [1]. Because of its economic value, the chestnut is an important resource in Europe [2]. In line with the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), European chestnut production sees Portugal (187,680 t) and Italy (43,000 t) as the major producer [3]. Furthermore, purchases of chestnut production grew by +20% (ISTAT, 2023). This increase is also linked to the attitude of consumers, who are now better informed and aware of the nutritional and beneficial effects of including chestnuts in their diet [4–9]. Several studies have highlighted their role in gluten-free diets for individuals with celiac disease, as soon as in the reduction of abdominal adiposity, coronary heart disease, cancer, and antimicrobial activity [10–12]. Consumers also estimate chestnut fruits for their organoleptic characteristics and their sweet taste [13], so the market tends to valorize the sensory characteristics as well as the nutritional properties [14]. In addition, the antioxidant properties of foods are becoming increasingly important, so given the antioxidant and

nutraceutical properties of chestnuts, there is an equal interest in high-quality chestnut cultivars for their bioactive components [15–19]. Although some research [16,18] has been carried out on the phenolic content and antioxidant activity of edible chestnut seeds, we thought it would be useful to go into more detail. Moreover, among the valuable nutritional features of the chestnut fruit there are the fatty acids. Chestnut lipids are low in saturated fatty acids (14.1–27.7%) and high in unsaturated (70–80%). The main individual fatty acids of chestnut fruits include linoleic acid (C18:2) (37.6–51.4%), followed by oleic acid (C18:1) (17.4–38.2%) and palmitic acid (C16:0) (12.0–17.3%) [15]. Oleic acid can reduce levels of harmful cholesterol in the blood, as is well known. Therefore, chestnut fatty acids due to its profile is important in many physiological processes, such as the regulation of plasma lipid levels, neuronal development, and cardiovascular protection [20–22]. Considering that the quality of food products guarantees their nutraceutical properties, more efforts should be made to advertise high-quality products among consumers. Since 1992, The European Union has enacted legislation (EC 2081/92) to safeguard the quality and uniqueness of typical foods, introducing PDO (Protected Designation of

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Origin) products. PDO products are the expression of the synergy between the environment and human activity, and represent outstanding quality linked to a particular area. According to Ismea 2022 report, Italy is the European leader in the number of products with denomination of origin (i.e., 845). In central Italy, a Sweet chestnut cultivar is cultivated, the source of the “Vallerano Chestnut”, a chestnut that was awarded the Protected Denomination of Origin (PDO) label by the European Union in 2009 [23]. The production area includes the territory of Vallerano, in the province of Viterbo, and the chestnut groves are located on the Cimini Mountains, a soil of volcanic origin, mainly at an altitude of 400–500 m above sea level. Chestnuts cultivated in this area are highly appreciated by consumers, thanks to their high-quality elements, the chamois-colored pellicle, the low percentage of septations, the seeds with almost no superficial grooves, the white, crunchy flesh, and the pleasantly sweet taste. Usually, local producers also produce flour from this variety of chestnuts, which is sold as is and used by private or companies to produce sweets, baked goods, and fresh pasta. Between some locations with different edaphoclimatic conditions, several researchers found significant differences [24]. They observed that total phenolics and antioxidants increased in the coldest environments. Therefore, chestnut fruits grown under the coolest conditions could be an exceptional source of phenolic compounds. Thus, they have a good potential to be used as a natural source of dietary antioxidants.

Several authors have reported on using chestnuts and their processed products to obtain functional foods [25]. Chestnut flour, for example, offers considerable possibilities for introducing new foods useful for those suffering from gluten intolerance. In addition, a recent study [26] has shown that the addition of chestnut flour to biscuits results in greater oxidative stability. Considering that there are no reports on the chestnuts cv. grown in the Cimini Mountains of central Italy, in this work their antioxidant activity, sensory profile, and fatty acids were studied for the first time, to evaluate the possibility of giving a new value to this food product both for its excellent taste and for providing biomolecules. Moreover, from a circular economy perspective, a nutritional and antioxidant comparison of the Vallerano chestnut without (VC) and with the pellicle by-product (VCP) was done with the purpose of giving an alternative added value to this product.

2. Materials and methods

2.1. Sample preparation

Samples of *Castanea* spp. fruits (5 kg) were collected in October 2023 in the zone of the Cimini Mountains, more precisely in Vallerano (province of Viterbo), in the area of the Protected Denomination of

Origin “Vallerano Chestnut” (N 42°23'06'', E 12°15'53''). The Vallerano chestnuts (VC) were from the Serangeli Company S.R.L., located in the Cimini Mountains (central Italy). The quality of the samples was evaluated by visual assessment, excluding those with defects (Fig. 1). This grading system is nowadays used by traders for the rapid assessment of the quality of the product and by inspectors for the designation of origin [27].

2.2. Morphological characteristics

Thirty chestnut fruits have been sampled at random for physical evaluation. After weighing each fruit, the morphological characteristics of length, width, thickness, geometric mean diameter, sphericity, volume, and area of the chestnuts were observed [28,29]. A digital caliper with 0.01 mm resolution was used to measure the dimensions of each chestnut (length, L; width, W; thickness, T). According to Mohsenin [30], the geometric mean diameter (D_g), sphericity (ϕ), arithmetic mean diameter (D_a), area (A), and volume (V) were calculated. Pellicle percentage of total chestnut was also measured.

2.3. Sensory analysis

The organoleptic characteristics of VC have been identified and described using sensory analysis, an important and widespread tool in the food industry [31]. The sensory evaluation was carried out by eight official sensory panelists, led by a panel leader [32], in a laboratory equipped for sensory analysis according to ISO 8589 [33] standards. The decision was made to carry out the sensory analysis on raw samples to gain the sensory traits of the chestnuts, excluding the influence of cooking. To cleanse the palate between samples, tasters were given mineral water. The development of a shared vocabulary of descriptive terms was the subject of three training sessions with judges. In the first phase, the panel members collaborated in group sessions and then evaluated the samples on their own. At the end of each session, the appropriate set of descriptors to use was discussed [34]. The selected descriptors, definitions, and associated reference standards that were used in the sensory analyses are listed in Table 1 [35–37]. Each descriptor was scored on a range with intervals ranging from 0 (absence of the descriptor) to 10 (maximum intensity of the descriptor) [38–41]. Finally, a subjective index of liking was used to rate each panelist's overall judgment based on the same scale. An analytical descriptive method, Quantitative Descriptive Analysis (QDA), was also used [27].



Fig. 1. Photograph of chestnut samples from the “Vallerano Chestnut” Protected Designation of Origin area.

Table 1

Descriptive terms of sensory attributes and their associated reference standards.

Descriptors	Sensory attribute definitions	Standards and reference materials
ease of peeling	ease of peeling the shell and pellicle away from the nut	different level of adherence of shell/pellicle to the nut (value 0 corresponds to hard, while value 10 corresponds to easy)
seed colour	external colour of the seed, after removing the pellicle	seed colour with a degree of darkness (value 0 corresponds to a light colour seed, while value 10 corresponds to dark)
degree of pellicle penetration into the kernel	degree of penetration of seed coat into the embryo	value 0 corresponds to a no penetration, while value 10 corresponds to strong penetration (visible >2.0 mm)
crunchiness	amount of noise generated when the sample is chewed at a fast rate with the back teeth	value 0 corresponds to a dried apple piece, while 10 corresponds to a fresh celery piece
astringent	sensation of drying, drawing-up or puckering of any of the mouth surfaces	diluted tannic acid solution (0.06–2 mg/mL)
sweetness	basic taste associated with sugar (sucrose)	diluted sucrose solution (0.5–6 g/L)
bitterness	basic taste associated with caffeine	diluted caffeine solution (0.03–0.2 g/L)
chestnut aroma	intensity of aroma of chestnut products	taste of chestnut
hazelnut aroma	Sweet, oil somewhat woody aromatic associated with hazelnuts	taste of hazelnut
almond aroma	Sweet cherry pit-like nutty aromatic associated with almonds	taste of almond
butter aroma	aromatics commonly associated with natural, slightly salted butter	taste of butter
caramel aroma	aromatics associated with caramel	taste of caramel
floral aroma	aromatics associated with flowers	taste of floral
aromatic intensity	characteristic flavor of chestnut at the seed break	aromatics commonly associated with chestnut

2.4. Total antioxidant capacity (TAC)

Total antioxidant capacity (TAC) of fresh-weight (FW) chestnut samples was conducted with and without pellicle (Vallerano chestnut without pellicle: VC; Vallerano chestnut with pellicle: VCP). For TAC, samples were extracted according to Molinari et al. [42]. Briefly, the samples were extracted overnight in the dark with a solvent consisting of methanol: water (80:20, v/v) in a ratio 1:25 (w/v). Then, the samples were centrifuged at 5000×g (ALC PK121R centrifuge; Bodanchemica s.r.l., Cagliari, Italy) for 10 min at 4 °C. The supernatants were collected and stored at −80 °C until further processing.

The total antioxidant capacity was assessed by ferric reducing antioxidant power (FRAP), and 2,2'-azino-bis (3-ethyl-benzothiazoline-6-sulfonic acid) (ABTS^{•+}) radical scavenging activity assays as described as follows.

FRAP assay was performed using the method described by Benzie and Strain [43], which was adapted for 96-well plates and an automatic reader (Infinite 2000, Tecan, Salzburg, Austria). The method is based on the reduction of the Fe³⁺-2,4,6-tri-pyridyl-s-triazine (TPTZ) complex to its ferrous form at a low pH. Briefly, 160 µL of FRAP assay solution (consisting of 20 mM ferric chloride solution, 10 mM TPTZ solution, and 0.3 M acetate buffer at pH 3.6) was prepared daily, mixed with 10 µL of the sample, standard, or blank, and dispensed into each well of a 96-well plate. The absorbance was measured at 595 nm at 37 °C after 30 min of

incubation. The results were expressed as mmol Fe²⁺ equivalents/g.

The ABTS^{•+} radical scavenging activity was evaluated by the Oxi-Select™ Trolox Equivalent Antioxidant Capacity (TEAC) Assay Kit (ABTS^{•+}) (Cell Biolabs INC.) following the manufacturer's instruction. The absorbance was recorded at 405 nm in an automatic reader (Infinite 2000, Tecan, Salzburg, Austria). A standard curve for Trolox was prepared and the antioxidant capacity was expressed as µmol of Trolox equivalents (TE)/g of DW.

2.5. Total phenolic compound (TPC)

The total phenolic compound (TPC) was determined using the Folin–Ciocalteu standard method as modified by Costantini et al. [44] and adapted for 96-wells plates and an automatic reader (Infinite 2000, Tecan, Salzburg, Austria). Briefly, 0.03 dm³ of deionized water, was added to 0.01 dm³ of ethanolic extract, 0.01 dm³ of Folin–Ciocalteu reagent, and 0.2 dm³ of 30% Na₂CO₃. After 30 min at RT, the absorbance of the mixture was measured at 725 nm in an automatic reader (Infinite 2000, Tecan, Salzburg, Austria). A gallic acid standard curve was prepared and the results were expressed as mg of gallic acid equivalents (GAE)/g of the sample.

2.6. Proximal composition

All chemicals were purchased from Sigma-Aldrich (St. Louis, MO, USA). Proximate composition was determined according to standard procedures of AOAC International [45] on both VC and VCP samples. In particular, crude protein content was estimated using the Kjeldahl method (AOAC 2001.11) (SpeedDigester K-425 and Distillation Unit K-350, BÜCHI, Labortechnik, AG, Switzerland) using a conversion factor of 6.25. Crude fat (AOAC 920.39) was extracted using a Soxhlet Extraction System B-811 (BÜCHI, Labortechnik, AG, Switzerland) with petroleum ether as solvent. Ash was determined in a muffle furnace at 550 °C for 4 h (AOAC 923.03). The content of total dietary fibers was determined by the enzymatic–gravimetric method (AOAC 991.43). Total carbohydrates were determined by difference (i.e., 100 – (g [protein + fat + ash + total dietary fiber] in 100 g of DW sample)). The energy value was calculated on fresh weight (FW), using the Atwater factor, as follows:

$$\text{Energy value (Kcal)} = (\% \text{Protein} \times 4) + (\% \text{Fat} \times 9) + (\% \text{Carbohydrate} \times 4) + (\% \text{total dietary fibers} \times 2)$$

Kjoule contents were calculated using the 4.184 factor on the calories obtained.

2.7. GC-MS determination of fatty acids (FAs) composition

The fatty acid content of the two chestnut samples (VC and VCP), was determined by GC/MS technique after lipid extraction and trans-methylation. In detail, the chestnuts were ground to a homogeneous powder and then combined with 20 mL diethyl ether/ethanol and mixed in an ultrasonic bath at 50 °C of temperature with agitation at 250 rpm for 30 min. Then, the solvent was removed by rotavapor, and the residue was dried under nitrogen. FAs such as methyl esters were obtained in the presence of boron trifluoride in methanol.

The analyses were performed by using a gas chromatograph coupled with a mass spectrometer Clarus 500 model Perkin Elmer (Waltham, MA, USA), equipped with a flame detector ionization (FID). 2 µL of each extract were injected into the column (Varian Factor Four VF-1) in splitless mode. The applied conditions of GC were the following: the injector was set to 280 °C and the oven temperature was programmed from 170 °C with the rate of 3 °C/min to 260 °C for 15 min. The mass spectrometer was operated at 70 eV (EI) in full scan mode in the range 40–550 *m/z*. The ion source and the connection parts temperature were set a 180 °C and 200 °C, respectively. The identification of fatty acids

was performed by matching their mass spectra with those stored in the Wiley 2.2 and Nist 11 mass spectra libraries database and by calculating the Linear Retention Indices (LRIs) using a series of alkane standards analyzed under the same conditions as that of the samples. LRIs were then compared with available retention data reported in the literature. The peak areas of the FID signal were used to calculate the relative concentrations of the components expressed as percentages without the use of an internal standard or any factor correction. All analyses were carried out in triplicate.

2.8. Statistical analysis

The statistical analysis was performed with the XLSTAT 2023.1.1 software (Addinsoft SARL, New York, USA) using a one-way analysis of variance. To describe statistical differences between means at a significance level of $p < 0.05$, Fisher's least significant difference test was used.

3. Results and discussion

3.1. Morphological characteristics of fruits

The study of the physical properties of the samples yielded interesting results. As reported in Table 2, chestnuts from the Vallerano area had length, width and thickness values (30, 24, and 20 mm, respectively) intermediate between those of "Chataigne" and those of Marrone cv. [46]. Furthermore, the geometric and arithmetic mean (24 and 25 mm, respectively) of the diameters of the chestnuts indicated VC samples were quite spherical, which could facilitate the operations of harvesting, processing, and conservation [47]. In addition, 88 nuts are required for 1 kg of VC fruit. This classifies it as a medium [13,40]. The commercial value of this variety is increased by the size and uniformity of the chestnuts, along with other characteristics. Due to its morphological traits, like a Marrone cv.-type chestnut, it is also well suited to the industrial production of candied chestnuts. The percentage of the pellicle in relation to the whole chestnut was around 6–10% (data not shown).

3.2. Sensory analysis

The sensory traits of the chestnuts from the Vallerano area are shown in Fig. 2. The most striking feature is the complexity of the aromatic profile. The radar chart shows that the sample is characterized by the presence of almond (7.5) and floral (7) aromas. The sensorial profile is also marked by aromatic notes of butter (3), hazelnut (3) and caramel (1.5). It is interesting to highlight the high values for chestnut aroma (8), crunchiness (8) and sweetness (7), as they are very similar to those found for the Marrone cv. in our previous work [46]. Crunchiness is particularly important as it significantly affects raw fruit quality as it produces a distinctive noise, which is regarded as a positive sensation as it is associated with quality in listening and freshness [48]. Moreover,

Table 2
Morphological characteristics of the chestnut samples from the "Vallerano Chestnut" Protected Designation of Origin area.

Morphological traits	Minimum	Maximum	Mean	Standard deviation
Weight (g)	11.25	11.40	11.30	0.07
Length (mm)	30.10	30.20	30.16	0.04
Width (mm)	24.10	24.20	24.15	0.05
Thickness (mm)	20.00	20.20	20.10	0.08
Geometric mean diameter (mm)	24.33	24.41	24.38	0.03
Arithmetic mean diameter (mm)	24.76	24.83	24.80	0.02
Surface area (mm ²)	1860.04	1871.38	1867	5
Sphericity (%)	0.80	0.81	0.80	0.01
Volume (mm ³)	7612.99	7682.80	7660	30

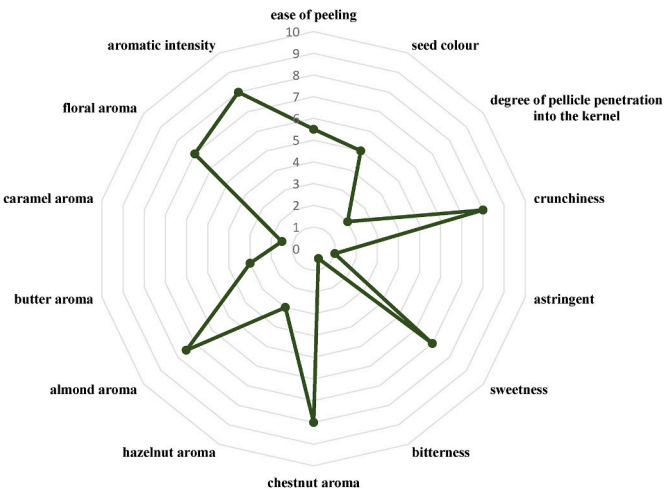


Fig. 2. Radar chart for sensory analysis of the chestnut samples from the "Vallerano Chestnut" Protected Designation of Origin area.

regarding the ease of peeling, its value (5.5) is intermediate between those reported by Frangipane et al. [46] for Marrone cv. (9.083) and "Chataigne" cv. (3.792). Particularly noteworthy is the low degree of pellicle penetration into the kernel (2). This trait is a key feature of the product. Indeed, it had a positive effect on the quality that adds value to its use in fresh and sweet markets. On the other hand, it is well known that both a high ease of peeling and a low degree of penetration of the skin into the kernel are considered high-value characteristics of chestnuts [29]. As mentioned above, our results also point to a high aromatic intensity (8). Several researchers [13,49] have highlighted that, together with other parameters, the ease of peeling and the higher aromatic intensity of the fruit make the Marrone cv. of superior quality. Well, the chestnuts from the Vallerano area have both of these qualities (Fig. 2). This finding is very close to the score achieved by the Marrone cv. which is considered to be of high value [46]. In this way, the sensory profile found in the chestnuts produced in the Vallerano area has many descriptors that make it an equally valuable product as the Marrone cv.

In order to better investigate the sensory characteristics of the analyzed chestnuts, a product characterization was carried out using XLSTAT sensory data analysis, which provides the descriptors that best discriminate the product. It was also possible to establish the most relevant characteristics of those sampled. Fig. 3 is very helpful in defining the chestnut sample. The blue color is associated with coefficients having a significant positive value and the red color with coefficients having a significant negative value. It can be seen that the chestnut analyzed has almond and chestnut aromas. It has no hazelnut aroma and is not astringent. Finally, the chestnuts received a high score in the panel's overall judgement (8), intermediate between the scores observed by Frangipane et al. [46] for Marrone cv (9.083) and "Chataigne" cv (6.042).

3.3. Total antioxidant capacity (TAC) and total phenolic compound (TPC)

The total phenolic compound (TPC) values together with the antioxidant activity of the chestnut samples as assessed by FRAP, and ABTS^{•+} assay are reported in Table 3. Both VC and VCP samples were analyzed. Significant differences in TPC and antioxidant capacity were found. The values were about twice as high in the TPC of VCP samples (2.37 mg GAE/g), ABTS^{•+} (784.47 μmol TE/g) and FRAP (1.17 mmol Fe²⁺/g) as in VC samples (TPC, 1.70 mg GAE/g; ABTS^{•+}, 376.99 μmol TE/g; FRAP, 0.64 mmol Fe²⁺/g). These results underline how the chestnut pellicle could represent a novel antioxidant resource and natural additive in functional foods, in agreement with Xie et al. [50]. The

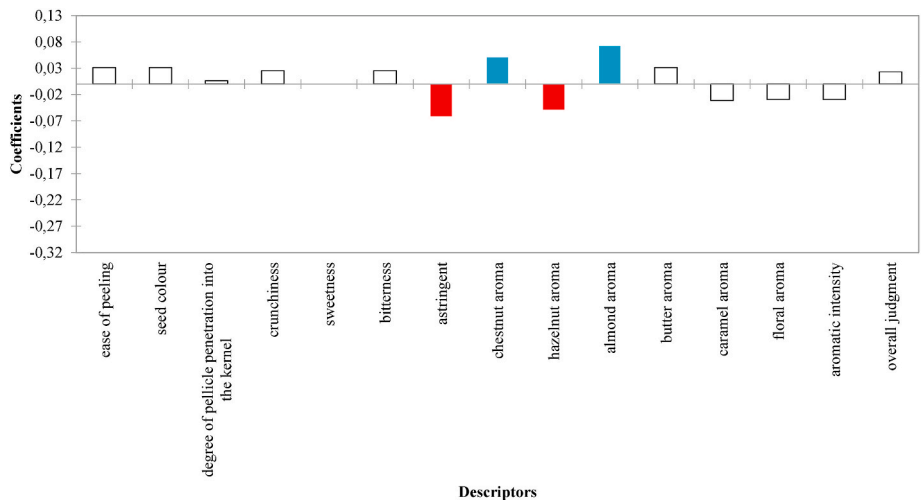


Fig. 3. Coefficients of the analysis of variance models of the chestnut samples from the “Vallerano Chestnut” Protected Designation of Origin area.

Table 3
Total phenolic compounds (TPC) and total antioxidant capacity (TAC) of chestnut samples without (VC) and with pellicle (VCP).

Sample	TPC	ABTS ⁺	FRAP
	mg GAE/g FW	μmol TE/g FW	mmol Fe ²⁺ /g FW
VC	1.70 ± 0.01 ^b	380 ± 20 ^b	0.64 ± 0.01 ^b
VCP	2.37 ± 0.06 ^a	780 ± 30 ^a	1.17 ± 0.08 ^a

TPC: total phenolic compounds; ABTS⁺: radical scavenging activity assays; FRAP: ferric reducing antioxidant power; FW: fresh weight; TE: Trolox equivalent. Means with different letters in the same column are significantly different (Tukey’s test, *p* < 0.05). Data are means ± standard deviation of three (*n* = 3) replicates.

high levels of TPC (1.70 mg GAE/g) found in chestnuts from the Vallerano area should also be noted. The TPC levels are similar to those described by Martinez et al. [19] and Suna et al. [51] for other varieties. With 376.99 μmol TE/g (ABTS⁺) and 0.64 mmol Fe²⁺/g (FRAP), the chestnut samples from Vallerano showed high values in terms of antioxidant capacity. It was also interesting to observe that in another study conducted on Chinese chestnut varieties [17], the antioxidant capacity (ABTS⁺, 24.83 μmol TE/g) was found to be lower than our results.

3.4. Proximal composition

Chestnut fruits are generally rich in carbohydrates. In our study, the total carbohydrate content of the chestnuts from the Vallerano area was 83.18 g/100 g of fresh weight (Table 4) and the data are lower than that reported by Ref. [13]. Carbohydrates are not only an important source of energy, but they also contribute to the sweetness of chestnuts, which is appreciated by consumers. It is generally accepted that chestnuts are low in fat, and in the present study, the fat content, although was slightly higher in the VCP sample (1.45 g/100 g) in comparison to VC sample (1.09 g/100 g), the difference is not statistically significant. The present

data was lower than that of Chinese chestnuts [52], but comparable to Marrone cv. [53]. The protein content of the chestnuts is 5.21%, in agreement with those reported by other researchers [13], also in this case the presence of the pellicles did not cause significant changes in protein content between VC and VCP samples. Ash contents were not different between VC and VCP samples, and comparable to Marrone cv. [53]. Conversely, a higher total dietary fiber content was found in VC samples in comparison to Marrone cv. and with a total dietary fiber content higher than 6 g/100 g of fresh weight falls under the European health nutritional claim “high in fibers” (Regulation EC No 1924/2006). As expected, the VCP sample showed a statistically greater quantity of fibers than VC, leading to the hypothesis that it could be a valuable ingredient for the enrichment of foods in fibers.

3.5. Fatty acid contents

GC–MS analyses was for the first time performed on VC and VCP samples and these data allowed the detection and identification of fatty acids (Table 5). The results confirmed that the lipid fraction of chestnuts is mainly composed of linoleic, oleic and palmitic acids, in agreement with other data on different chestnut cultivars [20,54]. As reported in previous studies [22], the saturated fraction was low in both VCP and VC (28% and 27.8%, respectively). Meanwhile, the percentage of unsaturated fatty acids is high in both VC (72%) and VCP (72.2%). Some differences were observed between samples with and without pellicle. Compared to those without pellicle, VCP contain more linoleic acid (55.3%), which is essential for their health benefits [21]. Furthermore, the comparison between VC and VCP showed a higher percentage of oleic acid in the absence of the pellicle (26.3% and 16.4% in VC and VCP respectively) and it is important to emphasize that oleic acid is the main component of plasma free fatty acids [55]. Some authors [56] have reported that these FAs have a protective role in cardiovascular diseases. Therefore, even if the lipid intake is negligible compared to the other macromolecular contents (Table 4), the high nutritional quality of the

Table 4
Proximate composition (g/100 g fresh weight - fw) of the chestnut samples from the “Vallerano Chestnut” Protected Designation of Origin area.

	Protein ^a	Fat	Carbohydrate ^b	Total dietary fibers	Ash	kcal/100 g fw	kJ/100 g fw
VC	5.2 ± 0.2 ^a	1.09 ± 0.01 ^a	84 ± 2	8.5 ± 0.5 ^b	2.06 ± 0.04 ^a	377	1577
VCP	5.4 ± 0.1 ^a	1.4 ± 0.2 ^a	77 ± 1	14.8 ± 0.2 ^a	1.98 ± 0.01 ^a	363	1519

VC: Vallerano chestnut; VCP: Vallerano chestnut with pellicle.
Data are means ± standard deviation of two (*n* = 2) replicates.

^a Conversion factor: 6.25.

^b As difference (i.e., 100 – (g [protein + fat + ash + total dietary fibers] in 100 g of fresh weight sample)).

Table 5

FAs content (percentage mean value $\pm$ standard deviation) of the chestnut samples from the “Vallerano Chestnut” Protected Designation of Origin area, as determined by GC–MS.

N°	COMPONENT ^a	LRI ^b	LRI ^c	VC (%) ^d	VCP (%) ^e
1	valeric acid C5:0	875	879	–	tr
2	lauric acid C12:0	1551	1559	–	tr
3	myristic acid C14:0	1762	1759	0.10 $\pm$ 0.01 ^a	0.11 $\pm$ 0.01 ^a
4	pentadecanoic acid C15:0	1841	1844	0.09 $\pm$ 0.01 ^a	0.10 $\pm$ 0.01 ^a
5	palmitoleic acid, C16:1n7	1928	1930	0.38 $\pm$ 0.02 ^a	0.52 $\pm$ 0.02 ^b
6	palmitic acid, C16:0	1974	1973	23 $\pm$ 3 ^a	20 $\pm$ 3 ^b
7	linoleic acid, C18:2n6	2155	2152	45 $\pm$ 5 ^a	55 $\pm$ 5 ^b
8	oleic acid, C18:1n9	21,673	2171	26 $\pm$ 2 ^a	16.42 $\pm$ 0.08 ^b
9	stearic acid, C18:0	2182	2178	4.41 $\pm$ 0.02 ^a	6.81 $\pm$ 0.04 ^b
10	cis-11-eicosenoic acid C20:0	2351	2356	–	0.32 $\pm$ 0.02
11	arachidic acid C20:0	2362	2359	0.21 $\pm$ 0.02 ^a	0.19 $\pm$ 0.01 ^a
12	heneicosanoic acid C21:0	2460	2463	0.19 $\pm$ 0.01 ^a	0.10 $\pm$ 0.01 ^b
13	behenic acid C22:0	2571	2567	0.40 $\pm$ 0.02 ^a	0.39 $\pm$ 0.02 ^a
14	tricosanoic acid C23:0	2665	2668	–	0.12 $\pm$ 0.01
15	lignoceric acid C24:0	2683	2685	–	0.22 $\pm$ 0.01
	SUM ^f			100	100
	Saturated FAs			28.0	27.5
	Unsaturated FAs			71.4	71.5

–: not detected. Means with different letters are significant different (t-student test, $p < 0.01$).

VC: Vallerano chestnut; VCP: Vallerano chestnut with pellicle.

^a The components are reported according to their elution order on apolar column (VF-1ms).

^b Linear Retention Indices measured on apolar column.

^c Linear Retention indices from literature.

^d Percentage mean values of chestnut without pellicle.

^e Percentage mean values of chestnut with pellicle.

^f Sum calculated on unrounded data; tr: percentage mean values $< 0.1\%$.

chestnuts analyzed is confirmed by our results.

4. Conclusions

Here, for the first time, an in-depth characterization of Vallerano chestnut in relation to the sensory, morphological, nutritional, and antioxidant features was done. The main conclusion is that the morphological, sensory and chemical characteristics of the chestnuts from the Vallerano area are similar to those of the Marrone cultivar, which is known for its high quality. These results will help to increase knowledge of the high-quality features of the analyzed chestnuts which are an essential part of Lazio’s culinary traditions and to promote them. Based on this knowledge, producers will be able to focus their entrepreneurial activity on the development of products with high added value, with a notable increase in budgets due to the greater market value. In the end, considering the high fiber and antioxidants contents found in the Vallerano chestnuts with pellicle, it could be speculated that a flour based on VCP could become a potential new functional ingredient with high nutritional value and it could be a powerful tool for the creation of a new circular economy around the chestnut chain. Further studies will be necessary on the integration of this ingredient into a food and on in vivo activity to understand the real potential.

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CRedit authorship contribution statement

Maria Teresa Frangipane: Writing – review & editing, Methodology, Data curation, Conceptualization. **Lara Costantini:** Writing – original draft, Supervision, Formal analysis. **Stefania Garzoli:** Writing – original draft. **Nicolò Merendino:** Validation, Supervision. **Riccardo Massantini:** Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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