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Chestnut as a culinary ingredient: Analysis of recipes and proposed innovative thematic menu☆

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ABSTRACT

Chestnuts are natural dried fruits grown in many regions of the globe and have been used in different gastronomic preparations for centuries. Chestnuts are part of the local gastronomic cultures in several regions and are also being used for culinary innovations. This work analysed 266 recipes containing chestnuts obtained from different sources, such as cookbooks or the internet. The recipes were classified according to different criteria, and data analysis included basic statistical tools, significance tests, factor analysis and cluster analysis.

The results showed that the utilisation of chestnuts was particularly frequent in main dishes containing meat of some sort (26.3%), as well as in desserts (24.4%). The chestnuts were usually added to the recipes mostly fresh, whole (24.1%) or cut (26.7%). The nature of the recipes was divided into classical or modern, being significantly associated with the form of incorporation of the chestnut, but not significantly associated with most of the variables used to classify the recipes (dish type, cooking, cooking method, preparation time, or moment of incorporation of the chestnut). Factor analysis indicated three factors, clearly differentiated, that in globally explained 58.1% of the variance. Cluster analysis allowed the establishment of four clusters of recipes, which were found significantly different according to all the variables used to classify the recipes. Ingredient analysis showed that the most frequent categories were spices, followed by vegetables & legumes and that the ingredients used in lower quantities were most frequently listed. Word clouds based on frequency indicated, in each of the categories, the most relevant ingredients, which were flour, butter, egg, pork, bacon, shrimp, onion, garlic, lemon, almond, salt, pepper, oil, and sugar. Lastly, a successful innovative thematic menu was developed and composed of recipes containing chestnuts, including one starter, one main dish, and one dessert.

This work allows to conclude about the diverse utilisation of chestnut as a gastronomic ingredient and not only as a dried fruit.

1. Introduction

Chestnuts have been cultivated for thousands of years in different regions of the globe, including in the Southern European regions (He et al., 2024). In Portugal, the species cultivated is *Castanea sativa* (Mill.), with varieties Martaínha, Longal, or Judia having a high commercial expression, but others have local importance, as recognised by the official attribution of the Protected Designation of Origin (PDO), according to European Regulations (Projeto Agro 448, 2008; Ribeiro et al., 2020). In Portugal, great emphasis is given to autochthone varieties that are well adapted to the local climatic conditions and soils (Costa et al., 2005). In Portugal, four PDO have been established for the production of autochthone varieties Côta, Martaínha, Longal and Judia. Among European countries, Portugal is the largest chestnut producer, with production areas located in the centre and north regions of Portugal (Cabo et al., 2019). The chestnut production has faced many challenges lately, including the effects of climate change and pests. Nonetheless, the sector has been able to adapt to such conditions, and the overall production rate has increased to provide quantities that comply with the demands of the well-structured and organised national chestnut supply chains (Cabo et al., 2019).

The consumption of chestnuts in Portugal is still rather limited to a

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short time related to the traditional intake in the harvest season, autumn, in which they are consumed toasted and/or cooked. However, new forms of consumption are expanding, including all-year-round use by preserving them frozen. It is also supported by growing demand for certain niche markets to meet specific dietary needs, such as gluten-free or nutritionally enriched products (Cabo et al., 2019).

Chestnuts contain expressive quantities of carbohydrates, including amylose and amylopectin, which are polysaccharides beneficial to the development of the gut microbiota and the production of short-chain fatty acids. Their fibre content also stimulates the development of beneficial probiotic bacteria, allowing the regulation of cholesterol levels and insulin response. Despite their relatively lower energy value as compared with other nuts, chestnuts contain polyunsaturated fatty acids, vitamins, and minerals of nutritional importance (vitamins C, B6 and folic acid, as well as calcium, iron, magnesium, potassium, phosphorus, zinc, copper, manganese and selenium). Chestnuts are also rich in bioactive compounds like lutein, zeaxanthin, or phenolic compounds that help protect cells (Carocho et al., 2015; Cruz et al., 2013; Mota et al., 2018; Taş-Küçükaydın et al., 2023).

The bioactive molecules naturally present in the chestnut have been reported as beneficial to human health. Additionally, at the nutritional level, this food has been traditionally used to replace potatoes, rice or wheat (Rodrigues et al., 2006). Although the level of protein is considered low compared to other nuts, the chestnut is becoming more in demand because it does not contain gluten, being therefore able to incorporate gluten-free products, for example, in the form of chestnut flour (Guiné et al., 2016; Paciulli et al., 2018; Rinaldi et al., 2017).

Apart from consumption raw and in gastronomic recipes, chestnut-derived products include chestnut flour, which can be used in a number of bakery and pastry preparations, chestnut beer, or liquor. In popular gastronomy, chestnuts have been used in multiple applications, including soup or meat dishes, apart from a high number of desserts, such as for example candied chestnuts (Candal et al., 2018; Comba et al., 2010; De Vasconcelos et al., 2010).

The aims of this work were to make an overview of the potential of chestnut as an ingredient in culinary preparations by means of a recipe analysis, as well as to propose an innovative thematic menu containing original recipes with chestnut.

2. Materials and methods

This work comprised the analysis of a random collection of 266 recipes that include chestnut in their formulations. The recipes were collected from printed culinary books, from recipes' eBooks and also from the internet, specifically from recipe websites. The analysis included different types of recipes, containing a wide diversity of possible utilisations of the chestnut. For the collection of the recipes, the inclusion criteria were:

1) Use different sources: while traditional cookbooks are a recognised form of dissemination of recipes and tend to cover a wide variety of domains (for example, more traditional cookbooks contain recipes broadly used or from more ancient times, and innovative cookbooks with modern recipes proposed by recognised chefs), the internet constitutes, nowadays, an endless source of information, and this is also true for recipes (it allows to retrieve recipes from different sources, covering different traditions, different types of usage and a wide variety of possibilities, according to the aims of the collection);
2) Recipes containing chestnut in different roles: it was a goal to include recipes containing chestnut in different forms, used in different types of dishes and with different contributions to the final composition.

The main goal was to gather a collection of recipes obtained from different sources, from those more traditional to those more innovative, while also covering a wide diversity of dishes. Based on the selection criteria and goals, the recipes database was organised by classifying them according to some defined criteria. These variables and the corresponding group categories that were used for the classification of the recipes are the following:

- Group 1: Type of recipe; including 3 sub-groups: Traditional; Innovative; Chef's recipe.
- Group 2: Dish type; including 9 sub-groups: Soup/Starter; Breakfast/Tea Snack; Main dish – Fish; Main dish – Meat; Main dish – Vegetarian; Main dish – Others (Shellfish, Pizzas, …); Dessert; Bakery/Cookies; Others (Toppings, sauces, …).
- Group 3: Involves cooking; including 2 sub-groups: Yes; No.
- Group 4: Cooking method: including 6 sub-groups: Boiling; Roasting; Grilling; Baking; Frying; Others.
- Group 5: Preparation time; including 4 sub-groups: Short (up to 15 min); Medium (from 15 to 30 min); Long (from 30 to 45 min); Very long (over 45 min).
- Group 6: Moment of incorporation of the chestnut; including 3 sub-groups: Beginning; Middle; End.
- Group 7: Form of incorporation of the chestnut in the recipe; including 5 sub-groups: Fresh – whole; Fresh – cut; In flour (dried and grinded); Frozen; Others.

The database was created in Excel containing the recipes' names, and all the classification criteria were applied to each of them. Besides, for each of the recipes, all other ingredients in the recipes, besides chestnut, were also included and categorised according to some food groups ('Cereals', 'Dairy & Eggs', 'Meat', 'Fish', 'Seafood', 'Vegetables & Legumes', 'Fruits', 'Herbs', 'Spices', 'Dried fruits & Nuts', 'Oils & drinks', 'Sauces', or 'Other ingredients'). Complementary to the Excel database, an SPSS database was also created to treat the statistical data collected.

To analyse the data, descriptive statistics, word clouds and statistical tests were used. The software SankeyMATIC, available online (https://sankeymatic.com/build/), was used to obtain the Sankey Diagram. Word clouds were produced with Word Cloud Generator, which is also available online (https://www.freewordcloudgenerator.com/generatewordcloud).

Frequencies and percentages were used to analyse all recipes according to the different classification criteria defined. Chi-squared tests were used to analyse the relations between the recipe variables, complemented with the determination of the Cramer's V coefficient as a measure of the association between the categorical variables tested. For the chi-square tests performed, the effects of variable distribution were considered significant at a level of 5% ($p < 0.05$). The Cramer's V coefficient assumes values between 0 and 1 as follows: for $V \approx 0.1$ the association is considered weak, for $V \approx 0.3$ the association is moderate, and for $V \approx 0.5$ or over, the association is strong (Witte and Witte, 2009).

The data were further analysed by using Factor Analysis (FA) accompanied by Cluster Analysis (CA). These two techniques are complemented by an incorporated analysis of variance (ANOVA). The use of factor analysis allows us to assess how the variables in the study define a possible grouping variable if it exists. In this way, it is possible to evaluate how the variables interconnect with each other, i.e., if they allow a dimension reduction by forming groups with some coherence between the variables. FA was applied to the variables under study using the extraction method Principal Components with Varimax rotation. The number of components extracted was determined based on the Eigenvalues greater than 1. The Kaiser-Meyer-Olkin (KMO) measure of the adequacy of the sample was calculated, and Bartlett's test was performed to evaluate correlations between variables (Broen et al., 2015). For reference, values of KMO over 0.5 are acceptable, and the higher they are, the more suited the data are for the use of FA techniques (Kaiser and Rice, 1974). Factor loadings with absolute values lower than 0.4 were excluded (Rohm and Swaminathan, 2004; Stevens, 2009).

The CA was applied to the factors extracted by FA, and to establish the adequate number of clusters, the agglomeration schedule coefficients were used. The algorithm used for CA with the hierarchical

method was Squared Euclidean Distance and Ward Linkage. After determining the number of clusters in five, the k-means was used, since it is a robust method, recommended and frequently used in CA (Dolnicar, 2002).

The SPSS - version 28 (IBM Corp., USA) was used for all statistical analyses.

3. Results

3.1. Recipe analysis

Table 1 presents the results for the classification of the 266 recipes according to the different criteria and sub-criteria. The distribution of the collected recipes by type of recipe is relatively even, with 33.5% of traditional recipes, 35.7% of innovative recipes and 30.8% of Chef's recipes. Regarding the dish type, higher representativeness was found for meat dishes and desserts (26.3% and 24.4%, respectively). With respect to cooking, a great majority of the recipes involved the cooking of some type (96.2%), with boiling being the most frequent method utilised in the chestnut recipes (30.5%), followed by roasting (25.2%) and then baking (21.4%). With respect to preparation time, the majority of the recipes involved a long time (over 45 min, 32.0%), but also a good number of recipes (30.5%) were prepared in a medium time (15–30 min). In most of the recipes, the chestnut is incorporated in the middle of the preparation (48.9%) or in the beginning (35.7%), and the most representative forms of addition of the chestnuts is fresh-cut (26.7%) or fresh-whole (24.1%).

The Sankey chart containing the flows of the distribution of the recipes according to the different classification criteria defined is presented in Fig. 1. The Sankey chart contains seven levels according to the criteria defined for the classification. The thickness of each of the flows in the Sankey diagram is directly proportional to the intensity of the variable in the study, in this case, the number of recipes. The flow analysis reveals that meat and desserts are the most relevant types of dishes containing chestnut as an ingredient among the 266 recipes analysed. The majority of these methods imply roasting as the preparation method. The flow analysis also shows that of the recipes that imply baking, most take a very long time to prepare. There is also a high number of recipes that use fresh-cut chestnuts added in the middle of the recipe preparation, as seen by the intensity of the flow between these two groups. It is also visible in a lower number of recipes that the chestnut is added at the end of the preparation, and those are quite evenly distributed according to the preparation time, just with a slight prevalence of recipes with very long preparation time.

Table 1
Distribution of the recipes with chestnut according to the classification criteria.

Groups	Sub-groups	N	%
Type of recipe	Traditional	89	33.5
	Innovative	95	35.7
	Chef's recipe	82	30.8
Dish type	Soup/Starter	33	12.4
	Breakfast/Tea Snack	10	3.8
	Main dish – Fish	23	8.6
	Main dish – Meat	70	26.3
	Main dish – Vegetarian	33	12.4
	Main dish – Others (Shellfish, Pizzas, …)	3	1.1
	Dessert	65	24.4
	Bakery/Cookies	18	6.8
	Others (Toppings, sauces, …)	11	4.1
Involves cooking	Yes	256	96.2
	No	10	3.8
Cooking method	Boiling	81	30.5
	Roasting	67	25.2
	Grilling	4	1.5
	Baking	57	21.4
	Frying	12	4.5
	Others	45	16.9
Preparation time	Short (up to 15 min)	36	13.5
	Medium (from 15 to 30 min)	81	30.5
	Long (from 30 to 45 min)	64	24.1
	Very long (over 45 min)	85	32.0
Moment of incorporation of the chestnut	Beginning	95	35.7
	Middle	130	48.9
	End	41	15.4
Form of incorporation of the chestnut in the recipe	Fresh - whole	64	24.1
	Fresh – cut	71	26.7
	In flour (dried and grinded)	12	4.5
	Frozen	51	19.2
	Others	68	25.6
Total number of recipes		**266**	**100.0**

Considering the hypothesis that the nature of the recipe could have a meaningful influence over other parameters analysed, further studies were conducted to evaluate possible differences, separating according to a more classical nature of the recipe (including the 89 recipes classified as traditional) or alternatively a more modern approach (including the 95 recipes classified as innovative plus the 82 recipes classified as Chef's originals, which are also naturally more innovative). Table 2 presents the results of the chi-square test for variable dish type as a function of the nature of the recipe, and these reveal no significant differences ($p > 0.05$) between the groups. As a result, the value of Cramer's V coefficient was indeed low ($V = 0.175$), indicating a weak association between these two variables in the study. Table 2 also presents the results of the chi-square tests for variables related to the preparation of the recipes (cooking, cooking method and preparation time) *versus* the nature of the recipe. The results once again show no significant differences ($p > 0.05$), and low values of the Cramer's coefficient (varying from 0.014 to 0.146). Table 2 still contains the results of the chi-square tests for variables related to the inclusion of chestnut into the recipes, namely the moment of incorporation and the form of incorporation. The results reveal no significant differences ($p > 0.05$) for the moment of incorporation, but the form of incorporation of the chestnut into the recipe is significantly different depending on the nature of the recipe ($p = 0.018$), although the Cramer's coefficient is still low ($V = 0.212$), indicative of a low association between variables.

3.2. Factor analysis

A factor analysis was made considering the variables used to classify the recipes ('Type of recipe', 'Dish type', 'Involves cooking', 'Cooking method', 'Preparation time', 'Moment of incorporation of the chestnut', 'Form of incorporation of the chestnut in the recipe'). The value of Kaiser-Meyer-Olkin obtained was over 0.5 (KMO = 0.579), and Bartlett's test was significant ($p < 0.01$), thus allowing to confirm the suitability of the data for the application of FA. The Measure of Sample Adequacy (MSA) values were all over 0.5, also confirming the adequacy of data (the lowest MSA was 0.500 for variable 'Involves cooking' and the highest was 0.609 for variable 'Form of incorporation of chestnut').

FA extracted three factors, which globally explained 58.1% of the variance in the data (F1 explaining 22.2%, F2 explaining 19.1% and F3 explaining 16.8% of variance), as shown in Table 3.

Fig. 2 presents the rotated component plot, showing distinctively the three factors presented in Table 4, in different parts of the stated space.

The coefficients of the agglomeration schedule obtained with CA using the hierarchical method Ward indicated the optimal number of clusters to establish as four (Figure A1 in Appendix A). After running the hierarchical cluster method, the k-means was used after fixing the number of clusters in four. The recipes were distributed into groups (the clusters) according to their correspondence in terms of the three factors defined earlier.

Table 4 presents the results of the cluster analysis made using k-

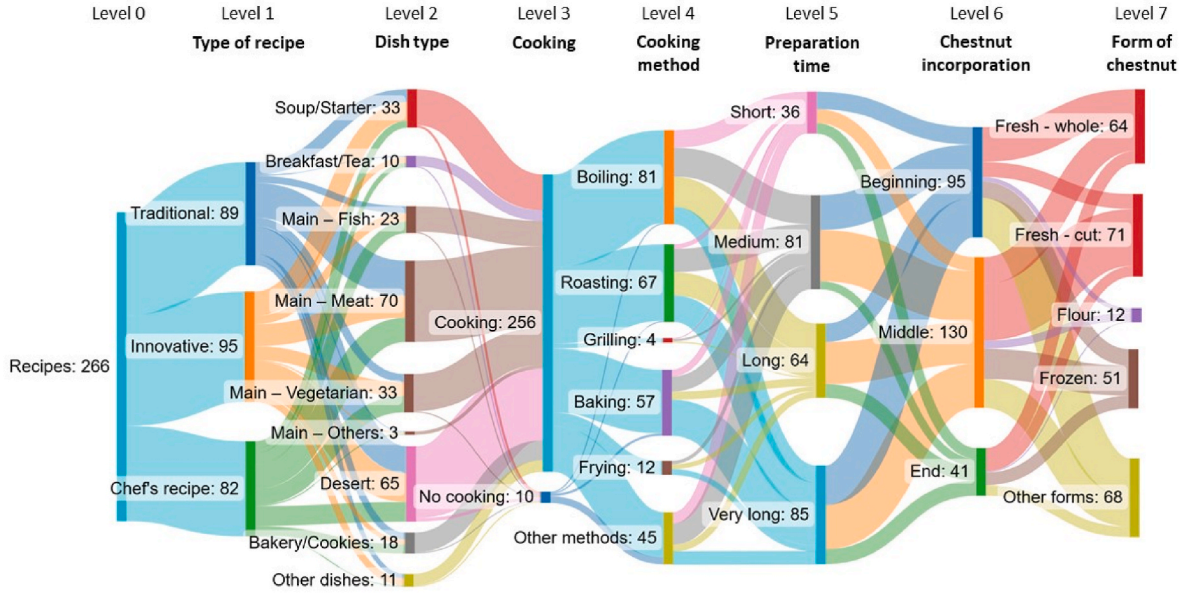

Fig. 1. Sankey diagram showing the flow distribution of recipes according to categories.

Table 2
Crosstabulation between Nature of the recipe and the classification variables.

Classification variables	Groups/Sub-groups	Nature of the recipe		Chi-square test		Cramer's coefficient V
		Classical (N = 89)	Modern (N = 177)	Chi^2	p	
Dish type	**Dish type**			8.184	0.416	0.175
	Soup/Starter	12.4%	12.4%			
	Breakfast/Tea Snack	1.1%	5.1%			
	Main dish – Fish	6.7%	9.6%			
	Main dish – Meat	33.7%	22.6%			
	Main dish – Vegetarian	7.9%	14.7%			
	Main dish – Others	1.1%	1.1%			
	Dessert	25.8%	23.7%			
	Bakery/Cookies	6.7%	6.8%			
	Other dishes	4.5%	4.0%			
Preparation variables	**Cooking**			0.056	0.813	0.014
	Yes	96.6%	96.0%			
	No	3.4%	4.0%			
	Cooking method			3.222	0.666	0.110
	Boiling	29.2%	31.1%			
	Roasting	27.0%	24.3%			
	Grilling	1.1%	1.7%			
	Baking	25.8%	19.2%			
	Frying	4.5%	4.5%			
	Others	12.4%	19.2%			
	Preparation time			5.701	0.127	0.146
	Short (≤15 min)	16.9%	11.9%			
	Medium (15–30 min)	37.1%	27.1%			
	Long (30–45 min)	18.0%	27.1%			
	Very long (>45 min)	28.1%	33.9%			
Chestnut variables	**Moment of incorporation**			0.677	0.713	0.050
	Beginning	34.8%	36.2%			
	Middle	47.2%	49.7%			
	End	18.0%	14.1%			
	Form of the chestnut			11.932	0.018	0.212
	Fresh - whole	33.7%	19.2%			
	Fresh - cut	25.8%	27.1%			
	Flour	5.6%	4.0%			
	Frozen	20.2%	18.6%			
	Other forms	14.6%	31.1%			
	Total	**100.0%**	**100.0%**			

Table 3
Results of the factor analysis.

Factor	% VE[a]	Variable	Loading
F1	22.2%	Type of recipe	0.739
		Preparation time	0.645
		Form of incorporation of the chestnut in the recipe	0.758
F2	19.1%	Dish type	0.813
		Moment of incorporation of the chestnut	−0.620
F3	16.8%	Involves cooking	0.861
		Cooking method	0.514

[a] %VE = Percentage of variance explained.

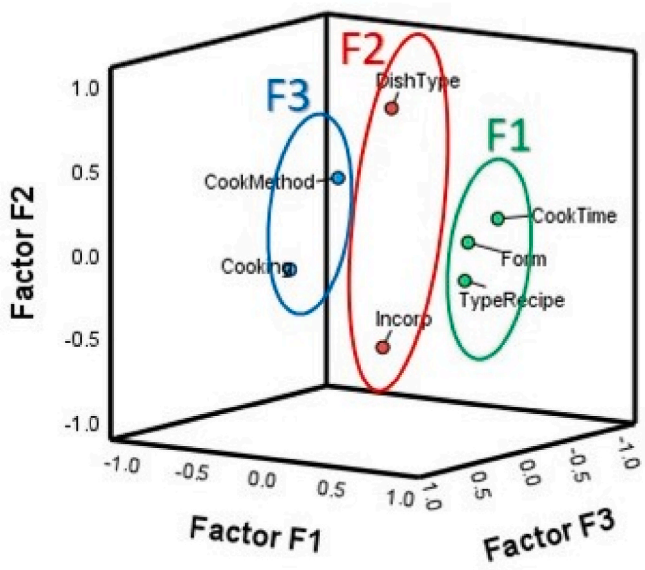

Fig. 2. Factor Analysis component plot for solution obtained with Principal Component Analysis and Varimax rotation.

Table 4
Results of the k-means cluster analysis.

Cluster	Recipes		Cluster centres		
	N	%	F1	F2	F3
C1	96	36.1	−0.650	−0.722	−0.217
C2	62	23.3	−0.572	1.201	−0.091
C3	10	3.8	0.031	−0.091	4.347
C4	98	36.8	0.996	−0.044	−0.083
ANOVA (p-value) →			<0.001	<0.001	<0.001

means. The cases (corresponding to the recipes) were distributed unevenly by the clusters, with lower representativeness in clusters C3 (3.8%) and C2 (23.3%). On the contrary, clusters C1 and C2 were quite similar, containing more than one-third of the recipes each. The results from ANOVA showed a significant ($p < 0.001$) differentiation between the factors.

After CA established the groups of recipes, a characterisation of the clusters was achieved through the crosstabs and chi-square tests, being the results presented in Table 5. For all variables, the p-value was significant ($p < 0.001$), and the Cramer's coefficients were over 0.3 in all cases, confirming that the association between the variables was moderate or strong. The results in Table 5 reveal that while most traditional and innovative recipes are in cluster C1, the Chef's recipes are mostly in cluster C4. With respect to the type of dish, cluster C2 includes most of the desserts, other main dishes, bakery/cookies and other types of recipes. In what concerns cooking, cluster C3 contains all the recipes that

Table 5
Association between cluster membership of the recipes and the classification variables.

Variables & Groups	Cluster membership (% of cases)				
	C1	C2	C3	C4	Total
Type of recipe[a]	p < 0.001; V = 0.512				
Traditional	48.3%	41.6%	3.4%	6.7%	100.0%
Innovation	51.6%	22.1%	4.2%	22.1%	100.0%
Chef's recipe	4.9%	4.9%	3.7%	86.6%	100.0%
Dish Type[a]	p < 0.001; V = 0.432				
Soup/Starter	69.7%	0.0%	6.1%	24.2%	100.0%
Breakfast/Tea Snack	40.0%	0.0%	10.0%	50.0%	100.0%
Main – Fish	56.5%	0.0%	4.3%	39.1%	100.0%
Main – Meat	57.1%	4.3%	0.0%	38.6%	100.0%
Main – Vegetarian	33.3%	12.1%	3.0%	51.5%	100.0%
Main dish – Others	0.0%	66.7%	0.0%	33.3%	100.0%
Dessert	7.7%	52.3%	4.6%	35.4%	100.0%
Bakery/Cookies	0.0%	50.0%	5.6%	44.4%	100.0%
Others	0.0%	90.9%	9.1%	0.0%	100.0%
Involves cooking[a]	p < 0.001; V = 1.000				
Yes	37.5%	24.2%	0.0%	38.3%	100.0%
No	0.0%	0.0%	100.0%	0.0%	100.0%
Cooking method[a]	p < 0.001; V = 0.307				
Boiling	54.3%	14.8%	1.2%	29.6%	100.0%
Roasting	50.7%	9.0%	1.5%	38.8%	100.0%
Grilling	75.0%	0.0%	0.0%	25.0%	100.0%
Baking	10.5%	49.1%	3.5%	36.8%	100.0%
Frying	16.7%	16.7%	0.0%	66.7%	100.0%
Others	15.6%	31.1%	13.3%	40.0%	100.0%
Cooking time[a]	p < 0.001; V = 0.283				
Short	50.0%	30.6%	8.3%	11.1%	100.0%
Medium	54.3%	25.9%	4.9%	14.8%	100.0%
Long	35.9%	9.4%	3.1%	51.6%	100.0%
Very long	12.9%	28.2%	1.2%	57.6%	100.0%
Chestnut incorporation[a]	p < 0.001; V = 0.318				
Beginning	11.6%	42.1%	6.3%	40.0%	100.0%
Middle	48.5%	16.2%	1.5%	33.8%	100.0%
End	53.7%	2.4%	4.9%	39.0%	100.0%
Form of the chestnut[a]	p < 0.001; V = 0.377				
Fresh – whole	48.4%	37.5%	3.1%	10.9%	100.0%
Fresh – cut	64.8%	22.5%	2.8%	9.9%	100.0%
In flour (dried and grinded)	16.7%	41.7%	8.3%	33.3%	100.0%
Frozen	29.4%	7.8%	2.0%	60.8%	100.0%
Others	2.9%	19.1%	5.9%	72.1%	100.0%

[a] Chi-square test p-value and Cramer's' coefficient.

did not involve cooking. For cooking time, cluster C1 includes more recipes with lower cooking time (short or medium), while cluster C4 contains more recipes with longer cooking time (long or very long). In regards to the moment of incorporation of the chestnut cluster C1 includes a high percentage of the recipes where the chestnut is incorporated in the middle or end. Finally, considering the form of the incorporation of the chestnut, cluster C4 clearly includes more recipes where the chestnut is used frozen, while in cluster C1 predominate recipes where the chestnut is added fresh (either whole or cut).

3.3. Ingredients analysis

Fig. 3(a) shows the 13 groups of ingredients, considering the number of ingredients in the database for the 266 recipes. A total of more than two thousand ingredients were registered (n = 2009), and the results reveal a predominance of the utilisation of ingredients classified as 'Spices' (n = 415), followed by 'Vegetables & Legumes', used 376 times. The least representative of the ingredients groups was 'Seafood', which was used only 7 times, and 'Fish' (n = 14). The ingredients were further classified according to their role in the recipe, so that Major ingredients accounted for 'Meat', 'Fish', 'Seafood', 'Cereals', 'Vegetables & Legumes'; Complementing ingredients accounted for 'Dairy & Eggs', 'Dried fruits & Nuts', 'Fruits'; while Minor ingredients referred to 'Oils &

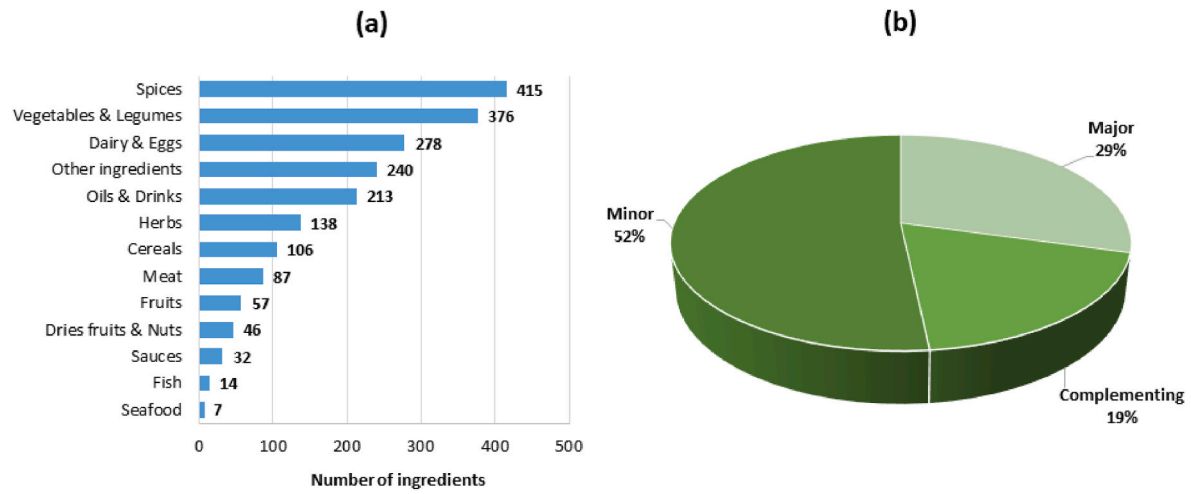

Fig. 3. Distribution of the ingredients according to the ingredient categories (a) and according to the role (b) (Total number of ingredients = 2009).

Drinks', 'Sauces', 'Herbs', 'Spices', and 'Other ingredients'. Fig. 3(b) shows the relative frequency of utilisation of the ingredients in terms of their role, with Minor ingredients being used more frequently (n = 1038) representing 52%, while Complementing ingredients being the less frequent (n = 381), representing 19%. This is because one recipe usually includes one or more of the Major ingredients and many Minor ingredients (different condiments), and sometimes does not include any of those in the group Complementing ingredients.

All the ingredients, according to their category, were used to generate word clouds, in which the relative size of the letters corresponds to the proportion in which the ingredients appear. As such, ingredients with a very large font appear many times while ingredients in very small font sizes appear very few times, sometimes only once or twice.

Fig. 4 presents the word clouds for six groups of ingredients and highlights the ingredients most used, i.e., those that were registered a higher number of times in the whole ingredients database. In this case, for group 'Cereals' (Fig. 4(a)), the most relevant ingredients were flour (n = 53), followed by rice (n = 13), puff-pastry (n = 11), and bread, oat and pasta (n = 7, for each of these three). In the category 'Dairy & Eggs' (Fig. 4(b)), the most used ingredients were egg (n = 84), butter (n = 73), milk (n = 49) and cheese (n = 28). For the 'Meat' group (Fig. 4(C)), the most frequent ingredients were pork (n = 20), bacon (n = 19), chicken (n = 10) and beef (n = 7). In what concerns the most frequent ingredients in categories 'Fish' (Fig. 4(d)) these include cod (n = 7) as the most frequent, but it is seen that, as compared to meet group, the recipes that include chestnut and fish are much less representative. Also, this was verified in what concerns seafood, with only one ingredient appearing in the 266 recipes studied, which was shrimp, appearing 7 times. This is why both categories were joined to generate one single cloud, as shown in Fig. 4(d). For the group 'Vegetables & Legumes' (Fig. 4(e)), also including tubers and other related ingredients, the most frequent were garlic (n = 95), onion (n = 91), tomato (n = 31), this was included in this group although being botanically a fruit, potato (n = 19) and carrot (n = 18), which botanically are tubers. The groups 'Fruits' and 'Dried Fruits & Nuts' were gathered in one single cloud (Fig. 4(f)), given the low number of different ingredients in both categories (only eight different types of fruit and ten different dried fruits or nuts). For this group, containing fruits, dried fruits and nuts, the most frequent ingredients were lemon (n = 20), used in different ways, from pulp to zest, almond (n = 16) and raisins (n = 10).

Fig. 5 also shows three clouds, one containing the ingredients in groups 'Herbs' plus 'Spices', for being strictly related, the second cloud refers to 'Oils & Drinks' plus 'Sauces', also for their strait connection, and the last word cloud, refers to the other ingredients not classified in previous categories. In what concerns the group' Herbs & Spices' (Fig. 5 (a)), very diverse ingredients were used, but the most relevant are salt (n = 157), pepper (n = 126), bay (n = 32), cinnamon (n = 31) and rosemary (n = 27). For the group containing 'Oils & Drinks & Sauces' (Fig. 5(b)), the most frequent ingredients were oil (n = 110), wine (n = 49), broth (n = 19) of different types from chicken broth to vegetable broth, Port wine (n = 12) and lemon juice (n = 7). Fig. 5(c) presents the 'Other ingredients', showing a prevalence of sugar (n = 95), cocoa (n = 33), mushrooms (n = 32), which are fungus, honey (n = 16) and yeast (n = 16) used in baked products.

3.4. *Proposed innovative thematic menu*

Complementary to the recipe analysis, experimental work was performed in order to propose an innovative thematic menu based on the chestnut. This was suggested to our research group by local producer's cooperatives in alignment with restaurants as a way to promote the endogenous product. The menu should incorporate one starter, one main dish and one dessert. For this, several attempts were made until the recipes were considered final (Fig. 6).

3.4.1. *Starter: Portobello mushrooms with bacon and chestnut*

- *List of ingredients for the mushrooms:* 5 Portobello mushrooms of good size, 1 red onion, 2 garlic cloves, 2 slices of bacon, 150 g of grated cheese, 20 g of parmesan cheese, salt, parsley, black pepper, 20 mL of olive oil, 10 cooked chestnuts.
- *List of ingredients for the cover:* 150 mL water, 90 mL oil, 5 raw chestnuts.
- *Preparation of the mushrooms:* Heat a frying pan, and when it is hot, add the olive oil, followed by the chopped garlic and onion and let it fry. Add the chopped bacon and let it fry, season with salt and pepper, and cook for 5 min or until achieving a golden-brown colouration. Remove the inside of the mushrooms and set aside. Add the reserved and finely chopped mushrooms to the previous preparation, still in the wok, and cook for 5 min. Adjust the flavour and seasonings. Add the cooked and cut chestnuts and let them sauté. At the end, add the parsley and mix. Stuff the mushrooms and cover with grated cheese. Bake at 180 °C for 10 min. When the mushrooms are cooked, remove from the oven, place them on the serving plate, and garnish with Parmesan cheese and chopped parsley.
- *Preparation of the cover:* Combine all ingredients in a blender until a homogeneous mixture is formed. Heat the frying pan, and when it is hot, pour a portion of the mixture into the pan (as if making a pancake). Leave it until it forms little holes and becomes crispy. Turn if

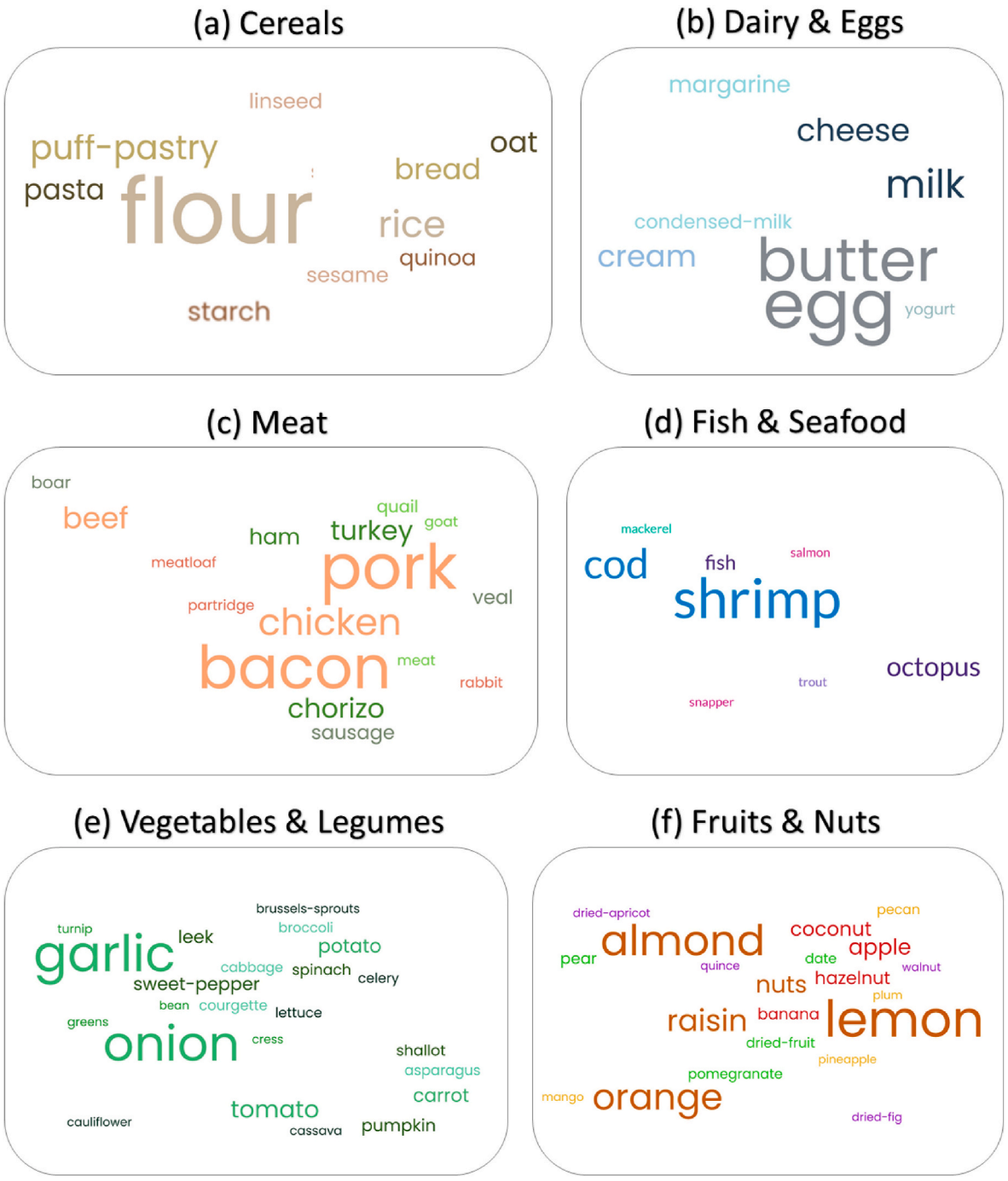

Fig. 4. Word cloud of the ingredients in categories (a) 'Cereals', (b) 'Dairy & Eggs', (c) 'Meat', (d) 'Fish & Seafood', (e) 'Vegetables & Legumes' and (f) 'Fruits & Nuts'.

necessary. After that, place it on a plate with absorbent paper. Once the mushroom is ready, just put the tile on a plate and the mushroom on top. Garnish with parmesan cheese and parsley.

3.4.2. Main dish: pork loin with chestnut puree and vegetables

- *List of ingredients for the pork:* 100 mL of olive oil, 100 g of margarine, 1 kg of pork loin, salt, 2 cloves of garlic, black pepper, 100 mL of white wine, 3 soup spoons of sweet pepper paste, 300 g of chestnuts, parsley.
- *List of ingredients for the pure:* One and a half kg of chestnuts, 50 g of margarine, 250 mL of milk, salt, and black pepper.
- *Preparation of the pork:* Boil the chestnuts in water, just enough to cover. Cut the loin into generous slices. Season the loins with salt, pepper, garlic, pepper paste, and white wine, and leave them to marinate for 1 h. In a frying pan, add the olive oil and margarine to fry the loins. After frying, reserve. Add the cooked chestnuts together with its boiling medium.
- *Preparation of the puree:* Start by cooking the chestnuts in water seasoned with salt. When they are cooked, drain the chestnuts, peel them, and turn them into puree. Finally, in a pan, add the chestnut puree, butter, and milk. Season with salt and pepper.

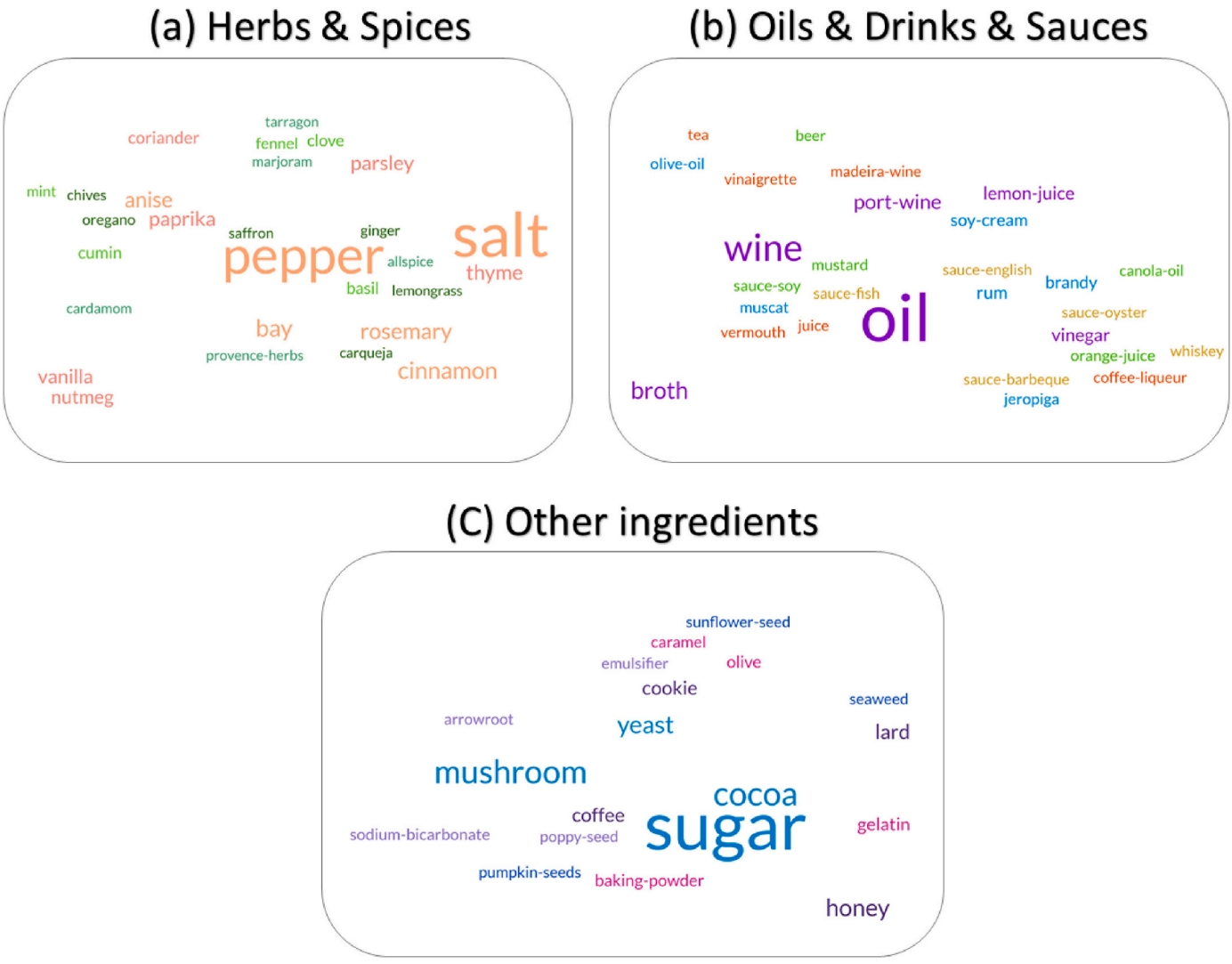

Fig. 5. Word cloud of the ingredients in categories (a) 'Herbs & Spices', (b) 'Oils & Drinks & Sauces' and (c) 'Other ingredients'.

Fig. 6. Thematic chestnut menu (starter, main dish, and dessert).

3.4.3. Desert: Dairy mousse with chestnut crumbs

- *List of ingredients:* 600 mL of cream, 2 soup spoons of sugar, 1 can of condensed milk, 400g chestnuts.
- *Preparation:* Boil the chestnuts in water. Beat the cream by adding the sugar until it becomes creamy. Add condensed milk. Crush the chestnuts, leaving small grains. Mix everything and put it in the refrigerator to cool until serving.

4. Discussion

The species *Castanea sativa* Mill is known as European chestnut because it is a unique species of the genus Castanea that is cultivated in Central Europe and the Mediterranean areas. Its presence dates back millennia, and this nut tree is widespread nowadays due to diffusion occurring in both natural and anthropic causes (Beghè et al., 2013). The chestnut constitutes a gastronomic patrimony that has been constructed over centuries in many European areas, such as Portugal (Borges et al., 2008) or Italy (Beghè et al., 2013). Its importance at the gastronomic level is one of the most relevant, by using the fruits as food, but other utilisations of this species are also relevant, like the exploitation of wood for furniture (Thaler et al., 2014) or barrels used to age beverages like wine for example, conferring special organoleptic features (Caldeira et al., 2010; Fernández de Simón et al., 2014). Additionally, the European chestnut tree has a relevant impact on landscape and environment, considering the resilience of the chestnut forests to fire (Seijo et al., 2018), and finally, it has also been referred to its role on social and cultural life (Beghè et al., 2013), with chestnuts being foods associated with certain social representations. In Portugal, traditionally, during the autumn and winter seasons, chestnuts are roasted on the street in practically all cities, where they are bought by the dozen in paper cones by pedestrians and consumed while hot for comfort (Lage, 2002). Furthermore, the chestnut is associated with the celebrations of Saint Martin (São Martinho) on the 11th of November, with festivities where it is the centrepiece together with the Jeropiga, a sweet alcoholic beverage also traditional in Portugal (Laranjo, 2022; Modesto et al., 1999).

Lately, the interest in chestnut and its derived food products has gained increased relevance, owing to their recognised nutritional value and health benefits. Hence, a diversity of initiatives have been implemented to support and develop chestnut culture, as well as its transformation and commercialisation (Beghè et al., 2013; Borges et al., 2008). In Portugal, a number of research projects have been implemented, such as the VALORCAST - Valorization of the chestnut and optimisation of its commercialisation, funded by European funds in the ambit of Rural Development 2014–2020 for Operational Groups (in the sense of Art 56 of Reg.1305/2013) (European Comission, 2018). In the publication by Correia et al. (2022) the transformation and characterisation of chestnut flour from Portuguese varieties for food applications is discussed, and in the publication by Gomes and Vilela (2022) an innovative application of the chestnut is proposed by boiling them in a wine syrup. Also, Guiné et al. (2023) discuss the utilisation of chestnut in traditional and innovative food products, also including the commercial use in the form of flour, the utilisation in bakery products (bread or cookies), commercialised in the dehydrated form, or transformed into candied chestnuts. The work by Foucher et al. (2022) describes the development of innovative candied chestnuts from Portuguese chestnut cultivars.

The chestnut fruits from some Portuguese chestnut varieties were characterised by a relatively high moisture content, considering the ranges for nuts. Also, they possess high amounts of starch and dietary fibre while presenting low-fat content. Nevertheless, the lipid and fatty acid profiles of Portuguese chestnuts include a healthy ratio between saturated and unsaturated fat, with 17% of saturated fatty acids while having 83% of unsaturated fatty acids (Borges et al., 2007, 2008; Gonçalves et al., 2010).

The chestnut fruits have a significant content of polyphenols and organic acids, which have antioxidant capacity, and therefore may have a protective effect against chronic diseases, besides their role in influencing the organoleptic characteristics of the products (Borges et al., 2008; Gonçalves et al., 2010). In fact, nuts in general, and chestnuts in particular, contain certain bioactive compounds that have been proven as beneficial for cardiovascular health. The consumption of higher amounts of nuts has demonstrated a negative association with cardiovascular diseases: 19% lower risk of cardiovascular diseases, 24% lower risk of coronary heart disease, 18% lower risk of stroke mortality, 15% lower risk of atrial fibrillation, and 19% lower risk of total mortality (Glenn et al., 2023; Sabaté et al., 2010). Nevertheless, the effectiveness of nuts in the incidence of stroke, stroke subtypes, peripheral arterial disease and heart failure has not been so clearly demonstrated (Glenn et al., 2023; Sabaté et al., 2010). Several healthy dietary patterns that include nuts are recommended by clinicians to prevent the onset of cardiovascular diseases. Among these stands the Mediterranean diet, the Nordic diet, the Dietary Approaches to Stop Hypertension (DASH), as well as vegetarian and Portfolio diets (Glenn et al., 2023).

Chestnut fruits and flour find application in gluten-free diets (Romano and Aponte, 2019), because they do not contain gluten, thus being safe to be consumed by people who suffer from celiac disease or by gluten (or wheat) sensitivity people, or simply by consumers who voluntarily avoid food products containing gluten for lifestyle and health-related beliefs (Romano and Aponte, 2019).

Although many studies focus on the chemical composition, nutritional value and bioactive compounds in chestnut, the studies that aim to investigate its culinary application are less frequent. The study by Santos et al. (2023) investigated the influence of cooking operations (roasting and boiling) on several physical-chemical and organoleptic characteristics of two Portuguese varieties of chestnuts (Longal and Judia). The results of consumer testing showed that the roasting processing produced chestnuts with the most appreciated sensory attributes in comparison with the boiled chestnuts (Santos et al., 2023). Also, a similar study was carried out by Gonçalves et al. (2020), focusing on the effect of the same cooking methods (roasting and boiling) on the secondary metabolite composition of chestnut fruits from three Protected Designation of Origin (PDO) areas in the Northern-East part of Portugal. Their results revealed that cooking processes significantly influenced both the primary and the secondary metabolite compositions of the chestnuts. The roasting operation produced chestnuts with higher protein content, higher insoluble and total dietary fibre, and lower fat content than boiled chestnuts. Furthermore, cooking increases citric acid content, particularly when used roasted instead of boiled, while decreasing the malic acid content. Finally, the authors observed that the roasted chestnuts had significantly higher gallic acid and total phenolics contents when compared to the raw samples, while the boiled chestnuts had higher gallic and ellagic acid contents than the raw ones (Gonçalves et al., 2020). As so, the cooking of chestnuts allows to obtain products with appreciated organoleptic characteristics, while also enhancing their nutritional value and bioactive compounds.

The results of the recipe analysis in the present work revealed a high number of varied applications of chestnuts into gastronomic preparations, and most especially, in main dishes based on meat, and desserts. From the selected 266 recipes, approximately one-third were traditional recipes, another third were innovative recipes, and the remaining one-third were Chef's originals. The great majority involved some type of cooking, particularly boiling, roasting, or baking. As to the form of incorporation of the chestnut into the recipe, it was mostly fresh, either whole or cut. The recipes' nature (classical or modern) was not found to be significantly associated with the dish type, cooking, cooking method, preparation time, or moment of incorporation of the chestnut, being, however, significantly associated with the form of incorporation of the chestnut. Factor analysis revealed three groups of variables: the first factor (F1), which included three variables, and the other two factors (F2 and F3), which included two variables each, which were clearly differentiated. Cluster analysis allowed the establishment of four groups of

recipes, the most representative being clusters C1 and C4. Further analysis revealed significant differences in the recipes' clusters according to all the variables used to classify the recipes, and moderate to strong associations according to Cramer's coefficients. A work by Mulík et al. (2022) analysed recipes from Mexican cuisine using edible flowers and observed that they are also incorporated into very different types of dishes, and in different forms.

The utilisation of culinary ingredients is much linked to locally available foods, herbs or spices, considering the historical perspective and the preservation of culinary traditions (Musaubach and Scaro, 2022; Veronesi et al., 2023). However, modern cuisine has largely expanded the range of ingredients, attending to the globalisation of the food markets and commercialisation of food and ingredients at a global level (Holtemöller and Mallick, 2016; Raynolds, 2012). Ingredients analysis indicated that the most frequent categories were spices, followed by vegetables & legumes, and it also showed that the minor ingredients, used in lower quantities in the recipe, were the majority of the ingredients listed in the recipes. Word analysis indicated in each of the categories the most relevant ingredients, which were flour, butter, egg, pork, bacon, shrimp, onion, garlic, lemon, almond, salt, pepper, oil, and sugar.

The role of local restaurants and their chefs in promoting local food products and ingredients is recognised. The work by Carmichael et al. (2023) highlights how chefs can help promote and increase the acceptability of local foods. In our work, a successful innovative thematic menu was developed composed of recipes all containing chestnut, including one starter (Portobello mushrooms with bacon and chestnut), one main dish (Pork loin with chestnut puree and vegetables) and one dessert (Dairy mousse with chestnut crumbs). This menu is expected to be implemented in local restaurants to help develop the chestnut sector in the region while providing consumers with differentiated flavours and gastronomic experiences based on a locally produced ingredient.

5. Implications for gastronomy

The results in this study are relevant from the gastronomic point of view because they highlight a number of aspects related to the use of chestnut as an ingredient in food preparations and culinary recipes. It shows the diversification of the use of this ingredient in a variety of dish types (Soup/Starter, Breakfast/Tea Snack, Main dish – Fish or Meat or Vegetarian), Dessert, Bakery/Cookies, or others), mostly cooked but also raw, and combining with a high number of other ingredients. These ingredients include a diversity of categories and act as major or minor ingredients (Major ingredients include Meat, Fish, Seafood, Cereals, Vegetables & Legumes; Complementing ingredients include Dairy & Eggs, Fruits, Dried fruits & Nuts; Minor ingredients include Oils & Drinks, Sauces, Herbs, Spices, and Other ingredients. Moreover, a thematic innovative menu was developed with recipes containing chestnuts to be used in restaurants that desire to promote them as local food or as an innovative food ingredient.

6. Conclusions

This work allowed us to conclude that chestnuts are a very versatile ingredient, used in a wide number of recipes and in various forms. The chestnuts can confer the gastronomic preparations distinct flavours and textures, and for that reason they are incorporated into starters, main dishes or desserts of different sorts.

The utilisation of chestnuts in culinary preparations constitutes a way of diversifying their utilisation, contributing to the added value in the sector, given the production of chestnuts in the Centre and North regions of Portugal.

Implications for gastronomy

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CRediT authorship contribution statement

Sofia G. Florença: Writing – review & editing, Writing – original draft, Investigation. **Paula M.R. Correia:** Writing – review & editing. **Maria João Lima:** Writing – review & editing. **Edite Teixeira-Lemos:** Writing – review & editing. **Cristina A. Costa:** Project administration. **Raquel P.F. Guiné:** Writing – original draft, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

All 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

Data will be made available on request.

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Appendix A

Figure A.1 shows the curve for determination of the number of clusters to form.

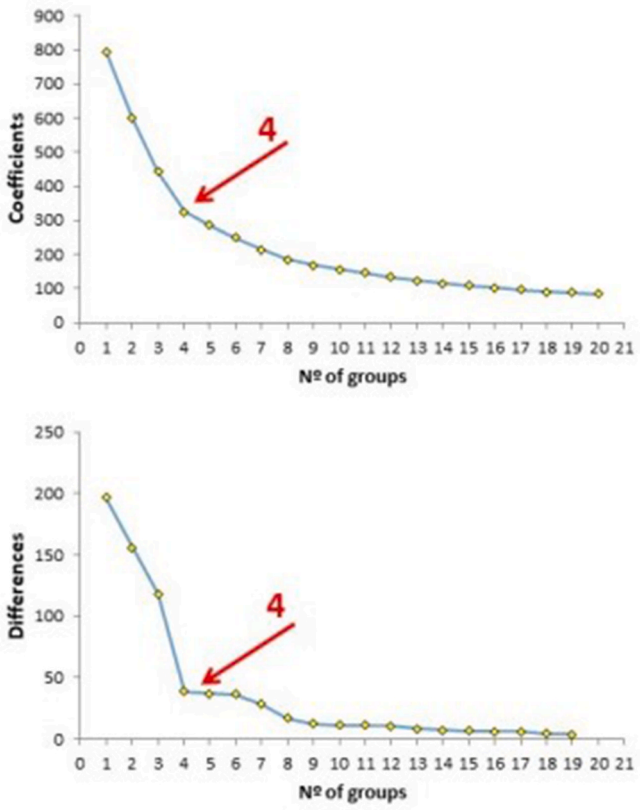

Fig. A.1. Agglomeration schedule coefficients in hierarchical cluster analysis by Ward method.

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