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Development of a New Pasta Product by the Incorporation of Chestnut Flour and Bee Pollen

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Abstract: This work aimed at developing fortified pastas incorporating chestnut flour (25–55%) and powdered pollen (5–20%), either separately or in combination, as well as the characterization of the products obtained. To this, a physical characterization was carried out (analyzing texture and color), complemented with chemical analyses to determine the nutritional composition. Results showed that adding chestnut flour over 40% to wheat-flour pasta shortened optimum cooking time and lowered cooking yield, and the addition to pasta prepared with wheat flour and eggs maintained approximately constant the cooking yield. Additionally, the incorporation of pollen powder (up to 20%) in pasta prepared with wheat flour and water or fresh egg shortened the cooking time and cooking yield, in both fresh and dried pasta. The most suitable percentages of the new ingredients were 50% for chestnut and 10% for pollen. Comparing with the control pasta recipe (wheat flour and egg), the addition of chestnut flour (50%) or pollen powder (10%) increased stickiness, adhesiveness and the darkening of the final product (fresh or dried) but maintained the firmness of the pasta. The cooking of fresh or dried pasta enriched with both ingredients turned the pasta clearer and slightly stickier. On the other hand, the addition of chestnut flour and pollen powder in pasta formulation delivered a nutritionally balanced product with high fiber, vitamins and minerals. Overall, chestnut flour and powdered pollen represent promising ingredients for the development of functional fresh and dried pasta formulations.

Keywords: color; texture; nutritional value; product development; optimal formulation

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1. Introduction

Pasta is a staple food all around the world, including the developing countries, and is consumed by people in all ages, from children to elderly, independently of their socio-economic status. Characteristics that define a high-quality pasta include firmness and elasticity, reduced cooking loss and stickiness, while being easy to prepare and presenting a good firmness once cooked. Nevertheless, regarding nutrition, pasta products tend to be energy-dense foods, with low contents of micronutrients, such as vitamins and dietary minerals, as well as bioactive compounds [1]. Pasta is made from dough without fermentation, being one of the most popular products, due to its easy formulation and processing [2]. Pasta can be, generally, made from durum wheat semolina or soft wheat flour to which water is added and then subjected to various mechanical actions to obtain the final texture [3]. When wheat flour is kneaded and hydrated, its proteins form a network called gluten, which endows the paste its capacities of extensibility, elasticity, tenacity, cohesion and gas retention [4,5]. The hydrothermal treatment of pasta allows the gelatinization of starch and the crosslinking of proteins. Besides the moisture content of the dough, operational conditions such as temperature or pressure, or the presence of small molecules (salt, sugar, acids) or macromolecules (hydrocolloids), can influence the starch interactions with water and the final properties [6].

Nowadays, pasta is present in countries all over the world, being one of the most consumed foods worldwide, due to its nutritional value, organoleptic characteristics and ease of preparation [7–9].

Pasta formulation can be easily diversified to obtain varied products by means of adequate enrichment and technological processes [8]. Over time, pasta has come to diversify not only in relation to its shape but also by the addition of other ingredients such as cereals, eggs, vegetables, spices, colorings and vitamins [2]. Modern trends indicate that the consumption of fortified foods is becoming more emphasized. Hence, because pasta is a staple food that can be easily fortified with non-traditional ingredients, there have been developments of specific pasta products incorporating ingredients that contribute to improve the amino acids and fatty acids profiles or those aimed at increasing the dietary fiber content or the presence of vitamins and dietary minerals [10–13]. Additionally, bioactive compounds can also be added to pasta to increase its health benefits, such as phenolic compounds with antioxidant activity, which can be incorporated from natural sources such as flowers, fruits or culinary herbs [14–16]. However, besides impacting the nutritive value and health protective effects, the addition of differentiated ingredients to the pasta formulation can influence cooking efficiency (cooking loss, cooking time) and sensory attributes (appearance, color and texture) [17–21].

Chestnuts contain more than twice as many carbohydrates as most nuts: 39.8% for chestnuts against 19.4% for cashew nuts, 12.6% for pistachios, 7.2% for almonds, 5.0% for pine nuts, 6.0% for hazelnuts or 3.6% for walnuts [22]. Chestnut flour is gluten free but, unlike other gluten-free flours, which are sometimes low in nutrients, chestnut flour provides high nutritional value. It is rich in dietary fiber, essential amino acids (due to the protein content), fatty acids (omega 3 and 6), vitamins (C and group B) and also provides important dietary minerals necessary for the body (calcium, magnesium, potassium) [2,23,24]. Consuming chestnut flour has proven health benefits and optimizes a large number of parameters in humans. Chestnut flour is important for intestinal health and works against low-density lipoprotein cholesterol (LDL-cholesterol). Numerous studies have confirmed the benefits of chestnuts on cardiovascular protection, on type 2 diabetes and on gallstones. Chestnut flour also helps to avoid several food allergies/intolerances: celiac disease, wheat allergy and non-celiac gluten sensitivity. Indeed, it is a gluten-free flour, suitable for people with celiac disease, gluten intolerance and those wishing to reduce gluten in their diet. However, because it does not include gluten, it has no bread-making properties, and therefore its incorporation into pasta may result in a higher difficulty in handling the dough [2,25–29].

Pollen contains various enzymes produced by bees to dissolve the solid shell that contains the nutrients inside each pollen grain, such as phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PPO), polyphenol peroxidase (POD) and superoxide dismutase (SOD) [30]. It is one of the most protein-rich products because it contains all the essential amino acids. The work by Bayram et al. [31] confirmed the presence of 32 forms of free amino acids in bee pollen, the most abundant being, in decreasing order, L-proline, L-asparagine, L-aspartic acid, L-glutamic acid, L-phenylalanine, L-tryptophan, gamma-aminobutyric acid and L-serine. Pollen also provides carbohydrates, water, fatty acids and phenolic compounds [2,32–34]. Bayram et al. [31] evaluated the phenolic composition of bee pollen and detected 16 compounds, with particularly high amounts of rutin, followed by isorhamnetin, kaempferol and myricetin.

The reviews by Denisow [35] and by Guiné [32] highlighted the beneficial effects of bee pollen on human health. Pollen enhances the body's natural defence system due to the presence of phytonutrients that have protective properties, such as antioxidant, antimicrobial, antifungal or anti-inflammatory activities. Additionally, it has protective effects on the liver and toxicity and has proven antimutagenic and anticancer activities.

The objective of this work was to incorporate chestnut flour and pollen powder into a basic pasta recipe, to produce enriched pasta formulations, due to the improved nutrition and health properties of these ingredients. Specifically, the aims were to optimize the pasta formulations and analyze the pasta obtained in terms of chemical composition (macronutrient value) and physical properties (color and texture).

2. Materials and Methods

2.1. Pasta Formulation and Preparation

The ingredients used in this work were purchased in a supermarket, except for the chestnut flour and the water, and they were acquired as follows:

- Wheat flour T55: flour obtained from wheat at extra fine grinding grade, Brand: Espiga;
- Wheat flour T65: flour obtained from wheat at fine grinding grade, Brand: Espiga;
- Wheat semolina: rough flour obtained from durum wheat, containing gluten, Brand: Espiga;
- Chestnut flour: obtained from grinding dried chestnuts, provided by the bread company Fábrica do Pão;
- Pollen powder: multiflora granulated bee pollen, Brand: Naturitas;
- Egg—chicken fresh eggs size L (large), Brand: Matinados;
- Water: tap water with quality for human consumption.

2.1.1. Preliminary Essays

In the first stage, it was necessary to select the pasta recipe with the best performance in order to be able to incorporate the chestnut flour and pollen powder under the best conditions. Therefore, a basic pasta recipe was optimized to serve as control. The basic flours used were wheat flour T55, wheat flour T65 and wheat semolina. Wheat flour type 55 in a fine flour, often used in many culinary preparations, white bread, pastries and pasta. Flour T 65 has a slightly higher granulometry, and semolina is a type of flour made from durum wheat. The three types of flour mentioned above were tested first with water and then with egg, for fresh pasta and dry pasta. The quantities used obeyed the proportion of a half quantity of water or egg for the quantity of flour or semolina. The formulations to optimize the control (FC) pasta were as follows:

FC1—50 g water + 100 g wheat flour T 55
FC2—50 g water + 100 g wheat flour T 65
FC3—50 g water + 100 g wheat semolina
FC4—50 g egg + 100 g wheat flour T 55
FC5—50 g egg + 100 g wheat flour T 65
FC6—50 g egg + 100 g wheat semolina

For the production of the pasta, the ingredients were mixed by hand, then pressed and cut in a home pasta-shaping machine (Figure 1). For higher homogenization and better rheological performance, the pasta was passed through the shaping machine several times, after folding in perpendicular directions each time. The machine allows adjusting the thickness of the pasta from 1 (thinner) to 6 (thicker).

The six obtained pasta samples are shown in Figure 2, in fresh form and after drying in a chamber at 40 °C for 12 h to evaluate if the drying operation would influence the properties of the pasta. The cooking time was established as a base of 10 min in boiling water (for 150 g of pasta was used 3 L of water, to which was added 1.5 g of salt) (Figure 3). Nevertheless, the samples were tested by the cooker to verify if this pre-established cooking time would be the adequate to achieve the desirable status of "al dente". Cooking was carried out with precision by respecting the standardized protocol (NF ISO 7304) in order to make it possible to compare the different samples. After cooking, the pasta was poured into a sieve and drained.

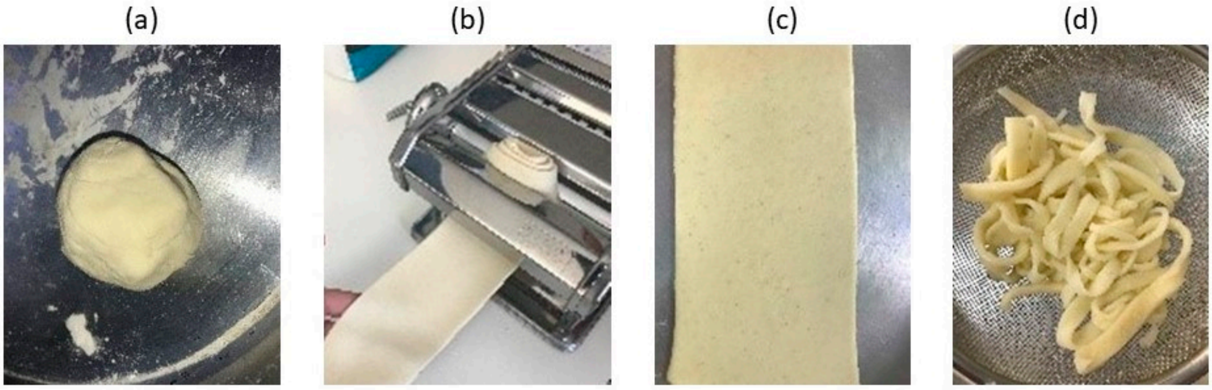

Figure 1. Pasta preparation: (**a**) dough obtained after mixing the ingredients; (**b**) shaping of the pasta; (**c**) shaped pasta obtained; (**d**) pasta after being cut into strips.

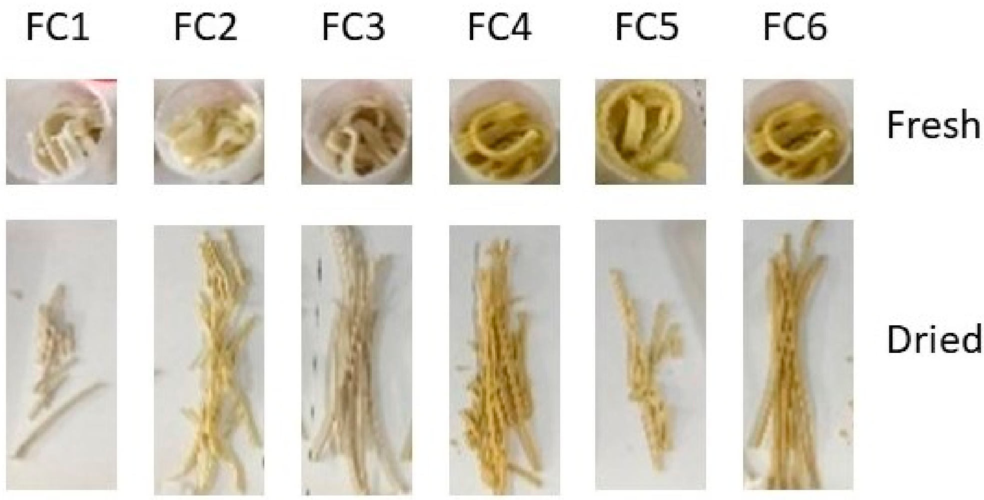

Figure 2. Preliminary pasta samples: fresh and dried.

The six formulations were evaluated in both alternatives (cooked fresh and cooked after drying) through a qualitative assessment, made by the laboratory technicians handling the samples, in order to evaluate the most promising formulation(s) for the desired objectives, i.e., to proceed to the next step of the research. The evaluations for each of the attributes evaluated (color, easy to manipulate without breaking, sticky, taste, texture in mouth, texture in hand) were made on a scale as follows: very unsatisfactory (− −), unsatisfactory (−), satisfactory (+), good (++), very good (+++) as summarized in Table 1. These preliminary results allowed the choosing of the best formulations for the control pasta recipe. Hence, for the next experiments, the two recipes chosen as control were FC2 (with water) and FC4 (with fresh egg), considering the overall performance either fresh or dried. In these two cases, the dough was easy to manipulate and not too sticky, and the pasta had a pleasant taste, a tender texture, good cooking ability and an attractive color.

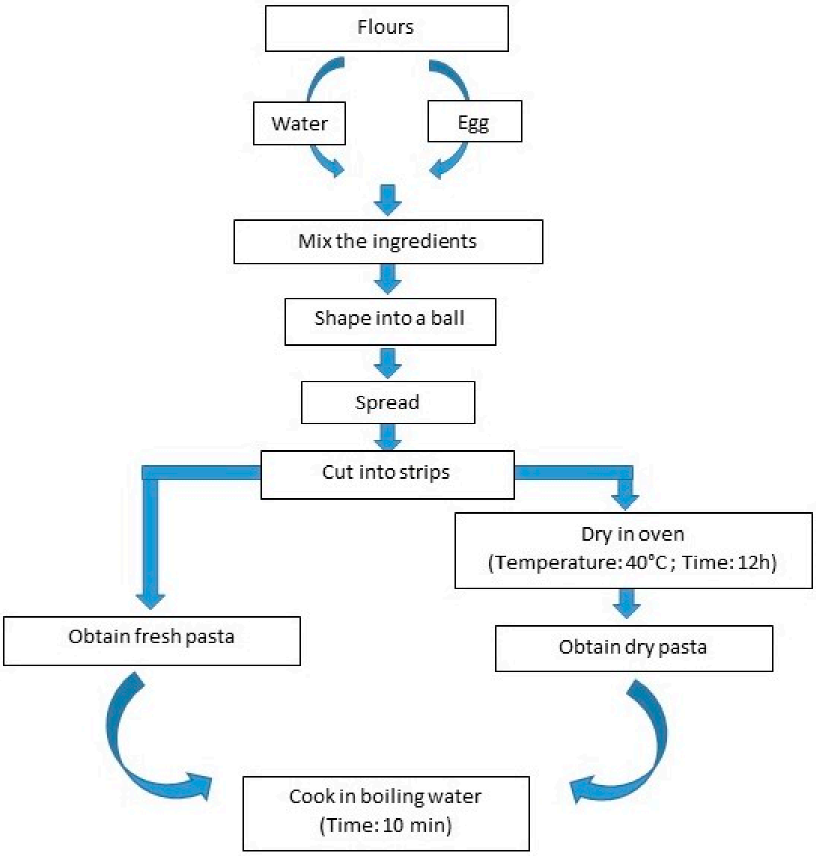

Figure 3. Production diagram for the pasta preparation.

Table 1. Appreciation of the six formulations tested for the control (FC) pasta.

	With Water			**With Egg**		
	FC1	**FC2**	**FC3**	**FC4**	**FC5**	**FC6**
FRESH [1]						
Color	−	++	−	+++	++	+++
Easy to manipulate without breaking	−	++	++	+++	−	+++
Sticky	+	++	++	−	−	−
Taste	+	++	++	+++	−	+++
Texture in mouth	−	+	+	+++	−	−
Texture in hand	+	+	−	+++	−	+
DRIED [1]						
Color	−	+	−	++	−	++
Easy to manipulate without breaking	− −	+	++	++	+	++
Sticky	++	+	−	−	−	−
Taste	−	++	++	++	−	− −
Texture in mouth	−	++	++	++	−	− −
Texture in hand	−	+	++	++	−	++

[1] Measurement scale: very unsatisfactory (− −), unsatisfactory (−), satisfactory (+), good (++), very good (+++).

2.1.2. Formulations Incorporating Chestnut and Pollen

Having the two formulations described above as reference (FC2 and FC4), the following formulations were designed to incorporate variable percentages of the target ingredients (chestnut flour and pollen powder), by partially replacing the flours used. Since this is the first attempt to incorporate this type of novel ingredient into pasta formulations, we could not find in the literature any recipes to help define the correct amounts of chestnut flour or bee pollen powder to add. Therefore, the strategy followed was to test a range of percentages for each of the ingredients. Hence, on this step, each ingredient was incorporated separately: chestnut flour in proportions varying from 25 to 55% (Table 2) and pollen powder varying from 5 to 20% (Table 3). These percentages were defined in relation to the total flour (wheat flour T65 or wheat flour T55, respectively for FC2 and FC4), i.e., not including the liquid (water or egg, respectively for FC2 and FC4). It is important to note that the mass of pasta obtained does not match the sum of the ingredients because some of the mass may adhere to the surface where it was mixed.

Table 2. Incorporation of chestnut flour into the control formulations with water and egg.

	% of Chestnut Flour [1]					
	0%	25%	30%	40%	50%	55%
	Formulations with Water					
	FC2	FC2-C25	FC2-C30	FC2-C40	FC2-C50	FC2-C55
Chestnut flour (g)	0	18.76	22.50	30.00	37.50	41.25
Wheat flour T65 (g)	75.00	56.25	52.50	44.99	37.50	33.75
Water (g)	37.49	37.50	37.50	37.50	37.50	37.50
Pasta obtained (g)	87.73	89.97	89.25	80.44	82.29	86.77
	Formulations with Egg					
	FC4	FC4-C25	FC4-C30	FC4-C40	FC4-C50	FC4-C55
Chestnut flour (g)	0	18.76	22.51	30.03	37.51	45.03
Wheat flour T55 (g)	75.01	56.24	52.49	45.01	37.49	30.00
Egg (g)	37.51	37.51	37.49	37.47	37.51	37.50
Pasta obtained (g)	108.6	107.2	105.0	99.87	94.77	95.06

[1] Defined in relation to the total flour (not including the liquid—water/egg).

Table 3. Incorporation of pollen powder into the control formulations with water and egg.

	% of Pollen Powder [1]				
	0%	5%	10%	15%	20%
	Formulations with Water				
	FC2	FC2-P5	FC2-P10	FC2-P15	FC2-P20
Pollen powder (g)	0	6.00	7.50	11.25	15.02
Wheat semolina (g)	75.00	69.00	67.50	63.75	60.01
Water (g)	37.49	37.50	37.60	37.54	37.51
Pasta obtained (g)	87.73	99.53	78.45	84.73	72.08
	Formulations with Egg				
	FC4	FC4-P5	FC4-P10	FC4-P15	FC4-P20
Pollen powder (g)	0	5.99	7.50	11.25	15.00
Wheat flour T55 (g)	75.01	68.99	67.51	63.75	60.01
Egg (g)	37.51	37.05	37.48	37.22	37.49
Pasta obtained (g)	108.6	86.99	83.19	74.08	85.65

[1] Defined in relation to the total flour (not including the liquid—water/egg).

It should be noted that the same amount of water was added, approximately, to all the pasta formulations, in order to evaluate the unique effect of chestnut flour incorporation on physicochemical properties of pasta.

In all cases, the mass of raw pasta obtained for each formulation was divided into 2 parts, one to be cooked fresh and the other to be dried and cooked after drying, following the same procedures as previously described. For these operations some evaluating quantitative indicators were calculated, according to Equations (1) and (2). These parameters were chosen as quality indicators because they are generally used and recommended in other scientific works: cooking yield, also sometimes defined as water abruption or water uptake [36–40] and drying loss, also known as weight loss [40–42].

$$\text{Cooking yield} = \text{Mass of cooked pasta}/\text{Mass of uncooked pasta} \times 100\% \quad (1)$$

$$\text{Drying loss} = \text{Mass of dried pasta}/\text{Mass of fresh pasta} \times 100\% \quad (2)$$

From these essays is was possible to select the most suitable percentages of these new ingredients, which were 50% for the chestnut flour and 10% for the pollen powder. Therefore, in the following step a final formulation was produced by incorporating both ingredients simultaneously in the percentages defined as optimal, but in this case only for the recipe that contained egg, being the most suitable. The formulation for this recipe is presented in Table 4.

Table 4. Formulation of egg pasta with 50% chestnut flour and 10% pollen powder.

	FC4-C50P10	% in Relation to the Mass of Solids	% in Relation to the Total Mass
Chestnut flour (g)	37.5	50.0	33.3
Pollen powder (g)	7.5	10.0	6.7
Wheat flour T55 (g)	30.0	40.0	26.7
Egg (g)	37.5	—	33.3
Total (g)	**75 [a]/112.5 [b]**	**100**	**100**
Pasta obtained (g)	**79.20**		

[a] Total mass of solid ingrediens; [b] Total mass of all ingredients.

2.2. Physical Properties

2.2.1. Color

For the evaluation of color, measurements were made using a handheld tristimulus colorimeter (Chroma Meter—CR-400, Konica Minolta, Japan). The measurement system used was the Cartesian coordinates L*, a* and b*. The L* axis represents lightness and varies from 0 (corresponding to no lightness, i.e., absolute black), to 100, which is maximum lightness (i.e., absolute white). The other axes are represented by a* and b* and they are at right angles to each other. The a* axis varies from green at one extremity (represented by −a*) to red at the other (+a*), whereas the b* axis varies from blue at one end (−b*), to yellow (+b*) at the other. Although in theory there are no extreme values of a* and b*, in practice they can frequently be numbered from −60 to +60. To perform the measurements, care was taken to promote similar light conditions when measuring the color of all samples, including the avoidance of direct sunlight and control of the incidence of artificial light. The calibration of the meter was done using a white tile, with illuminant D65 [43]. All evaluations were made on ten replicates.

Total color difference (*TCD*), also sometimes defined as ΔE, was calculated using Equation (3), which allows quantifying the overall color difference between a sample and the reference, which is this case was the control sample:

$$TCD = \sqrt{\left(L^* - L_0^*\right)^2 + \left(a^* - a_0^*\right)^2 + \left(b^* - b_0^*\right)^2} \quad (3)$$

where L_0*, a_0*, b_0* are the color coordinates for the reference sample [43–45].

A larger total color difference corresponds to a greater color change from the reference material, and one typical scale for evaluation of the color difference is as follows [46]: TCD values belonging to the interval [0.0–2.0] correspond to unrecognizable differences, TCD values belonging to the interval [2.0–3.5] correspond to differences possible to recognize by an experienced observer, and TCD values higher than 3.5 correspond to clear differences in the color of the samples under comparison.

2.2.2. Texture

Texture analysis was performed out using a texturometer TA.XT.Plus (Stable Micro Systems, Godalming, Surrey, UK). The analyses were made on 10 samples from each type of pasta tested and the values presented are the average values of the 10 measurements made for each property. The test used was cutting the stripe of pasta using a Blade Set with a knife HDP/BSK (Warner-Bratzler) [47,48]. The pre-test and test speeds were 2.0 mm/s and the post-test speed was 10.0 mm/s, considering a distance equal to 40 mm and a trigger force of 0.20 N. Each analysis produced a curve of force vs. distance, which allowed calculating two textural properties: firmness (force at highest peak), stickiness (force at lowest negative peak) and adhesiveness (area of the negative part of the curve) as shown in Figure 4.

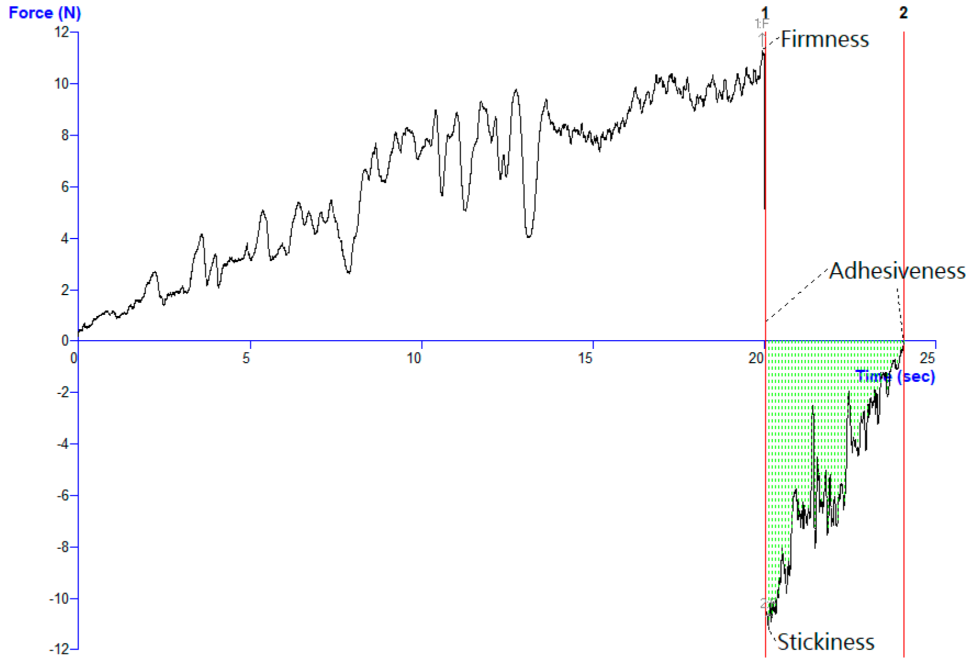

Figure 4. Graph of textural analysis performed to a pasta sample that allows obtaining the textural parameters hardness, adhesiveness and stickiness.

2.3. Chemical Analyses

The products developed were subject to physical–chemical analyses following the Portuguese standardized methodologies for evaluation. The moisture content was determined by drying at 101 °C until reaching a constant weight. Water activity was measured using a relative humidity meter (hygrometer-HS2, Rotronic, Switzerland) [49]. The fat content was assessed through Soxhlet extraction with petroleum ether [50]. Ash was measured through the Weende method after the calcination of the sample at 500 °C [51]. Crude protein was determined by the Kjeldahl method after mineralization [50], and crude fiber was determined by acidic digestion with sulfuric acid 1.25% (*v/v*) followed by alkaline digestion with sodium hydroxide 1.25% (*v/v*), using a Dosi Fiber Selecta [51]. Total carbohydrates was calculated by difference [52,53]. All measurements were made in three replicates.

2.4. Statistical Analyses

In order to confirm if the results obtained in terms of mean value were statistically different among samples, a statistical analysis was applied to the data obtained for all properties: chemical analyses, color and texture. A post-hoc Tukey HSD (honestly significant difference) test was used coupled to an analysis of variance (ANOVA) for comparison among three or more samples. Tukey's is a statistical test to identify the differences among groups of data and consists of a single multi-step process for comparison, carried out in conjunction with ANOVA. The test identifies where the difference between two mean values is higher than the standard error which could be expected.

For all statistical analyses the software SPSS version 24 (IBM, Inc., Armonk, NY, USA) was used, and the level of significance considered was 5% ($p < 0.05$).

3. Results and Discussion

3.1. Optimization of Pasta Formulation

The cooking time and cooking yield of pasta containing water and different percentages of chestnut flour are presented in Table 5. The optimum cooking time for all formulations of fresh pasta ranged from 10 to 5 min, respectively, for FC2 with 0% and 55% of chestnut flour. The reduction of optimal cooking time with the incorporation of chestnut flour could be due to decreased gluten content and discontinuity in the gluten network, promoting a faster moisture penetration of water into samples with lower protein content [54].

Table 5. Experiments for pasta containing water or egg plus chestnut flour at variable percentages.

Formulation with Water % of Chestnut Flour [1]	FC2 0%	FC2-C25 25%	FC2-C30 30%	FC2-C40 40%	FC2-C50 50%	FC2-C55 55%
FRESH						
Mass of fresh pasta (g)	31.61	37.65	36.51	38.59	35.88	37.26
Mass of cooked pasta (g)	63.43	81.71	83.60	67.58	64.11	65.00
Cooking time (min:s)	10:00	6:55	6:40	5:30	5:15	5:00
Cooking yield (%)	201	217	229	175	179	174
DRIED						
Mass of fresh pasta (g)	56.12	52.32	52.74	41.85	46.41	49.51
Mass of dried pasta (g)	32.19	33.29	35.59	28.04	31.22	32.89
Drying loss (%)	57	64	67	67	67	66
Mass of cooked pasta (g)	76.19	71.06	83.35	58.98	69.19	81.01
Cooking time (min:s)	11:58	7:17	6:46	6:30	7:44	9:00
Coking yield (%)	237	213	234	210	222	246
Formulation with Egg % of Chestnut Flour [1]	**FC4 0%**	**FC4-C25 25%**	**FC4-C30 30%**	**FC4-C40 40%**	**FC4-C50 50%**	**FC4-C55 55%**
FRESH						
Mass of fresh pasta (g)	32.98	37.31	35.40	38.09	39.02	38.04
Mass of cooked pasta (g)	60.00	66.72	61.96	65.11	62.45	66.25
Cooking time (min:s)	11:42	9:00	8:31	8:05	8:00	8:00
Cooking yield (%)	182	179	175	171	160	174
DRIED						
Mass of fresh pasta (g)	55.42	53.69	53.54	46.71	55.75	57.02
Mass of dried pasta (g)	38.68	36.21	37.87	30.88	25.49	28.95
Drying loss (%)	70	67	71	66	46	51
Mass of cooked pasta (g)	93.41	88.38	83.33	81.58	82.18	72.47
Cooking time (min:s)	17:25	16:12	15:00	14:00	14:00	18:00
Coking yield (%)	241	244	220	264	322	250

[1] Defined in relation to the total flour (not including the liquid—water/egg).

In the same line, the cooking yield was affected by the presence of chestnut flour in pasta formulations. However, the addition of 25% or 30% of chestnut flour was not enough to modify the solids loss and absorption of water in cooking, maintaining a cooking yield around 220% for both formulations. For the mixtures of 40%, 50% and 55% chestnut flour, the cooking yield (mass of cooked pasta/mass of uncooked pasta) decreased to around 175%, resulting in a higher cooking loss. Similarly, higher cooking loss was reported with the addition of an increasing percentage of chestnut flour (20–40%) in fresh pasta [24]. The presence of chestnut flour in the pasta formulations could have affected a proper gluten network development due to the lower amount of gluten proteins and higher amount of fiber and sugar solids that probably competed for gluten hydration. The disrupted or weak starch–gluten network could promote the higher leaching of gelatinized starch from the pasta during cooking and a change of water absorbed during cooking [55].

The drying of fresh pasta (FC2) promoted a drying loss of 55%, but, with the incorporation of chestnut flour, the value increased to around 67%, independently of the percentage of incorporation (25% to 55%). Hence, the presence of chestnut allowed higher retention of water during the drying process. This will impact the texture of the cooked pasta, namely in terms of firmness and stickiness.

Regarding cooking time, the dried pasta showed higher optimum cooking time than the correspondent fresh pasta. The same behaviour was observed in the cooking yield. The differences between fresh and dried pasta can be explained due to modifications of drying on the ingredient's components, namely protein and protein–starch interactions.

The addition of chestnut flour in pasta produced with egg (FC4) also shortened the cooking time with the increase in the proportion of chestnut flour (Table 5). However, the cooking yield was maintained approximately constant in all formulations, except in FC4-C50. The egg present in all formulations could contribute to the formation of a compact protein network in the pasta. Moreover, the egg's lipids interacted with amylose during cooking the pasta, limiting its solubility in water and the loss of dry matter during cooking [56,57]. Hence, even with the increase of chestnut flour, the loss of dry matter during cooking remained almost constant. Comparing the cooking yield to fresh and dried pasta, it is observed that the dried pasta increased the amount of absorbed water and prevented the starch from rupturing during cooking, in all formulations.

Table 6 presents the cooking time and cooking yield, respectively, for pasta containing water and egg, plus pollen powder up to 20%. The main components in pollen are carbohydrates (higher than 60%) followed by protein, water and lipid [58]. In general, and independently of the pasta being in fresh or dried forms, the increase of pollen powder in pasta formulations FC2 (wheat flour and water) or FC4 (wheat flour and egg) shortened the cooking time and the cooking yield. The higher loss of dry matter during cooking with the increasing proportions of pollen powder could be due to the solubilization of sugars, namely fructose and glucose originally from the pollen. However, the drying time and the cooking yield obtained for dried pasta were higher than the values found for fresh pasta, possibly due to modifications of the pasta components during the drying process.

Cooking time is one of the most important quality parameters of pasta for consumers, since a lower time to prepare the product is desirable. The cooking time depends mainly on the protein content in the pasta. High levels of gluten proteins form a strong matrix that inhibits the access of water to the starch and, consequently, extends the time of starch gelatinization. Another factor that influences the cooking time and cooking is the addition of egg to pasta, because it contributes to the strengthening of the protein matrix and the continuity of the protein starch matrix [38,59,60].

Based on the parameters controlled in the cooking process evaluated in this work and on the reported properties of the pasta nutrients, namely the biological value of its proteins and fatty acids, fiber and bioactive components, the best formulation was selected as presented in Table 7, i.e., 50% chestnut flour and 10% pollen powder incorporated into egg pasta. Globally, the cooking time and cooking yield are within the range of values obtained for FC4-C50 and FC5-P10.

Table 6. Experiments for pasta containing water or egg plus pollen powder at variable percentages.

Formulation with Water % of Pollen Powder [1]	FC2 0%	FC2-P5 5%	FC2-P10 10%	FC2-P15 15%	FC2-P20 20%
FRESH					
Mass of fresh pasta (g)	31.61	37.54	34.30	36.55	37.91
Mass of cooked pasta (g)	63.43	81.80	76.39	65.47	68.97
Cooking time (min:s)	10:00	8:00	8:25	6:50	6:53
Cooking yield (%)	201	218	223	179	182
DRIED					
Mass of fresh pasta (g)	56.12	61.99	44.15	48.18	34.17
Mass of dried pasta (g)	32.19	36.37	28.64	28.92	25.94
Drying loss (%)	57	59	65	60	76
Mass of cooked pasta (g)	76.19	101.2	57.63	59.92	56.38
Cooking time (min:s)	11:58	8:46	11:57	9:40	9:32
Cooking yield (%)	237	278	201	207	217
Formulation with Egg % of Pollen Powder [1]	**FC4 0%**	**FC4-P5 5%**	**FC4-P10 10%**	**FC4-P15 15%**	**FC4-P20 20%**
FRESH					
Mass of fresh pasta (g)	32.98	39.93	37.64	37.34	37.79
Mass of cooked pasta (g)	60.00	69.44	78.92	73.00	68.48
Cooking time (min:s)	11:42	12:30	6:35	8:56	10:07
Cooking yield (%)	182	174	210	196	181
DRIED					
Mass of fresh pasta (g)	56.12	47.06	45.55	36.74	47.86
Mass of dried pasta (g)	32.19	31.41	35.16	28.88	37.75
Drying loss (%)	57	67	77	79	79
Mass of cooked pasta (g)	76.19	62.70	70.76	61.95	77.23
Cooking time (min:s)	11:58	8:46	11:57	9:40	9:32
Coking yield (%)	237	200	201	215	205

[1] Defined in relation to the total flour (not including the liquid—water/egg).

Table 7. Pasta with egg and 50% chestnut flour and 10% pollen powder.

	Egg Formulation with 50% Chestnut Flour and 10% Pollen Powder (FC4-C50P10)	
	FRESH	**DRIED**
Mass of fresh pasta (g)	34.20	45.00
Mass of dried pasta (g)	—	31.70
Drying loss (%)	—	70
Mass of cooked pasta (g)	70.85	76.84
Cooking time (min:s)	9:00	12:00
Cooking yield (%)	207	242

3.2. Chemical Composition

The chemical properties of the pasta FC4 (prepared with wheat flour T55 and egg), the FC4 with 50% of chestnut flour (FC4-C50), the FC4 with 10% of pollen powder (FC4-P10) and the FC4 with a mixture of chestnut flour and pollen (FC4-C50P10) are presented in Table 8. The addition of egg in pasta determines to some extent its emulsifying properties and nutritional value, since eggs contain around 12% protein and about 12% fat, most of which is in the form of monounsaturated fatty acids [61].

Regarding moisture content, the different fresh pastas analyzed did not show present relevant differences. This result was mainly attributable to the same amount of liquid ingredient (egg) added to the formulations, giving a ratio of 0.33 for mass liquid ingredient (egg) to total mass. Despite the similar moisture content, the pastas enriched with chestnut (FC4-C50) and pollen powder (FC4-P10) showed a slightly higher water activity in comparison to the control, but the pasta enriched with chestnut and pollen powder FC4-C50P10 presented a lower value. The lower water activity of pasta enriched with chestnut and pollen powder can be due to the stronger water–protein interaction and to the high sugar content of the sample [62].

Table 8. Chemical composition of the optimal fresh cooked pastas, based on the egg formulation.

Property (Units) (1)	FC4 (2)	FC4-C50 (3)	FC4-P10 (4)	FC4-C50P10 (5)
Water activity (dimensionless)	0.924 ± 0.002 b	0.935 ± 0.003 c	0.944 ± 0.004 d	0.903 ± 0.001 a
Moisture (g/100 g sample)	32.43 ± 2.15 a	30.46 ± 0.52 a	32.23 ± 4.15 a	31.39 ± 0.295 a
Protein (g/100 g dm)	10.10 ± 0.47 a	12.96 ± 0.22 b	16.57 ± 0.15 d	14.67 ± 0.13 c
Fiber (g/100 g dm)	0.53 ± 0.86 a	1.63 ± 0.33 b	1.77 ± 1.01 b	1.53 ± 0.21 b
Fat (g/100 g dm)	6.65 ± 0.42 b	7.60 ± 1.01 c	5.70 ± 2.04 a	8.04 ± 0.96 d
Ash (g/100 g dm)	0.57 ± 0.02 a	1.57 ± 0.07 c	1.14 ± 0.03 b	1.67 ± 0.03 c
Carbohydrates (g/100 g dm) (6)	82.15	76.24	74.82	74.09

(1) dm = dry matter. (2) Control sample. (3) Egg formulation with 50% Chestnut flour. (4) Egg formulation with 10% pollen powder. (5) Egg formulation with 50% chestnut flour and 10% pollen powder. (6) Calculated by difference based on mean values of other components of dry matter. Statistical analysis: ANOVA with post-hoc Tukey's test ($p < 0.05$); mean values in the same line with the same letter are not statistically different.

The pasta enriched with chestnut flour and pollen power presented a higher amount of fiber (1.53 g/100 g dm) compared with the control sample (FC4 with 0.53 g/100 g dm). The increase of fiber content is attributable to the partial replacement of wheat flour by chestnut flour in pasta formulation, because the chestnut flour contains a much higher amount of total dietary fiber (12.31 g/100 g flour, dm) than wheat flour (2.56 g/100 g flour, dm) [63]. The fat content of enriched pasta (FC4-C50P10) is higher when compared with control (FC4), but it is also with noting that it has a high quality, taking into account the higher percentage of unsaturated fatty acids in chestnut flour as compared with wheat flour. Among fatty acids, the most representative in chestnuts are oleic and linoleic, representing about 78% of the total fatty acid fraction [64].

Enriched pasta (FC4-C50P10) was found to be richer in proteins (14.67 g/100 g dm) than control pasta (10.10 g/100 g dm). However, the increase of this nutrient in FC4-C50P10 can be attributed mainly to pollen powder, since the flour enriched with chestnut flour (FC4-C50) had a protein content of 12.96 g/100 g dm, while the flour enriched with pollen powder (FC4-P10) presented a value of 16.57 g/100 g dm. In fact, bee pollen is one of the most protein-rich products, with content ranging between 10% and 40% and with a proportion of essential amino acids ranging between 34.59% and 48.49%, depending on the botanical origin [65]. However, the protein content of chestnut flour (6.44 g/100 g flour, dm) presents high-quality proteins, with essential amino acids (~5.8%) contributing to the protein quality of FC4-C50P10 pasta [63,64].

Comparing FC4-C50P10 pasta with control pasta (FC4), the ash content increased three times, reflecting the correspondent rise in mineral content. The increase of mineral content of enriched wheat flour can be attributed either to bee pollen and chestnut flour having as predominant elements potassium, phosphorous and magnesium [64,66,67].

Overall, the enriched FC4-C50P10 pasta can be considered a nutritionally balanced product due to its high-quality proteins and high fiber content, besides the high content of polyunsaturated fatty acids, vitamins, minerals and potential bioactive compounds of chestnut flour and pollen powder ingredients [24,66].

3.3. Color

The color parameters (L*, a*, and b*) for FC4, FC4-C50, FC4-P10 and FC4-C50P10 in the fresh and dried states are presented in Figure 5. The values revealed that the FC4 fresh sample was clear due to the high lightness (L*) obtained (81 ± 0.5), being closer to the value +100 (which represents white). The addition of chestnut flour (FC4-C50) and pollen powder (FC4-P10) produced a decrease in lightness (L*), in the fresh samples more than in the dried ones. This change in lightness is possibly due to the slightly darker color of the ingredients added. The enriched FC4-C50P10 pasta showed a lightness of 66.23 ± 0.42 and

70.94 ± 0.45, respectively for fresh and dried forms, and the lightness of these samples was just slightly changed by cooking.

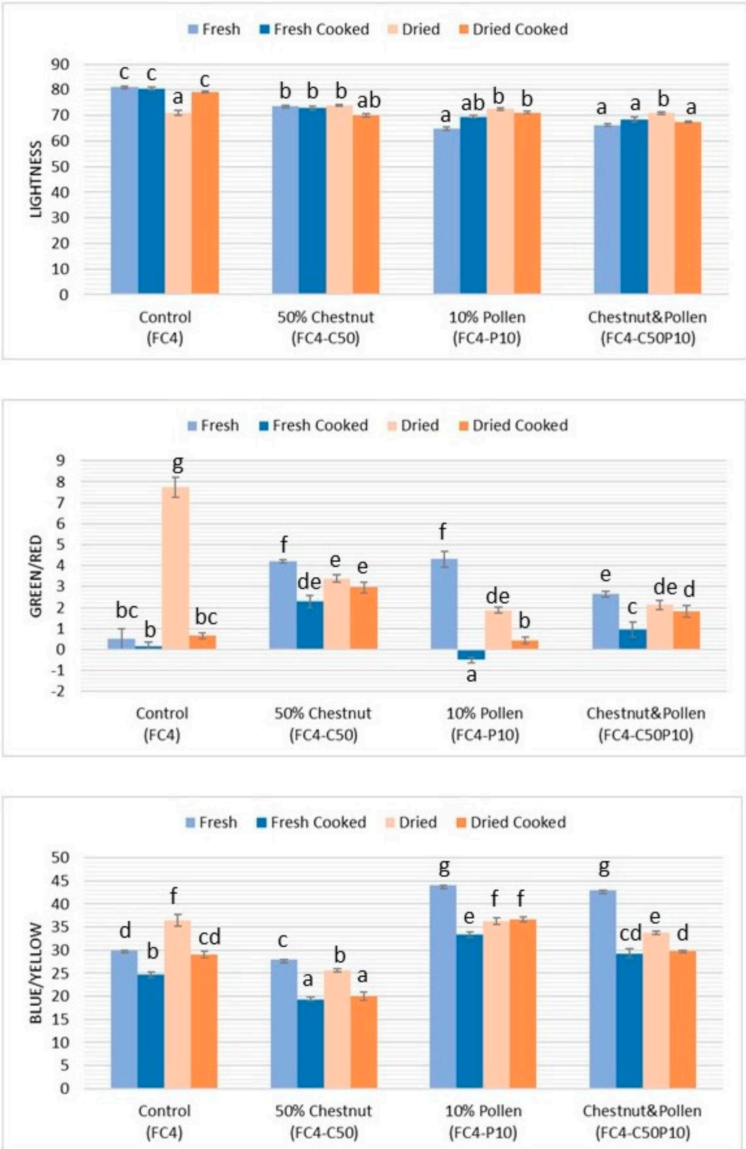

Figure 5. Color parameters of the pasta formulations developed. Statistical analysis: ANOVA with post-hoc Tukey's test ($p < 0.05$); bars with the same letter are not statistically different.

Regarding the value of redness, (+a*), it was found a value almost equal to zero for fresh pasta (uncooked and cooked) and also for the dried cooked pasta in the control sample (FC4). The addition of chestnut flour (FC4-C50) increased the redness of fresh and dried pasta (both uncooked and cooked). Chestnut flour is characterized by marked brownish components and colored pigments allowing the pasta to be darker and to show a red tone. The a* values obtained for fresh and dried pasta (FC4-C50P10) was, respectively, 2.64 ± 0.15 and 2.13 ± 0.21. The decrease of a* value with cooking suggests the thermal degradation of pigments that contribute to a red tone.

The yellow coloration of the control sample (+b*) can be mainly attributed to the high carotenoid content of egg yolks. However, the addition of chestnut flour (FC4-C50) decreased the pasta yellowness (+b*), while the addition of pollen powder (FC4-P10) improved this tone, due to the high yellowness of bee pollen (b* ranged between 12 to 69.6), depending on the botanic species [68]. With respect to the redness value, the cooked pasta (fresh or dried) also promoted the degradation of pigments, such as the carotenoids.

Because the individual color coordinates refer only to certain tones and because it is difficult to evaluate the overall change in color through the coordinates L*, a* and b* separately, the calculation of the total color difference allows the better quantification of a global change in color compared to a reference. Hence, the total color difference of pasta formulations, which results from a combination of the L*, a* and b* values, is shown in Figure 6. The results showed that, considering the control sample (FC4) as reference, the addition of pollen powder substantially changes color in the fresh samples, but when the pasta is dried, the total color change is lower. This is an important factor to have in mind in order to promote the drying of the pasta, as a way to improve the marketability of the product, since dried pasta has a very long shelf-life compared with its fresh counterpart.

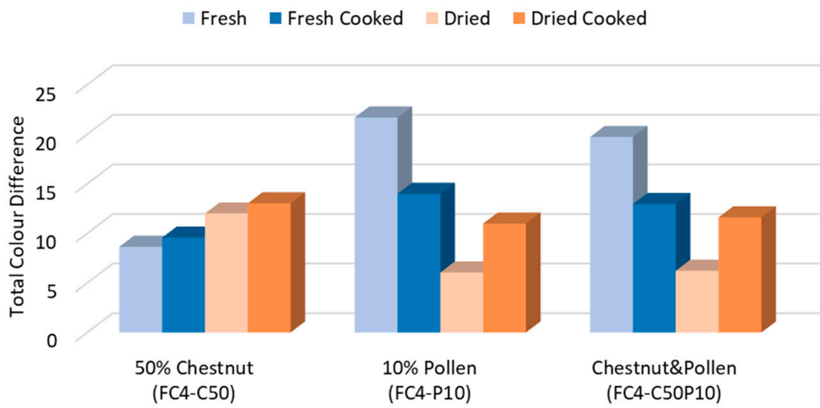

Figure 6. Color difference in relation to control.

3.4. Texture

In Figure 7, the textural parameters analyzed (firmness, stickiness and adhesiveness) are presented for fresh and dried pasta (both uncooked and cooked). The fresh control sample showed a firmness of 10 ± 0.5 N and the partial addition of chestnut flour (FC4-C50) or pollen powder (FC4-C50P10) did not result in a visible change of this textural parameter. In this case, independently of the addition of chestnut flour and pollen powder, the presence of egg (and particularly the egg white) in fresh samples may contribute to the formation of a compact protein network in pasta, giving origin to a firmer product [69]. Even though gluten has been associated with the firmness of pasta, the eventual lower gluten content in samples with the addition of chestnut flour did not seem to have a significant effect on this textural parameter. Moreover, the egg lipids' interaction with amylose, while cooking the pasta, limits its solubility in water, giving the same firmness to the fresh cooked pasta, independently of the addition of chestnut flour or pollen powder.

However, in the formulation with both ingredients (FC4-C50P10), the firmness was slightly increased to 15.52 ± 1.30 N, and the cooking process led to a lower firmness of cooked pasta texture. The decrease of firmness might be attributed to the higher water absorption during the process [55].

The drying process increased the firmness of the control pasta (FC4) by a factor of five, because the low water content of the dried product originated pasta with a hard and coarse texture (52.70 ± 4.94 N). However, the presence of chestnut flour and pollen powder in the dried sample (FC4-C50P10) decreased the firmness of pasta to around 33.35 ± 3.52 N. Contrary to the fresh pasta, the cooking of dried pasta decreased significantly the firmness of cooked pasta that results from the uptake of water absorbed during cooking.

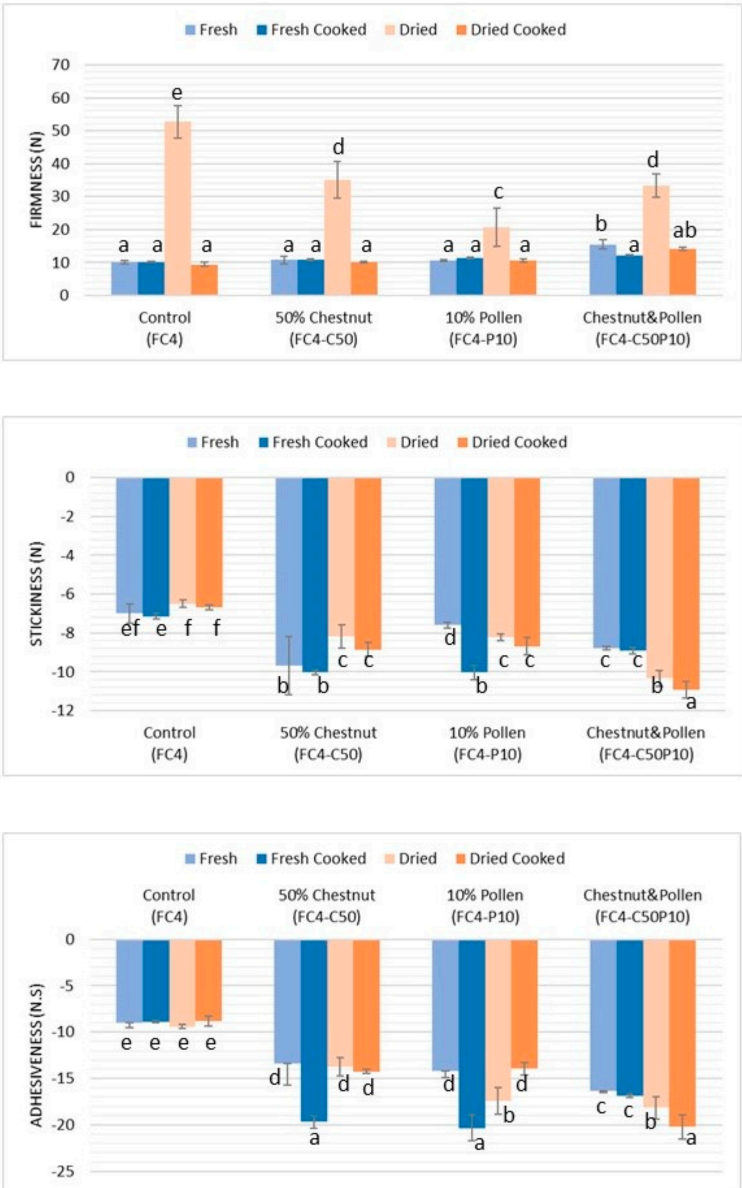

Figure 7. Textural parameters of the pasta formulations developed. Statistical analysis: ANOVA with a post-hoc Tukey's test ($p < 0.05$); bars with the same letter are not statistically different.

Stickiness and adhesiveness are usually associated with the formation of a surface layer of exudates (amylose and amylopectin) that give a clumping tendency to the strands [70]. Regarding these texture parameters, the addition of chestnut flour to pasta (fresh and dried) or cooking process resulted in stickier and more adhesive pastas [70]. Pasta cooking quality is determined by the physical competition between protein coagulation in a continuous network and starch swelling with exudate losses during cooking. If the later effect prevails, a pasta with a soft and usually sticky texture is obtained. Thus, the stickier nature of the cooked pasta might be due to the amylose and amylopectin solubilization and protein coagulation in discrete masses lacking a continuous framework [54,70].

4. Conclusions

The results allowed concluding that, in general, the addition of chestnut flour to pasta prepared with wheat shortened the optimum cooking time and cooking yield for percentages of chestnut flour higher than 40%, owing to the weakness of the starch–gluten network that promotes higher leaching of gelatinized starch during cooking. However, the addition of chestnut flour to pasta prepared with wheat flour and egg maintained the cooking yield approximately constant, since the egg contributes to the formation of a compact protein network and the interaction of lipids interaction amylose while cooking the pasta limits its solubility in water. The incorporation of pollen powder (up to 20%) in pasta prepared with wheat flour and water or egg shortened the cooking time and cooking yield, both in fresh and dried pasta.

The results highlight that the most suitable percentage of the new ingredients were 50% for chestnut and 10% for pollen. Comparing with the control pasta recipe (wheat flour and egg), the addition of chestnut flour or pollen powder increased the stickiness, adhesiveness and intensified the color of the final product (fresh or dried) while maintaining firmness. The cooking of fresh or dried pasta enriched with both ingredients turned the pasta clearer and slightly stickier.

Finally, the best pasta formulation with egg, wheat flour, chestnut and pollen powder in the percentages defined as optimal could be eventually considered a nutritionally balanced product due to its high-quality proteins and high fiber content, besides the high content of polyunsaturated fatty acids, vitamins, minerals and bioactive compounds. Therefore, it is recommended as future work to undertake a nutritional evaluation of the pasta developed in this study. Additionally, further studies would be necessary to investigate the sensory characteristics and the perception and acceptance of consumers.

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