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*Highlights (for review)

Highlights

- Chestnut flour addition to fresh pasta was studied from a physicochemical point of view.
- Chestnut flour showed higher water absorption than soft wheat flour.
- Cooking loss increased for increasing level of chestnut flour.
- Antioxidant activity was improved by chestnut flour replacement, even after cooking.
- ^{1}H NMR showed higher protons mobility increasing the chestnut flour replacement.

Quality evaluation of chestnut flour addition on fresh pasta

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Abstract

The present study investigated the effect of different levels of chestnut flour in formulations of soft wheat fresh pasta. A physicochemical characterization of flours, uncooked and cooked pasta was carried out. Chestnut flour showed higher water absorption properties than soft wheat flour or mix of them. Frozen water of pasta decreased for higher level of chestnut substitution, being instead water activity constant. During cooking chestnut enriched pasta showed higher solid loss for increasing levels of substitution, in relation with the reduction of hardness and deformability. Increasing percentages of chestnut flour were also reflected in a progressive darkening of the final products. Moreover, the increased antioxidant activity observed on enriched pasta, even after cooking, may be related to the high level of antioxidant compounds of chestnut flour. Proton molecular dynamics was also influenced by the formulation, as resulted by the higher protons mobility increasing the level of chestnut flour replacement.

KEYWORDS: chestnut, antioxidant, low resolution ^{1}H NMR, fresh pasta, texture.

1. Introduction

Pasta is a traditional cereal product widespread all over the world due to its convenience, nutritional quality and palatability (Cubadda, Carcea, Marconi & Trivisonno, 2007; Petitot, Boyer, Minier & Micard, 2010). Durum wheat is considered the most suitable raw material to produce high quality pasta, due to its cooking properties, colour, and aroma. As reported by Lee, Cho, Lee, Koh, Park and Kim (2002), these quality properties are the most influencing for consumer's satisfaction. Traditional pasta is characterized by the presence of gluten proteins (lending unique attributes to the rheology of the dough and influencing the quality of the cooked product), moreover it is a good source of carbohydrates with low glycaemic index (Gianibelli, Sissons & Batey, 2005; Sissons, Soh & Turner, 2007; Gimènez, González, Wagner, Torres, Lobo & Samman, 2013). Nevertheless, pasta is not considered a nutritionally balanced product due to its low protein biological value and low fibre content. On the other hand, its relatively simple formulation would make it perfect for conveying specific nutrients (fiber, antioxidants, etc.), maybe becoming in the future a functional product (Brennan & Tudorica, 2007).

Chestnut (*Castanea sativa* Miller) has been for centuries the main staple food for the population of the European mountain areas, playing a key role in the national economies. Due to the chestnut gall wasp, the chestnut cultivation is diminished, with a heavy impact on the productive chain (Sartor et al., 2015). Given the difficulties that the chestnut sector is suffering, the valorization of chestnut flour, a high value product at the base of many traditional recipes, may be a way to foster the value chain development.

In this domain, chestnut flour has been proposed as an interesting ingredient for the production of innovative and fortified product formulations (Dall'Asta, Cirlini, Morini, Rinaldi, Ganino & Chiavaro, 2013; Demirkesen, Mert, Sumnu & Sahin, 2010; Dokić, Nikolić, Šoronja–Simović, Pajin & Juul, 2014; Paciulli, Rinaldi, Cirlini, Scazzina & Chiavaro, 2016; Kosović, Jukić, Jozinović, AčKAr & Komlenić, 2016; Rinaldi, Paciulli, Dall'Asta, Cirlini & Chiavaro, 2015; Rinaldi, Paciulli, Caligiani, Scazzina & Chiavaro, 2017; Šoronja-Simović, Pajin, Šubarić, Dokić, Šereš & Nikolić, 2017). Chestnut flour is similar to cereal flours in regard to starch content (about 40-50% w / w), but it contains higher sucrose content (20-32%). Moreover, it contains high quality proteins composed of essential amino acids (5-8%), low lipid content (3.7%) and relatively high amount of fibres (10.8%) (Dall'Asta et al., 2013). The presence of fibres in chestnut flour is demonstrated to provide health benefits (De Vasconcelos, Bennett, Rosa & Ferreira- Cardoso, 2010), moreover the presence of nutritional (ω-3 fatty acids, vitamins E and C) and antioxidant (phenolics and tannins) compounds, may improve the nutritional value of the products (Demirkesen et al., 2010).

The effect of chestnut flour addition as ingredient for bakery products has been evaluated in some recent studies. Demirkesen et al., 2010 found that the presence of fiber in chestnut flour improves the functional properties of wheat bread dough, while the sugar content improves colour and flavour of the final products. Dall'Asta et al. (2013) compared breads formulated with chestnut flour to traditional wheat products finding that the increasing level of chestnut (20% and 50%) may improve nutritional and/or qualitative characteristics of the final products. Moreover, Rinaldi et al. (2015) reported a decrease of the staling process for chestnut breads in comparison to controls and attributed it to the high presence of fibre. Demirkesen (2016) and Paciulli et al. (2018) considered the chestnut flour supplementation in gluten free cookies in terms of rheological/quality characteristics and during storage.

To the best of our knowledge, only one research (Kosović et al., 2016) assessed the influence in physical and sensory properties of chestnut flour addition to pasta formulations. The addition of increasing level of chestnut flour (10, 15 and 20%) on durum wheat dry pasta formulations resulted in a decrease of water absorption during cooking. Moreover, modifications in textural attributes, reduction of optimal cooking time, increase of cooking loss, as well as colour modification were found. However, dried pasta differs from fresh pasta, not only for the lower moisture content, but also for the effects of drying on the ingredients components. Proteins coagulation, protein-starch interactions or starch gelatinization, are some of the effects with liked or disliked consequences on texture, surface quality and cooking properties of the final products. Browning and loss of some bioactives are also reported after pasta drying (De Noni & Pagani, 2010).

The effect of chestnut flour addition to fresh soft wheat pasta formulations has not been studied yet. Thus, in the present work, physicochemical properties (moisture content, water activity, frozen water content, cooking loss, texture and colour) and molecular dynamics by means of Time Domain ^{1}H Nuclear Magnetic Resonance (TD-NMR) of traditional fresh pasta enriched with different level of chestnut flour (20-40 %) were studied, with the preliminary idea to design functional products.

2. Material and methods

2.1 Samples preparation

Soft wheat flour (SWF) used in the present study was purchased in a local market. SWF had the following composition (as reported on product label, g/100 g sample): 73.7 g carbohydrates, 0.7 g lipids, 10.0 g proteins, 15.6 g moisture content. Chestnut flour (CF) was purchased from a social cooperative in Reggio Emilia (Italy) and showed the following composition (measured by NIR spettroscopy, FT NIR Tango, BRUKER): 78.3 g carbohydrates, 3.5 g lipids and 6.0 g proteins 12.2 g moisture content. Four different types of fresh pasta samples were formulated: 100g SWF (SWP), 80g SWF + 20g chestnut flour (CP20), 70g SWF + 30g chestnut flour (CP30), 60g SWF + 40g chestnut flour (CP40). The level of flour replacement was decided on the basis of a preliminary sensory acceptability test (data not shown). An untrained panel (30 people, 20-35 years old) was asked to rate from 0 "I don't like it at all" to 9 "I really like it very much" samples from 20g to 50g chestnut flour substitution. Over 40g replacement the product was no longer considered acceptable. For the dough preparation, 45 mL of water and 1 g of salt were added to a 100 g of flour and kneaded (15 min, speed 3) in a planetary mixer (Artisan, Kitchen Aid, USA), equipped with a hook-shaped probe. The amount of water was determined on the basis of preliminary tests until obtaining a workable dough for all the tested formulations. The same amount of water was added to all the pasta formulations, in order to evaluate the unique effect of chestnut flour supplementation. Salt was added, other than for taste, because it improves the rheological properties of the dough (Uthayakumaran, Batey, Day, & Wrigley, 2011). Despite the different absorption properties of soft wheat and chestnut flours, the same amount of water was added to all the formulations, to clearly relate physicochemical properties of pasta to the effect of chestnut flour supplementation. Then the dough was laminated with a pasta roller (Kitchen Aid, USA) up to 1 mm thickness. The pasta sheets were cut in "tagliatelle" shape (1.5 x 30 cm) and cooked in boiling water, with a ratio of 1:10 (pasta/water), for 5 minutes. Preliminary tests have been conducted to choose the optimum cooking time suitable for all the formulations. The same cooking time for all the formulations was used to avoid introducing another independent variable and evaluate the unique effect of chestnut flour supplementation. After cooking, pasta was drained, cooled at room temperature (25 °C, 15 min) and stored in a closed container. Physicochemical characterization was performed immediately after cooling. For each formulation two different batches were produced and analyzed.

2.2 Water absorption tests of flours

The evaluation of water binding capacity (WBC), water absorption index (WAI), water holding capacity (WHC) and water solubility index (WSI) were measured according to the methods described by Sarangapani, Thirumdas, Devi, Trimukhe, Deshmukh and Annapure (2016). Soft wheat and all blended between soft wheat and chestnut flours samples were tested. Four determinations were varried out for each sample.

2.3 Physicochemical characterization of pasta

2.3.1 Moisture content, water activity, frozen water and cooking loss

Moisture content (MC) of uncooked and cooked pasta samples was determined by oven drying (NSV 9035, ISCO, Milan, Italy) at 105 °C till constant weight. At least four replicates were analysed for each batch for each sample.

Water activity (at 25 °C) of uncooked pasta was measured by AQUA LAB (Decagon Devices Inc, Pullman, Washington, USA). Four replicates for each batch for each sample were measured.

Frozen water content (at the given experimental conditions; FW) was calculated from the endothermic peak around 0 °C (ice melting) measured with a Differential Scanning Calorimetry DSC Q100 (TA Instruments, New Castle, DE, USA). DSC was calibrated with indium (melting point: 156.6 °C, melting enthalpy: 28.71 J/g) and mercury (melting point: -38.83°C, melting enthalpy: 11.44 J/g). About 8–10 mg of sample (cooked or uncooked) were weighed (Ohaus AR2140, Florham Park, NJ, USA) and arranged into hermetic stainless-steel pans (Perkin Elmer, Waltham, MA, USA). An empty pan was used as reference. Samples were heated from -60°C to 120°C at 5°C/min. The curves were analysed (Universal Analysis Software, version 3.9A, TA Instruments) by the integration of the ice melting peak. FW was calculated according to the equation 1 (according to Curti, Carini, Tribuzio & Vittadini, 2014):

$$FW = \frac{Enthalpy\ Ice\ Fusion}{Latent\ \ Heat\ Ice\ Fusion * MC} * 100 \qquad \text{(Equation 1)}$$

where FW is frozen water [g frozen water/100 g water], Enthalpy Ice Fusion [J/g product], Latent Heat of Ice Fusion is 334 J/g ice and MC is Moisture Content [g water/100 g product]. At least triplicates were analysed for each sample for each batch.

The cooking loss (the amount of solids lost into cooking water) was determined according to AACC Method 66-50.01 (AACC, 2000). About 15 g of pasta were cooked in 150 mL of distilled water. Four replicates were analysed for each sample for each batch.

2.3.2 Texture, colour and antioxidant activity

Texture of uncooked and cooked samples was measured with a TA-TX2i Texture Analyzer equipped with a 25 kg load cell (Stable Micro Systems, UK). A two-dimensional extensibility test until complete fracture of the sample was used. A probe HDP/TPB equipped with 2 cm diameter propylene spherical probe (P/1sp) was driven to the center of sheets of pasta (squares of 9x9 cm) at test speed of 1 mm/s and to a distance of 40 mm making a biaxial extension of the samples. The measured parameters were hardness (N, maximum force at break) and modulus of deformation

(N/mm, ratio between hardness and distance at the breaking point) (Bejosano, Joseph, Lopez, Kelekci & Waniska, 2005; Carini, Vittadini, Curti, Antoniazzi &Viazzani, 2010). Ten replicates were measured for each sample for each batch.

Colour determination was performed on uncooked and cooked samples using a Minolta Colorimeter (CM 2600d, Minolta Co., Osaka, Japan) equipped with a standard illuminant D65 at room temperature (25°C). The Spectramagic Software (version 3.6) was used to measure the CIE-Lab colour parameters L^*, a^*, b^* (lightness, redness and yellowness, respectively), using 10° position of the standard observer. Six measurements were performed for each sample for each batch.

The radical-scavenging activity of flours, of uncooked and cooked pasta samples was evaluated by means of the DPPH assay, following the method previously described by Yu & Nanguet (2013) with some modifications. For the extraction of the antioxidant molecules, 100 mg of flour or 1 g of pasta were mixed, respectively with 5 and 10 ml of a methanol–water (70:30, mL:mL) solution, for 1 hour at room temperature. The extract was filtered through a pleated filter and dried in a rotavapor apparatus at 40°C, the residue was redissolved in 1 ml methanol–water (70:30, mL:mL) solution, 100 µl were mixed with 1.3 ml methanol and 1 ml 0.2 mmol/L DPPH methanolic solution. After incubation in the dark for 30 min at room temperature the absorbance at 517 nm was read by means of a PerkinElmer UV–visible spectrophotometer. Following the same procedure, a blank sample was also red.

The DPPH radicals scavenging activity was determined using the equation 2:

$$I\% = [(A^0 * A^1 / A^0)/100] \qquad \text{(Equation 2)}$$

where A^0 is the absorbance of the blank and A^1 is the absorbance of the samples.

For the quantification of the antioxidant capacity, a calibration curve with known concentrations of Trolox was used. Three measurements were performed for each sample (flours) and for each batch (pasta) and reported as µmol Trolox/g_{dw}.

2.3.3 ^{1}H molecular mobility

A low-resolution (20MHz) NMR spectrometer (the miniSpec, Bruker Biospin, Milano, Italy) working at 25.0 ± 0.1°C was used to investigate ^{1}H molecular mobility. Cooked pasta sample was compressed into the bottom of a 10 mm NMR tube, sealed with Parafilm® to prevent moisture loss and analysed. For all the experiments the recycle delay was 1 s (≥ 5 T_1). ^{1}H Free Induction Decay (FID) experiment was performed applying a single 90° pulse (scans: 32, dwell time: 7µs, acquisition window 0.5 ms). The experimental curves were fitted (Sigmaplot, v10, Systat Software Inc. USA) with a two-component model (exponential and Gaussian, Equation3); (Le Grand, Cambert & Mariette, 2007)

$$F(t): y0 + A * exp(-t / T_A) + B * exp[-(t / T_B)^2] \qquad \text{(Equation 3)}$$

(where *y0* is the FID decay offset, *A* and *B* are the intensities of each relaxation component, T_A and T_B the apparent relaxation times). ^{1}H transverse relaxation time (^{1}H T_2) experiment was carried out with a CPMG pulse sequence, with an interpulse spacing of 0.04 ms, 32 scans and 5000 data points. Quasi-continuous distributions of relaxation times were obtained using the UPENWin software (Alma Mater Studiorum, Bologna, Italy), setting up default values for all UPEN parameters (except LoXtrap = 1, to avoid extrapolation of times shorter than the first experimental point). $^{1}HT_2$ curves were also fitted with a discrete exponential model (Sigmaplot, v.10, Systat Software Inc. USA) to obtain relaxation times (ms) and relative abundances (%) of each proton population.

2.3.4 Statistical analysis

SPSS (version 24.0, SPSS Inc., Chicago, IL) was used to perform one-way analysis of variance (ANOVA) followed by Tukey's test ($p < 0.05$) for the comparison among the different formulations. A *t* test ($p < 0.05$) was carried out to compared uncooked and cooked sample. Correlation coefficients (r) were computed using Pearson's coefficient ($p \leq 0.05$).

3. Results and discussion

3.1 Water absorption tests of flours

The flour hydration (WBC and WHC) and gel hydration (WAI and WSI) properties of wheat flour (SWF), chestnut flour (CF) and wheat - chestnut flour mixtures (CF20, CF30, CF40) are reported in Table 1. No differences were observed in WHC values among chestnut flour, wheat flour or mix of them. WBC values resulted lower than WHC, showing also significant higher values for CF in comparison to the other flours. The application of the centrifugal force during WBC test may have removed the multilayer water retained in the same way by all flours, leaving a single-layer of bound water, much more abundant in the chestnut flour due to the presence of fibres and sugars, able to bind higher amount of water.

Moreover, the higher WSI values of CF can be justified by the higher amount of soluble components (Demiate, Oetterer & Wosiacki, 2001). On the other hand, for mixtures (CF20, CF30 and CF40) the percentage of chestnut flour was not enough to modify the water absorption properties in comparison to SWF.

3.2 Physicochemical characterization of pasta

3.2.1 Moisture content, water activity, frozen water and cooking loss

In table 2 moisture content (MC, g water/100 g sample) of uncooked and cooked pasta samples (SWP, CP20, CP30 and CP40) are reported.

Both uncooked and cooked pasta samples did not show significant differences among formulations. For uncooked pasta this result was mainly attributable to the same amount of water added to the formulation, on the other hand for cooked chestnut enriched pasta the absence of differences among samples, despite the WAI values of flours, may be attributed to a flattening effect of the cooking process. The water uptake after cooking was around 16% for all the formulations.

Despite the similar moisture content, uncooked chestnut enriched samples (CP20, CP30, CP40) showed significantly ($p \leq 0.05$) lower a_w than SWP (Table 2). Similarly, Carini, Curti, Spotti and Vittadini (2012) observed lower water activity in fresh pasta enriched with soy and carrots ingredients in comparison to the control and attributed this phenomenon to the stronger water-protein interaction or high sugar content of the enriched samples.

The frozen water content (FW) (Table 2) in uncooked pasta samples significantly decreased with the increase of chestnut flour in the pasta formulation (~52%, ~51%, ~44% and ~38% in SWP, CP20, CP30 and CP40, respectively). This result, in accordance with a_w, may be due to the larger amount of sugars and fiber in the chestnut pasta formulations in comparison to SWP. The presence of soluble solids would have increased the viscosity of the hydrophilic phase with a consequent decrease ability of the water molecules to form ice crystals (Chinachoti, 1993; Vittadini, Clubbs, Shelhammer & Vodovotz, 2004; Carini et al., 2012). As expected, higher values of frozen water were measured for cooked pasta (84-90%) than the uncooked one, because of the large amount of water absorbed during cooking. For cooked pasta, only in the presence of 40% chestnut flour (CP40) a significantly lower value of FW (~84%) than the other samples was observed.

The amount of solids loss in cooking water (Table 2) was significantly affected by the presence of chestnut flour in pasta formulations. SWP showed the lowest value of lost solids during cooking (2.63%), while CP40, as expected, showed the highest value (3.76%). Similarly, it was reported higher cooking losses with the addition of increasing percentage (10-20%) of chestnut flour in dry pasta (Kosović et al., 2016). 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 (Guler, Köksel & Ng, 2002; Aravind, Sissons, Egan, Fellows, Blazek & Gilbert, 2012).

3.2.2 Texture analysis, Colour parameters and Antioxidant activity

Table 3 showed the results of texture analysis. The two-dimensional extensibility test showed a significantly decrease of hardness in uncooked samples for increasing addition of chestnut flour. The same trend was observed in the cooked samples. These differences may be attributed to a lower amount of gluten proteins that may have altered the development of a tenaciuos structure in the chestnut enriched samples (Guler et al., 2002; Aravind et al., 2012; Kaur, Sharma, Nagi & Ranote, 2013; Kosović et al., 2016), as confirmed also by the high inverse correlation (r=-0.992, p<0.01) between texture parameters and solids loss (Table 2). Looking at the effect of cooking on pasta hardness, il can be observed a significantly increase in all samples. The positive correlation found between hardness of the cooked pasta and WAI (r= 0.992, p<0.01) indicates the role of starch gelatinization and protein coagulation on the structural changes of pasta during cooking (Severini, De Pilli, Derossi & Giuliani, 2015). The extensibility values followed the same trend of hardness, resulting progressively lower with increasing percentages of chestnut flour and confirming the destabilizing effect of chestnut flour on the proper gluten network development.

The addition of CF showed a significant and progressive decrease of lightness (L*), both in uncooked and cooked samples, with uncooked always significantly higher than cooked (Table 3). At the same time, redness (+a*) and yellowness (+b*) progressively increased in CP20, CP30, CP40 in comparison to SWP. Being chestnut flour characterised by marked brownish components and coloured pigments, pasta with chestnut flour was found darker and with red/yellow tone (both in uncooked and cooked), as previoulsy reported in wheat and gluten free breads (Rinaldi et al., 2015; Demirkesen 2016), biscuits (Paciulli et al., 2018) and pasta as well (Kosović et al., 2016). As expected, the cooking process, due to water absorption and solids loss, lowered the colour parameter a* and b*.

CF showed higher antioxidant activity (10.36 μmol/g_{dw}) in comparison to SWF (0.30 μmol/g_{dw}). These results were already observed in other studies and attributed to the high content of phenolic compounds of CF belonging from chestnut integuments (Dall'Asta et al., 2013; Rinaldi et al., 2015). As reported by Pasqualone et al. (2016), the main aim of pasta supplementation is to increase the antioxidant activity. The production of pasta formulations with natural ingredients, with the aim to produce nutritional improved products, is a field already explored by other authors. The tendency to use antioxidant from natural sources was previously studied by other authors on fresh pasta (Ma, Guo, Liu, Xu & Wang, 2013; Armellini, Peinado, Pittia, Scampicchio, Heredia & Andres, 2018). Ma et al. (2013), using exclusively different cultivars of buckwheat flour (Yuqiao4#, Wensha and

Dingbian red flower) to produce noodles, found 1.09, 0.90 and 0.87 mmol Trolox eq./100 g d.w. respectively, after 3 min of cooking. On the other hand, Armellini et al. (2013) obtained DPPH ~4 μmol Trolox eq/g dry base, after 3 min of cooking, using 0.1% of saffron in pasta formulation.

In the present study, the antioxidant activity (Table 3) of uncooked pasta increased with CF addition, reaching the maximum value (1.527 μmol/g_{dw}) in uncooked CP40. A similar trend was observed in cooked samples, where SWP showed 0.195 μmol Trolox eq/g_{dw} and increased to 1.751 μmol Trolox eq/g_{dw} in CP40. These results are attributable to the presence of phenolic compounds of chestnut flours. Moreover, similarily to the observations of Armellini et al. (2018), cooked samples showed, in general, higher antioxidant activity than uncooked maybe because the cooking process increased the availability or extractability of antioxidant compounds revealed with the DPPH method.

3.2.3 ^{1}H Molecular mobility

^{1}H FID experiment (Figure 1a) was used to study the more rigid protons of the cooked pasta. The FID decay was faster in SWP indicating a higher rigidity of the protons in this system, if compared with other samples. FIDs became progressively less steep, denoting increasing mobility for increasing amount of chestnut flour in pasta. The presence of CF (i.e. higher amount of fiber and sugars) could have modified the interactions between water and solids and/or the water molecules displacement towards different domains (Carini et al., 2012). In Figure 1b the relaxation time (TA) and relative abundance (%A) of the more rigid proton population (A) obtained by the curves fitting are reported. Population B was not considered in the discussion because it showed relaxation times similar to those observed in ^{1}H T_2. TA resulted in the range 14-15 μs in all samples, while %A significantly decreased in pasta containing CF (≈ 82% in SWP and ≈79% in CP40). The protons relaxing in this relaxation time range were previously attributed to solid CH protons of crystalline and amorphous starch and proteins not in contact with water (Kim & Cornillon, 2001; Curti et al., 2015). The higher mobility observed in pasta containing CF could be due to an altered gluten development and starch phase gelatinization, as also suggested by the linearly relation found between %PopA and FW (r=0.979, p< 0.05), hardness (r=0.969, p< 0.05) and cooking loss (r=-0.984, p< 0.05).

Representative ^{1}H T_2 distributions of relaxation times for all pasta samples (Figure 2) showed the presence of four not completely resolved ^{1}H populations (C, D, E and F), with C the more rigid and F the more mobile.

Relaxation times (T_2C, T_2D, T_2E and T_2F) and relative abundances (PopC, PopD, PopE and PopF) are reported in Figure 3. Average relaxation time of population C (T_2C) (Figure 3a) was ~0.37 ms in SWP and CP20 while it significantly decreased in CP30 (0.24 ms) and CP40 (0.28 ms). Population C abundance (Figure 3a) resulted on average ≈10% with sligthy differences among samples without a specific trend attributable to the presence and addition level of CF. Population D (Figure 3b) relaxed at 3.5 ms in SWP with a significantly decrease to 3.0 ms observed in samples containing CF (no significant differences among different chestnut flour containing samples were found). On the other hand, PopD was 32.4% in SWP and significantly decreased to 30.4% and 28.5% respectively for CP30 and CP40 (Figure 3b). Moreover, T_2D was correlated with WBC (r=-0.972, p<0.05), while PopD with WAI and hardness (r=0.992 and 0.999, p<0.01, respectively), and with cooking loss (r=-0.996, p<0.01). The most abundant population E, that resulted partially overlapped with population D in all samples (Figure 2), became narrower when chustnut flour was included in the pasta formulation indicating a more homogeneous system and a faster molecular exchange (Littardi et al., 2019). T_2E (Figure 3c) relaxed at 12.6 ms in SWP and steadily decreased for increasing level of CF (9.6 ms in CP40) indicating a decrease of mobility of these protons (T_2E correlated with WBC and hardness, r=-0.975, and 0.991, p<0.05, respectively). Conversely, the relative abundance of PopE (Figure 3c) significantly increased starting from 50.9% in SWP and reaching 52.4% in CP20 and CP30 and 55.8% in CP40 (PopE e correlated with FW, r=-0.984, p<0.05). The last and more mobile population F, previously attributed to lipids (Hemdane, Jacobs, Bosmans, Verspreet, Delcour & Courtin, 2017; Littardi et al., 2019) relaxed in the relaxation time range ≈46-50 ms in all the samples and represented ~6-7% of total relaxing protons (Figure 3d), without significant differences between SWP and chestnut flour enriched samples. The more rigid populations, C and D, were previously attributed to amorphous gelatinized starch (Littardi et al., 2019) while the most abundante population E to the molecular mobility both of starch and gluten domain. Overall, taking in mind the correlation between molecular (protons relaxation times and relative abundances) and mesoscopic and macroscopic parameters, it could be hypothesized that the addition of chestnut flour altered both a proper gelatinization of starch and plasticization and coagulation of gluten at molecular level. Higher water binding and adsorbption capacity due to higher amount of fiber and sugars of chestnut flour if compared with soft wheat flour affected water redistribution at molecular level when chestnut flour was included in pasta formulation. The presence of chestnut flour in turn affected starch gelatinization and gluten network development at molecular level resulting in pasta with lower hardness and higher cooking loss.

4. Conclusions

The present study was one of the first evaluating the physico-chemical modifications produced on fresh pasta formulations by the addition of chestnut flour. Furthermore, the characterization was carried out not only by traditional analysis techniques, but also by low resolution ^1H NMR relaxometry, which is less common for the study of pasta and gives information on molecular mobility and dynamics. Molecular properties highlighted different water redistribution at molecular level in pasta containing chestnut flour that was related to worse macroscopic quality properties that is softness and higher cooking loss. On the other hand, the presence of chestnut flour in the pasta formulation delivered a pleasant brown color and nutritional (antioxidant activity) performances, even after cooking.

Overall, it was evidenced that chestnut flour represents a promising ingredient for the development of functional fresh pasta formulations. Nevertheless, further studies would be necessary to improve the structure of final product and to investigate sensory perception, also in the view of using chestnut flour in formulation for gluten free pasta, where a proper structure and nutritional value are fundamental requirements.

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References

AACC, American Association of Cereal Chemists. (2000). Approved methods of the AACC (10th ed.). St. Paul, USA: Am Assoc Cereal Chem.

Aravind, N., Sissons, M., Egan, N., Fellows, C. M., Blazek, J., & Gilbert, E. P. (2012). Effect of β- glucan on technological, sensory, and structural properties of durum wheat pasta. *Cereal Chemistry*, *89*(2), 84-93. https://doi.org/10.1094/CCHEM-08-11-0097.

Armellini, R., Peinado, I., Pittia, P., Scampicchio, M., Heredia, A., & Andres, A. (2018). Effect of saffron (Crocus sativus L.) enrichment on antioxidant and sensorial properties of wheat flour pasta. *Food chemistry*, *254*, 55-63. https://doi.org/10.1016/j.foodchem.2018.01.174.

Bejosano, F. P., Joseph, S., Lopez, R. M., Kelekci, N. N., & Waniska, R. D. (2005). Rheological and sensory evaluation of wheat flour tortillas during storage. *Cereal chemistry*, *82*(3), 256-263. https://doi.org/10.1094/CC-82-0256.

Brennan, C. S., & Tudorica, C. M. (2007). Fresh pasta quality as affected by enrichment of non-starch polysaccharides. *Journal of Food Science, 72*(9), S659-S665. https://doi.org/10.1111/j.1750-3841.2007.00541.x.

Carini, E., Vittadini, E., Curti, E., Antoniazzi, F., & Viazzani, P. (2010). Effect of different mixers on physicochemical properties and water status of extruded and laminated fresh pasta. *Food Chemistry*, *122*(2), 462-469. https://doi.org/10.1016/j.foodchem.2009.05.031.

Carini, E., Curti, E., Spotti, E., & Vittadini, E. (2012). Effect of formulation on physicochemical properties and water status of nutritionally enriched fresh pasta. *Food and bioprocess technology*, *5*(5), 1642-1652. https://doi.org/10.1007/s11947-010-0476-4.

Chinachoti, P. (1993). Water mobility and its relation to functionality of sucrose-containing food systems. *Food technology (USA)*.

Cubadda, R. E., Carcea, M., Marconi, E., & Trivisonno, M. C. (2007). Influence of gluten proteins and drying temperature on the cooking quality of durum wheat pasta. *Cereal Chemistry*, *84*(1), 48-55. https://doi.org/10.1094/CCHEM-84-1-0048.

Curti, E., Carini, E., Tribuzio, G., & Vittadini, E. (2014). Bread staling: effect of gluten on physico-chemical properties and molecular mobility. *LWT-Food Science and Technology*, *59*(1), 418-425. https://doi.org/10.1016/j.lwt.2014.04.057.

Curti, E., Carini, E., Diantom, A., Cassotta, F., Najm, N. E. O., D'Alessandro, A., & Vittadini, E. (2015). Effect of Glycerol and Gluten on Mechanical Properties and 1 H NMR Mobility of Cooked Pasta. *Food biophysics*, *10*(4), 474-480. https://doi.org/10.1007/s11483-015-9414-3.

Dall'Asta, C., Cirlini, M., Morini, E., Rinaldi, M., Ganino, T., & Chiavaro, E. (2013). Effect of chestnut flour supplementation on physico-chemical properties and volatiles in bread making. *LWT-Food Science and Technology, 53*(1), 233-239. https://doi.org/10.1016/j.lwt.2013.02.025.

De Noni, I., & Pagani, M. A. (2010). Cooking properties and heat damage of dried pasta as influenced by raw material characteristics and processing conditions. *Critical reviews in food science and nutrition*, 50(5), 465-472. https://doi.org/10.1080/10408390802437154.

De Vasconcelos, M. C., Bennett, R. N., Rosa, E. A., & Ferreira- Cardoso, J. V. (2010). Composition of European chestnut (Castanea sativa Mill.) and association with health effects: fresh and processed products. *Journal of the Science of Food and Agriculture, 90*(10), 1578-1589. https://doi.org/10.1002/jsfa.4016.

Demiate, I. M., Oetterer, M., & Wosiacki, G. (2001). Characterization of chestnut (Castanea sativa, Mill) starch for industrial utilization. *Brazilian Archives of Biology and Technology*, *44*(1), 69-78. http://dx.doi.org/10.1590/S1516-89132001000100010.

Demirkesen, I., Mert, B., Sumnu, G., & Sahin, S. (2010). Utilization of chestnut flour in gluten-free bread formulations. *Journal of Food Engineering, 101*(3), 329-336. https://doi.org/10.1016/j.jfoodeng.2010.07.017.

Demirkesen, I. (2016). Formulation of chestnut cookies and their rheological and quality characteristics. *Journal of Food Quality, 39*(4), 264-273. https://doi.org/10.1111/jfq.12209.

Dokić, L., Nikolić, I., Šoronja–Simović, D., Pajin, B., & Juul, N. (2014). Sensory characterization of cookies with chestnut flour. *International Scholarly and Scientific Research & Innovation*, *8*(5), 416-419. https://doi.org/10.5281/zenodo.1092193.

Gianibelli, M. C., Sissons, M. J., & Batey, I. L. (2005). Effect of source and proportion of waxy starches on pasta cooking quality. *Cereal chemistry, 82*(3), 321-327. https://doi.org/10.1094/CC-82-0321.

Giménez, M. A., González, R. J., Wagner, J., Torres, R., Lobo, M. O., & Samman, N. C. (2013). Effect of extrusion conditions on physicochemical and sensorial properties of corn-broad beans (Vicia faba) spaghetti type pasta. *Food chemistry, 136*(2), 538-545. https://doi.org/10.1016/j.foodchem.2012.08.068.

Güler, S., Köksel, H., & Ng, P. K. W. (2002). Effects of industrial pasta drying temperatures on starch properties and pasta quality. *Food Research International*, *35*(5), 421-427. https://doi.org/10.1016/S0963-9969(01)00136-3.

Hemdane, S., Jacobs, P. J., Bosmans, G. M., Verspreet, J., Delcour, J. A., & Courtin, C. M. (2017). Study of biopolymer mobility and water dynamics in wheat bran using time-domain 1H NMR relaxometry. *Food chemistry*, *236*, 68-75. https://doi.org/10.1016/j.foodchem.2017.01.020.

Kaur, G., Sharma, S., Nagi, H. P. S., & Ranote, P. S. (2013). Enrichment of pasta with different plant proteins. *Journal of food science and technology*, *50*(5), 1000-1005. https.//doi.org/10.1007/s 13197-011-0404-2.

Kosović, I., Jukić, M., Jozinović, A., AčKAr, Đ., & Komlenić, D. K. (2016). Influence of chestnut flour addition on quality characteristics of pasta made on extruder and minipress. *Czech journal of food sciences, 34*(2), 166-172. https://doi.org/10.17221/451/2015-CJFS

Kim, Y. R., & Cornillon, P. (2001). Effects of temperature and mixing time on molecular mobility in wheat dough. *LWT-Food Science and Technology*, *34*(7), 417-423. https://doi.org/10.1006/fstl.2000.0717.

Lee, C. H., Cho, J. K., Lee, S. J., Koh, W., Park, W., & Kim, C. H. (2002). Enhancing β- carotene content in Asian noodles by adding pumpkin powder. *Cereal chemistry, 79*(4), 593-595. https://doi.org/10.1094/CCHEM.2002.79.4.593.

Le Grand, F., Cambert, M., & Mariette, F. (2007). NMR signal analysis to characterize solid, aqueous, and lipid phases in baked cakes. *Journal of agricultural and food chemistry*, *55*(26), 10947-10952. https://doi.org/10.1021/jf071735r.

Littardi, P., Diantom, A., Carini, E., Curti, E., Boukid, F., Vodovotz, Y., & Vittadini, E. (2019). A multi- scale characterisation of the durum wheat pasta cooking process. *International Journal of Food Science & Technology*, *54*(5), 1713-1719. https://doi.org/10.1111/ijfs.14057.

Ma, Y. J., Guo, X. D., Liu, H., Xu, B. N., & Wang, M. (2013). Cooking, textural, sensorial, and antioxidant properties of common and tartary buckwheat noodles. *Food Science and Biotechnology*, *22*(1), 153-159. https://doi.org/10.1007/s10068-013-0021-0.

Paciulli, M., Rinaldi, M., Cirlini, M., Scazzina, F., & Chiavaro, E. (2016). Chestnut flour addition in commercial gluten-free bread: a shelf-life study. *LWT-Food Science and Technology, 70*, 88-95. https://doi.org/10.1016/j.lwt.2016.02.034.

Paciulli, M., Rinaldi, M., Cavazza, A., Ganino, T., Rodolfi, M., Chiancone, B., & Chiavaro, E. (2018). Effect of chestnut flour supplementation on physico-chemical properties and oxidative stability of gluten-free biscuits during storage. *LWT*, *98*, 451-457. https://doi.org/10.1016/j.lwt.2018.09.002.

Pasqualone, A., Gambacorta, G., Summo, C., Caponio, F., Di Miceli, G., Flagella, Z., Marrese, P.P., Piro, G., Perrotta, C., De Bellis, L., & Lenucci, M. S. (2016). Functional, textural and sensory properties of dry pasta supplemented with lyophilized tomato matrix or with durum wheat bran extracts produced by supercritical carbon dioxide or ultrasound. *Food chemistry*, *213*, 545-553. https://doi.org/10.1016/j.foodchem.2016.07.006.

Petitot, M., Boyer, L., Minier, C., & Micard, V. (2010). Fortification of pasta with split pea and faba bean flours: Pasta processing and quality evaluation. *Food Research International, 43*(2), 634-641. https://doi.org/10.1016/j.foodres.2009.07.020.

Rinaldi, M., Paciulli, M., Dall'Asta, C., Cirlini, M., & Chiavaro, E. (2015). Short- term storage evaluation of quality and antioxidant capacity in chestnut–wheat bread. *Journal of the Science of Food and Agriculture, 95*(1), 59-65. https://doi.org/10.1002/jsfa.6843.

Rinaldi, M., Paciulli, M., Caligiani, A., Scazzina, F., & Chiavaro, E. (2017). Sourdough fermentation and chestnut flour in gluten-free bread: A shelf-life evaluation. *Food chemistry, 224*, 144-152. https://doi.org/10.1002/jsfa.6843.

Sarangapani, C., Thirumdas, R., Devi, Y., Trimukhe, A., Deshmukh, R. R., & Annapure, U. S. (2016). Effect of low-pressure plasma on physico–chemical and functional properties of parboiled rice flour. *LWT-Food Science and Technology, 69*, 482-489. https://doi.org/10.1016/j.lwt.2016.02.003.

Sartor, C., Dini, F., Marinoni, D. T., Mellano, M. G., Beccaro, G. L., Alma, A., Quacchia A., & Botta, R. (2015). Impact of the Asian wasp Dryocosmus kuriphilus (Yasumatsu) on cultivated chestnut: Yield loss and cultivar susceptibility. *Scientia Horticulturae*, 197, 454-460. https://doi.org/10.1016/j.scienta.2015.10.004.

Severini, C., De Pilli, T., Derossi, A., & Giuliani, R. (2015). Effects of drying processing conditions on the quality of uncooked and cooked pasta made up of nonconventional raw material. *Cereal Chemistry*, *92*(4), 350-357. https://doi.org/10.1094/CCHEM-08-14-0174-R.

Sissons, M. J., Soh, H. N., & Turner, M. A. (2007). Role of gluten and its components in influencing durum wheat dough properties and spaghetti cooking quality. *Journal of the Science of Food and Agriculture, 87*(10), 1874-1885. https://doi.org/10.1002/jsfa.2915.

Šoronja- Simović, D., Pajin, B., Šubarić, D., Dokić, L., Šereš, Z., & Nikolić, I. (2017). Quality, sensory and nutritional characteristics of cookies fortified with chestnut flour. *Journal of food processing and preservation*, *41*(1), e12887. https://doi.org/10.1111/jfpp.12887.

Uthayakumaran, S., Batey, I. L., Day, L., & Wrigley, C. W. (2011). Salt reduction in wheat-based foods-technical challenges and opportunities. *Food Australia*, 63(4), 137-140.

Yu, L., & Nanguet, A. L. (2013). Comparison of antioxidant properties of refined and whole wheat flour and bread. *Antioxidants, 2*(4), 370-383. https://doi.org/10.3390/antiox2040370.

Vittadini, E., Clubbs, E., Shellhammer, T. H., & Vodovotz, Y. (2004). Effect of high pressure processing and addition of glycerol and salt on the properties of water in corn tortillas. *Journal of Cereal Science*, *39*(1), 109-117. https://doi.org/10.1016/j.jcs.2003.08.002.

Captions for figures

Figure 1. FIDs curves (a), relaxation time, FID TA, and relative abundance, %PopA, (b) in control (SWP) and chestnut pasta (CP20, CP30, CP40). Different superscript letters indicate significant differences ($p \leq 0.05$).

Figure 2. Representative ^{1}H T_2 quasi-continuous distributions of control (SWP) and pasta added with chestnut flour (CP20, CP30, CP40).

Figure 3. Relaxation time (T_2C, T_2D, T_2E, T_2F) and relative abundance (PopC, PopD, PopE, PopF) of protons populations in control (SWP) and pasta added with chestnut flour (CP20, CP30, CP40). Different superscript letters indicate significant differences ($p \leq 0.05$).

Table 1. Water absorption properties of flours and mixtures[1]

	WBC (g/g)	WHC (g/g)	WAI (g/g)	WSI (g/100g)
SWF	1.789 ± 0.031 b	7.135 ±0.178 a	5.834 ±0.238 b	0.102 ± 0.013 b
CF	2.053 ± 0.043 a	6.540 ± 0.161 a	6.831 ± 0.237 a	0.299 ± 0.022 a
CF20	1.853 ± 0.047 b	6.779 ± 0.666 a	5.867 ± 0.359 b	0.089 ± 0.046 b
CF30	1.841 ± 0.025 b	7.039 ± 0.191 a	5681 ± 0.591 b	0.085 ± 0.054 b
CF40	1.854 ± 0.029 b	6.806 ± 0.292 a	5.526 ± 0.056 b	0.118 ± 0.027 b

[1]Different letters, in the same column, indicate significant differences ($p \leq 0.05$).

Abbreviations: WBC, water binding capacity; WHC, water holding capacity; WAI, water absorption index; WSI, water solubility index; SWF, soft wheat flour; CF, chestnut flour; CF20, CF30, CF40, pasta enriched with 20, 30 and 40% of chestnut flour, respectively.

Table 2. Moisture content (MC, g water/100 sample), frozen water content (FW, g frozen water/100 g water) and cooking loss (%) of the studied pasta samples.[1]

	MC (%)		$\mathbf{a_w}$	**FW** (%)		**Cooking loss** (%)
	uncooked	cooked	uncooked	uncooked	cooked	
SWP	38.37 ± 2.10 a	54.10 ± 1.59 a	0.975 ± 0.002 a	51.76 ± 3.31 a	90.45 ± 2.52 a	2.63 ± 0.05 c
CP20	35.90 ± 2.07 a	52.58 ± 0.98 a	0.967 ± 0.005 b	50.57 ± 4.19 a	89.61 ± 2.14 a	2.75 ± 0.04 c
CP30	36.89 ± 1.85 a	52.54 ± 1.04 a	0.962 ± 0.002 b	44.48 ± 3.86 b	88.99 ± 2.32 a	3.16 ± 0.05 b
CP40	36.30 ± 1.20 a	53.00 ± 0.82 a	0.961 ± 0.008 b	38.32 ± 3.08 c	84.35 ± 2.50 b	3.76 ± 0.03 a

[1]Different letters, in the same column, indicate significant differences ($p \leq 0.05$).

Abbreviations: SWP, soft wheat pasta; CP20, CP30, CP40, pasta enriched with 20, 30 and 40% of chestnut flour

Table 3. Texture (Hardness and Distance), colour parameters (L*, a*, b*) and antioxidant activity of the studied pasta samples[1].

	Texture analysis				DPPH (µmol Trolox eq/g_{dw})	
	Hardness (N)		Distance (mm)			
	uncooked	cooked	uncooked	cooked	uncooked	cooked
SWP	1.88 ± 0.08 a	2.10 ± 0.35 a	54.27 ± 1.03 a	24.04 ± 2.94 a	0.166 ± 0.064 d	0.195 ± 0.014 d
CP20	1.15 ± 0.02 b	2.07 ± 0.26 a	47.08 ± 2.88 b	22.68 ± 2.29 b	0.602 ± 0.069 c	0.418 ± 0.039 c
CP30	0.94 ± 0.07 c	1.79 ± 0.18 b	31.02 ± 1.04 c	22.03 ± 2.25 bc	0.862 ± 0.019 b	1.007 ± 0.035 b
CP40	0.91 ± 0.12 c	1.54 ± 0.22 c	28.99 ± 2.51 c	20.48 ± 2.38 c	1.527 ± 0.006 a	1.751 ± 0.067 a
	Colour parameters					
	L*		**a***		**b***	
	uncooked	cooked	uncooked	cooked	uncooked	cooked
SWP	80.46 ± 0.29 a	72.96 ± 0.39 a	-0.04 ± 0.31 c	-6.29 ± 0.53 d	13.42 ± 0.69 b	12.70 ± 0.69 b
CP20	72.09 ± 0.86 b	63.17 ± 0.68 b	4.14 ± 0.07 b	1.59 ± 0.28 c	15.59 ± 0.68 a	13.1 ± 0.75 b
CP30	70.06 ± 0.65 c	61.19 ± 0.91 c	5.53 ± 0.33 a	2.62 ± 0.30 b	15.46 ± 0.47 a	13.84 ± 0.65 a
CP40	68.16 ± 0.61 d	60.03 ± 0.40 d	5.63 ± 0.31 a	3.60 ± 0.26 a	15.26 ± 0.31 a	14.06 ± 0.25 a

[1]Different letters, in the same column, indicate significant differences ($p \leq 0.05$).

Abbreviations: SWP, soft weat pasta; CP20, CP30, CP40, pasta enriched with 20, 30 and 40% of chestnut flour, respectively.

Figure 1

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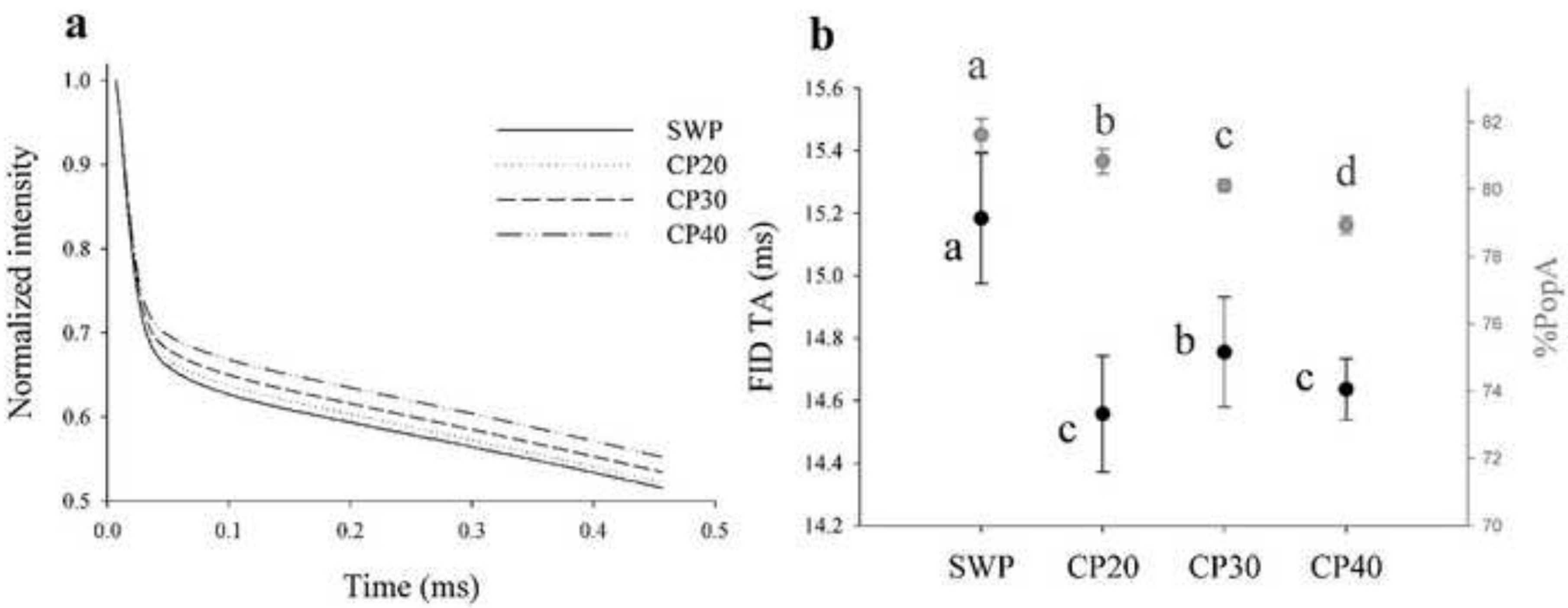

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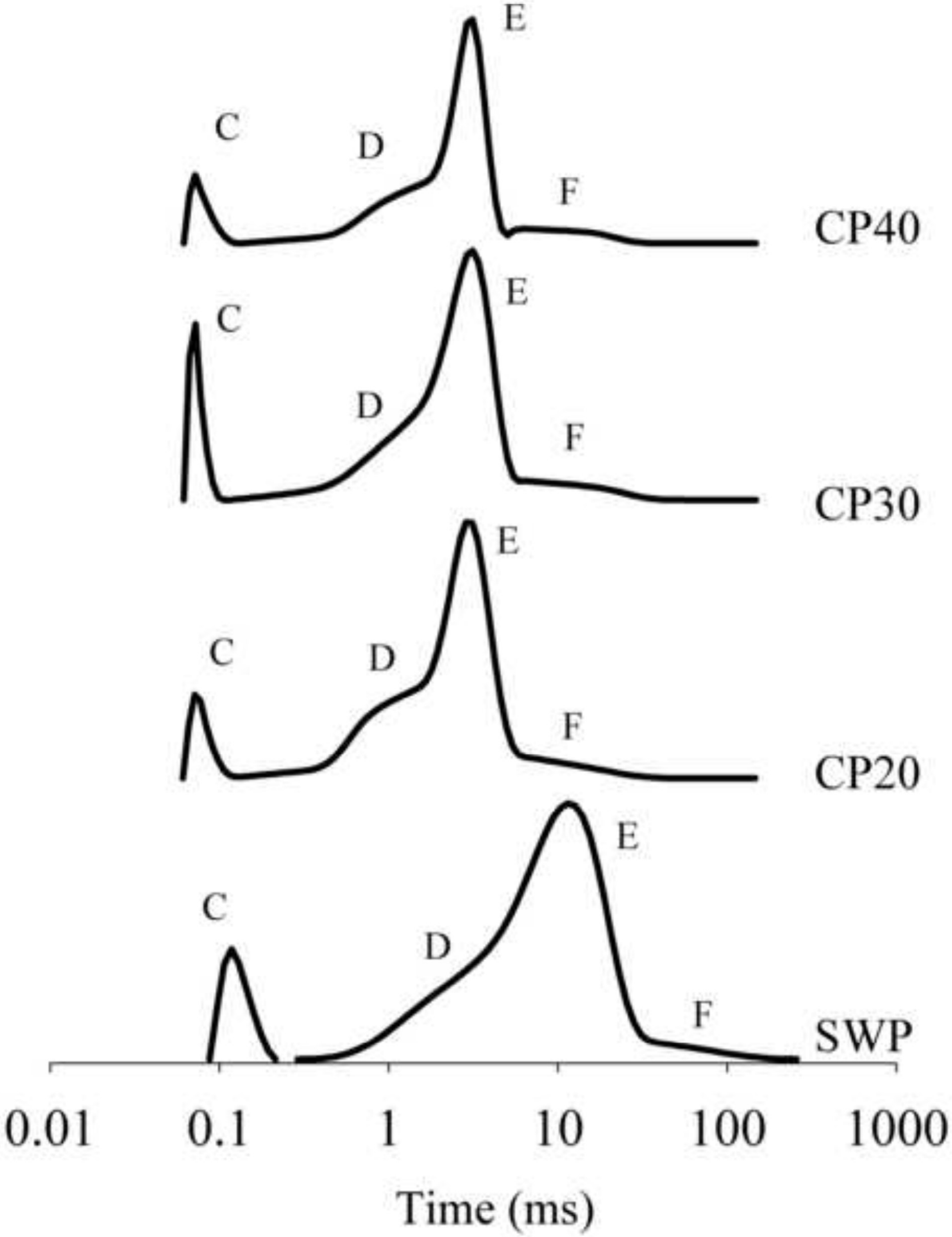

Figure 3

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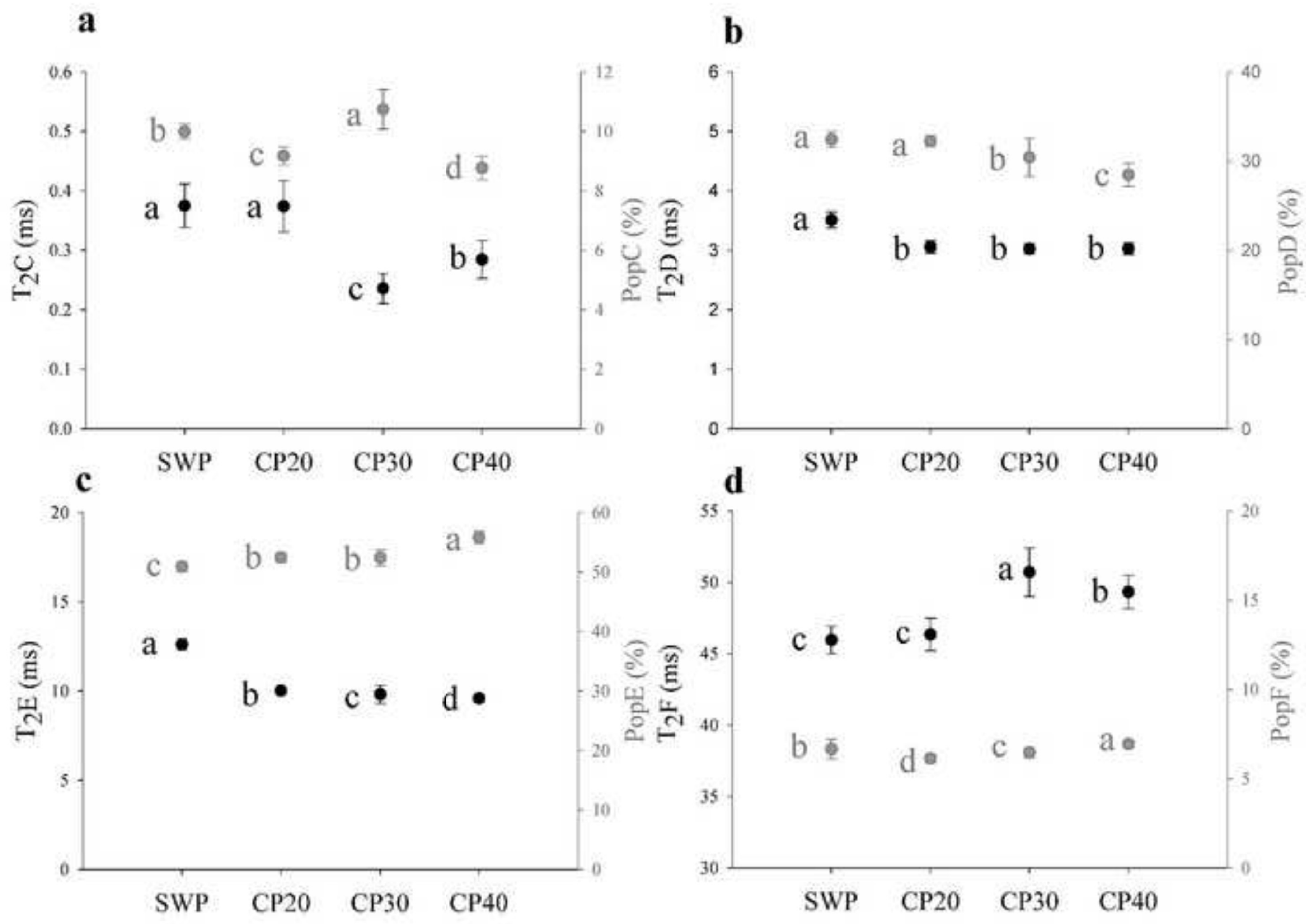

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Author contributions

PAOLA LITTARDI: Methodology; Data curation; Writing - original draft. MARIA PACIULLI: Conceptualization; Investigation; Methodology; Writing - review & editing. ELEONORA CARINI: Conceptualization; Data curation; Investigation; Methodology; Writing - review & editing. MASSIMILIANO RINALDI: Conceptualization; Methodology; Supervision; Validation; MARGHERITA RODOLFI: Formal analysis; Investigation; Methodology; EMMA CHIAVARO: Conceptualization; Project administration; Resources; Writing - review & editing.

Conflict of Interest

Authors declare that there is no any conflict of interest.