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1 Title: Quality characteristics of pasta enriched with buckwheat flour

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Abstract:

The addition of pseudocereal flours to semolina is becoming more and more popular to improve the nutritional quality of the resultant pasta. The aim of this study was the property evaluation of pasta made on industrial scale from a mixture of buckwheat flour and durum wheat semolina. The characterization of samples belonging to different pasta producers took into account the evaluation of chemical properties, pasting behavior, water uptake at 25 °C and 90 °C, mechanical properties of the dry product, cooking behavior (cooking losses, weight increase, instrumental firmness and adhesiveness) and surface characteristics monitored by image analysis. The product characterization highlighted high heterogeneity of the mechanical properties of the uncooked and cooked products (breaking stress: 17.57÷43.81 N/mm^2; adhesiveness: 5.49÷7.38 J), solid loss into cooking water (4.25÷4.99%), and water absorption (80.65÷92.95%). The great variability may be due to the different raw-materials and processing conditions adopted by each pasta producer.

Key words: pasta, buckwheat flour, texture, image analysis, cooking

1. Introduction

Semolina from durum wheat is recognized to be the most suitable raw material for pasta production due to its unique colour, flavor, and cooking quality (De Noni and Pagani, 2010). The reasons for the present success and diffusion of pasta also depends on the possibility of using other flours (such as oat and barley), pseudocereals (such as buckwheat) and legumes (such as lentils), alone or mixed with semolina, which are interesting from the point of view of fibre and/or protein sources, in order to satisfy the demand for healthy food.

Buckwheat is characterized by an excellent nutrient profile thanks to its high protein quality, the presence of high amounts of fibre, vitamins, and minerals (Aubrecht and Biacs, 2001), and digestible starch, which makes this pseudocereal recommended for diabetics (Edwardson, 1996). It is also a source of bioactive compounds (flavonoids, sterols, etc.) with health-promoting effects (Aubrecht and Biacs, 2001). Thus, the use of buckwheat flour in the formulation of high quality, healthy products such as pasta (Rayas-Duarte et al., 1996; Alamprese et al., 2007), bread (Fessas et al., 2008; Lin et al., 2009), and biscuits (Baljeet, et al., 2010) is increasingly attracting the attention of food scientists.

With regards to Italy, the most famous dish made with buckwheat flour is *Pizzoccheri*, obtained from a mixture of buckwheat flour, durum wheat semolina, and coarse semolina (Pagani et al., 2007). In the artisan process, an aliquot of buckwheat flour (generally from 20 to 25%) is added to fine and coarse semolina, and the dough (about 35% moisture) is formed into *Pizzoccheri* by sheeting (tagliatella-shaped; width less than 1 cm) and consumed within 1-2 days. On the industrial scale, this type of pasta can be prepared by using different technologies: the dough can be formed by sheeting or by extrusion; in addition, the extrusion and sheeting steps can be combined. As it can be assimilated to a dried pasta, its quality can be evaluated considering different features related both to the characteristics of the dry product, such as colour, fracturability, surface appearance and evenness, and to cooking behavior in terms of cooking loss, consistency, and adhesiveness of the cooked product (D'Egidio et al., 1990; Lucisano et al., 2008). The addition of buckwheat flour in

relevant percentages (30-50%) to wheat semolina or flour to produce dry pasta is responsible for the increased fragility of the pasta structure, a higher loss of organic matter into the cooking water and a different texture, compared with semolina pasta (Rayas-Duarte et al., 1996; Manthey et al., 2004). No information is available on the overall characteristics of *Pizzoccheri*, a product traditionally made by small companies that follow their own production rules and trust their own experience. Moreover, these producers are interested in obtaining the Protected Geographical Indication (PGI) denomination for *Pizzoccheri*. This denomination expresses a strong bond between the product and the region (EEC Council Regulation No. 2081/92). Nevertheless this dependence does not require that all phases of the transformation process be performed in a particular geographical area. A PGI product nonetheless complies with strict production regulations established for the process, and compliance with these regulations is assured by inspection.

The objective of the present work is to give a complete overview of *Pizzoccheri* features made by the three most important industrial *Pizzoccheri* producers currently present in Italy. The characteristics of *Pizzoccheri* products were evaluated both in their raw state and after cooking using conventional and innovative approaches in order to understand the physical arrangement and the macromolecular interactions in each sample and describe the heterogeneity of these commercial products. In fact, this wide characterization could provide useful information for obtaining the PGI denomination for *Pizzoccheri*.

2. Material and method

2.1 Pizzoccheri samples

Three different *Pizzoccheri* brands (coded A, B, and C) were bought from the Italian market. For each brand, three batches were purchased from three different stores, and analysed. The samples coded B and C were produced in the Valtellina valley, a small area in the north of Italy. The sample coded A was produced in Lombardy, outside of the Valtellina area.

Both sample A and C were formed into short-strands pasta, with an average length of 67.1 mm and 50.5 mm, respectively (Table 1). Brand B was formed into long-shape pasta (like skein pasta) and

for this reason it was cut into pieces of 6 cm before analysis (Figure 1). The width of the samples ranged from 7.40 mm for sample B to 7.81 mm for sample C; and the thickness varied from 1.42 mm (sample B) to 1.52 mm (sample C).

2.2 Chemical composition

Before chemical analyses, *Pizzoccheri* were ground with a laboratory mill (IKA Universalmuhle M20, Janke and Kunkel GmbH & CoKG, IKA Laborteknic, Staufen Germany) to particles size less than 500 μm. The moisture and ash content of the pasta samples were determined according to official standard methods AACC 44-15 and AACC 08-12 (2001). The total nitrogen content was evaluated following the official standard method AOAC 920.87 (1999); a factor of 5.7 was used to convert the nitrogen content to protein content (% db). All these evaluations were made at least in triplicate. Total starch was determined enzymatically using the "Total Starch Assay Kit" (AACC 76-13, 2001; Megazyme International Ireland Ltd., Bray Business Park, Bray, Co. Wicklow, Ireland). The damaged starch content refers to the amount of starch that, being quickly susceptible to α-amylase hydrolysis, had been mechanically damaged during milling. In the this work, the enzymatic approach was used to characterize the samples in an attempt to assess the influence of the technological process on starch organization. Susceptibility to α-amylase was determined using the "Starch Damage Assay Kit" (AACC 76-31, 2001; Megazyme International Ireland Ltd., Bray Business Park, Bray, Co. Wicklow, Ireland). The results are the average of a minimum of four replicates.

2.3 Pasting properties

The pasting profiles of ground pasta were carried out according to Mariotti et al. (2005), using a MicroVisco-Amylo-Graph (MVAG) (Brabender OHG, Duisburg, Germany). An aliquot of 12 g was dispersed in 100 mL of distilled water, scaling both flour and water weight on 14% flour moisture basis. The pasting properties were evaluated under constant conditions (speed: 250 rpm; sensitivity: 300 cm g_f) using the following time-temperature profile: heating from 30 °C up to 95 °C; holding at 95 °C for 30 min; cooling from 95 °C to 50 °C; holding at 50 °C for 30 min, and

cooling from 50 °C to 30 °C. The heating and cooling phases were carried out with a temperature gradient of 3 °C/min. The analysis was repeated at least twice and the parameters of pasting properties were determined using the software provided with the instrument (Viscograph version 2.3.7).

2.4 Hydration test

An aliquot of 10 g of samples was placed in a beaker containing 200 ml of water (pasta:water ratio = 1:20) at 25 °C and 90 °C. These temperatures were maintained constant placing the beakers in a thermostatic bath. After 5, 10, 15, 30, 60, and 180 minutes at 25 °C, and 2, 5, 7, 10, 12, 15, 30, and 45 minutes at 90 °C, *Pizzoccheri* were removed from the water, drained for one minute, carefully blotted with tissue paper to remove superficial water, and weighed. The analysis was repeated for each batch at least twice. The results were expressed as $(W_1–W_0)*100/W_0$, where W_1 is the weight of the hydrated sample and W_0 is the weight of the dry sample.

2.5 Solid content of cooking water and water absorption

Cooking loss was evaluated by determining the amount of solids lost into the cooking water (D'Egidio et al., 1990). An aliquot of 50 g of pasta was cooked in 500 ml of boiling natural spring water (pasta:water ratio = 1:10) with no salt added. Pasta samples were cooked until the optimum cooking time (OCT) suggested by each companies and reported in the label: 12 minutes for sample A; 10 minutes for sample B; 15 minutes for sample C. After cooking, the volume of water was brought to the initial volume. Dry matter was determined on 25 ml of cooking water, dried to constant weight at 105 °C. The residue was weighed, reported as percentage of the dry material, and expressed as grams of matter loss/100 g of pasta.

The increase of pasta weight due to cooking was evaluated by weighing pasta before and after cooking. The results were expressed as $(W_1–W_0)*100/W_0$, where W_1 is the weight of cooked pasta and W_0 is the weight of the uncooked sample.

2.6 Texture properties

The texture properties of *Pizzoccheri* were evaluated before and after cooking using a Texture Analyzer TA-HD (Stable Micro Systems, Surry, UK). A calibrated load cell of 500 N was used for the collection of data (500 points per second).

The fracture properties of the uncooked samples were evaluated by a three-point bending test with the appropriate holder (HDP/3PB – Three Point Bend) having a 61 mm span length. A portion of sample with a length of about 5 cm was put on the holder and was deformed up to the broken point with a blade (speed: 10mm/s). Measurements were replicated on 30 strands for each brand. Strain and stress were calculated from the force-distance curve. In particular, strain at the breaking point (ε) was calculated according to Bruns and Bourne (1975): $\varepsilon = 6*D*d/L^2$, where D is the depth of sample (mm); d is the distance at the break point (mm), and L is the distance between the support (61 mm). The stress (σ; N/mm^2) corresponding to the stress required to break the sample was calculated by the following expression: $\sigma = 3PL/2bD^2$, where P is the load at the break point (N), L is the distance between the support (61 mm), b is the sample width (mm), and d is the depth of sample (mm).

The compression test performed on the cooked samples was made according to the method "Adhesive testing for cooked pasta". For this purpose 6 strands of *Pizzoccheri* were cooked at the OCT, cooled for 20 minutes and placed in a support block HDP/PFS - Pasta Firmness stickiness (Stable Microsystems, Surry, UK). This support blocks the *Pizzoccheri* strands while leaving the possibility of access to the square piston to compress the product. Sample strands were compressed with a speed of 1 mm/s up to a load of 50 N and maintained compressed at the same load for 3 seconds, before removal of the load. The test was repeated 7 times for each sample. From the compression curve the following parameters were obtained and considered as indicator of product stickiness: Young Modulus (N/mm^2), Adhesiveness (J) corresponding to the negative area of force-time curve (N*s).

2.7 Surface texture characteristics by Image Analysis

The images of 6 *Pizzoccheri* for each batch of each commercial brand were taken before and after cooking at their OCT, using a flatbed scanner (Epson Perfection 3170 Photo, Seiko Epson Corp., Japan), at 600 dpi (dots per inch) of resolution and a colour depth of 24 bits in standard conditions. The images were saved as TIFF format and then processed using a dedicated software (Image Pro-Plus 4.5.1.29, Media Cybernetics Inc, UK).

The assessment of surface texture of uncooked and cooked products was performed on a surface of 501pxl * 101pxl extracted from the images of the *Pizzoccheri* and was used for creating the data set of 108 images for samples, 54 for uncooked and 54 for cooked products. After conversion in 8-bit grayscale, the surface texture of each image was evaluated and expressed in terms of heterogeneity (HTG). This parameter is defined as the fraction of pixels whose intensity value deviates more than 10% compared to the average intensity of the entire image. A heterogeneity value equal to 0 corresponds to a homogeneous surface (smooth surface); on the other hand, a value equal to 1 corresponds to a heterogeneous surface (rough surface).

2.8 Statistical analysis

The data were processed by STATGRAPHIC®*Plus* for Windows v. 5.1. (StatPoint Inc. Virginia, U.S.A.). A one-way analysis of variance (ANOVA) was performed using the Least Significant Differences (LSD) test to compare the sample means; differences were considered significant at $p<0.05$.

3. Results and discussion

3.1 Pizzoccheri characterization

All samples were prepared by using coarse semolina, buckwheat flour and *durum wheat* semolina as the main ingredients. Only brands A and C stated the amount of buckwheat flour added to the semolina (25% for both samples). Due to the commercial origin of the products, the composition of raw materials was unknown.

3.2 Chemical composition

The chemical composition of *Pizzoccheri* is shown in Table 1. The protein content ranged from 11.7 to 13.5% d.b., in every case higher than the minimum fixed by Italian law for conventional pasta from *durum wheat* semolina. Therefore, the integration of semolina with buckwheat flour assured a good protein amount, as the most currently grown cultivars yield seeds with 11-15% protein (Mazza and Oomah, 2005). Sample B showed the lowest starch content (67.8% d.b.), considerably lower than the amount declared in label, and a higher ash content probably related to the use of less refined flours. No significant difference in either the protein or starch content was detected between sample A and C (Table 1).

Italian law establishes the maximum moisture and ash values only for dried pasta from *durum wheat* semolina (Italian law n°580, 4 July 1967 modified by the presidential decree n°187, 9 February 2001). Even if no indication has been proposed for *Pizzoccheri* pasta, all samples had moisture contents below 10.55% (Table 1), similar to the semolina products. The ash content of the samples ranged from 1.09 (sample A) to 1.64% d.b. (sample B). The significant differences between sample B and the other two brands can be related to the quantity and/or the quality of the raw materials, as processing seems not to affect this parameter (Manthey and Hall, 2007). Regardless of the nature of the flours, the mineral content in all the samples is higher than in semolina pasta (max 0.90% d.b., according to the Italian law). At the same time, the ash content in *Pizzoccheri* was lower compared to whole wheat pasta (1.35% according to Olivera and Salvadori, 2006). Even if the ash content in buckwheat seeds (1.37-1.67% d.b.) is lower than in wheat, semolina-buckwheat mixture contained more ash than semolina alone, as reported by Manthey and Hall (2007). The addition of buckwheat flour at 25% replaced minerals removed by milling *durum wheat* into semolina (Manthey and Hall, 2007).

3.3 Starch properties

The damaged starch content represents the amount of starch granules suitable to being quickly hydrolyzed by α-amylase as a consequence of physical modifications to the native structural organization. In the case of dry pasta, the damaged starch is a marker of the physical changes

induced by thermal treatments, such as extrusion and drying (Marti et al., 2010; Mariotti et al., 2011).

According to previous works (Mariotti et al., 2006; Lacavalla et al., 2010), the amount of damaged starch due to wheat and buckwheat milling is usually lower than 3-4% (buckwheat 1.5-2.2%). Therefore, the higher values observed for *Pizzoccheri* demonstrate that starch granules undergo relevant physical stresses during pasta-making, especially during the forming and drying phase. The damaged starch content varied from 10.9% of sample C to 11.3% of sample A (Table 2). The process conditions used to prepare sample C seem to promote a more compact structure of the product, as argued by the lower α-amylase susceptibility.

The starch modifications detected by the enzymatic hydrolysis with α-amylase could also be responsible for changes in the pasting properties of starch granules. Changes in viscosity of *Pizzoccheri* during heating and cooling are shown in Table 2. This approach is conventionally adopted for the evaluation of pasting properties of starch and flours. In this work, investigating the pasting properties of dry pasta could give information on molecular changes promoted by pasta-making process (Marti et al., 2010; Mariotti et al., 2010). All the samples showed a typical viscoamylographic curve, with an increase in viscosity during the heating step, a decrease in viscosity during the prolonged heating of the suspension (evaluated by the breakdown index), and an increase in viscosity during the cooling period (evaluated by the setback index) (Table 2). Sample B showed the lowest pasting temperature (Table 2), probably as a consequence of the lowest amount of total starch and the highest protein content in this sample (Table 1). Moreover, this behaviour could be attributed to changes to the molecule arrangement that occurred during processing and resulting in a product in which starch granules showed a higher ability to absorb water and swell when heated in excess of water. On the other hand, starch present in samples A and C appeared to be more rigid to water access and more stable during the heating step (low breakdown index). During the holding period at 95 °C, the product slurries were subjected to high temperatures and mechanical shear stress which further disrupted starch granules, resulting in

amylose leaching out. This period is commonly associated with a breakdown in viscosity, which was higher in sample B than in the other two *Pizzoccheri* brands (Table 2). During cooling, the viscosity increased as a result of the formation of a gel structure. This phase is commonly described as the setback region and is related to the re-association between starch molecules, especially amylose. During cooling, sample B showed the lowest final viscosity and the lowest setback value, indicating a lower rate of starch retrogradation, probably related to the use of less refined flours (lower starch and to the higher protein content of this sample) (Santos et al., 2008) (Table 2). Even if samples A and C had a similar behavior during the heating phase, sample C reached the highest peak viscosity (Table 2).

3.2 *Hydration test*

The ability of pasta products to absorb water, i.e. the weight gain during cooking, is affected by both raw material composition and processing conditions. Moreover, it is considered to be one of the most important characteristics for a producer of *Pizzoccheri* pasta (personal communication). The kinetics of water uptake of *Pizzoccheri* samples at 25 °C and 90 °C are shown in Figure 1a and 1b, respectively, for times longer than the optimal cooking time (Table 4) with the aim of better investigating the porosity of the samples.

Water absorption at room temperature (25 °C) can be related both to the presence of hydrophilic macromolecules, such as fibre, and to the samples' structural features determined by the technology adopted during *Pizzoccheri* production. In fact, starch gelatinization and protein coagulation, which accompany the cooking at 90 °C, could certainly mask the macrostructure characteristics of the products (Maache-Rezzoug and Allaf, 2005). Sample B had the highest water uptake capacity at any sampling time (Figure 2a). Even after 5 minutes of soaking in water, the amount of water absorbed by sample B was higher than that absorbed by samples A and C. A similar trend, with a significant difference, was observed after 10 minutes of soaking. The increase of the soaking time highlighted greater differences between the samples (Figure 2a). The statistical analysis indicates that sample B had significantly different absorption ability in comparison with the other two

commercial brands ($p<0.05$). A less compact structure and a high porosity could be responsible for the faster penetration of water in sample B. On the other hand, the lower amount of water absorbed by sample C suggests a greater compactness of the sample with, potentially, a lower extent of leaching phenomena during cooking.

The absorption kinetics at 90 °C showed that samples A and B absorbed a higher amount of water than sample C, at any soaking time (Figure 2b). The high water absorption capacity of sample B confirmed its higher swelling ability exhibited by the micro-viscoamylographic test, in comparison with samples A and C (Table 3). No significant difference was observed between sample A and B up to 12 minutes of soaking. In addition, the higher the soaking time, the higher the differences among them ($p<0.05$). This behavior could be related to the macromolecular changes induced by heat that occurred close to the optimal cooking time of each *Pizzoccheri* brand (Table 3). The technological history of the samples seemed to be responsible for the peculiar structure of the product that resulted in a lower absorption capacity for the sample C. Moreover, the hydration capacity could account for the choice of the cooking time recommended by each *Pizzoccheri* producers: the lower the water absorption, the longer the cooking time.

3.3 Solid content of cooking water and water absorption

Cooking losses are considered a useful indicator of overall spaghetti cooking performance (D'Egidio et al., 1990). The solid losses of *Pizzoccheri* were within the range (4.3% - 5.0%) (Table 3) and they are comparable to those of conventional pasta from semolina and whole semolina pasta (4.2% and 3.6%, respectively; data not shown). The addition of non-gluten forming flours diluted the gluten network and interrupted and weakened the overall structure of pasta, allowing leaching of soluble solids into the cooking water (Pagani, 1986). Moreover, the high amount of fibre contained in *Pizzoccheri* (2.7%d.b.) accounted for the weakening of the gluten network and for the slight increase of cooking losses. Buckwheat bran contains 12% soluble fibre (Steadman et al., 2001) and part of it leaches out of the products during cooking (Manthey et al., 2004). The amount of buckwheat (25%) added to *durum wheat* did not dramatically increase the amount of solid losses,

despite the dilution of the gluten network created by buckwheat proteins. Similar results were obtained in a previous work, in which the authors concluded that since pasta from buckwheat flour has cooking losses equal or lower than pasta made from semolina alone, it presented excellent cooking characteristics (Chillo et al., 2008).

Sample A was able to absorb the highest amount of water (93%) and, at the same time, to release the highest quantity of material into the boiling water (5%). This behavior was probably due to a looser pasta structure at its optimal cooking time (12 minutes). The result confirmed the differences in structure compactness detected during the hydration test at 90 °C: the water uptake for sample A, B and C was respectively 93%, 81% and 86% after soaking for the optimal cooking time of each brand (12, 10 and 15 minutes for sample A, B, and C, respectively) (Figure 1a).

3.4 Texture properties

The texture properties of pasta before and after cooking are summarized in Table 3. The three commercial brands presented significant differences in breaking strength before cooking ($p<0.05$). In particular, sample C exhibited higher strain and stress values at rupture, compared to samples A and B. The compactness of sample C reflected its behavior in cold and hot water: the lower the fragility, the lower the absorption values (Figure 1). It is well known that the breaking strength of pasta is highly dependent on the die type (Lucisano et al., 2008) and the extrusion conditions (Pagani et al., 1989). The low breaking stress and strain of sample A in its dry state is indicative of a loose internal structure, accounting for high water adsorption and cooking losses (Table 3).

Even after cooking, sample C showed a higher firmness than sample A. On the other hand, no significant differences were detected between samples A and C for adhesiveness (Table 3). The higher values of Young modulus detected in samples B and C can be related to the starch and protein arrangement in the *Pizzoccheri* products, accounting for the low amount of water absorbed during cooking (91 and 89%, respectively) and for the lower amount of starch released in cooking water (4.3 and 4.5%, respectively) compared to sample A. Regarding adhesiveness, sample B exhibited the lowest values, and consequently the best cooking behaviour.

3.5 Surface texture characteristics by Image Analysis

Surface texture is often used to describe the surface characteristics of a material (Zheng et al., 2006). It is a parameter immediately perceived by sight, and it anticipates a specific tactile perception (Chen, 2007). In this study, the heterogeneity (HTG) parameter was used to describe the surface texture of the samples before and after cooking, in order to gain information on the degree of roughness and, consequently, on the product structure (Figure 3).

The HTG before and after cooking is shown in Figure 4. In all samples, a decrease in HTG was detected after cooking, highlighting that cooking increased surface homogeneity ($p<0.05$). The surface roughness of the dry products is related to the conditions applied during the pasta shaping step, while starch and its physiochemical properties certainly play an important role in structural changes during cooking. In particular, before cooking, sample A had a more heterogeneous surface than samples B and C ($p<0.05$), showing a rough and uneven surface, features that can easily be perceived even by simple observation and tactile assessment of the product (Figure 3). It is worth noting that sample A also presented a lower resistance to fracture indicating a looser internal structure that is probably one of the reasons for the irregular surface. On the contrary, sample B showed a smoother and less wrinkled surface. The different surface properties could be related to the processing conditions (forming roller, type of die, etc.) (Lucisano et al., 2008).

The surface properties are one of the products characteristics that may help to explain pasta cooking behaviour: the rougher the surface of the uncooked products, the higher the solid content of cooking water (Table 4). In fact, samples with high HTG value (roughness surface) expose a greater area to water action during cooking and, consequently, a high amount of material can be released on the pasta surface and, consequently, into the cooking water .

Regarding the change in HTG values after cooking, samples A and C were characterized by a greater decrease in the HTG index compared to sample B (66% and 20%, respectively), suggesting that cooking slightly affected the roughness of product B.

The 3D representation of the grey level surface distribution (Figure 3) can help to forecast the sensation perceived by the consumer: a rough and uneven surface in the uncooked samples, and a smoother surface after cooking.

4. Conclusions

The results obtained by different and complementary approaches provided an overall characterization of pasta enriched with buckwheat flours, commercialized by the three most important *Pizzoccheri* producers currently present in Italy. The three products showed highly different properties which may be due not only to the raw material characteristics (mainly semolina quality) but also to the processing conditions adopted by each producers. Presumably, brand B focuses on the choice of good quality raw materials (semolina with high protein content), providing a product with low solid loss in cooking water and low adhesiveness. Sample A, on the contrary, is characterized by the worst performance during cooking (high cooking losses and adhesiveness) that can be related to a lower protein content and, consequently, a discontinuous structure. The processing conditions adopted for both samples are effective in creating a porous network that is able to absorb a higher amount of water than sample C. On the other hand, sample C is obtained by using a technology suitable for creating a more compact structure. These observations enable us to hypothesize different technological processes for each sample. In the extrusion process commonly used for semolina pasta production, the dough is submitted to significant shear stresses, which can weaken the protein structure (Pagani et al., 1989), but, at the same time, to pressure (9-10 MPa) responsible for giving the product a high compactness, allowing it to withstand cooking (Petitot et al., 2009). On the other hand, the sheeting process by rolls allows the protein to align in a continuous network whose goodness strongly depends on protein quantity and quality. Further studies are underway to better understand the effect of both raw material characteristics and processing conditions (sheeting and/or extrusion) on the physical properties and cooking quality of buckwheat enriched pasta.

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1 Table 1. Geometrical and chemical characterization of *Pizzoccheri* samples.

2 Table 2. Damaged starch and pasting properties of *Pizzoccheri* samples.

3 Table 3. Cooking and textural properties of *Pizzoccheri* samples.

4 Figure 1. *Pizzoccheri* shape.

5 Figure 2. Absorption kinetics at 25 °C (a) and 90 °C (b) of *Pizzoccheri* samples.

6 Figure 3. Sample images: colour images of *Pizzoccheri* before (a) and after (d) cooking; 2D and 3D
7 representation of grey level surface distribution before (b; c) and after cooking (e; f).

8 Figure 4. Heterogeneity of *Pizzoccheri* before and after cooking.

Table 1. Geometrical and chemical characterization of *Pizzoccheri* samples.

Pizzoccheri	Length (cm)	Width (mm)	Thickness (mm)	Moisture (%)	Ash (% d.b.)	Protein (% d.b.)	Total starch (% d.b.)
Sample A	**6.71b**	**7.47a**	**1.49b**	**10.6b**	**1.09a**	**11.8a**	**72.7b**
Sample B	*****	**7.40a**	**1.42a**	**9.6a**	**1.64b**	**13.5b**	**67.8a**
Sample C	**5.05a**	**7.81b**	**1.52b**	**10.6b**	**1.13a**	**11.7a**	**72.7b**

Means followed by different letters in a column are significantly different at $p<0.05$.

*nest shaped *Pizzoccheri*

Table 2. Damaged starch and pasting properties of *Pizzoccheri* samples.

Pizzoccheri	Damaged starch (% d.b.)	Pasting Temperature (°C)	Peak Viscosity (BU)	Final Viscosity (BU)	Breakdown (BU)	Setback (BU)
Sample A	**11.3c**	**67b**	**230a**	**441b**	**77a**	**286b**
Sample B	**11.1b**	**64a**	**261b**	**356a**	**116c**	**212a**
Sample C	**10.9a**	**71c**	**276c**	**537c**	**75a**	**365c**

Means followed by different letters in a column are significantly different at $p<0.05$.

1 Table 3. Cooking and textural properties of *Pizzoccheri* samples.

Pizzoccheri	Optimal cooking time (min)	Water absorption (%)	Solid content of cooking water (g/100g)	Before cooking		After cooking	
				Stress (N/mm^2)	Strain	Young Modulus (N/mm^2)	Adhesiveness (J)
Sample A	**12**	**97c**	**5.0b**	**17.57a**	**3.76a**	**0.48a**	**7.09b**
Sample B	**10**	**91a**	**4.3a**	**22.28b**	**6.15b**	**0.58b**	**5.49a**
Sample C	**15**	**89b**	**4.6ab**	**43.91c**	**6.05b**	**0.58b**	**7.38b**

2 Means followed by different letters in a column are significantly different at $p<0.05$.

3

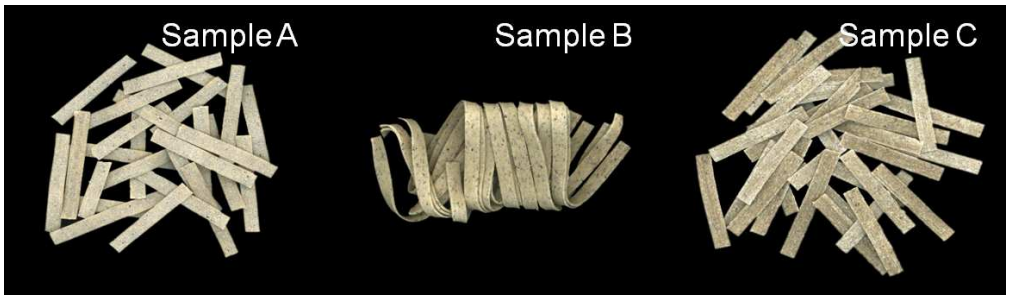

Figure 1. Pizzoccheri shape.
196x56mm (150 x 150 DPI)

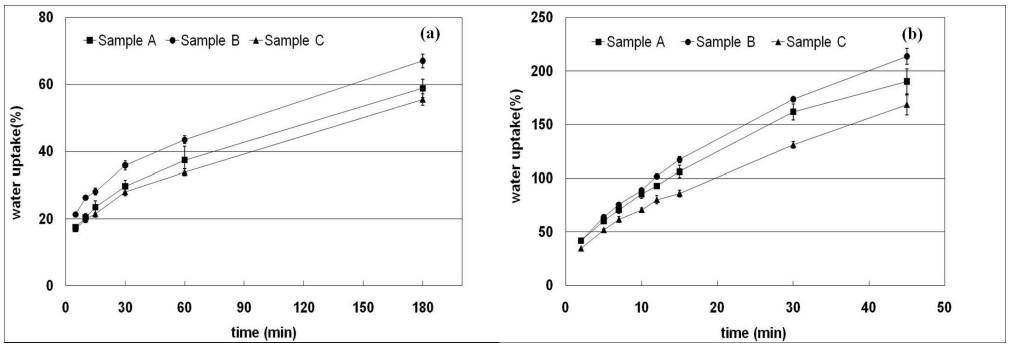

Figure 2. Absorption kinetics at 25 °C (a) and 90 °C (b) of Pizzoccheri samples.
368x124mm (150 x 150 DPI)

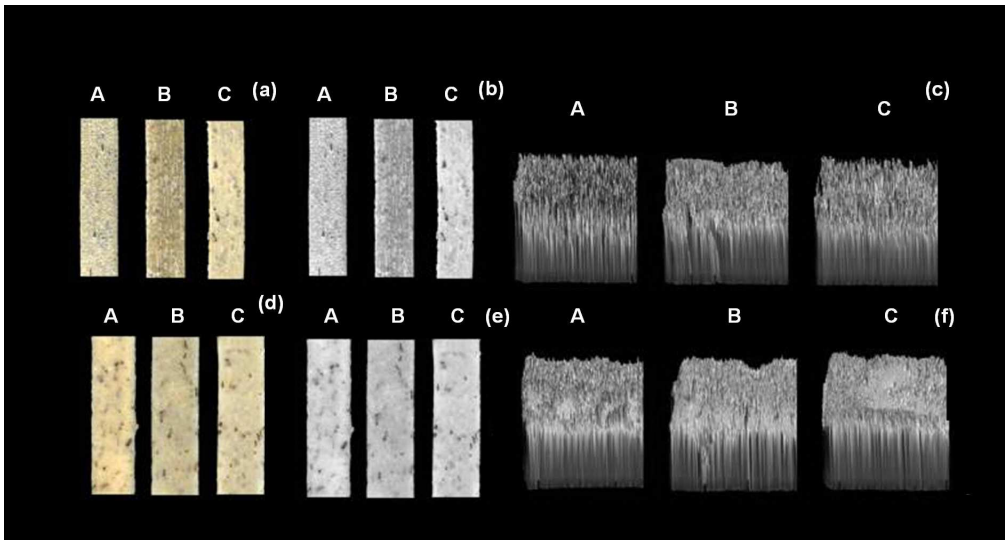

Figure 3. Sample images: colour images of Pizzoccheri before (a) and after (d) cooking; 2D and 3D representation of grey level surface distribution before (b; c) and after cooking (e; f).
317x169mm (150 x 150 DPI)

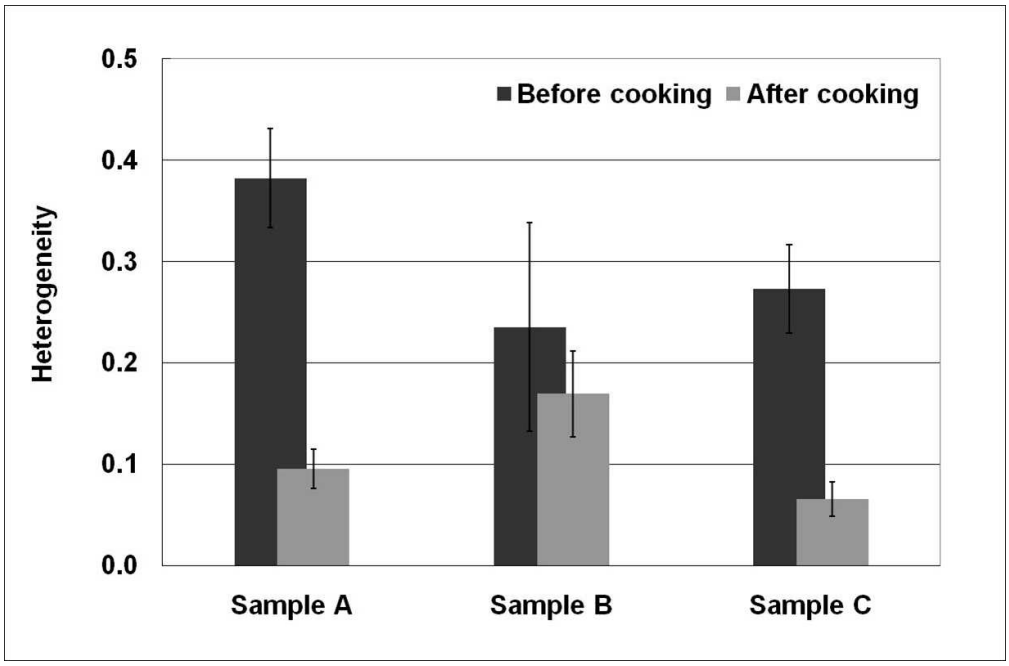

Figure 4. Heterogeneity of Pizzoccheri before and after cooking.
259x169mm (120 x 120 DPI)