Effect of broad bean (*Vicia faba*) addition on starch properties and texture of dry and fresh pasta

Karima Tazrart[a,b], Farid Zaidi[b], Ana Salvador[a], Claudia Monika Haros[a*]

[a]Institute of Agrochemistry and Food Technology (IATA-CSIC), Av. Agustín Escardino 7 Parque Científico, 46980 Paterna-Valencia, Spain

[b]Faculté des Sciences de la Nature et de la Vie. Université de Bejaia, 06000 Bejaia, Algeria

*Corresponding author. Mailing address: Institute of Agrochemistry and Food Technology (IATA-CSIC), Av. Agustín Escardino 7, Parque Científico, 46980 Paterna-Valencia, Spain. Phone: +34 96 390 00 22, Fax: +34 96 363 63 01, E-mail: cmharos@iata.csic.es

ABSTRACT

Two kinds of pasta were produced: dry *Maccheronccinis* pasta and fresh *Cicatellis* pasta. Four formulations were made for each type: control pasta made with 100% semolina and enriched pasta containing different levels of broad bean flour. Thermal properties were measured using Differential Scanning Calorimetry and revealed that only dried pasta induced gelatinization peaks. Enriched samples had higher $T_{0,}$ T_p *and* T_c values but lower gelatinization enthalpy than the control. Retrogradation temperature tended to decrease as the level of bean flour increase, both in dry and fresh pasta. The Rapid Visco Analyser data revealed significantly ($p<0.05$) lower values for pasting temperature in dried pasta. All other parameters showed higher values for *Maccheronccinis* compared to *Cicatellis.* Peak, trough and final viscosities, breakdown and setbacks decreased as the percentage of added flour increased. Texture analysis showed that fresh pasta was stickier than dry pasta, while firmness was similar between the two types.

Keywords: *Maccheronccinis*, *Cicatellis*, Differential Scanning Calorimetry, Rapid Visco Analyser, Texture

1. Introduction

Pasta presents a unique combination of cheapness, ease of preparation and high nutritive value (Colonna, Barry, Cloarec, Bornet, Gouilloud et al., 1990). Durum wheat (*Triticum turgidum L. Var. Durum*) semolina is the preferred raw material for the production of high quality pasta (Feillet & Dexter, 1996). Pasta products made from durum wheat varieties of superior quality result in a bright yellow colour. They retain firmness after cooking and resist to surface disintegration and stickiness (D'Egidio, Mariani, Nardi, Novaro & Cubadda, 1990).

Starch presents up to 80% of semolina dry matter. It makes a major contribution to eating quality and texture of wheat-based foods (Maningat & Seib, 1997). In durum wheat pasta, starch gelatinization and protein coagulation cause the major structural changes during cooking. Both transformations occur at approximately the same temperature and moisture level (Sozer, Dalgiç & Kaya, 2007).

Cooking of pasta results in the complete gelatinization of starch that requires at least few minutes depending on the type of pasta (dry or fresh), its composition (presence of other ingredients than semolina) and shape (macaronis, vermicelli, spaghettis). Starch retrogradation could positively affect the quality of pasta. In fact, in order to decrease stickiness, prevent the dissolution of solids into the boiling water and obtain a characteristic chewiness (Bustos, Perez & Leon, 2011).

Legumes are the second major source for human next to cereals and play an important role in the human diet in developing countries (Singh, Raina, Bawa, & Saxena, 2004). Their addition to semolina in pasta production is a way to enhance its nutritional quality due to the amino acids' complementarity of cereals and legumes and the higher dietary fibre intake. Among legumes, broad beans (*Vicia faba*) represent a source of energy, protein, folic acid, niacin, vitamin C, magnesium, potassium, iron and dietary fiber (Azasa, Wassim, Mensi, Abdelmouleh, Brini et al., 2009).

Broad bean supplementation could present a technological challenge, mainly with high addition levels and the study of the thermal and pasting properties of raw material and resulting pasta's starch becomes important to understand the relationship between cooking behaviour and morphological changes of pasta before and after cooking, and the variability that could occur between dry and fresh pasta.

Determination of the textural parameters including firmness and stickiness after pasta cooking is of great importance from the point of product acceptability by the consumers (Sozer et al., 2007). Broad bean addition could negatively affect the texture of pasta because of the weakening of pasta structure (Petitot, Boyer, Minier & Micard, 2010).

The objective of the present work was to evaluate the effect of increasing levels of broad bean addition to semolina when producing dry and fresh pasta on starch properties, as determined by DSC and RVA and the resulting impact on the texture of cooked products.

2. Material and methods

2.1. Materials

Durum wheat semolina was of the type commonly used for pasta production and was kindly supplied by "Belladauna" and "Manfredonia" factories (Foggia, Italy). Broad beans were cultivated and harvested in a mountainous region (Feraoun township, Bejaia-Algeria), dehulled and ground with a traditional mill. The obtained flour was then sieved to pass through a 500 µm mesh screen.

2.2. Dry and fresh pasta production

Dry pasta produced was of the *Maccheronccinis* type, following the specifications of Belladauna factory (Foggia, Italy), as described by Tazrart, Zaidi, Lamacchia & Haros (2016), which was drying during 16 h at ~55ºC. Produced fresh pasta had the shape of *Cicatellis* and was manufactured according to the requirements of Manfredonia factory (Foggia, Italy) as illustrated by Tazrart, Lamacchia, Zaidi & Haros (2016). Finally, it was pasteurized at ~70°C. Four formulations were made for each type of pasta (*Maccheronccinis* and *Cicatellis*); a control made of exclusively durum wheat semolina (semolina 1 in the case of *Maccheronccinis*, semolina 2 in the case of *Cicatellis*) and enriched pastas where 10, 30 and 50% semolina were replaced by broad bean flour. Semolina used for dry pasta production (semolina 1) was different from the one used for fresh pasta (semolina 2). The two types of pastas were manufactured in two different factories, and each factory uses its particular brand of raw materials.

2.2.1. DSC measurement

DSC measurements were made with a Perkin-Elmer DSC-7 (Norwalk, CT). The DSC was calibrated with indium. Durum wheat semolina, broad bean flour, ground dried pasta and freeze-dried fresh pasta samples of 10 mg were directly weighed into DSC stainless steel pans (PE 0319-0218) and distilled water (3:1, water to sample) was added, according to Marti, Pagani & Seetharman (2011).

After sealing, pans were heated from 25 to 120°C at 10°C/min, using an empty pan as a reference. The heated-cooled pans were then stored at 4°C for 7, 15 and 21 days, heated again in the DSC from 25 to 120°C at 10°C/min. Measurements were performed in triplicate. The recorded parameters were: onset temperature (T_0), peak temperature (T_p), and conclusion temperature (T_c) of gelatinization and retrogradation. Straight lines were drawn between T_0 and T_c and the enthalpy associated with starch gelatinization (ΔH_g) and retrogradation (ΔH_r) was calculated as the area enclosed by the straight line and endotherm curve. It was expressed in J per g of starch.

2.2.2. Pasting properties

The pasting properties of raw materials, dry and fresh pasta samples were determined using a Rapid Visco Analyser (RVA, Perten 4500). The analysis was performed based on the AACC approved method 76-21.01 (AACC, 2000). Previously, fresh pasta was dried in aluminum pans in an oven at 40ºC overnight. Later, dried pasta was ground and sieved before the analysis. Samples were prepared by mixing 3.5 g of the flour/ground samples with 25 mL of distilled water. Samples were then held at 50°C for 1 min, heated to 95°C for 3.42 min, held at 95°C for 2.7 min, cooled to 50°C in 3.88 min, and held at 50°C for 2 min. Parameters (Pasting temperature, peak viscosity, trough viscosity, breakdown, final viscosity and setback were determined in triplicate).

2.2.3. Texture analysis

The texture parameters (firmness and stickiness) were determined for dry and fresh pasta using the Texturometer TA.XT.plus Texture analyser (Stable Micro Systems, Godalming, Surrey, Gu 71YL, England) according to method 16.50 (AACC, 2000). 25 g of pasta were cooked in 250 mL of distilled water for their previously determined optimum cooking times (Tazrart, Zaidi, Lamacchia & Haros, 2016; Tazrart, Lamacchia, Zaidi & Haros, 2016), drained, washed with approximately 50 mL distilled water, maintained for 1 min in 300 mL cold water, and then left to rest for approximately 15 min as described by Ormenese & Chang (2002). The Light Knife Blade (A/LKB) probe was used to determine firmness. The fixed parameters were a pre-test speed (10 mm/s), test speed (1 mm/s), post-test speed (10 mm/s), trigger force (2g) and distance (8 mm in the case of dry pasta and 7.5 mm in the case of fresh pasta). Firmness was calculated as the maximum force peak obtained. A cylinder probe of ½" diameter (P/0.5) was used to determine stickiness. The fixed parameters for both dry and fresh pasta were a pre-test speed (10 mm/s), test speed (1 mm/s), post-test speed (10 mm/s), compression force (100g), hold time (2s), trigger force (2g) and maximum tracking speed (5 mm/s). Stickiness was calculated as the maximum peak force to separate the probe from the sample's surface upon probe retraction.

At least 7 readings were made for both the texture parameters evaluated.

2.2.4. Sensory Evaluation

Preliminary sensory evaluation was carried out with 22 consumers. Pasta samples of each formulation were separately evaluated. Codes were assigned to samples to insure an objective judgment. Pasta was first cooked to the optimum cooking time, then, submitted to tasters immediately after cooking. For the estimation of general acceptability, a rating scale from 1 to 5 as one: extremely dislike, two: dislike, three: neither like nor dislike, four: like, five: extremely like, was used (Chen, Resurreccion & Paguio, 1996).

2.3. Statistical analysis

Multiple sample comparison of the means (ANOVA) and Fisher's least significant differences (LSD) were applied to establish statistical significant differences between samples. All statistical analyses were carried out with the software Statgraphics Plus 7.1 (Bitstream, Cambridge, MN) and differences were considered significant at $p<0.05$.

3. Results and discussion

3.1. Thermal properties of raw materials, dry and fresh pasta samples

3.1.1. Gelatinization

The thermal properties of raw materials and different pasta formulations are shown in Tables 1-3. Two endotherms were observed, the first is related to the gelatinization of starch and the second peak (which occurs at 90-95°C) is associated to the dissociation of the amylose-lipid complex (Putseys, Lambert & Delcour, 2010) (Table 3). Gelatinization of starch is the loss of double helical crystalline structure of the external chains of amylopectin (Chavan, Shahidi, Hoover & Perera, 1999). Significant differences ($p<0.05$) were recorded in T_0 and T_p between semolina 1, semolina 2 and broad bean flour, whereas, T_c showed differences only between durum wheat semolinas and broad bean flour. ΔH_g remained almost constant among raw materials.

Broad bean flour showed the highest T_0 and T_p (58.2°C and 64.4°C respectively). High T_p indicate more perfect crystals or a higher co-operative unit, that is, longer chains in the crystal or larger crystal size (Hoover & Ratnayak, 2002). Gelatinization temperature is negatively correlated with the amount of amylopectin short branch chains and positively correlated with amylopectin long branch chains. The gelatinization enthalpy (ΔH_g) is slightly lower in semolina compared to broad bean flour. It is related to the characteristics of starch granule such as the degree of crystallinity and the granule size (Bogracheva, Mears & Hedley, 2006).

The ΔH_g tended to be higher in semolina than in dry pasta (from 7.1 J/g of starch to 4.1-6.2 J/g of starch), although these differences are not statistically significant with the exception of the formulation with 50% of faba beans. A partial melting of starch during drying at 55°C is conceivable because the effective T_o is at 53.4±0.2ºC for semolina 1. This is in agreement with the results reported by Petitot, Brossard, Barron, Larré, Morel et al. (2010). Dried pasta presented low ΔH_g because of the presence of partially gelatinized starch granules, which require less energy to melt (Biliaderis, 1992; Zweifel, Conde-Petit, & Escher, 2000).

Gelatinization temperatures are influenced by the molecular architecture of the crystalline region corresponding to the distribution of amylopectin short chains in these samples. In dry pasta, T_0, T_p and T_c were slightly higher in enriched samples compared to the control, whereas, ΔH_g decreased proportionally with the substitution level (from 6.2 J/g of starch in the control, to 5.7, 4.9 and 4.1 J/g of starch in 10, 30 and 50% bean-enriched pasta respectively). The differences in T_p may be attributed to the differences in amylose content, brain-chain length of amylopectin (Singh, Singh, Kaur, Sodhi & Gill, 2003), lipid-complexed amylose chains (Hoover & Ratnayak, 2002) and crystalline to amorphous ratio in granule architecture (Tester & Morrison, 1990).

Kaur, Sandhu & Lim (2010) reported that the internal arrangement of starch granules may result in differences in the gelatinization temperature and the difference in crystallinity degree might result in the variation in gelatinization enthalpy. Our results agree with those reported by Gimenèz, Gonzalez, Wagner, Torres, Lobo et al. (2013) who stated that, in corn-broad bean spaghetti, the areas corresponding to the native structure of starch are greater than in the control. They attributed this to the fact that an important portion of native starch in leguminous flours is encapsulated by cell walls that make its hydration and later gelatinization difficult (Granito, Torres & Guerra, 2003). Aravind, Sissons, Egan & Fellows (2012) found that the incorporation of pollard to pasta leads to an increase in all the DSC parameters (T_0, T_p and T_c). This is in accordance with our results.

ΔH_g have been related to the degree of crystallinity in starch granules (Bogracheva et al., 2006). As crystallinity is mainly a property of amylopectin molecule, a starch with high amylopectin content would be expected to have a high gelatinization enthalpy. The increase of ΔH_g is also associated to the variation in chain-length distribution of amylopectin because more energy is needed to dissociate longer chains (Klein, Pinto, Vanier, Zavareze Eda, Colussi et al., 2013). On the other hand, the gelatinization characteristics do not only depend on the starch source and chemical structure, it is also influenced by the environmental conditions such as non-ionic compounds/electrolytes, annealing, heat-moisture treatment as well as hydrophilic hydrocolloids, among other factors (Liu, 2005). The samples supplemented with faba bean presented significantly in a higher concentration of dietary fibre, minerals and proteins (Tazrart, Zaidi, Lamacchia & Haros, 2016) which affect water distribution and its availability. The limited amounts of water produces a decrease of gelatinization enthalphy (Tester & Morrison, 1990). This fact is independent of the gelatinization value of the raw materials, which were analyzed in an excess of water without the treatment of pasta (Tazrat, Zaidi, Lamacchia & Haros, 2016).

Cicatellis thermograms didn't show any gelatinization peak. This is probably due to the fact that the starch of these samples is already gelatinized owing to the pasteurization treatment applied during pasta making process which was performed at around 70°C (temperature usually allowing the starch to gelatinize) (Tazrart, Lamacchia, Zaidi & Haros, 2016).

3.1.2. Retrogradation

The DSC was run for one and two weeks but no clear retrogradation peaks could be observed. Upon refrigeration for 21 days, the amylopectin components begin to re-organize causing recrystallisation of the chains (Table 2). Retrogradation involves rapid crystallization of amylose and slow recrystallisation of amylopectin (Biliaderis, 1992).

Semolina 1, semolina 2 and broad bean flour showed significant differences in T_0, T_p, T_c and ΔH_r ($p<0.05$). Higher T_p and ΔH_r were recorded for broad bean flour. Retrogradation is highly correlated with starch sources (Qazi, Rakshit & Tran, 2011). The decrease in ΔH_r for semolina may be attributed to the damage of starch or starch granule size. Broad bean flour addition didn't have a significant impact on the retrogradation temperature of both dry and fresh pasta samples. ΔH_r was inversely correlated with the broad bean flour addition level both in *Maccheronccinis* and *Cicatellis*. Hence, traditional dry and fresh pasta showed significantly the highest ΔH_r values (0.62 and 0.77 J/g of starch in control dry and fresh pasta respectively). The decrease in ΔH_r of enriched samples may be attributed to the presence of non-starch polysaccharides from bean flour that may impede the formation of three dimensional starch network, preventing hydrogen bonds between amylose and amylopectin from forming during retrogradation (Yoshimura, Takaya & Nishinari, 1996).

In the same tendency, Li, Zhang, Zhu, Peng & Zhang (2012) reported that green tea powder addition significantly reduced the retrogradation ratio of pasta samples. On the other hand, Wu, Meng, Yang, Tao & Xu (2015) reported an opposite behaviour for mung bean enriched pasta, where rising mung bean starch concentration resulted in an increase of ΔH_r.

3.1.3. Amylose-lipid complex

The interaction between starch and lipids is a well-known phenomenon in the food industry. It is involved in the bread shelf-life increase and the pasta stickiness decrease (Eliasson, 1994). For the same amylose or the same starch, the properties of the complex depend on the lipid. Raw materials showed no significant differences in T_0 and T_p and a slight difference in T_c and ΔH, with the highest enthalpy recorded in semolina 1 (Table 3). Dried pasta samples showed differences between the control and broad bean enriched pasta in T_0, T_p and ΔH, whereas the final temperature remained almost constant in all the formulations. Among the dry pasta samples, 10% enriched pasta showed the highest T_0, T_p and T_c and the transition enthalpy tended to increase proportionally with the substitution level. Among fresh pasta samples, traditional *Cicatellis* showed higher values for T_0, T_p and T_c compared to enriched samples. 10 and 50% enriched fresh pasta showed the highest enthalpies.

The results of melting temperatures and enthalpy values of the second symmetrical endotherm of reversible dissociation of the amylose-lipid complexes are in agreement with studies on semolina or pasta (Zweifel, Conde-Petit, & Escher, 2000). Amylose-lipid complex transition at a low melting temperature found was assumed to be formed when rapid nucleation and was morphologically described by a random distribution of the basic structural element occurs (Tufvesson, Wahlgren & Eliasson, 2003). On the other hand, the enthalpies were higher comparing in absence of cooking, but during the extrusion or drying there is localized heating that would promote the formation of the complex before cooking and increase the enthalpies values. The amount of lipids not seem to have an effect on the differences observed between samples because they are almost constant between formulations. The lipid content in dry pasta was between 1.89±0.01 and 2.02±0.04 g/100 g d.m., and in fresh pasta between 1.44±0.17 and 1.48±0.03 g/100 g d.m. Besides, although pasta contains an appreciable amount of protein, transformation of the protein fraction during heating involves only a small enthalpy change that are not measurable as phase transition as it was reported by other researchers (Zweifel, Conde-Petit, & Escher, 2000).

3.2. Pasting properties of raw materials, dry and fresh pasta samples

Rapid Visco Analyser (RVA) is an effective instrument for measuring pasting properties of starch (Blazek & Copeland, 2008). The pasting properties of dry and fresh pasta are summarised in Table 4. The formulations of dry pasta didn't show significant differences in pasting temperatures between them. The same tendency was observed for fresh pasta formulations. On the other hand, there was a significant difference ($p<0.05$) between the two types of pasta and the highest values were found in *Cicatellis*. This indicates that starch in fresh pasta has a higher resistance to swelling and rupture.

Breakdown is caused by structural disruption of gelatinized starches at high temperature and is affected by the amylose content and fine structure of amylopectin (Yuan, Lu, Cheng & Li, 2008). *Maccheronccinis* formulations showed significant differences in breakdown viscosity ($p<0.05$) that tend to decrease as the amount of added bean flour increase (597 cP in the control against 470, 415 and 305 cP in 10, 30 and 50% enriched pasta, respectively). This indicates that control *Maccheronccinis'* starch is more susceptible to shear (Hughes, Hoover, Liu, Donner, Chibbar et al., 2009).

The peak viscosity provides a measure of the thickening power of starch, which indicates the ability of the granule to swell freely before physical breakdown (Kaur, Fazilah & Karim, 2011). Setbacks reveal the increased viscosity of gelatinized samples during cooling and results from the association among leached amylose chains during swelling (Wu et al., 2015). The higher peak viscosity indicates larger water binding capacity of the starches in dry pasta blends. Control pasta showed the highest peak viscosity. This is related to the lower amylose content of durum wheat starch compared to broad bean starch. Li, Tian, Liu, Wang, Wu et al. (2015) also reported lower peak viscosity and breakdown values for green tea enriched noodles. *Maccheronccinis* had significantly ($p<0.05$) higher peak, trough, final viscosities and setback than *Cicatellis*.

The final viscosity and setback values provide a measure of amylose retrogradation tendency. The higher final viscosity and setbacks of starches suggests their higher tendency towards retrogradation. Final viscosity is higher in exclusively semolina 1 made *Maccheronccinis,* which shows that traditional dry pasta starch pastes have more ability to retrograde and form a strong gel after cooling. In the same trend, Wood (2009) reported that 10 and 15% chickpea-fortified spaghetti had lower final viscosities than control spaghetti but 25 and 30% substitution levels induced higher peak viscosities with lower final viscosities and setbacks.

3.3. Texture

Firmness corresponds to the force required to compress a pasta strand between molar teeth. Resilience (Stickiness) assesses the ability of the pasta strand to regain its original shape after the first compression (Epstein, Morris & Huber, 2002). Increasing the amount of broad bean flour in dry and fresh pasta samples had an effect on enriched pasta stickiness (Table 5). In *Maccheronccinis*, only 30 and 50% enriched pasta were significantly different compared to traditional pasta in stickiness and in *Cicatellis* only 50% enriched pasta was significantly different from the control pasta. Our results disagree with those reported by Wood (2009) who reported lower stickiness in chickpea fortified spaghetti. This may be attributed to the variations among legume species. Petitot et al. (2010) found that legume addition had a moderate impact on pasta stickiness, which is similar to our results. The higher stickiness in enriched pasta is probably related to the higher dietary fibre presence from broad bean flour, which caused the formation of discontinuities and cracks inside the pasta and weakened its structure (Petitot et al., 2010; Wood, 2009).

Cicatellis showed generally higher stickiness than *Maccheronccinis* as illustrated in Table 5, firmness decrease as the substitution level increase both in dry and fresh pasta samples. Enriched samples showed significant differences between them and compared to the controls. Our results don't agree with those reported by (Petitot et al. 2010) who observed higher firmness in legume enriched pasta, but are in accordance with the findings of Granito et al. (2003) and Wojtowicz & Mosciki (2014) who detected lower firmness in common bean and legume fortified pasta respectively. Broad bean flour contains no gluten and its addition to durum wheat semolina diluted and weakened the gluten matrix, which leaded to decreased pasta firmness. In the same trend, Sissons, Egan & Gianibelli (2005) showed that gluten content increased spaghettis firmness. Moreover, it is noticed that a correlation exists between retrogradation of starch in pasta and firmness. In fact, pastas having a lower rate of retrogradation exhibited less firmness.

3.4. Sensory evaluation

Statistical analysis revealed that overall evaluation is different between traditional and enriched dry or fresh pasta (from 3.2-3.6 for control samples to 2.2-2.4 for enriched pasta, $p<0.05$). The degree of perception of the different attributes does not depend in any case on the concentration of broad bean flour in the pasta formulation (data not shown).

4. Conclusions

Changes in gelatinization properties directly affect the cooking quality, as higher Tp and lower ΔH values for enriched pasta mean longer cooking time and lower energy assumption respectively. In pasta products, starch retrogradation is often associated with an increase in firmness and springiness after cooking, which could positively affect the quality of extruded products. Enriched pastas showed higher stickiness and a lower rate of retrogradation, which resulted in a reduced firmness compared to the controls, notably related to the dilution and weakening of the gluten matrix. Producing pasta substituted with high levels of legume flour was technologically possible and the obtained products showed adequate texture and sensory quality.

Acknowledgements

This work was financially supported by the Project PROMETEO/2017/189 from the Generalitat Valenciana, Spain. The internship grant of Karima Tazrart from University Abderrahmane Mira Bejaia, Algeria is gratefully acknowledged.

References

AACC. (1999). General Pasting Method for Wheat or Rye Flour or Starch Using Rapid Visco Analyzer. *In International Approved Methods of Analysis* (11th eds.), method 76-21.01; AACC International: St Paul, MN, USA.

Aravind, N., Sissons, M., Egan, N., & Fellows, C. (2012). Effects of insoluble dietary fibre addition on technological, sensory, and structural properties of durum wheat spaghetti. *Food Chemistry,* 130, 299-309.

Azasa, M.S., Wassim, K., Mensi, F., Abdelmouleh, A., Brini, B., Kraïem, M.M. (2009). Evaluation of faba beans (*Vicia faba L. var. minuta*) as a replacement for soybean meal in practical diets of juvenile Nile tilapia *Oreochromis miloticus*. *Aquaculture.* 287, 174-179.

Biliaderis C.G. (1992). Structures and phase transitions of starch in food systems. *Food Technology,* 46(6), 98-101.

Blazek, J., & Copeland, L. (2008). Pasting and swelling properties of wheat flour and starch in relation to amylose content. *Carbohydrate Polymers,* 71, 380-387.

Bogracheva, Y.Y., Mears, C., & Hedley, C.L. (2006). The effect of heating on the thermodynamic characteristics of potato starch. *Carbohydrate Polymers,* 63, 323-330.

Bustos, M.C., Perez, G.T., & Leon, A.E. (2011). Sensory and nutritional attributes of fibre-enriched pasta. *LWT-Food Science and Technology*, 44, 1429-1434.

Chavan, U.D., Shahidi, F., Hoover, R., & Perera, C. (1999). Characterisation of beach pea (*Lathyrus maritimus L.*) starch. *Food Chemistry,* 65, 61-70.

Chen, A.W., Resurreccion, A.V.A., Paguio, L.P. (1996). Age appropriate hedonic scales to measure food preferences of young children. *Journal of Sensory Studies*, 11, 141-163.

Colonna, P., Barry, J. L., Cloarec, D., Bornet, F., Gouilloud, S., & Galmiche, J. P. (1990). Enzymic susceptibility of starch from pasta. *Journal of Cereal Science,* 11, 59-70.

D'Egidio, M. G., Mariani, B. M., Nardi, S., Novaro, P., & Cubadda, R. (1990). Chemical and technological variables and their relationships: a predictive equation for pasta cooking quality. *Cereal Chemistry,* 67, 275-281.

Eliasson, A.C. (1994). Interactions between starch and lipids studied by DSC. *Thermochimica Acta,* 246, 343-356.

Epstein, J., Morris, C.F., & Huber, K.C. (2002). Instrumental texture of white salted noodles prepared from recombinant inbred lines of wheat differing in the three granule bound starch synthase (waxy) genes. *Journal of Cereal Science,* 35(1), 51-63.

Feillet, P., & Dexter, J. E. (1996). Quality requirements of durum wheat for semolina milling and pasta production. In J. E. Kruger, R. R. Matsuo, & J.W. Dick (Eds.), Pasta and noodle technology (pp.95-131). St. Paul: *The American Association of Cereal Chemists*.

Giménez, M.A., Gonzalez, R.J., Wagner, J., Torres, R., Lobo, M.O., & Samman, N.C. (2013). Effect of extrusión conditions on physicochemical and sensorial properties of corn-broad beans (*Vicia faba*) spaghetti type pasta. *Food Chemistry*, 136, 538-545.

Granito, M., Torres, H., & Guerra, M. (2003). Development and evaluation of wheat, corn, cassava and beans pasta. *Interciencia*, 28 (7), 372-378.

Hoover, R., & Ratnayak, W.S. (2002). Starch characteristics of black bean, chickpea, lentil, navy bean and pinto bean cultivars grown in Canada. *Food Chemistry*, 78, 489-498.

Hughes, T., Hoover, R., Liu, Q., Donner, E., Chibbar, R., & Jaiswal, S. (2009). Composition, morphology, molecular structure and physicochemical properties of starches from newly released chickpea (*Cicer arietinum L.*) cultivars grown in Canada. *Food Research International*, 42, 627-635.

Kaur, B., Fazilah, A., & Karim, A. A. (2011). Alcoholic-alkaline treatment of sago starch and its effect on physicochemical properties. *Food and Bioproducts Processing*, 89, 463-471.

Kaur, M., Sandhu, K. S., & Lim, S. T. (2010). Microstructure, physicochemical properties and in vitro digestibility of starches from different Indian lentil (*Lens culinaris*) cultivars. *Carbohydrate Polymers*, *79*, 349-355.

Klein, B., Pinto, V. Z., Vanier, N. L., Zavareze Eda, R., Colussi, R., do Evangelho, J. A., Gutkoski, L. C., & Dias, A. R. (2013). Effect of single and dual heat-moisture treatments on properties of rice, cassava, and pinhao starches. *Carbohydrate Polymers*, *98*, 1578-1584.

Li, M., Zhang, J.H., Zhu, K.X., Peng, W., Zhang, S.K., Wang, B., Zhu, Y.J., & Zhou, H.M. (2012). Effects of superfine green tea powder on the thermodynamic, rheological and fresh noodle making properties of wheat flour. *LWT- Food Science and Technology*, 46, 23-28.

Li, W., Tian, X., Liu, L., Wang, P., Wu, G., Zheng, J. Ouyang, S., Luo, Q., & Zhang, G. (2015). High pressure induced gelatinization of red adzuki bean starch and its effects on starch physicochemical and structural properties. *Food Hydrocolloids*, 45, 132-139.

Liu, Q. Understanding starches and their role in foods. In: Food carbohydrates: Chemistry, Physical Properties, and Applications, Ed. Steve W. Cui. CRC Taylor & Francis, pp. 309-356.

Maningat, C.C., & Seib, P.A. (1997). Update on wheat starch and its uses (261-284). In Proc. Int. Wheat Quality Conf. J.L. Steele and O.K. Chung (eds). Grain Industry Alliance: Manhattan, KS.

Marti, A., Pagani, M.A., & Seetharman, K. (2011). Understanding starch organisation in gluten free pasta from rice flours. *Carbohydrate Polymers,* 84, 1069-1074.

Ormenese, R. C. S. C., & Chang, Y. K. (2002). Macarrão de arroz: características de cozimento e textura e comparação com o macarrão convencional e aceitação pelo consumidor. *Brazilian Journal of Food Technology,* 6(1), 91-97.

Petitot, M., Boyer, L., Minier, C. H., & Micard, V. (2010). Fortification of pasta with split pea and faba bean flours: Pasta processing and quality evaluation. *Food Research International*, 43, 634-641.

Putseys, J., Lambert, L., & Delcour, J. (2010). Amylose-inclusion complexes: Formation and identity. *Journal of Cereal Science,* 51 (3), 238-247.

Qazi, I. M., Rakshit, S. K., Tran, T. (2011). Effect of physico-chemical properties of tropical starches and hydrocolloids on rice gels texture and noodles water retention ability. *Starch-Stärke*, *63*, 558-569.

Singh, N., Singh, J., Kaur, L., Sodhi, N.S., & Gill, B.S. (2003). Morphological, thermal and rheological properties of starches from different botanical sources. *Food Chemistry,* 81, 219-231.

Singh, S., Raina, C. S., Bawa, A. S., & Saxena, D. C. (2004). Sweet potato-based pasta product: optimization of ingredient levels using response surface methodology. International *Journal of Food Science and Technology,* 39, 191-200.

Sissons, M.J., Egan, N.E., & Gianibelli, M.C. (2005). New insights into the role of gluten on durum pasta quality using reconstitution method. *Cereal Chemistry,* 82, 601-608.

Sozer, N., Dalgıç, A.C., & Kaya, A. (2007). Thermal, textural and cooking properties of spaghetti enriched with resistant starch. *Journal of Food Engineering,* 81, 476-484.

Tazrart, K., Lamacchia, C., Zaidi, F., & Haros, M. (2016). Nutrient composition and *in vitro* digestibility of fresh pasta enriched with *Vicia faba. Journal of Food Composition and Analysis,* 47, 8-15.

Tazrart, K., Zaidi, F., Lamacchia, C., & Haros, M. (2016). Effect of durum wheat semolina substitution with broad bean flour (*Vicia faba*) on the *Maccheronccini* pasta quality. *European Food Research and Technology,* 242, 477-485.

Tester, R.F., & Morrison, W.R. (1990). Swelling and gelatinization of cereal starches 1. Effects of amylopectin, amylose and lipids. *Cereal Chemistry,* 67, 551-559.

Wojtowicz, A., & Mosciki, L. (2014). Influence of legume type and addition level on quality characteristics, texture and microstructure of enriched pre-cooked pasta. *LWT- Food Science and Technology,* 59, 1175-1185.

Wood, J. A. (2009). Texture, processing and organoleptic properties of chickpea fortified spaghetti with insights to the underlying of mechanism of traditional durum pasta quality. *Journal of Cereal Science,* 49, 128-133.

Wu, F., Meng, Y., Yang, N., Tao, H., & Xu, X. (2015). Effects of mung bean starch on quality of rice noodles made by direct dry flour extrusion, *LWT - Food Science and Technology,* 63, 1199-1205.

Yoshimura, M., Takaya, T., & Nishinari, K. (1996). Effects of konjac-glucomannan on the gelatinization and retrogradation of corn starch as determined by rheology and differential scanning calorimetry. *Journal of Agricultural and Food Chemistry*, 44, 2970-2976.

Yuan, M. L., Lu, Z. H., Cheng, Y. Q., & Li, L. T. (2008). Effect of spontaneous fermentation on the physical properties of corn starch and rheological characteristics of corn starch noodle. *Journal of Food Engineering*, 85, 12-17.

Zweifel, C. Conde-Petit, B., & Escher, F. (2000). Thermal Modifications of Starch During High-Temperature Drying of Pasta. Cereal Chemistry, 77(5), 645–651

Table 1: Gelatinization parameters of starch of raw materials and dry pasta samples

Samples		T_0 (°C)	T_p (°C)	T_c (°C)	ΔH_g (J/g starch)
Raw materials	Semolina 1	53.4±0.2 ^{b}	59.8±0.5 ^{a}	67.3±0.7 ^{ab}	7.1±1.2 ^{cd}
	Semolina 2	54.9±0.2 ^{d}	61.1±0.1 ^{b}	68.2±0.2 ^{bc}	7.1±0.3 ^{cd}
	Broad bean flour	58.2±0.4 ^{e}	64.4±0.5 ^{c}	71.7±0.6 ^{d}	7.9±0.3 ^{d}
Maccheronccinis **Dry pasta**	Control	52.6±0.3 ^{a}	59.6±0.1 ^{a}	67.04±0.4 ^{a}	6.2±0.4 ^{bc}
	10% bean	54.1±0.4 ^{bc}	59.9±0.4 ^{a}	68.1±0.2 ^{abc}	5.7±0.4^{b}
	30% bean	54.1±0.3 ^{bcd}	61.3±0.2 ^{b}	68.6±0.7 ^{c}	4.9±0.1 ^{ab}
	50% bean	54.8±0.3 ^{cd}	61.4±0.1 ^{b}	68.8±0.1 ^{c}	4.1±0.1 ^{a}
Cicatellis **Fresh pasta**	Control	n.d.	n.d.	n.d.	n.d.
	10% bean	n.d.	n.d.	n.d.	n.d.
	30% bean	n.d.	n.d.	n.d.	n.d.
	50% bean	n.d.	n.d.	n.d.	n.d.

Results are given as the mean of triplicate determinations. ^{a,d} Means in the same column followed by different superscript letters differ significantly ($p<0.05$). ($T_{0,}$ onset gelatinization temperature; $T_{p,}$ peak gelatinization temperature; $T_{c,}$ conclusion gelatinization temperature; ΔH_g, enthalpy change of gelatinization).

n.d. no detected

Table 2: Retrogradation parameters of starch of raw materials, dry and fresh pasta samples

Samples		***T₀*** **(°C)**	***Tₚ*** **(°C)**	***T꜀*** **(°C)**	**ΔHᵣ (J/g starch)**
Raw materials	Semolina 1	48.1±0.2 ^{d}	51.8±0.1 ^{ab}	56.1±0.5 ^{ab}	0.12±0.01 ^{b}
	Semolina 2	50.20±0.05 ^{e}	52.3±0.1 ^{bc}	57.1±0.1 ^{bc}	0.070±0.007 ^{a}
	Broad bean	46.2±0.1 ^{bc}	56.8±0.1 ^{f}	64.5±0.1 ^{f}	4.2±0.1 ^{i}
Maccheronccinis **Dry pasta**	Control	47.1±0.1 ^{cd}	50.3±0.1 ^{a}	54.3±0.1 ^{a}	0.620±0.004 ^{g}
	10% bean	42.6±0.7 ^{a}	52.5±0.2 ^{bc}	61.4±1.5 ^{de}	0.45±0.04 ^{f}
	30% bean	45.4±0.3 ^{b}	53.6±0.3 ^{cd}	60.6±1.2 ^{d}	0.24±0.03 ^{d}
	50% bean	50.10±0.09 ^{e}	51.7±1.4 ^{ab}	60.1±0.1 ^{d}	0.14±0.04 ^{b}
Cicatellis **Fresh pasta**	Control	48.4±0.1 ^{d}	54.3±0.0 ^{de}	59.6±0.2 ^{d}	0.77±0.05 ^{h}
	10% bean	45.5±0.5 ^{b}	55.1±0.2 ^{de}	63.3±1.5 ^{ef}	0.510±0.008 ^{b}
	30% bean	41.1±1.2 ^{a}	54.5±0.8 ^{de}	67.4±0.2 ^{g}	0.36±0.09 ^{e}
	50% bean	50.5±0.8 ^{e}	55.8±0.8 ^{ef}	59.1±0.2 ^{cd}	0.200±0.005 ^{c}

Results are given as the mean of triplicate determinations. ^{a,i} Means in the same column followed by different superscript letters differ significantly ($p<0.05$). ($T_{0,}$ onset gelatinization temperature; $T_{p,}$ peak gelatinization temperature; $T_{c,}$ conclusion gelatinization temperature; ΔH_r, enthalpy change of retrogradation).

Table 3: Amylose-lipid complex transition parameters of raw materials, dry and fresh pasta samples

Samples		***T₀*** **(°C)**	***T_p*** **(°C)**	***T_c*** **(°C)**	**ΔH (J/g starch)**
Raw Materials	Semolina 1	85.8±0.1 ^{cd}	91.8±1.1 ^{b}	96.3±0.5 ^{a}	1.7±0.2 ^{ef}
	Semolina 2	85.8±0.7 ^{cd}	93.01±0.18 ^{bc}	102.0±0.1 ^{ef}	1.23±0.07 ^{bc}
	Broad bean	85.2±0.08 ^{bcd}	92.02±0.16 ^{b}	97.3±0.4 ^{ab}	1.38±0.04 ^{bcdef}
Maccheronccinis **Dry pasta**	Control	92.7±0.2 ^{e}	94.20±0.09 ^{cd}	99.3±0.1 ^{cd}	0.50±0.01 ^{a}
	10% bean	92.9±0.8 ^{e}	95.6±0.1 ^{de}	101.4±1.5 ^{ef}	1.1±0.1 ^{b}
	30% bean	84.6±0.8 ^{abc}	92.0±0.1 ^{b}	100.6±0.5 ^{def}	1.7±0.1 ^{def}
	50% bean	83.4±0.5 ^{a}	92.5±0.3 ^{b}	100.3±0.6 ^{de}	1.8±0.1 ^{f}
Cicatellis **Fresh pasta**	Control	86.3±0.3 ^{d}	96.0±0.1 ^{e}	102.3±0.49 ^{f}	1.34±0.04 ^{bcde}
	10% bean	84.0±0.3 ^{ab}	94.3±0.8 ^{de}	102.0±0.3 ^{ef}	1.64±0.05 ^{def}
	30% bean	83.3±0.3 ^{a}	90.1±0.5 ^{a}	98.3±0.4 ^{bc}	1.31±0.06 ^{bcd}
	50% bean	83.2±0.4 ^{a}	89.7±0.5 ^{a}	96.5±0.1 ^{ab}	1.57±0.12 ^{cdef}

Results are given as the mean of triplicate determinations. ^{a,f} Means in the same column followed by different superscript letters differ significantly ($p<0.05$). (T_{0}, onset gelatinization temperature; T_{p}, peak gelatinization temperature; T_{c}, conclusion gelatinization temperature; ΔH, transition enthalpy).

Table 4: Pasting properties of raw materials, dry and fresh pasta samples

Sample		$\boldsymbol{P_{temp}}$ **(°C)**	**PV (cP)**	**BD (cP)**	**FV (cP)**	**SB (cP)**	**Trough (cP)**
Raw materials	Semolina 1	87.20±0.03 ^{cd}	1826±7 ^{i}	152±4 ^{c}	3549±22 ^{j}	1876±10 ^{g}	1674±12 ^{g}
	Semolina 2	87.6±0.6 ^{cde}	1474±5 ^{f}	52.5±0.7 ^{b}	1317±35 ^{b}	1750±28 ^{g}	1422±6 ^{f}
	Broad bean	76.70±0.03 ^{a}	759±10 ^{b}	18±4 ^{a}	1390±4 ^{b}	648.5±0.7 ^{b}	741±5 ^{b}
***Maccheronccinis* Dry pasta**	Control	85.60±0.03 ^{b}	1989.1±1 ^{j}	597±19 ^{g}	2936±1 ^{h}	1544±19 ^{f}	1393±19 ^{f}
	10%bean	85.6±0.2 ^{b}	1685±19 ^{h}	470±14 ^{f}	2732±11 ^{g}	1517±16 ^{f}	1215±5 ^{e}
	30% bean	85.1±0.6 ^{bc}	1559±1 ^{g}	415±11 ^{e}	2613±47 ^{f}	1469±37 ^{f}	1144±9 ^{d}
	50% bean	84.7±0.1 ^{bc}	1371±4 ^{e}	305±4 ^{d}	2315±2 ^{d}	1249±2 ^{e}	1066.0±0.1 ^{c}
***Cicatelli*s Fresh pasta**	Control	89.2±0.5 ^{def}	1222±6 ^{d}	46±3 ^{ab}	2320±4 ^{e}	1144±1 ^{d}	1176±2 ^{de}
	10% bean	89.2±0.5 ^{def}	1026±49 ^{c}	17±7 ^{a}	1975±2 ^{d}	966±45 ^{c}	1009±42 ^{c}
	30% bean	89.7±0.1 ^{f}	738±4 ^{b}	34±4 ^{ab}	1407±13 ^{c}	704±13 ^{b}	704.1±0.1 ^{b}
	50% bean	89.60±0.03 ^{ef}	525±19 ^{a}	26.5±0.7 ^{ab}	970±28 ^{a}	472±11 ^{a}	498±16 ^{a}

Results are given as the mean of triplicate determinations. ^{a,j} Means in the same column followed by different superscript letters differ significantly ($p<0.05$). ($P_{temp,}$ pasting temperature; PV, peak viscosity; TV, trough viscosity; BD, breakdown; FV, final viscosity; SB, setback; cP, centipoises).

Table 5: Stickiness and firmness of dry and fresh pasta samples

Samples		Stickiness (N)	Firmness (N)
	Control	0.0018±0.0006 ^{d}	17.7±0.9 ^{f}
Maccheronccinis	10% bean	0.0027±0.0006 ^{cd}	15.9±0.6 ^{de}
Dry pasta	30% bean	0.0035±0.0007 ^{bc}	12.2±0.5 ^{c}
	50% bean	0.0045±0.0012 ^{ab}	10.2±0.3 ^{b}
	Control	0.0038±0.0001 ^{bc}	17.1±1.1 ^{ef}
Cicatellis	10% bean	0.0045±0.0009 ^{ab}	14.9±0.5 ^{d}
Fresh pasta	30% bean	0.0050±0.0008 ^{ab}	12.5±0.9 ^{c}
	50% bean	0.0060±0.0008^{a}	8.1±0.6 ^{a}

Results are given as the mean of septuplicate determinations. ^{a,f} Means in the same column followed by different superscript letters differ significantly (*p<0.05*).