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Effect of Four Types of Dietary Fiber on the Technological Quality of Pasta

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The development of dietary fiber-enriched foods permits to obtain products with functional properties but can cause several problems in technological quality. The aim of this study was to study the quality of pasta obtained by replacing bread wheat flour with resistant starch II (RSII), resistant starch IV (RSIV), oat bran (OB) and inulin (IN) with the purpose of improving their nutritional quality. RSII, RSIV, OB and IN were substituted for a portion of bread wheat flour at levels 2.5%, 5.0%, 7.5% and 10.0%. Cooking properties, amylose and inulin losses, color and texture were measured. Finally, nutritional quality of enriched pasta was evaluated by protein losses during cooking and total dietary fiber. Microstructure of pasta was analyzed by scanning electron microscopy. Addition of RSII into pasta formulation improved the quality of the final product. RSIV-enriched pasta presented an improvement in textural characteristics and OB affected cooking properties positively up to 5% of substitution. Inulin was lost during cooking; besides, its addition negatively affected the technological quality of pasta. The results obtained in this study prove that it is possible to elaborate pasta with acceptable cooking quality and with improved nutritional characteristics by adding 10% of RSII and RSIV and 5% of OB.

Key Words: pasta, resistant starch, amylase, oat fiber, inulin

INTRODUCTION

The special characteristics and compositional qualities of pasta have placed it in an important position in modern society's daily diets (Sozer et al., 2007): it is easy to cook (Brennan et al., 2004) and store, it is a low glycemic food product (Tudorică et al., 2002), it has low sodium content, it has cholesterol-free fat and it is rich source of complex carbohydrates (Chillo et al., 2008).

Dietary fiber has been identified as an important component of a healthy diet and it is defined as the component of plant cells that resist digestion by human digestion enzymes. Such components include cellulose, hemicellusose, lignin, inulin, resistant starch (RS) and other constituents distributed in the bran and starchy endosperm parts of the grain (Lunn and Buttriss, 2007). Consumption of these components has been associated with the reduced risk of chronic diseases (Liu et al., 1999; Charalampopoulos et al., 2002; Kaur and Gupta, 2002; Topping, 2007; Shahidi, 2009). But particularly, the insoluble fraction of dietary fiber has been associated with reduced risk in diabetes (Meyer et al., 2000) and coronary heart disease (Jenkins et al., 2000).

Resistant starch is defined as that fraction of dietary starch that escapes digestion in the small intestine. It is divided into four fractions: RS1, RS2, RS3 and RS4. These are also called type I, II, III and IV starches (Sajilata et al., 2006). Type II and IV are the ones used like ingredients in the formulation of functional foods. RS type I is resistant because it is in a physically inaccessible form. RS type II is in a certain granular form that is resistant to enzyme digestion. Types I and II represent residues of starch forms, which are digested very slowly and incompletely in the small intestine. Type III RS is the most resistant one and is the mainly retrograded amylose formed during cooling of gelatinized starch. RS type IV is the one where novel chemical bonds other than α-(1-4) or α-(1-6) are formed (Sajilata et al., 2006).

Hull-oat fiber contains β-glucans (~25%), arabinoxylans and Klason lignin (~50%; Manthey et al., 1999); β-glucan is a group of linear polymers of glucose molecules linked by 70% of β-(1-4) and 30% of β-(1-3)-linkages. Lignin is a phenolic compound with a very complex structure; it is relatively hydrophobic and considered an insoluble dietary fiber (Liu, 2007).

Inulin is not simply one molecule; it is a polydisperse β-(2-1) fructan (Phelps, 1965) and classified as soluble dietary fiber (Lunn and Buttriss, 2007). Most of the

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inulin commercially available on the industrial food ingredient market today is either synthesized from sucrose or extracted from chicory roots (Ninness, 1999).

Especially in pasta, it is possible to vary the choice of the ingredients involved in the manufacture to obtain a wide range of pasta products (Fardet et al., 1998). So, it is necessary to evaluate in what way a change in formulation affects cooking properties, since these are important factors that influence consumer acceptance and product quality (Lee et al., 2002).

Formulating pasta with dietary fiber produces modifications that may cause many problems in the quality of the final product; in consequence, more research has to be done to better understand how different fiber additions affect pasta quality, cooking properties and texture.

In order to obtain a good-quality final product with better health promoting properties, the main objective of this study was to study the quality of the pasta formulated with insoluble (RS type II, RS type IV and oat bran) and soluble fiber (inulin).

MATERIALS AND METHODS

Materials

Bread wheat flour without additives was given by Industrias Alimenticias Tiranti S.R.L. (Argentina): moisture content: 12.38 ± 0.07, protein 10.6 ± 0.2, ash 0.54 ± 0.01 and total dietary fiber 5.7 ± 0.4.

RS type II (Hi maize 260, National Starch) and RS type IV (Novelose 480, National Starch), were supplied by Gelfix S.A. (Buenos Aires, Argentina). RSII is high-amylose maize starch (70% of amylose) and RSIV is defined as phosphated distarch phosphate, a cross-linked high-amylose maize starch. Oat bran (Canadian Harvest® Oat Fibers 200/58 series, Sunopta, USA) and inulin (Orafti HP, Beneo-Orafti Latin America, São Paulo, Brazil) were supplied by Saporiti S.A., Argentina.

Pasta Making

Pasta was made using commercial bread wheat flour, water and four types of dietary fiber. Resistant starch type II (RSII) and type IV (RSIV), oat bran (OB) and inulin (IN) were incorporated into recipes by replacing wheat flour in four proportions (w/w): 2.5%, 5.0%, 7.5% and 10.0%, resulting in RSII2.5, RSII5.0, RSII7.5, RSII10.0, RSIV2.5, RSIV5.0, RSIV7.5, RSIV10.0, OB2.5, OB5.0, OB7.5, OB10.0, IN2.5, IN5.0, IN7.5 and IN10.0 samples, respectively. An additional sample with no fiber included was also prepared as a control. Preparation of pasta was established using 50 g of flour, 500 mg of salt (NaCl) and distilled water through trial and error until appearance, sheeting and handling properties were obtained to produce a visually optimum dough prior to lamination. The crumbly dough was sheeted using a laboratory sheeting machine obtaining a sticky 0.90 mm-thick sheet. Then, it was cut into strips approximately 2 mm wide and 15 cm long using cutting rolls. Pasta was then dried at low temperature in two steps: the first one was 30 min at 30 °C without controlling humidity in an air convection drier; the second step was performed at 45 °C in a humidity-controlled (75%) drier for 17.5 h. The samples were wrapped in cling film and stored in airtight containers at room temperature until needed.

Pasta Quality Parameters

Cooking procedure

All cooking tests were performed in duplicate. Pasta (4 g) was broken into pieces of 5 cm and cooked in boiling distilled water (200 mL). Boiling was kept at this level for the entire cooking period.

The Optimum Cooking Time

Optimum cooking time (OCT) was determined as the time when the white inner core of the pasta disappeared after cross-cutting it with a razor blade, according to method 16-50 (AACC, 2000) and/or after compressing the pasta between two glass slides in 30 s intervals. The OCT was determined as 10 min for control sample, 8.5 min for OB2.5 and IN2.5, 8.0 min for RSII2.5, 7.5 min for RSII5.0, RSIV2.5, RSIV5.0, RSIV7.5, RSIV10.0, OB5.0, OB7.5, OB10.0, IN5.0 and IN7.5; and 7.0 min for RSII7.5, RSII10.0 and IN10.0.

After cooking and draining, the samples were analyzed for water absorption, swelling index, color and texture analysis. Cooking water was used for the determination of cooking, amylose and inulin losses.

Water Absorption

Water absorption of drained pasta was determined as Equation (1) (Tudorică et al., 2002).

$$\text{Water absorption}\ (\%) = \frac{W1 - W2}{W2} \times 100 \qquad (1)$$

where $W1$ is the weight of cooked pasta and $W2$ the weight of raw pasta.

Swelling Index

Swelling index of cooked pasta (grams of water per gram of dry pasta) was evaluated by drying cooked pasta samples to constant weight at 105 °C, expressed as Equation (2) (Tudorică et al., 2002).

$$\text{Swelling index} = \frac{W1 - W3}{W3} \qquad (2)$$

where $W1$ is the weight of cooked product and $W3$ the weight after drying.

Cooking Loss

Cooking loss of pasta was determined in water collected from each sample by evaporation to constant weight in an air oven at 105 °C. The residue was weighed and reported as percentage of the raw pasta sample (Tudorică et al., 2002).

Color of Cooked Pasta

Color of cooked pasta was determined with a Minolta 508 d spectrophotometer (Ramsey, NJ). Eight-millimetre measurement apertures, D65 illuminant, 10° angle of observer according to approved methods 14-22 (AACC, 2000), were set. Cooked strands of pasta were laid in parallel to cover an area about 5 cm wide on a black background (~0% reflectance). At least 10 readings were taken from the cooked pasta strand and recorded as CIE-LAB, L^* (lightness), a^* (redness–greenness) and b^* (yellowness–blueness) values.

Cooked Spaghetti Textural Analysis

A texture analyzer (TA-xT2i, Stable Micro Systems, Godalming, UK) equipped with a Windows version of the Texture Expert Software package was used to make texture analyses; the parameters determined were pasta hardness, springiness, cohesiveness and chewiness. For all measurements, TA-XT2i was equipped with a 25 kg load cell and an HDP/PFS pasta firmness-stickiness probe was fixed to the texturometer. All samples were cooked on the day of determination. Before testing the samples, excess water was blotted with an absorbent paper. The probe compressed the samples at a rate of 2.0 mm/s to 70% strain. The probe was retracted and followed by a second compression cycle after 2 s. The variables (hardness, springiness, cohesiveness and chewiness) were recorded through 10 measurements for each sample in three different zones, on two samples prepared on different occasions, totaling 20 measurements. Pasta hardness was defined as the peak force attained during the first compression. Springiness was defined as the rate at which a deformed sample went back to its undeformed condition after the deforming force is removed, calculated as the ratio of distance of the first half of the second peak to the distance of the first half of the first peak. Cohesiveness was defined as the ratio of the area under the second peak to the area under the first peak. Chewiness was defined as the product of hardness, cohesiveness and springiness.

Amylose Content in Cooking Water

Pasta samples (5 g) were cooked in 100 mL of water until OCT. An aliquot of 10 mL was used to determine the percentage of amylose content in cooking water. The amylose leached to cooking water was determined using the Megazyme amylose and amylopectin assay kit (Megazyme International, Ireland) according to the procedure described by Gibson et al. (1997). Results were expressed as grams of amylose lost during cooking of 100 g of pasta.

Inulin Content in Cooking Water

To determine inulin content in cooking water, an anion exchange high-performance liquid chromatography (HPLC) method following extraction of inulin was used according to Zuleta and Sambucetti (2001). The chromatographic equipment consisted of a Waters 6000A pump system, a Waters injector with a 50-íL sample loop, a refractive index detector (Waters R40) and an integrator (Data Module Waters). HPLC conditions were an Aminex HPX-87C (Bio-Rad) anion-exchange column, with deionized water at 85 °C as the mobile phase at a flux rate of 0.6 mL/min.

The inulin content in cooking water was expressed as grams of inulin loss during the cooking of 100 g of pasta.

Scanning Electron Microscopy

The microstructure of transversely fractured cooked pasta was investigated by scanning electron microscopy (SEM; Leo EVO VP, Cambridge, England) of gold-coated (using a Pelco 91000 sputter coater) freeze-dried samples. The micrographs were taken using 3000× magnification.

Nutritional Parameters

Protein Losses

Protein losses were determined as follows: protein content of uncooked pasta (PU) was calculated from wheat flour protein content; this value was used to estimate the protein content of cooked pasta if no protein was leached to cooking water, while the protein content of cooked pasta (PC) was determined by Kjeldahl method and the nitrogen conversion factor used was 5.7. Pasta samples were cooked and dried overnight at 100 °C and then milled prior to analyses. The percentage of protein losses were expressed in dry basis as Equation (3).

$$\text{Protein losses}\,(\%) = \frac{100 \times \text{PU}}{100 - \text{Cooking loss}\,(\%)} - \text{PC} \quad (3)$$

Total Dietary Fiber

Cooked pasta (1 g) was dried at 100 °C overnight and milled for total dietary fiber content determination according to method 32-05 (AACC, 2000). Two replicates from two different sets of lamination were analyzed. Results were expressed as the percentage of total dietary fiber in dry basis.

Statistical Analysis

The results for the different analysis of fiber-enriched pasta were compared by the Di Rienzo, Guzmán and Casanoves means-comparison test (Di Rienzo et al., 2009). This uses multivariate analysis of conglomerates in a matrix obtained from the sample mean. This allowed the samples to be grouped according to descending levels of preference (A, B and C) and with a degree of significance of $p = 0.05$. These analyses were performed using the Infostat Statistical Software (Facultad de Ciencias Agropecuarias, UNC, Argentina).

RESULTS AND DISCUSSION

Pasta Quality Parameters

All fiber-enriched pasta samples showed a decrease in water absorption and swelling index compared to control (Table 1). The inclusion of both types of resistant starches, RSII and RSIV, showed a significantly decrease in water absorption and swelling index, while the concentration of fiber increased. This agrees with the fact that RSs have a lower water-holding capacity than other fibers (Nugent, 2005).

Table 1. Cooking properties of fiber enriched pasta.

Sample[a]	Water absorption (g/100 g pasta)	Swelling index	Cooking losses (g/100 g pasta)
Control	164 a	2.15 a	6.1 f
RSII2.5	150 b	2.03 c	6.2 f
RSII5.0	148 c	1.98 d	5.5 h
RSII7.5	145 c	1.96 d	5.5 h
RSII10.0	136 d	1.85 f	5.3 i
RSIV2.5	152 b	1.96 d	5.8 g
RSIV5.0	144 c	1.91 e	6.0 f
RSIV7.5	139 d	1.86 f	5.9 g
RSIV10.0	138 d	1.86 f	5.7 g
OB2.5	155 b	1.87 f	6.0 f
OB5.0	150 b	1.98 d	5.7 h
OB7.5	151 b	2.05 c	6.3 e
OB10.0	155 b	2.09 b	6.8 d
IN2.5	152 b	1.98 d	6.4 e
IN5.0	156 b	2.04 c	7.2 c
IN7. 5	156 b	2.07 b	7.6 b
IN10.0	156 b	2.08 b	8.0 a

[a]Resistant starch type II enriched pasta (RSII), Resistant Starch type IV enriched pasta (RSIV), Oat bran enriched pasta (OB) and Inulin enriched pasta (IN).
Values are the average of triplicate measurements on the duplicate sample. Values followed by the same letter within a column are not significantly different ($p > 0.05$).

Results for oat bran and inulin showed the highest water absorption and swelling index values (in both cases less than control). Both fibers showed no differences in water absorption while the level of substitution of fiber increased. The swelling index showed a significant increase as both fibers additions increased; this observation agrees with the high water-holding capacity, a characteristic of these fibers (Phelps, 1965; Manthey et al., 1999).

Cooking loss is one of the most important parameters that affect consumer acceptance in this type of products (Sissons et al., 2005; Fu, 2008); so, it is of great use to predict the overall cooking performance of pasta. All fiber-enriched pasta samples showed cooking losses which did not exceed the expected values for durum wheat pasta (lower than 8%; Dick and Youngs, 1988).

Table 1 illustrates that decreased cooking losses were obtained for the samples containing RSII and RSIV (less than the control), while pasta containing IN showed increased cooking loss values compared with control.

RS type II containing pasta showed a progressive and significant reduction in cooking losses with increasing fiber concentration. These results support those already observed by Brennan et al. (1996) and by Tudorică et al. (2002), which suggested a strong interaction among hydrated soluble fiber network and the protein-starch matrix.

Cooking losses for pasta with RS type IV were similar or less than control. In this case, results can be explained in terms of the interactions between the fiber added and the protein–starch matrix. These interactions may not be sufficiently strong, as in the case of RSII, to encapsulate the native starch and thus inhibit the diffusion of solids to cooking water. The differences found between the two types of resistant starches are explained by the fact that RSII (high-amylose maize starch) has a similar structure to native starch (Sajilata et al., 2006), so that it can integrate to pasta structure well and thus contribute to strengthen it. On the other hand, RSIV is a chemically modified cross-linked starch with a very different structure (Woo and Seib, 2002) so, it could not interact so well and many empty spaces may be generated in the protein–starch matrix when the fiber is added into pasta formulation.

Oat bran-enriched pasta had a different performance in cooking losses compared with RSII and RSIV. At 2.5% and 5.0%, the values were similar or significantly lower than control and at 7.5% and 10.0%, the cooking loss increases. One hypothesis that could explain how oat bran affects the cooking properties of pasta is that at low concentrations, the fiber may be dispersed and incorporated into the protein–starch matrix. On the other hand, at higher degrees of substitution, disruptions in the protein matrix by oat bran particle became important and would promote water absorption and facilitate starch granule swelling and rupture. So, inclusion of more than 5.0% of this type of fiber into the structure generates a disruption of protein–starch matrix. These results parallel the data obtained by Manthey et al. (2004) in a study that included wheat bran.

Cooking losses in pasta containing inulin presented an increase compared to control, indicating a disruption of the protein–starch matrix and so a decrease in pasta quality. These results parallel those obtained by Tudorică et al. (2002).

The principal component of cooking losses is amylose (Fortini, 1988). A strong protein–starch matrix in pasta can inhibit the diffusion of amylose to cooking water during cooking time, so that it is an important quality parameter to determine the integrity of protein–starch matrix.

The amylose content in cooking water showed values that ranged from 3.21 g/100 g pasta (for pasta containing RSII at 10%) to 4.91 g/100 g pasta (for pasta containing IN at 10%) with a control sample showing an amylose content of 3.56 g/100 g pasta (Figure 1).

RS type II-enriched pasta showed reduced amylose content in cooking water when more than 2.5% of fiber was added when compared with the control. This agrees with the results obtained in cooking properties and supports the hypothesis that the fiber forms a network around starch granules, encapsulating them during cooking and restricting excessive swelling and diffusion of the amylose content.

Pasta containing RSIV showed changeable amylose content values in cooking water. At 2.5%, it presented lesser values than control. At 5.0% of substitution, the amylose leached to cooking water increased, while with higher levels of substitution, the amylose decreased again. Amylose content in oat bran enriched-pasta cooking water showed the same tendency observed in cooking losses. Pasta with inulin addition presented the highest amylose content in cooking water, which agrees with the high cooking losses observed, but considering that pasta with 10.0% of substitution with inulin presented a cooking loss of 8.0% and the amylose loss was 4.91%, it is clear that the last one is not the major factor in cooking losses.

Inulin is characterized as a soluble fiber, with increasing solubility at increasing temperature (Phelps, 1965). In this regard, it is essential to determine inulin losses during cooking.

Inulin losses during cooking were determined in cooking water and the values obtained were: 3.1% for pasta with 2.5% of IN, 5.7% for pasta with 5.0% of IN, 6.7% for pasta with 7.5% of IN and 10.1% for pasta with 10.0% of IN substitution. These results correlate with observations in cooking and amylose losses and illustrate that all inulin added is leached to cooking water during cooking, thus showing the problems of adding soluble fiber in products cooked in boiling water.

The color of pasta is an important quality factor for consumers. In pasta products made from semolina, the higher the L^* and b^* values, the more desirable the product. Among L^*, b^* and a^* parameters, the first two are considered more important as pasta color attributes (Rayas-Duarte et al., 1996).

Color analysis results are shown in Table 2. Pasta with RSII showed significantly high L^* values compared with control (except for 2.5% of RSII addition) and RSIV presented a significant decrease in L^* compared to control with no significant differences between levels of substitution.

For oat bran enriched pasta, the L^* parameter showed a significant decrease while fiber was incorporated in formulation. Pasta with inulin presented an increased L^* parameter. With respect to b^* parameter,

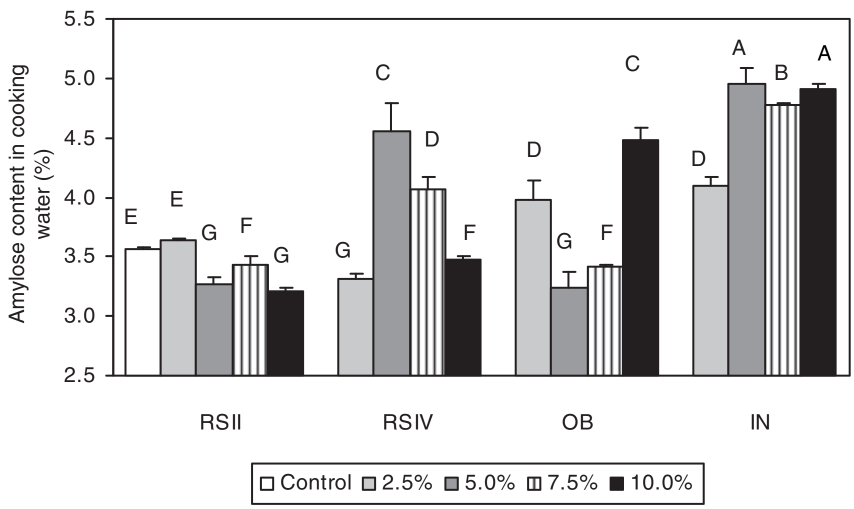

Figure 1. Amylose content in cooking water after cooking fiber enriched pasta. Columns with the same letters are not significantly different ($p < 0.0$).

Table 2. Color parameters of fiber enriched pasta.

Samples[a]	L^*	b^*	a^*
Control	70.4 c	14.0 f	−0.49 f
RSII2.5	71.1 c	14.3 e	−0.55 f
RSII5.0	72.0 a	13.9 f	−0.46 F
RSII7.5	71.8 a	14.3 e	−0.51 f
RSII10.0	71.8 a	13.8 g	−0.25 d
RSIV2.5	70.0 d	14.0 f	−0.12 c
RSIV5.0	70.0 d	13.0 i	−0.24 d
RSIV7. 5	69.9 d	11.5 j	−0.38 e
RSIV10.0	69.7 d	10.8 k	−0.41 e
OB2.5	69.3 e	16.8 d	−0.39 e
OB5.0	68.1 f	18.9 c	−0.11 c
OB7.5	67.4 g	20.4 b	0.05 b
OB10.0	66.5 h	21.8 a	0.37 a
IN2.5	71.1 b	13.6 g	−0.41 e
IN5.0	71.4 a	13.2 h	−0.48 f
IN7.5	71.0 b	13.4 g	−0.52 f
IN10.0	71.3 b	13.1 h	−0.52 f

[a]Resistant starch type II enriched pasta (RSII), Resistant Starch type IV enriched pasta (RSIV), Oat bran enriched pasta (OB) and Inulin enriched pasta (IN).
Values are the average of triplicate measurements on the duplicate sample. Values followed by the same letter within a column are not significantly different ($p > 0.05$).

Table 3. Textural characteristics of fiber enriched pasta.

Samples[a]	Hardness (*N*)	Springiness	Cohesiveness	Chewiness (*N*)
Control	1.39 b	0.88 a	0.68 a	0.83 a
RSII2.5	1.35 c	0.89 a	0.66 a	0.80 a
RSII5.0	1.41 b	0.87 a	0.68 a	0.84 a
RSII7.5	1.34 c	0.89 a	0.69 a	0.82 a
RSII10.0	1.46 a	0.86 b	0.67 a	0.81 a
RSIV2.5	1.41 b	0.84 b	0.66 b	0.68 b
RSIV5.0	1.48 a	0.85 b	0.67 a	0.71 b
RSIV7.5	1.50 a	0.87 a	0.67 a	0.69 b
RSIV10.0	1.50 a	0.85 b	0.65 b	0.71 b
OB2.5	1.32 c	0.87 a	0.66 b	0.68 b
OB5.0	1.34 c	0.85 b	0.64 b	0.69 b
OB7.5	1.22 d	0.85 b	0.64 b	0.66 c
OB10.0	1.22 d	0.82 c	0.61 c	0.62 c
IN2.5	1.06 e	0.87 a	0.68 a	0.63 c
IN5.0	1.08 e	0.87 a	0.69 a	0.64 c
IN7.5	1.24 d	0.85 b	0.69 a	0.66 c
IN10.0	1.22 d	0.82 c	0.68 a	0.69 b

[a]Resistant starch type II enriched pasta (RSII), Resistant Starch type IV enriched pasta (RSIV), Oat bran enriched pasta (OB), and Inulin enriched pasta (IN).
Values are the average of triplicate measurements on the duplicate sample. Values followed by the same letter within a column are not significantly different ($p > 0.05$).

it is remarkable that while RSIV showed a decrease with the addition of fiber (except for 2.5% of RSIV addition) and oat bran presented high values in b^* parameter, which is an important improvement in quality for this type of wheat flour-based products.

These results agree with the fact that RS fibers and inulin are white, so that the L parameter was altered with the fiber substitution. In the other hand, oat bran is yellow; so, the L^* parameter decreases and b^* parameter increases.

Results for a^* parameter showed an increase while oat bran was being added to formulation due to lignin. This is the major component in this fiber; it is aromatic and so more Maillard reactions could occur. Redness also increased.

The textural characteristics of pasta play an essential role in determining the final acceptance by consumers. Results obtained in this study showed that the textural characteristics of the pasta may be affected by the type and rate of fiber inclusion into pasta. Pasta hardness, springiness, cohesiveness and chewiness results are presented in Table 3.

It is remarkable from textural that addition of RSII to the pasta formulation significantly affected hardness.

RS type IV showed the highest values in hardness; no differences were observed between different levels of fiber inclusion (except 2.5%); this agrees with the fact that cross-linking starches are characterized for a low degree of gelatinization and an increase in gelatinization temperature. These observations were related to the mobility of amorphous chains in the starch granule as a result of the intermolecular bridges (Singh et al., 2007).

The addition of oat bran appeared to interfere with the structure of pasta, thus lowering pasta hardness. This interference agrees with the general tendency of pasta to decrease springiness while fiber is being added; considering that springiness is related to the development of protein–starch matrix, the decrease is another evidence of the disruption caused by oat bran inclusion, which agrees with results obtained by Sozer et al. (2007). The same behaviour was observed for cohesiveness and chewiness.

Inulin-enriched pasta showed the lowest values in hardness and chewiness, since all inulin was leached to cooking water generating holes in protein–starch matrix, which explains the decrease in springiness while substitution increases. No differences were observed in cohesiveness.

Scanning Electron Microscopy

In order to evaluate the integrity of protein starch matrix in fiber-enriched pasta, the microstructure of pasta was analyzed by SEM.

SEM techniques were used to investigate the structural integrity of pasta with addition of fiber. Samples with 10% of ARII, ARIV and OB and a control sample were evaluated.

Internal structure of cooked pasta is shown in Figure 2. Control sample presented swollen and

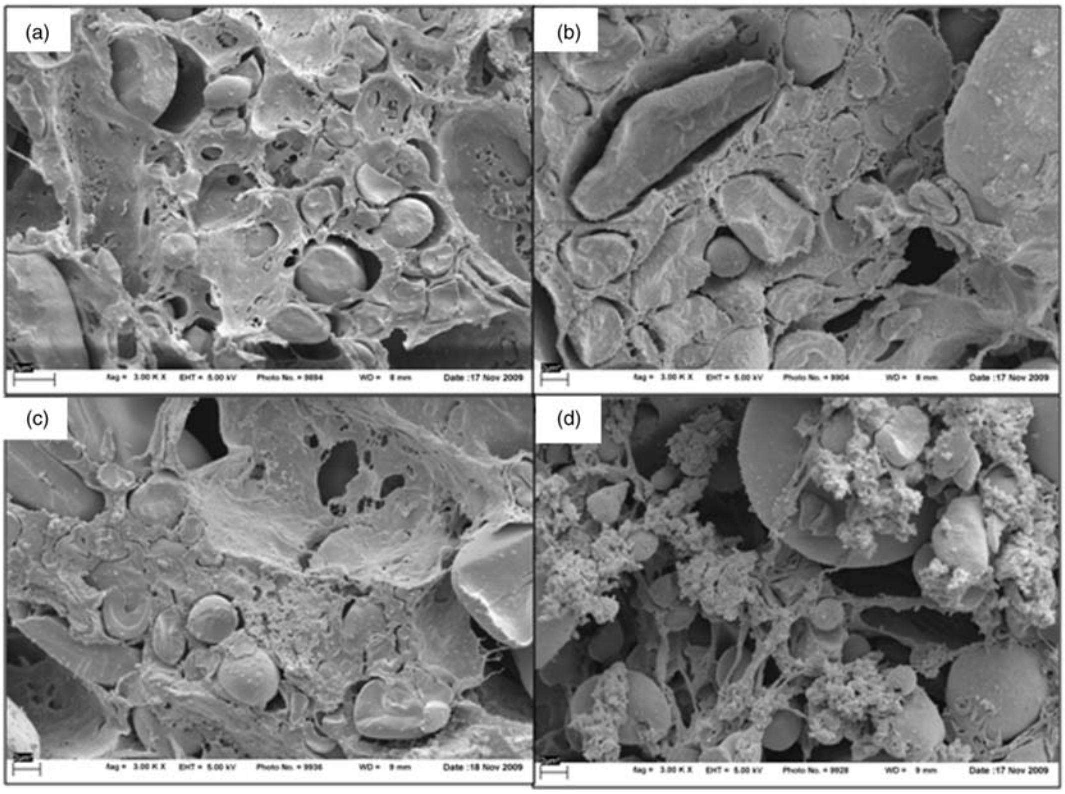

Figure 2. Typical scanning electron microscopy images obtained on the control sample (a) and samples having 10% of RSII, RSIV, and OB (b, c and d, respectively).

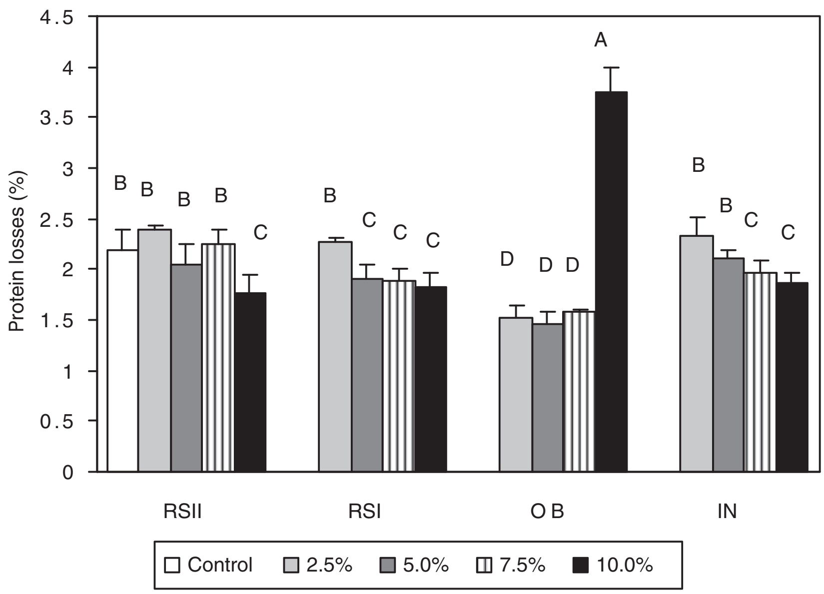

Figure 3. Protein losses of cooked fiber enriched pasta. Control sample presented a protein loss value of 2.19%. Columns with the same letters are not significantly different ($p < 0.05$).

gelatinized starch granules which appear to be integrated in a developed protein matrix to form a compact structure, with a few starch granules no gelatinized (Figure 2a). Pasta with addition of RSII (Figure 2b) presented an internal structure with a further dense protein–polysaccharide–starch matrix compared to control, gelatinized and no gelatinized starch granules were also present.

RSIV-enriched pasta micrographs (Figure 2c) showed a protein matrix similar to control sample, but the degree of gelatinization of starch granules seem to be higher in this enriched pasta.

In contrast to this observation, pasta with OB micrographs (Figure 2d) presented a weaker protein network, starch granules were not completely embedded in that film and OBs appear not to be associated with protein matrix. Many holes were also apparent between protein and starch granules.

These results agrees with results obtained in the cooking properties evaluation for all types of fiber-enriched pasta.

Nutritional Parameters

The evaluation of the nutritional quality of fiber-enriched pasta is important to relate this product with healthy properties. One aspect of nutritional evaluation in products like pasta is to analyze which types of nutrients are lost during cooking; because of this, protein losses were evaluated (Figure 3). RSII-enriched pasta showed protein losses not significantly different from control (except for 10%). This agrees with the idea that RS increases cooking quality of pasta, inhibiting the leaching of solids to cooking water reported by Sozer et al. (2007).

Pasta with RSIV showed a decrease in protein losses with increased levels of substitution. This may be because the RSIV integrates into the structure encapsulating the native starch, which agrees with the results obtained for cooking properties.

Oat bran-enriched pasta showed, at low degrees of substitution (2.5%, 5.0% and 7.5%), lower protein losses during cooking, when compared to control. This may be because this type of fiber generates a semisolid network that inhibits protein losses. At 10% of substitution, protein losses increased dramatically because the fiber added generated an important disruption in the protein network. All these observations agree with the results obtained in the cooking properties evaluation.

Pasta with inulin addition presented a significant decrease in protein losses during cooking at 7.5% and 10.0% because inulin hydrates quickly, making starch and protein fractions of the pasta more discrete and less incorporated into a matrix. During cooking, all inulin is leached to cooking water; the starch is not encapsulated and may form a 'starchy' layer at the surface of the product (Tudorică et al., 2002) that restricts leaching of proteins.

Total dietary fiber contents were determined in RSII, RSIV and OB; inulin enriched pasta was not analyzed because no inulin was present in cooked pasta (Figure 4).

Total dietary fiber values (g/100 g pasta) ranged from 6.4% (for 2.5% of substitution with RSIV) to 14.3% (for 10% of substitution with OB), with a control sample showing a value of 5.1% of total dietary fiber.

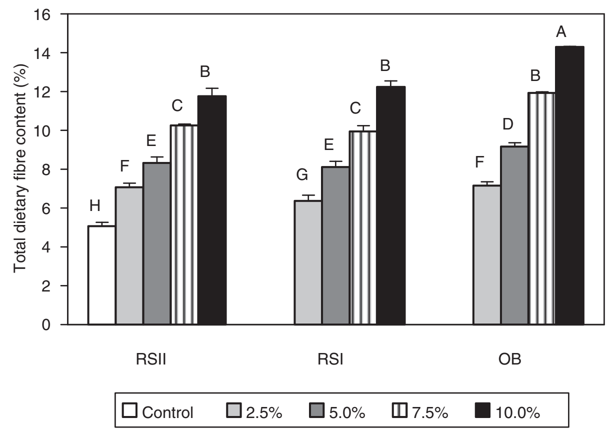

Figure 4. Total dietary fiber of cooked insoluble enriched pasta. Control sample presented a total dietary fiber value of 5.1%. Columns with the same letters are not significantly different ($p < 0.05$).

Addition of three different types of insoluble dietary fiber results in a significant increase in total dietary fiber contents, when compared to control. This implies that despite the results obtained in cooking losses, no significant fiber was lost during cooking.

The dietary fiber content of a normal serving (100 g) of pasta with 10% addition of any of these insoluble fibers covers around 37% and 57% of the dietary reference intakes for fiber in male and female, respectively (Institute of Medicine of the National Academies, 2005).

CONCLUSION

From the overall results, it could be concluded that the addition of fibers to wheat flour modifies the quality of pasta. This study confirms that the addition of inulin, a soluble fiber, negatively alters the structure of pasta and that during cooking all the fiber is lost in cooking water, giving a poor quality product with high cooking losses. In consequence, the inclusion of inulin in products cooked in boiling water should be avoided because it lacks a technological or nutritional support.

At the same time, the inclusion of oat bran into pasta positively affects the cooking properties of final products up to 5.0% of substitution. Conversely, although RSs are considerable insoluble dietary fibers, their inclusion into pasta results in pasta with improved final quality, very low cooking losses and increased hardness.

Pasta in which resistant starches (RSII and RSIV) and oat bran replaced 10% and 5% of wheat flour, respectively, were considered acceptable and could be labeled as 'good' fiber sources, since they provide 11.8% for RSII, 12.2% for RSIV and 14.3% for OB of total dietary fiber, compared to the 5.1% in the all wheat pasta.

The production of food products with good technological quality and high fiber content represents a contribution to dietary improvement in the general population. Considering the physiological effects of insoluble fiber, its incorporation into pasta has the potential to regulate glycemic response without compromising the quality of the final product. Further work is required to identify clearly the interactions between insoluble fiber and protein–starch matrix and how this affects starch degradation and reduction in glucose release.

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