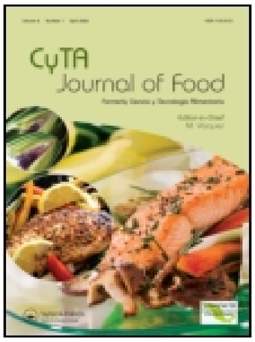

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Gluten-free spaghetti with unripe plantain, chickpea and maize: physicochemical, texture and sensory properties

Espagueti sin gluten de plátano macho inmaduro, garbanzo y maíz: características fisicoquímicas, de textura y evaluación sensorial

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The purpose of this investigation was to determine the physicochemical, textural and sensorial characteristics of gluten-free spaghetti elaborated with unripe plantain, chickpea and maize flours. Luminosity (L^*) of the uncooked gluten-free spaghetti was not significantly different from control sample, but in cooked spaghetti, L^* value was different. The diameters of raw spaghetti (gluten-free and control) were similar, but lower diameters were determined in cooked gluten-free spaghetti; however, some composites had similar water absorption values. Gluten-free spaghetti had higher hardness, cohesiveness and chewiness than the control but had lower elasticity. The maximum peak viscosity was lower in the gluten-free spaghetti than in the control, and no breakdown viscosity was observed, although high setback viscosity was found. The overall sensorial acceptability was similar in the gluten-free spaghetti among the different formulations, but it was significantly lower than the control. It is possible to prepare gluten-free pasta with textural and overall acceptability.

Keywords: banana flour; firmness; water absorption; color; viscosity

El objetivo de esta investigación fue determinar las propiedades fisicoquímicas, características de textura y aceptación de espagueti sin gluten elaborado con harinas de plátano verde, garbanzo y maíz. La luminosidad (L^*) de los espaguetis sin gluten crudos no fue diferente al control, pero en espaguetis cocidos el valor de L^* fue diferente. El diámetro de los espaguetis crudos (sin gluten y control) fueron similares, pero los espaguetis sin gluten cocidos presentaron diámetros inferiores que el control; sin embargo, algunas muestras presentaron valores de absorción de agua similares al control. Los espaguetis sin gluten presentaron mayor dureza, cohesividad y masticabilidad que el control, pero menor elasticidad. El pico de viscosidad máximo fue menor en los espaguetis sin gluten que el control. La aceptabilidad sensorial fue similar en los espaguetis sin gluten, pero fue significativamente menor que en el control. Es posible preparar pasta sin gluten de textura y sabor aceptable.

Palabras clave: harina de plátano; firmeza; absorción de agua; color; viscosidad

Introduction

Pasta products, largely consumed all over the world, play an important role in human nutrition due to its convenience, cost and palatability. They are convenient food products that are easy to store, cook, handle and present themselves as ideal vehicle for improving the nutritional quality of diets. Pasta is traditionally manufactured from durum wheat semolina; however, several studies have been carried out to increase its nutritive value by partially or totally adding/replacing durum wheat with flour from other sources such as cereal and/or pulses (Brennan, 2008; Chillo et al., 2010; Feillet & Dexter, 1996; Gallegos-Infante et al., 2010). Furthermore, there has been a growing interest in the search for ingredients for the production of gluten-free cereal-based products, due to the increased awareness of celiac disease (CD) prevalence. CD is a specific disorder of intestinal absorption whose only treatment is a strict adherence to a gluten-free diet. This has lead to an increased the demand for gluten-free products such as pasta (Kowlessar, 1972; Schoenlechner, Drausinger, Ottenschlaeger, Jurackova, & Berghofer, 2010), which has encouraged extensive gluten-free food product research and development. Wang, Bhirud, Sosulski, and Tyler (1999) and Chillo et al. (2010) tried different extruding techniques in gluten-free pasta manufacture; Huang, Knight, and Goad (2001), Singh, Raina, Bawa, and Saxena (2004) and Chillo, Laverse, Falcone, and Del Nobile (2007) studied the effect of starches and gums on the production of nongluten pasta; and Schoenlechner et al. (2010) and Mastromatteo, Chillo, Iannetti, Civica, and Del Nobile (2011) evaluated the use of different nonconventional flours in the development of gluten-free pasta. However, more research is needed since nonconventional flours often do not have a similar quality as that of durum wheat semolina. Moreover, it has been reported that gluten-free products lack dietary fiber and other important nutriments such as certain vitamins and minerals (Hager, Axel, & Arendt, 2011). Therefore, it is very important to develop gluten-free foodstuffs with high nutritional quality ingredients (Calderón de la Barca, Rojas-Martínez, Islas-Rubio, & Cabrera-Chávez, 2010; Chillo et al., 2007).

Rich-protein and dietary fiber ingredients such as pulse flours can be added to substitute gluten in pasta manufacture. Chickpeas *(Cicer arietinum)* are excellent source of proteins containing high levels of complex carbohydrates and unsaturated

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fatty acids, rich in vitamins and minerals, and relatively free from antinutritional factors (Muzquiz & Wood, 2007; Reyes-Moreno, Romero-Urias, Milan-Carrillo, & Gomez-Garza, 2000; Wood & Grusak, 2007). Additionally, spaghetti with chickpea flour has been shown to significantly lower glycemic index (GI) compared with traditional durum spaghetti (Goñi & Valentín-Gamazo, 2003). Chickpea inclusion increased the mineral and fat content (Goñi & Valentín-Gamazo, 2003; Osorio-Díaz, Agama-Acevedo, Mendoza-Vinalay, Tovar, & Bello-Pérez, 2008) and improved the physical properties of the lasagna dough (Sabanis, Makri, & Doxastakis, 2006).

Furthermore, since it has been recently reported that the intake of refined sugars in celiac patients is high (Hager et al., 2011), the addition of a good source of indigestible carbohydrates is of importance. Several studies have suggested that consumption of unripe plantain (*Musa paradisiaca L.*) exerts a beneficial effect on human health; this is associated with indigestible components as resistant starch (RS) (Faisant, Buléon et al., 1995, Faisant, Gallant, Bouchet, & Champ, 1995). Plantain flour has also been successfully added to whole grain bars (Utrilla-Coello, Agama-Acevedo, Osorio-Díaz, Tovar, & Bello-Pérez, 2011), bread (Juárez-García, Agama-Acevedo, Sáyago-Ayerdi, Rodríguez-Ambriz, & Bello-Pérez, 2006) and spaghetti (Ovando-Martínez, Sáyago-Ayerdi, Agama-Acevedo, Goñi, & Bello-Pérez, 2009), demonstrating that its addition results in a higher RS content and a lower starch digestion rate.

Maize flour contains 7–13 g/100 g protein, is uniquely rich in dietary fiber and has very low fat content (Paredes-López, Serna-Saldívar, & Guzmán-Maldonado, 2000). Maize flour is the preferred ingredient in the preparation of extruded products and has been widely used in the development of gluten-free foods such as pasta (Mastromatteo et al., 2011; Schober & Bean, 2008).

The aforementioned characteristics of chickpea, unripe plantain and maize flours were taken to elaborate pasta that presented a lower predicted GI than durum wheat semolina pasta (Flores-Silva, Berrios, Pan, Osorio-Díaz, & Bello-Pérez, 2014).

Pasta obtained from nonconventional flours should emulate the characteristics of traditional pasta products, such as color, cooking properties, texture (including elasticity, firmness and reduced adhesiveness) and taste. Since these are important factors that affect product quality, texture, color, low breakage susceptibility to dry conditions and ultimately consumer acceptance, they are considered indicators of food quality. It has been stated that texture determines the identity of the product and is often cited as a reason for liking or disliking of foods (Kent & Evers, 1994; Wilkinson, Dijksterhuis, & Minekus, 2001). The color of spaghetti is used as a quality parameter that is directly associated to its acceptability. Similarly, sensory properties and hedonic pleasure are important attributes in food product development (Tuorila & Cardello, 2002). Pasta based on nonconventional flours needs to achieve a proper compromise between satisfactory sensorial and functional properties (Lee et al., 2002; Mastromatteo et al., 2011). There is only limited research available so far in the utilization of unripe plantain, chickpea and maize flours for pasta production. In addition, most of the published research substituted only small amounts of durum wheat flour with alternate food ingredients. Hence, the objective of the present study was to produce gluten-free spaghetti with unripe plantain, chickpea and maize flours and to evaluate its physicochemical and texture properties as well as its sensory acceptance.

Materials and methods

Raw materials

Unripe plantain (*M. paradisiaca L.*), chickpea (*C. arietinum* L.) flour, white corn (*Zea mays* L.) flour and semolina were used to make the spaghetti. The unripe plantain was considered to be stage 2 (Aurore, Parfait, & Fahrasmane, 2009) and was bought from a market at Cuautla, Morelos, México, and the flour was obtained by using the procedure of Ovando-Martínez et al. (2009). Chickpea flour, white corn flour and semolina were purchased at the establishment, Giusto's Vita-Grain of San Francisco, California, USA.

Spaghetti formulation and processing

Spaghetti with 100% durum wheat semolina (control) and the gluten-free formulations with different percentages of unripe plantain, chickpea and white corn flour (Table 1) were prepared following the extrusion and drying procedure of Hernandez-Nava, Berrios, Pan, Osorio-Diaz, and Bello-Perez (2009). Two batches of each formulation were prepared for further evaluation.

Color

The color of the dried and cooked spaghetti was measured using a Minolta CM-508D colorimeter (Minolta Co., Ltd., Osaka, Japan). Briefly, the spaghetti samples were milled (Udy Corporation, Fort Collins, CO, USA) and passed through a 0.5-mm screen prior to color evaluation. The measurements were made holding the milled sample in direct contact with the colorimeter reading surface. This particular model performs eight measurements for each shot and gives an average of the luminosity (L^*), a^* (red/green) and b^* (yellow/blue) values. The values of chroma (C^*) and hue angle (h^*) for each sample were also calculated using the following formulas (MINOLTA, 1993):

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

$$h^* = \arctan\left(b^*/a^*\right)$$

Table 1. Flour percentages used in spaghetti formulations.

Tabla 1. Porcentajes de harinas utilizados en las formulaciones de espaguetis.

Ingredients (%)					
Unripe plantain	Chickpea	Corn	Semolina	CMC	Sample identification
30	70	0	0	0.5	**S30a**
30	65	5	0	0.5	**S30b**
25	65	10	0	0.5	**S25b**
25	60	15	0	0.5	**S25c**
20	70	10	0	0.5	**S20a**
20	65	15	0	0.5	**S20b**
15	70	15	0	0.5	**S15a**
15	65	20	0	0.5	**S15b**
0	0	0	100	0	**Control**

CMC = carboximetilcelulose.
Chickpea levels: *a* = 70; *b* = 65; *c* = 60.

CMC = carboximetilcelulosa.
Niveles de harina de garbanzo: *a* = 70; *b* = 65; *c* = 60.

Spaghetti diameter

The diameter of the dried and cooked spaghetti was determined based on a standard protocol (Petitot, Boyer, Minier, & Micard, 2010). The midpoint of 20 individual strands of spaghetti taken randomly was measured using a digital caliper (Model CD-6″, Mitutoyo Corp., Kawasaki, Japan). The results are the average of these measurements.

Water absorption

Ten grams of spaghetti samples were cut into 5-cm-long pieces, cooked in 300 ml boiling distilled water for 8 min. The spaghetti was then drained and rinsed with 20 ml distilled water at room temperature for 2 min. The samples were weighed after reaching room temperature. Water absorption was determined as [(weight of cooked drained pasta – weight of raw pasta)/weight of raw pasta] × 100.

Cooked spaghetti firmness

The firmness of spaghetti was determined using the AACC method 66-50 (American Association of Cereal Chemists [AACC], 2000). The 5-cm-long samples were analyzed using a TA-XT2 (Texture Technology Corp., Scarsdale, NY, USA) texture analyzer equipped with a blade of acrylic. Firmness was determined by measuring the work (N/cm) required to break five strands of cooked spaghetti.

Cooked spaghetti texture analysis

Two batches of cooked pasta were prepared for each product. In each case, four subsamples were evaluated by texture profile analysis (TPA) using the texture analyzer (Stable Micro System, Godalming, UK) within 5 min after cooking. Different texture analyses were performed: spaghetti hardness, adhesiveness, elasticity (or tensile strength) and chewiness. For all the measurements, the TA-XT2 was equipped with a 25-kg load cell. All the samples were prepared and kept until measured according to the approved AACC method (66-50 pasta cooking quality – firmness; AACC, 2000).

Pasting properties

The viscosity of the spaghetti was determined using a Rapid Viscosity Analyzer (Newport Scientific, Ltd., Narrabeen, Australia) interfaced with a computer equipped with Thermocline software for Windows (Newport Scientific Ltd.). Prior to the analysis, the dried and cooked spaghetti samples were milled and sieved through a 0.5-mm mesh; then 25 ml HPLC grade water and 3.5 g sample were mixed in an rapid viscoanalyzer (RVA) canister. The viscosity profile consisted of maintaining the mixture at 25°C for 2 min to stabilize it, then the temperature was increased to 95°C over a period of 5 min, and it was held there for 3 more minutes. After that, in a 3-min period, the temperature decreased and reached 25°C where it was kept for 2 min. The peak viscosity and final viscosity were determined, and the data was recorded in centipoise (cP).

Sensory evaluation

A panel of 30 untrained judges evaluated the acceptability of the cooked spaghetti. Panelists were asked to assess their degree of liking using a 9-point hedonic scale, where 9 = like extremely and 1 = dislike extremely. The sensory evaluation was targeted to flavor, texture and general acceptance of the product. The test was conducted in a USDA-approved sensory evaluation room under an orange light.

Statistical analysis

Results were expressed by mean ± standard error (SE). Differences among the means obtained in each of the determinations were evaluated by one-way analysis of variance (ANOVA) with a significance level of $\alpha = 0.05$ using the statistical package Minitab 15 (Minitab Inc., State College, PA, USA).

Results and discussion

Color of raw spaghetti

Table 2 shows the color parameter of raw gluten-free spaghetti elaborated with different formulations. L^* of the gluten-free spaghetti decreased significantly ($P < 0.05$) when compared with the control sample. In general, spaghetti with the highest corn concentration (20% and 15%) had higher L^*; the addition of unripe plantain flour (UPF) decreased the L^* value in the spaghetti, and this effect was augmented by the addition of chickpea. UPF and chickpea flours present a cream color, which decreases the L^* value in the composite. Additionally, the L^* reduction is due to the pigments produced during the polyphenol oxidase–mediated browning reaction upon the phenolic compounds present in the UPF (Rodríguez-Ambriz, Islas-Hernández, Agama-Acevedo, Tovar, & Bello-Pérez, 2008).

Table 2. Raw extruded spaghetti color determination[1].

Tabla 2. Determinación de color en espaguetis crudos[1].

Spaghetti	L^*	a^*	b^*	C^*	h^*
S30a	78.84 ± 0.06^{d}	1.17 ± 0.01^{c}	14.08 ± 0.06^{f}	14.13 ± 0.06^{e}	85.25 ± 0.03^{c}
S30b	78.55 ± 0.07^{d}	1.11 ± 0.01^{d}	14.08 ± 0.05^{f}	14.12 ± 0.05^{e}	85.48 ± 0.03^{b}
S25b	78.90 ± 0.08^{d}	1.12 ± 0.01^{d}	$14.23 \pm 0.06^{e,f}$	14.27 ± 0.06^{e}	85.50 ± 0.04^{b}
S25c	79.52 ± 0.07^{c}	$1.14 \pm 0.01^{c,d}$	14.83 ± 0.06^{c}	14.87 ± 0.06^{c}	85.60 ± 0.03^{b}
S20a	78.98 ± 0.08^{d}	1.31 ± 0.01^{a}	15.11 ± 0.06^{b}	15.16 ± 0.06^{b}	85.03 ± 0.03^{d}
S20b	80.12 ± 0.07^{b}	1.23 ± 0.01^{b}	14.53 ± 0.04^{d}	14.58 ± 0.04^{d}	85.15 ± 0.03^{c}
S15a	79.59 ± 0.08^{c}	1.22 ± 0.01^{b}	14.54 ± 0.06^{d}	14.59 ± 0.06^{d}	85.19 ± 0.04^{c}
S15b	79.63 ± 0.09^{c}	1.21 ± 0.01^{b}	14.36 ± 0.04^{e}	$14.41 \pm 0.04^{d,e}$	85.19 ± 0.03^{c}
Control	83.83 ± 0.07^{a}	0.91 ± 0.01^{e}	15.68 ± 0.05^{a}	15.68 ± 0.05^{a}	89.32 ± 0.02^{a}

[1]Mean ± SE, $n = 30$. Means in columns not sharing the same letter are significantly different at $P < 0.05$. For sample identification, see Table 1.

[1]Los valores son la media de treinta repeticiones ± error estándar. Medias con diferente letra dentro de la misma columna son significativamente diferentes a $P < 0,05$. Ver Tabla 1 para identificación de las muestras.

Addition of diverse legume flours to spaghetti decreased the *L** value (Zhao, Manthey, Chang, Hou, & Yuan, 2005). However, spaghetti partially substituted with banana starch (5%–20%) presented *L** values between 80.3 and 83.8 (Hernandez-Nava et al., 2009); and those partially substituted with UPF (15%, 30% and 45%) showed *L** values between 80.8 and 83.9 (Agama-Acevedo et al., 2009). The slight decrease in *L** values in the gluten-free spaghetti may not influence their acceptability by consumers, because pasta products with diverse colors (green, black, brown, etc.) are readily commercially available. Control spaghetti presented lower *a** values and higher *b** values than gluten-free spaghetti (Table 2), indicating that the color of the spaghetti analyzed were situated in the red–yellow quadrant with low intensity. In general, the different blends did not largely affected the *a** and *b** values. Spaghetti partially substituted with UPF showed *a** values between 1.33 and 0.97 and *b** values between 13.8 and 9.6 (Agama-Acevedo et al., 2009). The *C** values showed similar pattern as that of *b**, with very similar values. The decrease in *C** value in the gluten-free samples indicates that the color of these spaghetti were less saturated than the control. Spaghetti partially substituted with banana starch (5%–20% w/w) showed *C** values of 15.1 for the control sample and 9.4 for the spaghetti with the highest banana starch content (Hernandez-Nava et al., 2009). Gluten-free spaghetti presented *C** values in a narrow range (15.7 and 14.1). The *h** was higher in the control sample than in the gluten-free spaghetti. This parameter indicates the aspect of color that we describe by words such as yellow, green, blue or red. A red color has *h** around 0, while *h** of 90 is indicative of pure yellow. Based on the results the control spaghetti presents a yellow color, and the gluten-free samples appear yellow–red.

Color of cooked spaghetti

The cooked gluten-free spaghetti samples were generally less bright (*L**), more red (*a**) and less yellow (*b**) than the control spaghetti ($P > 0.05$) (Table 3). The *L** values of the gluten-free samples decreased with the addition of plantain flour, and in general, the cooked spaghetti followed the same tendency as the uncooked samples but with lower values. Kamil, Hussien, Ragab, and Khalil (2011) observed a decrease in *L** value of wheat spaghetti that underwent a cooking process, and Manthey, Yalla, Dick, and Badaruddin (2004) reported this same tendency as the moisture content of spaghetti added with buckwheat flour increased. The *L** values obtained in this study were similar to those reported by Wood (2009) for cooked spaghetti added with chickpea flour (71.2–75.9) and higher than those reported for cooked commercial spaghetti between 52.5 and 56.9 (Martinez, Ribotta, León, & Añon, 2007). The *a** and *b** values were slightly higher than those of the uncooked spaghetti samples; however, they showed the same tendency and remained in the red–yellow quadrant. Higher *a** (1–10.5) and *b** (18.3–22.4) range values were obtained by Petitot et al. (2010) in spaghetti added with pea and bean flours and 3.42–6.52 and 27–30.6 by Wood (2009) for spaghetti with chickpea flour, respectively. *C** values of cooked spaghetti were higher than those of the uncooked samples. Control spaghetti presented the highest saturation level; and in the gluten-free spaghetti the saturation degree decreased with the addition of UPF. This same tendency was reported by Hernandez-Nava et al. (2009) for spaghetti produced with added plantain starch. The *h** for the experimental cooked spaghetti was lower than its uncooked counterpart. However, these color measurements still group them in the yellow–red color space. The *h** of the control remained the same, suggesting that even after cooking it maintains its yellow color. Yellow color in semolina and pasta is a traditional – rather than functional – mark of quality.

Diameter and water absorption (%) of extruded spaghetti

The diameter of the uncooked spaghetti ranged between 1.58 and 1.60 mm (Table 4), and there were no significant differences between the control and the gluten-free spaghetti ($P > 0.05$). These values are lower than those reported by Agama-Acevedo et al. (2009) (1.82–2.1 mm) for spaghetti produced with added UPF and higher than those obtained by Petitot et al. (2010) for extruded spaghetti with pea and bean flours (1.56 mm). However, they are similar to those reported in extruded spaghetti with unripe plantain starch (1.55–1.61 mm) (Hernandez-Nava et al., 2009). The difference between these studies may be attributed to the process used for the preparation of spaghetti; it has been observed that by using an extruder during spaghetti elaboration uniformed diameters are obtained. In the cooked samples, there were significant differences ($P < 0.05$) between the diameters of the gluten-free spaghetti and the control. Control spaghetti had the biggest diameter, followed by the spaghetti with 30% of UPF. Both samples increased in diameter up to 50% with respect to their uncooked counterparts. There were no significant differences ($P > 0.05$) in the diameter of the cooked spaghetti with 25%,

Table 3. Cooked extruded spaghetti color determination[1].

Tabla 3. Determinación de color en espaguetis cocidos[1].

Spaghetti	*L**	*a**	*b**	*C**	*h**
S30a	70.83 ± 0.06[e]	1.66 ± 0.01[c]	14.75 ± 0.07[e]	14.85 ± 0.07[e]	83.13 ± 0.04[g]
S30b	69.97 ± 0.05[f]	1.94 ± 0.01[a]	15.43 ± 0.08[c]	15.56 ± 0.08[c]	82.82 ± 0.02[h]
S25b	72.34 ± 0.06[c]	1.31 ± 0.01[e]	14.82 ± 0.07[d]	14.88 ± 0.07[d]	84.93 ± 0.02[b]
S25c	71.39 ± 0.05[d]	1.57 ± 0.01[d]	14.98 ± 0.07[d]	15.07 ± 0.07[d]	84.01 ± 0.02[d]
S20a	72.17 ± 0.06[c]	1.72 ± 0.01[c]	15.40 ± 0.06[c]	15.49 ± 0.06[c]	83.63 ± 0.03[e]
S20b	72.63 ± 0.08[c]	1.67 ± 0.02[c]	15.63 ± 0.07[c]	15.72 ± 0.07[c]	83.90 ± 0.04[d]
S15a	74.47 ± 0.04[b]	1.61 ± 0.01[d]	16.34 ± 0.06[a]	16.42 ± 0.06[a]	84.38 ± 0.03[c]
S15b	72.98 ± 0.06[c]	1.85 ± 0.01[b]	16.08 ± 0.09[b]	16.19 ± 0.10[b]	83.43 ± 0.03[f]
Control	81.66 ± 0.07[a]	0.95 ± 0.00[f]	16.52 ± 0.06[a]	16.52 ± 0.06[a]	89.20 ± 0.02[a]

[1]Mean ± SE, $n = 30$. Means in columns not sharing the same letter are significantly different at $P < 0.05$. For sample identification, see Table 1.

[1]Los valores son la media de treinta repeticiones ± error estándar. Medias con diferente letra dentro de la misma columna son significativamente diferentes a $P < 0,05$. Ver Tabla 1 para identificación de las muestras.

Table 4. Diameter and water absorption (%) of extruded spaghetti[1].

Tabla 4. Diámetro y absorción de agua (%) de espaguetis extrudidos[1].

Spaghetti	Water absorption (%)[2]	Diameter of raw spaghetti (mm)[3]	Diameter of cooked spaghetti (mm)[3]
S30a	163.62 ± 2.91^{b}	1.59 ± 0.01^{a}	2.43 ± 0.02^{b}
S30b	177.13 ± 4.07^{a,b}	1.59 ± 0.00^{a}	2.42 ± 0.02^{b}
S25b	185.03 ± 2.18^{a}	1.58 ± 0.00^{a}	2.30 ± 0.02^{b,c}
S25c	183.97 ± 4.24^{a}	1.58 ± 0.00^{a}	2.34 ± 0.02^{b,c}
S20a	168.43 ± 3.64^{b}	1.58 ± 0.00^{a}	2.33 ± 0.02^{b,c}
S20b	180.93 ± 4.23^{a}	1.59 ± 0.01^{a}	2.36 ± 0.01^{b,c}
S15a	175.53 ± 5.68^{a,b}	1.58 ± 0.01^{a}	2.34 ± 0.02^{b,c}
S15b	182.93 ± 4.36^{a}	1.60 ± 0.00^{a}	2.27 ± 0.02^{c}
Control	186.13 ± 5.17^{a}	1.60 ± 0.01^{a}	2.50 ± 0.02^{a}

[1]Mean ± SE. Means in columns not sharing the same letter are significantly different at $P < 0.05$. For sample identification, see Table 1.
[2]$n = 3$.
[3]$n = 20$.

[1]Los valores son la media ± error estándar. Medias con diferente letra dentro de la misma columna son significativamente diferentes a $P < 0{,}05$. Ver Tabla 1 para identificación de las muestras.
[2]$n = 3$.
[3]$n = 20$.

20% and 15% of UPF, showing a diameter increment of 41%–48%. Differences on diameters between cooked gluten-free spaghetti and control spaghetti could be attributed to the total starch (TS) content of the samples. Control spaghetti with the highest TS content (75%) presented the biggest diameter, meanwhile gluten-free spaghetti with lower TS content (~55%–59%) had lower diameters (Flores-Silva et al., 2014). It is well known that during cooking, gelatinization of starch is characterized by swelling of the granules, and this may be taking place on a lower extent on the gluten-free samples, thus affecting their diameters.

The water absorption of the gluten-free spaghetti ranged from 163% to 186%. No significant differences ($P > 0.05$) between control and gluten-free spaghetti with 60% and 65% of chickpea flour were found; however, the control spaghetti absorbed more water. The samples with the higher chickpea flour content (S30a, S20a and S15a) had the lowest water absorption. It has been reported that spaghetti with lower protein content absorbs more water than spaghetti with higher protein content (Holliger, 1963). This could be attributed to a strongly formed protein network that prevents water diffusion into the starch granules (Sözer & Kaya, 2003).

Texture attributes of cooked spaghetti

Table 5 shows the results of the texture analysis of the gluten-free spaghetti. There were no significant differences ($P > 0.05$) in firmness among control spaghetti and experimental gluten-free spaghetti S30a, S30b, S25b and S20b. The firmness values of the gluten-free samples were in a narrow range (0.06–0.07 N/cm) and did not show a pattern. Hernandez-Nava et al. (2009) obtained similar values (~0.06 N/cm) in spaghetti with unripe plantain starch and observed that the firmness decreased with addition of unripe plantain starch. Rayas-Duarte, Mock, and Satterlee (1996) and Brennan and Tudorica (2007) reported a similar pattern of spaghetti firmness added with pseudocereals (amaranth and buckwheat) and nonstarch polysaccharides (NSPs). The gluten-free spaghetti developed in this study did not show the same tendency, which could be due to the higher protein content of the samples. It has been reported that by increasing the protein content of wheat spaghetti its firmness increased (Nobile, Baiano, Conte, & Mocci, 2005). Zhao et al. (2005) reported that firmness of spaghetti added with pulses (good proteins source) increased in samples with higher levels of addition.

The control spaghetti had the lowest hardness value and significant differences ($P < 0.05$) were found among the control and the gluten-free samples. Agama-Acevedo et al. (2009) reported higher hardness values (38.24–40.20 N) in spaghetti with UPF, and Petitot et al. (2010) observed an increase in spaghetti hardness when 35% of pea or bean flour was added. The cohesiveness parameter gave an indication on how the sample holds together upon cooking. Gluten-free spaghetti had higher cohesiveness values than the control sample. The cohesiveness value of control spaghetti was similar to those reported by Sözer and Kaya (2003) (0.58–0.88) for commercial wheat spaghetti evaluated at different cooking times and different salt concentrations. The elasticity of the gluten-free spaghetti was significantly lower ($P < 0.05$) than that of control spaghetti (made from 100% durum wheat semolina). Brennan and Tudorica (2007) added pasta with NSPs at different levels and reported that increasing levels of NSP lead to a decreased elasticity due to a weakening effect of pasta structure. The chewiness of the gluten-free spaghetti increased significantly ($P < 0.05$) compared with the control. This pattern is related to the higher cooking loss values of the gluten-free spaghetti than the control spaghetti because the same cooking time (8 min) was used for all the samples. Agama-Acevedo et al. (2009) reported similar results in spaghetti added with UPF.

Table 5. Texture attributes of cooked spaghetti[1].

Tabla 5. Atributos de textura de espaguetis cocidos[1].

Spaghetti	Firmness (N/cm)	Hardness (N)	Cohesiveness	Elasticity	Chewiness (N)
S30a	0.071 ± 0.02^{a}	15.42 ± 0.46^{a}	0.82 ± 0.04^{a}	1.02 ± 0.01^{b}	12.99 ±1.02^{a}
S30b	0.069 ± 0.01^{a}	14.74 ± 0.57^{a}	0.78 ± 0.05^{a}	1.01 ± 0.01^{b}	11.65 ± 0.93^{a}
S25b	0.071 ± 0.02^{a}	15.44 ± 0.64^{a}	0.81 ± 0.06^{a}	1.01 ± 0.01^{b}	12.70 ± 1.22^{a}
S25c	0.065 ± 0.01^{b}	15.67 ± 0.77^{a}	0.83 ± 0.02^{a}	1.00 ± 0.01^{b}	13.05 ± 0.71^{a}
S20a	0.065 ± 0.02^{b}	16.71 ± 0.59^{a}	0.70 ± 0.03^{a,b}	1.03 ± 0.01^{b}	12.00 ± 0.73^{a}
S20b	0.070 ± 0.01^{a}	15.25 ± 0.70^{a}	0.76 ± 0.04^{a}	1.00 ± 0.01^{b}	11.74 ± 0.96^{a}
S15a	0.066 ± 0.01^{b}	17.03 ± 0.76^{a}	0.76 ± 0.05^{a}	1.01 ± 0.01^{b}	13.19 ± 1.32^{a}
S15b	0.065 ± 0.02^{b}	16.63 ± 0.63^{a}	0.80 ± 0.03^{a}	1.01 ± 0.01^{b}	13.54 ± 0.84^{a}
Control	0.072 ± 0.01^{a}	9.36 ± 0.06^{b}	0.63 ± 0.04^{b}	1.10 ± 0.05^{a}	6.42 ± 0.51^{b}

[1]Mean ± SE, $n = 7$. Means in columns not sharing the same letter are significantly different at $P < 0.05$. For sample identification, see Table 1.

[1]Los valores son la media ± error estándar, $n = 7$. Medias con diferente letra dentro de la misma columna son significativamente diferentes a $P < 0{,}05$. Ver Tabla 1 para identificación de las muestras.

Pasting profile

Gluten is the main structure-forming protein in wheat flour and is responsible for the elastic and extensible characteristics of the dough, therefore, the replacement of gluten by nongluten ingredients results in a great challenge from the rheological point of view. The pasting characteristics of the control raw (100% semolina) flour and the composite gluten-free flours were determined and are presented in Figure 1. The viscosity profile of the flours during a heating–cooling cycle was recorded by using the RVA. The pasting profile of the control flour was very typical of a gluten-based dough, with the highest peak viscosity, breakdown and setback. The starch type (granule size, amylose/amylopectin ratio and chain-length distribution of amylopectin) is responsible for this pasting profile. The pasting profile is important during cooking of the spaghetti due to the amount of water that it can retain in its structure, affecting the cooking quality and textural characteristics of the product.

Gluten substitutes in the formulation of gluten-free spaghetti could act as polymeric substances that mimic the viscoelastic properties of gluten-containing doughs. Compared with the control flour the composite gluten-free flours exhibited lower pasting temperature, lower maximum viscosity (gelatinization) and final viscosity or setback (retrogradation). The difference was less pronounced as the percentage of UPF increased from 15% to 30% in the composite flours, while the other flours in the blend (chickpea and corn) did not show much influence on those parameters. The gelatinization occurs as the temperature rises, which increases mechanical strength of dough. This is an important factor to consider when gluten-free flours are to be used for gluten-free spaghetti for obtaining a viscous system that holds the food components cohesively in the matrix. Marco and Rosell (2008) reported that as a consequence of the initial starch gelatinization, dough consistency increased, improving the mechanical and handling properties of the rice flour dough compared with those of the dough mixed with water at 25°C. The pasting profile of the composite gluten-free flours reflected that the fabrication of gluten-free spaghetti containing up to 30% UPF was considered highly acceptable.

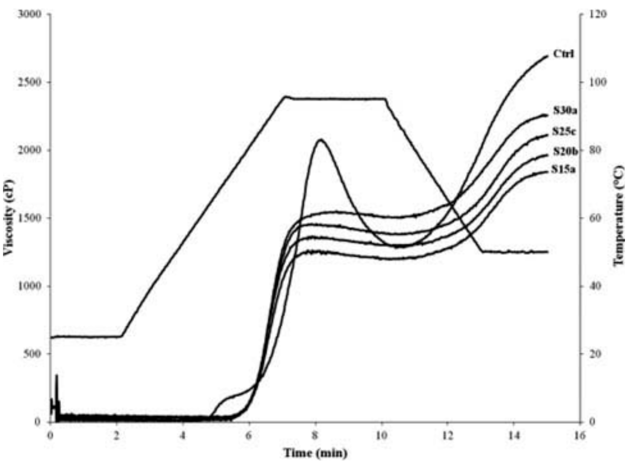

Figure 1. Raw extruded spaghetti viscosity profile (for sample identification, see Table 1).

Figura 1. Perfil de viscosidad de espaguetis extrudidos (ver Tabla 1 para identificación de las muestras).

Table 6. Sensory evaluation of spaghetti.

Tabla 6. Evaluación sensorial de espaguetis.

Spaghetti	Overall acceptability[1]
S30a	4.97 ± 0.26[b]
S30b	4.77 ± 0.35[b]
S25b	5.21 ± 0.24[b]
S25c	5.50 ± 0.28[b]
S20a	5.40 ± 0.31[b]
S20b	5.00 ± 0.27[b]
S15a	5.80 ± 0.26[b]
S15b	5.67 ± 0.33[b]
Control	7.17 ± 0.20[a]

[1]Mean ± SE, n = 40. Means in columns not sharing the same letter are significantly different at $P < 0.05$. For sample identification, see Table 1.

[1]Los valores son la media ± error estándar, n = 40. Medias con diferente letra dentro de la misma columna son significativamente diferentes a $P < 0,05$. Ver Tabla 1 para identificación de las muestras.

Sensory evaluation

The results of the sensory evaluation test (Table 6) revealed that the control spaghetti received the highest score of acceptability of 7.17, while all the gluten-free spaghetti ranged above the mean value of 4.5. No significant differences ($P > 0.05$) between gluten-free spaghetti samples were found. This meant that the panelists were not able to distinguish any flavor difference between the spaghetti with higher/lower content of plantain flour. The acceptability of the experimental gluten-free spaghetti samples was about 70% of the control semolina spaghetti. Therefore, based on the tasters who participated in the sensory evaluation, gluten-free could be considered a product of good acceptability by consumers.

Conclusions

Gluten-free spaghetti made from a mixture of unripe plantain, chickpea and maize flours showed to have great potential for commercial application due to its firmness, hardness, cohesiveness and chewiness, similar or higher than semolina wheat spaghetti used as control. Also, some physicochemical characteristics of the gluten-free spaghetti, such as the diameter and water absorption, were similar to the control sample. The result of sensory evaluation of the products concluded that the overall acceptability of the gluten-free spaghetti was about 70% compared with the control spaghetti. The sensory evaluation was done without the use of a flavoring sauce (e.g., tomato-base sauce), which would have improved the acceptability of the gluten-free spaghetti. Therefore, it would be important that in future sensory evaluation of these type of products, the use of flavoring agents may be added, as traditionally used by consumers. The use of UPF, chickpea and maize in the fabrication of gluten-free spaghetti is a novel approach to provide with a healthy alternative, to traditional gluten containing pasta products, to the large population of consumers suffering of the CD and gluten sensitivity.

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