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Original article

Formulation optimisation of gluten-free functional spaghetti based on quinoa, maize and soy flours

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Summary In this work, the formulation of non-conventional gluten-free fresh and dry pasta based on quinoa, maize and defatted soy was optimised. Results showed that the dough samples with high content of maize had the higher value of elongation and shear viscosity and then increased dough firmness. The pre-gelatinised maize content also affected the rheological properties by increasing the dough firmness. Regarding the dry spaghetti sensorial properties, the surface response plot showed that the overall acceptability of both non-cooked and cooked spaghetti increases with the increase of the pre-gelatinised maize content and the decrease of the quinoa flour, whereas the soy flour did not affect the overall quality. In particular, the pre-gelatinised maize improved the resistance to break and the taste of non-cooked and cooked spaghetti, respectively. Regarding the fresh spaghetti, results showed that the overall acceptability for fresh non-cooked spaghetti increases with the increase of the pre-gelatinised maize content and with the decrease of the quinoa flour; whereas, only the pre-gelatinised maize content affected the overall acceptability of fresh cooked spaghetti.

Keywords Quinoa, maize, soy, rheological characteristics, sensorial properties.

Introduction

Pasta is one of the most consumed foods in the world and is a traditional product obtained from semolina. According to the Italian legislation 'Pasta' is defined as the product obtained by extrusion or lamination and successive drying (to 12.5% maximum water content) of a dough made of durum wheat semolina and water (DPR, 2001). The Italian legislation also allows the use of soft wheat flour in the 'fresh pasta' recipe and requires storage of the product at temperatures less than 4 °C. If 'fresh pasta' is packed before sale, it should fulfils additional requirements: it must be subject to a pasteurisation treatment, stored at temperature, $< 4 \pm 2$ °C, have moisture content greater than 24% and water activity in the 0.92–0.97 range (DPR, 2001; Carini *et al.*, 2009).

In the last decades, consumer demands in the field of food production have changed considerably. Consumers more and more believe that foods contribute directly to their health (Young, 2000; Mollet & Rowland, 2002). Today foods are not intended to only satisfy hunger and to provide necessary nutrients for humans but also to prevent nutrition-related diseases and improve physical and mental well-being of the consumers (Roberfroid, 2000; Menrad, 2003). In this regard, functional foods play an outstanding role. The appeal of pasta amongst consumers has made this food product a potential vehicle for highly nutritious compounds. Pasta products can be fortified with supplements from various high protein sources to improve their nutritional properties (Marconi & Carcea, 2001).

Currently, many gluten-free products available on the market are of low quality, exhibiting poor mouth feel and flavour (Arendt *et al.*, 2002). Cooked pasta from durum wheat semolina maintains good texture, resists surface disintegration, and retains a firm structure or 'al dente' consistency characteristics (Liu *et al.*, 1996) compared to the non-conventional pasta. In fact, gluten is the main structure-forming protein in flour, therefore its removal results in major problems. Pre-gelatinisation can help to improve functional properties and give body and texture to the product. In the literature, it has also been reported that substances that swell in water could replace gluten in the dough (Sivaramakrishnan *et al.*, 2004). Dairy proteins and hydrocolloids can be used to mimic the viscoelastic properties of gluten and result in improved structure mouth feel, acceptability and shelf

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life (Lazaridou *et al.*, 2007). Similar findings ware found by Tudorica *et al.* (2002) in a study on inulin-enriched pasta incorporated with guar gum.

Grains different from durum wheat have been used (as partial or total substitutes) to manufacture ‘pasta’ that provides health benefits over and above basic nutrition (Kasarda, 2001). The amount of high protein flour that can be added to or substituted for semolina represents a compromise between nutritional improvement of the pasta and achievement of satisfactory sensory and functional properties (Marconi & Carcea, 2001).

Quinoa (*Chenopodium quinoa*) is a pseudo-cereal that can be used to produce gluten-free cereal based products (Tosi *et al.*, 1996; Gambus *et al.*, 2002; Taylor & Parker, 2002; Chillo *et al.*, 2009). Quinoa has high protein content (14–16%) (Koziol, 1990, 1992) and in particular, the amino acid composition of seed protein is rich in histidine and lysine. Quinoa has a relatively high quantity of vitamins and minerals, iron and calcium (Risi & Galwey, 1984); moreover, lipids present in the quinoa seeds appear to have a high quality edible vegetable oil, similar in fatty-acid composition to soybean oil (Wood *et al.*, 1993) and are particularly rich in linoleate and linolenate (Koziol, 1990).

Soybean (*Glycine max*) flours are used in many countries because they are a good resource of vegetable proteins (38–40%), fat (18–20%), lysine (5–6%), and other biologically active components (isoflavones) that may be effective in reducing the risk of coronary heart diseases and several cancers (Murphy *et al.*, 1999; Trainer & Holden, 1999; Hasler, 2002).

Maize flour is derived from grounded and desiccated seed of the maize plant (also commonly called corn in many English countries), *Zea mays*. It is the second most produced and consumed flour after wheat flour, competing with rice flour. Maize contains 7–13 g/100 g proteins, is uniquely rich in dietary fibre, vitamin B6, magnesium and it has very low fat content (Paredes-Lòpez *et al.*, 2000).

The objective of this research was to produce gluten-free functional pasta, both dry and fresh, to evaluate the effects of the non-conventional flours used (quinoa, maize and soy) on the sensorial quality and the dough rheological properties. In order to optimise the formulation of the non-conventional gluten-free pasta, an experimental design Central Composite Design (CCD) was developed varying the amount of the used flours.

Materials and methods

Spaghetti preparation

Quinoa, heat-treated maize and defatted soy flours were supplied from Bongiovanni mill (Mondovì, Cuneo, Italy). In order to prepare the non-conventional dough a portion of heat-treated maize flour was pre-gelatinised (pre-gelatinised starch named as PS). In particular, water mixed with flour was heated at 80 °C to obtain pre-gelatinised starch. Afterwards, the pre-gelatinised starch was cooled at about 40 °C, then it was added to the soy, quinoa and heat-treated maize flour and kneaded for 20 min. After kneading, the samples were extruded. The amount of quinoa, soy and pre-gelatinised maize varied according to a three factor, five-level CCD. The heat-treated maize flour percent mass fraction added to dough was set as the complement to 100% of the percent mass fraction of the above-mentioned flours. The percentage mass fraction of raw materials used to prepare the spaghetti samples is reported in Table 1. Dry and fresh spaghetti samples were produced from a pilot plant made of a kneader-extruder (60VR, Namad, Rome, Italy) and a dryer (SG600, Namad). The extruder was equipped with a screw (30 cm in length, 5.5 cm in diameter), which ended with a bronze die (diameter hole of 1.70 mm). The screw speed was 50 rpm. The process conditions applied were the following: drying temperature I step 50 °C, drying time I step 60 min, drying temperature II step 80 °C, drying time II step 300 min, drying temperature III step 70°C, drying time III step 40 min. Moreover, the water content for all samples was 43.65% (*w/w* dough basis). Two batches for each run of the experimental design were produced.

Dough rheological properties

Rheology is of considerable importance in the manufacture of various foods as it influences the machinability, processing conditions and quality of products

Table 1 Composition of the seventeen runs of the CCD used in the preparation of the spaghetti.

	Quinoa flour (%)	Soy flour (%)	Maize flour PS[a] (%)
Run 1	7.5	2.5	23.75
Run 2	7.5	2.5	31.25
Run 3	7.5	7.5	23.75
Run 4	7.5	7.5	31.25
Run 5	22.5	2.5	23.75
Run 6	22.5	2.5	31.25
Run 7	22.5	7.5	23.75
Run 8	22.5	7.5	31.25
Run 9	15	5	27.5
Run 10	15	5	20
Run 11	15	5	35
Run 12	15	0	27.5
Run 13	15	10	27.5
Run 14	0	5	27.5
Run 15	30	5	27.5
Run 16	15	5	27.5
Run 17	15	5	27.5

[a]Pre-gelatinised starch (% w/w flour basis).

(Chuang & Yeh, 2006). Capillary rheometer was used in this work to determine elongation and shear viscosity that is the measure of the resistance of a fluid that is being deformed, by either shear stress or extensional stress. In particular, elongation and shear viscosity of each dough sample were investigated by means of a Rosand capillary rheometer (Malvern Instruments, Malvern, Worcester, UK) equipped with twin cylinders. Two different length dies with the same diameter (1 mm) were selected to measure the entry pressure losses. The length of left die was of 10 mm and the pressure was of 10 psi. Whereas, the length of right die was of 0.25 mm and the pressure was of 150 psi. The experiments were carried out at 30°C and at shear rate between 10 and 2000 s^{-1}. The rheological behaviour is studied using the following power law model that satisfactory fitted the experimental data:

$$\tau_S = K \cdot \dot{\gamma}_S^n \quad (1)$$

and

$$\tau_c = L \cdot \dot{\gamma}_e^m \quad (2)$$

where τ_s and τ_e are the shear stress [Pa] and extensional stress [kPa], K and L are the consistency indices [Pa·s^n and kPa·s^n, respectively], the $\dot{\gamma}_S$ and $\dot{\gamma}_e$ are the shear and extension rate [1/s], and n and m are the flow indices (dimensionless). The elongation and shear viscosity (η_e and η_s, respectively) were calculated on the range of shear and extension rate tested by using the following power law model (McGlashan & Mackay, 1999; Bertuzzi *et al.*, 2007):

$$\eta_S = K \cdot \dot{\gamma}_S^{n-1} \quad (3)$$

and

$$\eta_e = L \cdot \dot{\gamma}_e^{m-1} \quad (4)$$

The Bagley correction was applied to all data from Rosand rheometer. Three measurements of the viscosity experiment were performed on each sample of the two batches.

Sensory analysis

Dry and fresh spaghetti samples were submitted to a panel of ten trained tasters in order to evaluate the sensorial attributes. The panellists were selected on the basis of their sensory skills (ability to accurately determine and communicate the sensory attributes such as appearance, odour, flavour and texture of a product) (Meilgaard *et al.*, 1999). Prior to testing, the panellists were however trained in sensory vocabulary and identification of particular attributes, by evaluating commercial conventional and non-conventional spaghetti.

The panellists were asked to indicate colour, odour, homogeneity, resistance to break and overall acceptability of non-cooked spaghetti, both dry and fresh. In addition, the bulkiness for fresh spaghetti was evaluated instead of the resistance to break. Moreover, each spaghetti sample was cooked at different times and tested by the panel to estimate the optimal cooking time that was 7 min for dry samples and 4 min for fresh samples. Elasticity, firmness, bulkiness, adhesiveness, colour, odour, taste and overall acceptability of cooked spaghetti, both dry and fresh, were also evaluated. To this aim, a nine-point hedonic rating scale, where 1 corresponded to extremely unpleasant, 9 to extremely pleasant and 5 to satisfactory was used to quantify each attribute (Chillo *et al.*, 2007; Petitot *et al.*, 2010).

Statistical analysis

The rheological and sensorial properties of spaghetti manufactured with maize, quinoa and soy flours as affected by different amount of the above flours were evaluated in this study. Quinoa, soy and pre-gelatinised maize flours varied according to a three factor, five-level CCD, as reported in Table 1. The lowest and highest levels of independent variables studied were chosen from results of preliminary laboratory tests. A statistical software (StatSoft, Inc., Tulsa, OK, USA) was used to generate surface response plots that permitted evaluation of the linear, quadratic and interactive effects of the independent variables on the selected dependent variables ($P < 0.05$). Moreover, the results of the rheological and sensorial analysis were compared by a one-way variance analysis (ANOVA). A Duncan's multiple range test, with the option of homogeneous groups ($P < 0.05$), was carried out to determine significant differences between spaghetti samples. STATISTICA 7.1 for Windows (StatSoft, Inc.) was used for this aim.

Results and discussion

Good quality pasta is defined as having high degree of firmness and elasticity, which is mainly termed as 'al dente' (Antognelli, 1980; Pomeranz, 1987). Proper evaluation of pasta cooking quality requires consideration of a number of factors including elasticity, firm pasta structure, reduced adhesiveness, water absorption, low cooking loss, etc. Moreover, pasta based on non-conventional flours needs to achieve a proper compromise between satisfactory sensorial and functional properties.

In this study the formulation of gluten-free pasta was optimised. To this purpose, the mass percents of the flours used to manufacture the spaghetti samples, such as quinoa, defatted soy and pre-gelatinised maize, was varied according to a CCD. Moreover, maize percent mass fraction was set as the complement to 100% of the percent mass of the above-mentioned flours. In particular, the central values of the CCD were chosen from results of preliminary laboratory tests. In fact, the quinoa flour showed a good ability to form a physical network such as that formed by gluten, therefore a higher content was used if compared to soy flour despite its bitter taste. The soy flour was added to the dough in order to improve the functional properties of the pasta. Moreover, the higher pre-gelatinised maize mass was used to improve both the spaghetti taste and texture. In the following, elongation and shear viscosity data of the manufactured dough as well as the sensory characteristics of dry and fresh spaghetti samples are presented and discussed.

Rheological measurement

Figures 1 and 2 show elongation and shear viscosity as a function of extension rate and shear rate, respectively. As can be inferred from these figures, the viscosity increases with shear rate showing a shear-thickening behaviour of the dough (Carriere, 1999).

From Figs 1 and 2, it can be seen that the run 14 sample shows the higher value of both elongation and shear viscosity with respect to the other samples. In fact, the consistency indices *L* and *K* for that sample (Table 2), obtained by fitting eqns 1 and 2 to the experimental data, showed statistically significant highest values along with the run 2 sample; on the other hand, the run 15 sample showed the lower value of elongation and shear viscosity. Table 2 highlights that sample run 15 had the lowest value of the consistency indices *L* and *K*. Also the run 8 sample showed the lowest value of the consistency index *L* and a value of *K* among the lowest compared to the other samples investigated. Results suggest that either the absence or low quinoa flour content and the high amount of maize flour increase the dough firmness. Moreover, even if the differences among the measured values of the gelatinisation degree (data not shown) were small (maximum value found is 0.6%), results showed that also the maize flour PS affected the dough firmness; in fact the run 2 sample having a lower amount of maize flour with respect to the run 1 sample showed an higher value of firmness because of an higher amount of maize flour PS. The same result was found for the samples run 3 and 4. Jancurová *et al.* (2009) found that the addition of pseudocereals to wheat flour reduced the mechanical

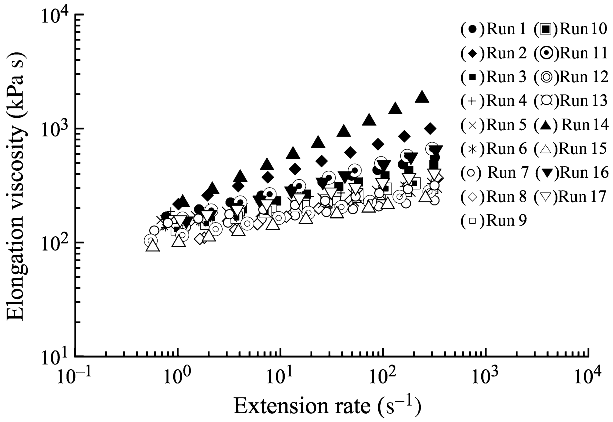

Figure 1 Elongation viscosity as a function of extension rate for all manufactured spaghetti samples.

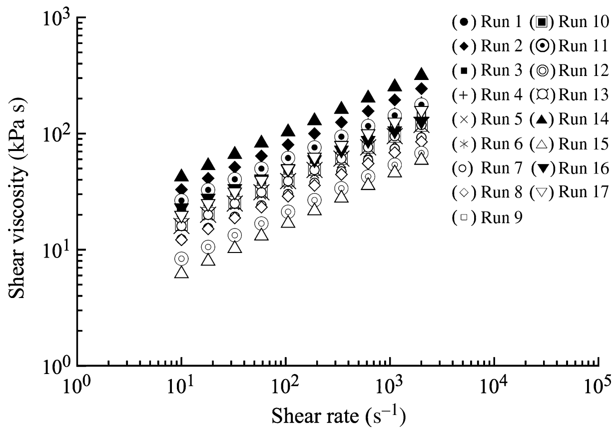

Figure 2 Shear viscosity as a function of shear rate for all manufactured spaghetti samples.

Table 2 Values of the consistency indices (*L* and *K*) and the flow indices (*m* and *n*) obtained by fitting eqns 1 and 2 to the experimental data.

	L	m	K	n
Run 1	177.94^{i}	1.198^{fg}	8.15^{de}	1.395^{d}
Run 2	216.75^{m}	1.270^{l}	13.80^{g}	1.377^{bcd}
Run 3	145.90^{def}	1.208^{gh}	10.82^{f}	1.363^{bc}
Run 4	190.73^{l}	1.096^{ab}	11.48^{f}	1.37^{bcd}
Run 5	162.12^{h}	1.082^{a}	7.03^{cd}	1.353^{b}
Run 6	141.17^{cde}	1.133^{cd}	6.70^{c}	1.372^{bcd}
Run 7	134.10^{cd}	1.097^{ab}	5.09^{b}	1.381^{bcd}
Run 8	95.99^{a}	1.230^{hi}	5.23^{b}	1.366^{bcd}
Run 9	160.65^{gh}	1.103^{abc}	8.95^{e}	1.366^{bcd}
Run 10	131.06^{c}	1.174^{ef}	6.99^{cd}	1.371^{bcd}
Run 11	158.12^{fgh}	1.251^{il}	11.60^{f}	1.358^{b}
Run 12	114.41^{b}	1.159^{de}	3.36^{a}	1.395^{d}
Run 13	153.08^{efgh}	1.126^{bc}	6.69^{c}	1.378^{bcd}
Run 14	214.83^{m}	1.392^{m}	17.62^{h}	1.379^{b,c,d}
Run 15	99.76^{a}	1.162^{de}	2.33^{a}	1.424^{e}
Run 16	147.66^{efg}	1.256^{il}	10.87^{f}	1.324^{a}
Run 17	157.47^{fgh}	1.165^{e}	8.04^{d,e}	1.392^{c,d}

resistance index with respect to the control dough. On the other hand, lower amounts of quinoa in the dough (up to 5 mass %) did not impair the dough's elasticity that means good formability (workability) of dough (Anjum *et al.*, 2007).

The difference in the levels of dough softening observed with the flours under investigation may be caused by the different quality of the starch grains. Mixing of different starches can be used to impart desired properties such as improved pasting behaviour (Chen *et al.*, 2003) and texture (Karam *et al.*, 2005). Properties of blended starches have been reported to be associated with several factors, such as starch concentration (Liu & Lelievre, 1992), mixing ratio of the distinct starches (Chen *et al.*, 2003), chemical composition of the starches, especially the amylose content (Ortega-Ojeda *et al.*, 2004), swelling-solubility power (Chen *et al.*, 2003), and, most important, the interactions between the granules (Obanni & BeMiller, 1997). On the basis of the above considerations, it is difficult to establish the reasons of the observed behaviours of samples on the base of available data.

Obanni & BeMiller (1997) claimed that the greater amylose leaching from one component of some starch blends may inhibit the granular breakdown in the other component. Moreover, in a study of starch gelatinisation in a rice and wheat starch blend, Liu & Lelievre (1992) found at low starch concentration (< 30%) DSC thermograms are the sum of each individual component in the mixture, but non-additive behaviour was found at higher starch concentration because of the competition for water. Ortega-Ojeda & Eliasson (2001) also reported that at low starch concentration (20%), each individual component in the mixture independently gelatinised, whereas at higher starch concentration (50%) they did not.

Regarding the other samples, the trend of the viscosity curves ranged between the maximum and minimum viscosity value measured for the other samples.

Sensory analysis of dry spaghetti samples

The sensorial properties of the dry spaghetti samples are listed in Table 3. In particular, the sensorial attributes of cooked and non-cooked pasta were determined. The overall acceptability of the non-cooked pasta did not show significant difference among samples, with the exception of run 14 sample that had a very positive score probably because of a high value of resistance to break. This result is correlated to that obtained for the rheological properties; in fact the run 14 dough samples showed the higher values of the elongation and shear viscosity and then higher values of the consistency indices compared to the other doughs. The resistance to break of dry spaghetti could be related to several process parameters such as dough rheological properties,

Table 3 Sensory characteristics of dry cooked and non-cooked spaghetti samples.

	Non-cooked spaghetti					Cooked spaghetti							
Samples	Colour	Odour	Homogeneity	Resistance to break	Overall acceptability	Elasticity	Firmness	Bulkiness	Adhesiveness	Colour	Odour	Taste	Overall acceptability
Run 1	$7.4^{cd} \pm 0.6$	$7.2^{ab} \pm 0.7$	$6.6^{cdef} \pm 1{,}2$	$5.6^{a} \pm 0.9$	$6.2^{ab} \pm 0.4$	$5.2^{a} \pm 0.8$	$5.0^{a} \pm 0.7$	$6.6^{bc} \pm 0.5$	$5.8^{a} \pm 1.5$	$6.8^{bc} \pm 0.8$	$6.8^{ab} \pm 1.3$	$6.0^{ab} \pm 0.7$	$6.0^{a} \pm 0.7$
Run 2	$7.0^{bcd} \pm 0.6$	$7.2^{ab} \pm 0.4$	$6.0^{abcdef} \pm 1$	$5.4^{a} \pm 0.9$	$5.8^{ab} \pm 0.4$	$5.0^{a} \pm 1.2$	$4.6^{a} \pm 2.0$	$6.4^{bc} \pm 0.5$	$5.6^{a} \pm 0.5$	$6.4^{abc} \pm 0.9$	$6.8^{ab} \pm 1.3$	$6.0^{ab} \pm 1.2$	$5.8^{a} \pm 0.8$
Run 3	$6.6^{abcd} \pm 0.5$	$6.8^{ab} \pm 0.4$	$6.4^{bcdef} \pm 0.9$	$4.6^{a} \pm 1.0$	$5.8^{ab} \pm 0.4$	$5.4^{a} \pm 1.2$	$5.0^{a} \pm 1.2$	$6.4^{bc} \pm 0.9$	$5.4^{a} \pm 1.1$	$6.4^{abc} \pm 0.9$	$6.2^{ab} \pm 1.3$	$5.6^{ab} \pm 1.1$	$5.6^{a} \pm 0.9$
Run 4	$6.4^{abcd} \pm 1.0$	$6.6^{ab} \pm 0.5$	$6.0^{abcdef} \pm 1.1$	$4.8^{a} \pm 1.2$	$5.8^{ab} \pm 0.7$	$5.2^{a} \pm 1.3$	$5.0^{a} \pm 1.0$	$6.0^{abc} \pm 1.0$	$4.8^{a} \pm 1.6$	$6.4^{abc} \pm 0.9$	$6.2^{ab} \pm 1.3$	$5.6^{ab} \pm 1.5$	$5.2^{a} \pm 1.1$
Run 5	$5.2^{a} \pm 0.4$	$6.2^{ab} \pm 0.7$	$4.6^{ab} \pm 0.9$	$4.2^{a} \pm 1.5$	$4.8^{a} \pm 0.7$	$5.4^{a} \pm 1.1$	$5.4^{a} \pm 0.5$	$5.8^{abc} \pm 0.8$	$5.0^{a} \pm 1.6$	$6.0^{ab} \pm 1.0$	$4.8^{a} \pm 1.6$	$5.8^{ab} \pm 0.8$	$5.0^{a} \pm 0.7$
Run 6	$5.6^{ab} \pm 0.9$	$6.0^{ab} \pm 1.0$	$5.2^{abcd} \pm 0.4$	$4.2^{a} \pm 1.8$	$4.8^{a} \pm 0.7$	$5.8^{ab} \pm 1.1$	$5.6^{a} \pm 0.5$	$6.0^{abc} \pm 0.7$	$4.6^{a} \pm 1.6$	$6.4^{abc} \pm 1.1$	$4.8^{a} \pm 1.8$	$5.8^{ab} \pm 0.8$	$5.2^{a} \pm 0.8$
Run 7	$5.2^{a} \pm 0.7$	$5.8^{a} \pm 1.1$	$4.4^{a} \pm 0.9$	$4.2^{a} \pm 2.0$	$5.2^{ab} \pm 1.2$	$5.2^{a} \pm 0.8$	$5.4^{a} \pm 0.9$	$6.4^{bc} \pm 1.8$	$6.6^{a} \pm 0.9$	$5.4^{ab} \pm 0.9$	$6.2^{ab} \pm 0.8$	$5.2^{ab} \pm 0.8$	$5.6^{a} \pm 1.1$
Run 8	$5.8^{ab} \pm 1.1$	$6.0^{ab} \pm 1.6$	$4.8^{abc} \pm 0.7$	$4.0^{a} \pm 1.1$	$4.8^{a} \pm 0.4$	$5.4^{a} \pm 0.9$	$5.2^{a} \pm 1.1$	$6.4^{bc} \pm 2.1$	$5.4^{a} \pm 1.1$	$5.4^{ab} \pm 0.9$	$6.4^{ab} \pm 0.9$	$5.8^{ab} \pm 0.4$	$5.2^{a} \pm 0.4$
Run 9	$6.2^{abc} \pm 0.7$	$6.4^{ab} \pm 0.9$	$5.8^{abcdef} \pm 0.7$	$5.8^{a} \pm 1.2$	$5.8^{ab} \pm 0.7$	$6.0^{ab} \pm 0.1$	$5.6^{a} \pm 1.1$	$6.4^{bc} \pm 0.9$	$6.0^{a} \pm 0.7$	$6.6^{abc} \pm 1.1$	$7.0^{ab} \pm 1.0$	$6.6^{b} \pm 0.9$	$6.2^{ab} \pm 0.4$
Run 10	$5.8^{ab} \pm 0.4$	$6.4^{ab} \pm 0.9$	$5.8^{abcdef} \pm 1.2$	$5.4^{a} \pm 1.4$	$5.6^{ab} \pm 1.0$	$5.8^{ab} \pm 0.4$	$6.2^{a} \pm 0.8$	$6.0^{abc} \pm 0.7$	$5.8^{a} \pm 0.4$	$7.0^{bc} \pm 1.0$	$7.0^{ab} \pm 0.7$	$6.6^{a} \pm 0.5$	$6.0^{a} \pm 0.1$
Run 11	$6.6^{abcd} \pm 1.0$	$6.6^{ab} \pm 1.0$	$5.8^{abcdef} \pm 1.2$	$5.2^{a} \pm 1.2$	$5.8^{ab} \pm 1.2$	$5.4^{a} \pm 0.5$	$6.4^{a} \pm 0.5$	$5.6^{abc} \pm 1.1$	$5.6^{a} \pm 1.1$	$6.0^{ab} \pm 0.7$	$6.0^{ab} \pm 0.7$	$5.8^{ab} \pm 0.4$	$5.5^{a} \pm 0.7$
Run 12	$7.4^{cd} \pm 0.5$	$7.2^{ab} \pm 0.7$	$7.2^{ef} \pm 0.7$	$5.2^{a} \pm 1.1$	$6.0^{ab} \pm 1.0$	$6.2^{ab} \pm 0.4$	$6.4^{a} \pm 0.5$	$7.2^{c} \pm 0.4$	$6.4^{a} \pm 1.1$	$7.0^{bc} \pm 1.2$	$6.8^{ab} \pm 1.6$	$5.6^{ab} \pm 1.1$	$5.8^{a} \pm 1.3$
Run 13	$5.4^{a} \pm 0.9$	$6.2^{ab} \pm 0.7$	$4.8^{abc} \pm 1.2$	$5.6^{a} \pm 0.9$	$6.2^{ab} \pm 1.1$	$6.2^{ab} \pm 0.8$	$6.2^{a} \pm 0.4$	$5.0^{ab} \pm 1.0$	$5.2^{a} \pm 0.8$	$4.8^{a} \pm 1.3$	$5.2^{a} \pm 1.3$	$4.8^{a} \pm 0.4$	$5.4^{a} \pm 0.5$
Run 14	$7.8^{d} \pm 0.7$	$7.6^{b} \pm 1.0$	$7.4^{f} \pm 1.2$	$8.2^{b} \pm 0.7$	$8.0^{c} \pm 0.6$	$7.2^{b} \pm 0.4$	$6.4^{a} \pm 1.3$	$4.4^{a} \pm 0.5$	$5.0^{a} \pm 1.2$	$8.0^{c} \pm 0.7$	$8.0^{b} \pm 0.7$	$8.2^{c} \pm 0.4$	$7.4^{b} \pm 0.4$
Run 15	$6.2^{abc} \pm 0.4$	$6.6^{ab} \pm 0.5$	$5.8^{abcdef} \pm 0.7$	$4.8^{a} \pm 0.8$	$5.8^{ab} \pm 0.7$	$5.4^{a} \pm 0.9$	$6.4^{a} \pm 0.5$	$6.6^{bc} \pm 0.8$	$6.4^{a} \pm 0.9$	$5.6^{ab} \pm 1.1$	$5.6^{ab} \pm 1.1$	$5.2^{ab} \pm 0.8$	$5.4^{a} \pm 0.5$
Run 16	$6.2^{abc} \pm 0.4$	$6.8^{ab} \pm 0.4$	$6.8^{def} \pm 1.2$	$5.6^{a} \pm 0.9$	$6.2^{ab} \pm 0.7$	$5.8^{ab} \pm 0.4$	$6.4^{a} \pm 0.5$	$5.4^{abc} \pm 0.9$	$5.6^{a} \pm 0.5$	$5.6^{ab} \pm 0.9$	$6.2^{ab} \pm 1.3$	$6.4^{ab} \pm 1.1$	$6.0^{a} \pm 0.1$
Run 17	$5.8^{ab} \pm 1.1$	$6.6^{ab} \pm 0.9$	$5.4^{abcde} \pm 1.0$	$5.8^{a} \pm 0.7$	$6.4^{b} \pm 0.5$	$5.6^{ab} \pm 0.9$	$6.2^{a} \pm 0.8$	$5.6^{abc} \pm 0.5$	$5.4^{a} \pm 0.5$	$6.0^{ab} \pm 1.0$	$6.0^{ab} \pm 1.6$	$6.0^{ab} \pm 0.7$	$6.0^{a} \pm 0.7$

spaghetti composition, thermal treatment to which the spaghetti samples were subjected during the drying process. In fact, as reported in literature, severe drying conditions may promote the formation of a strong protein network, responsible for the higher resistance of pasta to compression and tensile forces (Petitot *et al.*, 2009). The surface response plot was generated to better illustrate the dependences between the selected variables (Fig. 3). As can be observed from the above figure, the overall acceptability of non-cooked spaghetti increases with the increase of the maize flour PS and the decrease of the quinoa flour (R = 0.9966, adjusted R^2 = 0.9917). In particular, the maximum value of the overall acceptability was observed at the lowest concentration of the quinoa flour (0%) and at a high concentration of maize flour PS (27.03%), whereas the soy flour did not affect this attribute. This composition corresponded to that of the run 14 sample.

Also in the case of cooked spaghetti, the overall acceptability of the run 14 sample significantly differs to the other samples showing the highest score. This result is because of the improvement of the taste caused to the absence of the quinoa flour. The quinoa constituents bring about a bitter taste that affects negatively the overall acceptability of the pasta (Stuardo & San Martín, 2008). It is worth noting that all samples were scored closed or above acceptability threshold (i.e., five) from all sensorial attributes point of view.

To better understand the individual and interactive effects of quinoa flour, soy flour and maize flour PS on the cooked spaghetti overall acceptability, the surface response plots were analysed. Also in this case, a high concentration of maize flour PS (26.17%) and the lowest concentration of quinoa flour (0%) corresponded to a highest score of overall acceptability (data not shown). Moreover, as can be observe in Fig. 4 the maximum value of overall acceptability was obtained at the maize flour PS concentration of 26.17% and at the soy flour concentration of 4.25% (R = 0.9984, adjusted R^2 = 0.9957).

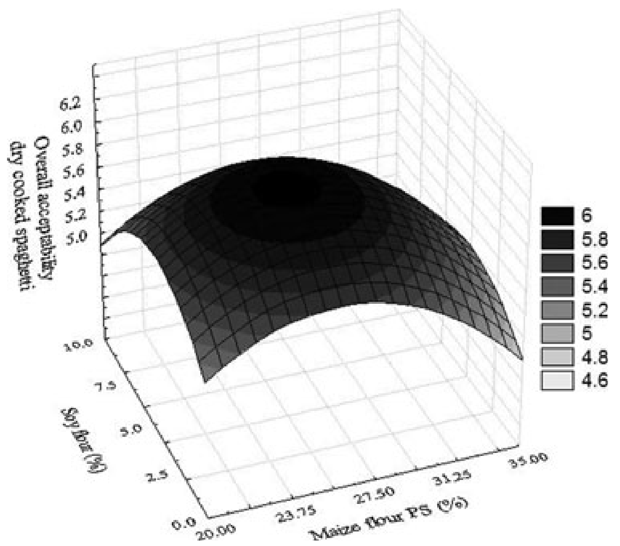

Figure 4 Effect of the interaction [Soy flour]–[Maize flour PS] on the independent variable. Overall acceptability of dry cooked spaghetti.

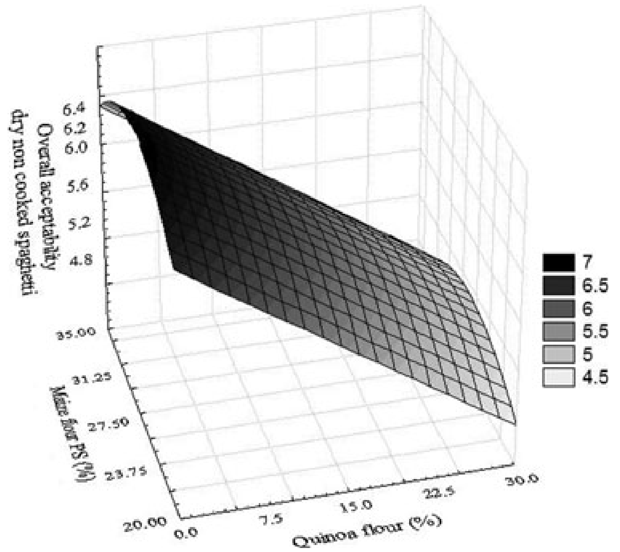

Figure 3 Effect of the interaction [Quinoa flour]–[Maize flour PS] on the independent variable. Overall acceptability of dry non-cooked spaghetti.

Sensory analysis of fresh spaghetti samples

Table 4 shows the sensorial properties of the fresh spaghetti samples. Results highlight that both non-cooked and cooked fresh pasta did not show significant differences among the sample. Moreover, all the investigated sensorial attributes had a score very positive (above 7), only the bulkiness and adhesiveness attributes of the cooked pasta showed values closed to the threshold limit.

The differences between samples were more marked for the dry pasta. Therefore, most probably the thermal process is the main responsible of the modifications of the pasta structure.

The surface response plot was generated to better illustrate the dependences between the selected variables. The overall acceptability for fresh non-cooked spaghetti increases with the increase of the maize flour PS and with the decrease of the quinoa flour (data not shown). In particular, the maximum value of overall acceptability was obtained at a high concentration of maize flour PS (30.78%) and at the lowest concentration of quinoa flour (0%). Regarding the fresh cooked spaghetti, only the maize flour PS affected the overall acceptability

Table 4 Sensory characteristics of fresh cooked and non-cooked spaghetti samples

	Non-cooked spaghetti					Cooked spaghetti							
Samples	Colour	Odour	Homogeneity	Bulkiness	Overall acceptability	Elasticity	Firmness	Bulkiness	Adhesiveness	Colour	Odour	Taste	Overall acceptability
Run 1	$7.9^{a} \pm 0.2$	$8.0^{c} \pm 0.1$	$8.0^{b} \pm 0.3$	$8.8^{b} \pm 0.4$	$8.3^{c} \pm 0.4$	$6.0^{b} \pm 0.3$	$6.9^{a} \pm 0.2$	$4.9^{a} \pm 0.4$	$5.4^{a} \pm 0.4$	$7.6^{a} \pm 0.5$	$7.8^{c} \pm 0.4$	$7.6^{c} \pm 0.9$	$7.0^{abc} \pm 1.0$
Run 2	$8.0^{a} \pm 0.1$	$8.0^{c} \pm 0.1$	$7.8^{b} \pm 0.3$	$8.8^{b} \pm 0.4$	$8.3^{c} \pm 0.4$	$6.1^{b} \pm 0.2$	$6.8^{a} \pm 0.4$	$5.5^{a} \pm 0.3$	$5.6^{a} \pm 0.5$	$7.6^{a} \pm 0.5$	$7.7^{bcd} \pm 0.4$	$7.5^{c} \pm 0.5$	$7.0^{abc} \pm 1.0$
Run 3	$7.8^{a} \pm 0.2$	$7.9^{c} \pm 0.2$	$8.7^{c} \pm 0.4$	$8.9^{b} \pm 0.2$	$8.1^{bc} \pm 0.2$	$4.6^{a} \pm 0.4$	$6.9^{a} \pm 0.2$	$5.5^{a} \pm 0.3$	$5.4^{a} \pm 1.1$	$7.8^{a} \pm 0.4$	$7.7^{c} \pm 0.4$	$7.9^{c} \pm 0.2$	$7.2^{bc} \pm 0.3$
Run 4	$8.0^{a} \pm 0.3$	$7.6^{bc} \pm 0.4$	$8.7^{c} \pm 0.4$	$9.0^{b} \pm 0.1$	$8.0^{bc} \pm 0.3$	$6.1^{b} \pm 0.2$	$6.8^{a} \pm 0.4$	$5.4^{a} \pm 0.5$	$4.8^{a} \pm 1.6$	$7.5^{a} \pm 0.5$	$7.8^{c} \pm 0.3$	$7.5^{c} \pm 0.5$	$6.7^{abc} \pm 0.3$
Run 5	$8.0^{a} \pm 0.3$	$7.5^{abc} \pm 0.5$	$9.0^{c} \pm 0.1$	$8.0^{a} \pm 0.3$	$7.0^{a} \pm 0.3$	$6.3^{bc} \pm 0.3$	$7.0^{ab} \pm 0.3$	$5.8^{a} \pm 0.8$	$5.0^{a} \pm 1.6$	$7.6^{a} \pm 0.5$	$7.9^{c} \pm 0.2$	$7.4^{c} \pm 0.9$	$7.5^{c} \pm 0.3$
Run 6	$7.9^{a} \pm 0.2$	$7.0^{ab} \pm 0.3$	$7.9^{b} \pm 0.5$	$8.9^{b} \pm 0.2$	$7.0^{a} \pm 0.5$	$6.0^{b} \pm 0.4$	$7.4^{ab} \pm 0.4$	$6.0^{a} \pm 0.7$	$4.6^{a} \pm 1.1$	$7.7^{a} \pm 0.4$	$7.0^{abd} \pm 0.3$	$5.8^{a} \pm 0.8$	$5.9^{a} \pm 0.5$
Run 7	$7.0^{b} \pm 0.3$	$6.9^{a} \pm 0.2$	$7.0^{a} \pm 0.3$	$8.9^{b} \pm 0.2$	$7.0^{a} \pm 0.5$	$6.8^{d} \pm 0.3$	$7.4^{ab} \pm 0.4$	$6.1^{a} \pm 0.7$	$6.2^{a} \pm 0.8$	$7.7^{a} \pm 0.4$	$6.8^{a} \pm 0.4$	$5.8^{a} \pm 0.4$	$6.0^{ab} \pm 0.7$
Run 8	$7.7^{a} \pm 0.3$	$7.5^{abc} \pm 0.5$	$8.8^{c} \pm 0.3$	$8.9^{b} \pm 0.2$	$7.5^{ab} \pm 0.5$	$7.1^{d} \pm 0.2$	$7.0^{ab} \pm 0.3$	$5.6^{a} \pm 1.3$	$5.4^{a} \pm 1.1$	$7.9^{a} \pm 0.2$	$7.3^{abcd} \pm 0.4$	$5.8^{ab} \pm 0.4$	$6.9^{abc} \pm 0.5$
Run 9	$7.7^{a} \pm 0.3$	$7.5^{abc} \pm 0.5$	$8.9^{c} \pm 0.2$	$8.9^{b} \pm 0.2$	$7.6^{abc} \pm 0.4$	$6.9^{d} \pm 0.4$	$6.9^{a} \pm 0.2$	$5.6^{a} \pm 1.3$	$5.4^{a} \pm 1.1$	$7.9^{a} \pm 0.2$	$7.3^{abcd} \pm 0.4$	$5.8^{ab} \pm 0.4$	$6.9^{abc} \pm 0.5$
Run 10	$7.9^{a} \pm 0.2$	$7.4^{abc} \pm 0.5$	$8.8^{c} \pm 0.3$	$8.7^{b} \pm 0.4$	$8.0^{bc} \pm 0.3$	$7.3^{d} \pm 0.3$	$7.6^{b} \pm 0.2$	$6.0^{a} \pm 0.7$	$5.8^{a} \pm 0.4$	$6.0^{b} \pm 1.0$	$7.5^{bcd} \pm 0.5$	$6.9^{bc} \pm 0.5$	$7.8^{c} \pm 0.4$
Run 11	$7.9^{a} \pm 0.2$	$8.0^{c} \pm 0.1$	$8.0^{b} \pm 0.3$	$8.8^{b} \pm 0.4$	$8.3^{c} \pm 0.4$	$6.0^{b} \pm 0.3$	$6.9^{a} \pm 0.2$	$4.9^{a} \pm 0.4$	$5.4^{a} \pm 0.4$	$7.6^{a} \pm 0.5$	$7.8^{c} \pm 0.4$	$7.6^{c} \pm 0.9$	$7.0^{abc} \pm 1.0$
Run 12	$8.0^{a} \pm 0.1$	$8.0^{c} \pm 0.1$	$7.8^{b} \pm 0.3$	$8.8^{b} \pm 0.4$	$8.3^{c} \pm 0.4$	$6.1^{b} \pm 0.2$	$6.8^{a} \pm 0.4$	$5.5^{a} \pm 0.3$	$5.6^{a} \pm 0.5$	$7.6^{a} \pm 0.5$	$7.7^{cd} \pm 0.4$	$7.5^{c} \pm 0.5$	$7.0^{abc} \pm 1.0$
Run 13	$7.8^{a} \pm 0.2$	$7.9^{c} \pm 0.2$	$8.7^{c} \pm 0.4$	$8.9^{b} \pm 0.2$	$8.1^{bc} \pm 0.2$	$4.6^{a} \pm 0.4$	$6.9^{a} \pm 0.2$	$5.5^{a} \pm 0.3$	$5.4^{a} \pm 1.1$	$7.8^{a} \pm 0.4$	$7.7^{c} \pm 0.4$	$7.9^{c} \pm 0.2$	$7.2^{bc} \pm 0.3$
Run 14	$8.0^{a} \pm 0.3$	$7.6^{bc} \pm 0.4$	$8.7^{c} \pm 0.4$	$9.0^{b} \pm 0.1$	$8.0^{bc} \pm 0.3$	$6.1^{b} \pm 0.2$	$6.8^{a} \pm 0.4$	$5.4^{a} \pm 0.5$	$4.8^{a} \pm 1.6$	$7.5^{a} \pm 0.5$	$7.8^{c} \pm 0.3$	$7.5^{c} \pm 0.5$	$6.7^{abc} \pm 0.3$
Run 15	$8.0^{a} \pm 0.3$	$7.5^{abc} \pm 0.5$	$9.0^{c} \pm 0.1$	$8.0^{a} \pm 0.3$	$7.0^{a} \pm 0.3$	$6.3^{bc} \pm 0.3$	$7.0^{ab} \pm 0.3$	$5.8^{a} \pm 0.8$	$5.0^{a} \pm 1.6$	$7.6^{a} \pm 0.5$	$7.9^{c} \pm 0.2$	$7.4^{c} \pm 0.9$	$7.5^{c} \pm 0.3$
Run 16	$7.9^{a} \pm 0.2$	$7.0^{ab} \pm 0.3$	$7.9^{b} \pm 0.5$	$8.9^{b} \pm 0.2$	$7.0^{a} \pm 0.5$	$6.0^{b} \pm 0.4$	$7.4^{ab} \pm 0.4$	$6.0^{a} \pm 0.7$	$4.6^{a} \pm 1.1$	$7.7^{a} \pm 0.4$	$7.0^{ab} \pm 0.3$	$5.8^{ab} \pm 0.8$	$5.9^{a} \pm 0.5$
Run 17	$7.0^{b} \pm 0.3$	$6.9^{a} \pm 0.2$	$7.0^{a} \pm 0.3$	$8.9^{b} \pm 0.2$	$7.0^{a} \pm 0.5$	$6.8^{cd} \pm 0.3$	$7.4^{ab} \pm 0.4$	$6.1^{a} \pm 0.7$	$6.2^{a} \pm 0.8$	$7.7^{a} \pm 0.4$	$6.8^{a} \pm 0.4$	$5.8^{ab} \pm 0.4$	$6.0^{ab} \pm 0.7$

(data not shown) and the maximum value was recorded at a flour concentration of 26.08%.

Conclusions

In this work, an experimental design was used in order to optimise the formulation of the non-conventional gluten-free pasta and to point out the effects of the quinoa, maize and soy flours used on the quality characteristics of the manufactured spaghetti. In particular, the rheological properties of doughs and the sensorial attributes of the spaghetti samples were evaluated. Results highlight that the sample with high content of maize and without quinoa had the higher values of elongation and shear viscosity, therefore a higher firmness. Moreover, also the maize flour PS affected the rheological properties by increasing the dough firmness. The other samples showed a trend that ranged between the maximum and minimum viscosity value measured for the other samples.

Regarding the sensorial analysis, the overall acceptability of the cooked and non-cooked dry spaghetti did not differ significantly, with the exception of the sample with the highest maize content and without quinoa. Both cooked and non-cooked fresh spaghetti samples did not show statistically different values from overall acceptability point of view and the scores were positive for most the sensorial attributes.

In conclusion, the obtained results seem to be a good compromise for the choice of products that bring benefits to health. In fact, both fresh and dry non-conventional pasta tested in this study could be a suitable alternative to conventional pasta based on their superior nutritive value.

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