Assessment of techno-functional and sensory attributes of tiger nut fresh egg tagliatelle

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Abstract

This work aims to evaluate the effect of tiger nut flour -TNF- (rich in insoluble fiber, minerals and lipids of healthy fatty acid profile) incorporation on the techno-functional and sensory attributes of durum wheat fresh egg tagliatelle. Durum wheat semolina was replaced by 10, 20 and 30% (w/w) of TNF and the resultant tiger nut tagliatelles were compared to traditional pasta (100% durum semolina). The maximum substitution level was chosen in order to obtain tagliatelle with fair techno-functional properties and acceptable sensory quality. In addition, the 30% substitution level assures a product with more than 3% of fiber content. The cooking properties, texture, colour attributes, sensory profile and water uptake kinetics of tagliatelle were evaluated. The proximate chemical composition and particle size distribution of raw materials was assessed as well. The higher cooking loss, water absorption ratios and swelling indexes associated with higher substitution levels of TNF resulted in a darker and stickier product, with a lower firmness, hardness and cohesive structure. The overall acceptability of tiger nut pasta depends more on visual and textural characteristics than on taste. No significant

changes on the initial water absorption rate during cooking were observed between the control and tiger nut pasta.

Keywords: fresh pasta; tiger nut; texture; colour; sensory attributes; cooking properties.

1. Introduction

Pasta is a staple food produced mostly by mixing durum wheat semolina and water. It is widely consumed across the world and has become a popular carbohydrate dish thanks to its long shelf life, low cost, simple preparation and sensory characteristics (Mastromatteo et al. 2012; Foschia et al. 2013). Pasta products made from durum wheat are characterized by the proteins that form a viscoelastic network and their optimal dough properties during the mixing and extrusion steps (Mariotti et al. 2011), thus producing better strength and stability in the final product. Common pasta, produced by using durum wheat semolina, has better quality characteristics (cohesive and elastic dough, minimal cooking loss, no stickiness, reasonable firmness after cooking, etc.) than non-conventional pasta. Gluten is the key of the structure-forming protein in flour, and it is responsible for the viscoelastic properties of the dough. Gluten contributes to the appearance and texture of many cereal products, especially of baked goods. Total or partial gluten replacement results in major problems and work for bakers, and presently, many gluten free products available on the market are of reduced quality, presenting poor mouthfeel and flavour (Arendt et al. 2002). Furthermore, gluten is considered the most important factor in terms of pasta cooking quality, and it is responsible for the elasticity and "al dente" texture of pasta. It is perhaps the most important pasta quality parameter, as it is highly appreciated by consumers. Due to the increased concern for health awareness, nutritious pasta products rich in fiber and micronutrients -and having a low glycaemic index- may be preferable. In the last years, various healthy ingredients have been used in the production of pasta in order to enhance its nutritional profile or confer different functional properties. However, the amount of raw material that can be used as a substitute for wheat semolina, or which can be added to wheat flour, represents a compromise between the nutritional improvement and satisfactory sensory properties of pasta (Chillo et al. 2008). The possibility of using non-durum wheat ingredients to improve the nutritional or functional characteristics of pasta products has been widely investigated. Legumes such as peas, field beans, lentils, field peas, split peas, faba beans or chickpea flours high in proteins, have been used to improve the nutritional value of pasta

(Wójtowicz and Moscicki 2014; Gallegos-Infante et al. 2010). Other authors have studied the effect of adding soluble and insoluble fibers, vitamins and minerals on pasta quality (Aravind et al. 2012a; Aravind et al. 2012b; Knuckles et al. 1997). The addition of dietary fiber can further reduce the glycaemic index and introduce other health benefits (Aravind et al. 2012a; Yokoyama et al. 1997). Recently, Kaur et al. (2012) analysed the functional properties of pasta enriched with a variable content of cereal bran. Results are promising as 15% (wheat, rice and oat) or 10% (barley) replacement levels can be achieved without negatively affecting the physicochemical, sensory and cooking properties of dried pasta. Nevertheless, most of these works are about dried pasta and to the authors' knowledge, no research has been conducted on composite fresh egg pasta, based on replacing durum wheat semolina with tiger nut flour. Tiger nut (Cyperus esculentus L.) is a sweet brown coloured tuber that is grown worldwide in its different varieties, in warm and temperate regions such as Southern Europe and Africa. Although it is underutilised in many countries of the world, tiger nut is an important crop in Spain (Ukwuru et al. 2011), where it is used to produce a milky beverage -for human consumption- called "horchata de chufa". It is a tuber that is rich in carbohydrates, lipids, fiber, some minerals (potassium, phosphorus and calcium) and vitamin E and C (Sánchez-Zapata et al. 2012). This tuber is also rich in lipids (23-31g/100g) with a fatty acid profile similar to olive and hazelnut oil. Consequently, in addition to its high fiber content (8-15g/100g), this confers healthy properties to this tuber (Alegría-Torán and Farré-Rovira 2003; Sánchez-Zapata et al. 2012). Recently, many authors have shown a growing interest in the potential of the tiger nut as an important source of food nutrients. Accordingly, scientific studies on tiger nuts have been conducted mainly focusing on the qualitative and quantitative assessment of its nutritional properties and on the utilization of these components for industrial food purposes. Tiger nut flour could be used in bakery products (Chinma et al. 2010) as well as elaborating gluten-free bread with good baking and nutritional characteristics (Aguilar et al. 2014; Demirkesen et al. 2013). By considering the tiger nut as a potential source of food nutrients, this work was aimed at studying the effect of tiger nut flour incorporation, up to 30%, on the techno-functional and sensory properties of fresh egg tagliatelle. The water absorption index, swelling index, cooking loss, firmness, hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, colour and sensory attributes were evaluated. A maximum 30% substitution level was chosen in order to obtain acceptable quality standard tagliatelle with more than 3% fiber content ("source of fiber").

2. Materials and methods

2.1. Raw materials

Commercial durum wheat semolina -abbreviated as DWS- (Harinas Villamayor, S.A., Huesca, Spain), tiger nut flour -abbreviated as TNF- (Tigernuts Traders S.L., Valencia, Spain) and pasteurised liquid egg -abbreviated as PLE (Avícola Llombai, S.A., Valencia, Spain) was used.

The raw materials were analysed for their moisture content, ash, fat, protein and fiber, according to the American Association of Cereal Chemists approved methods (AACC, 2000). The digestible carbohydrates were determined by difference (100 – per cent estimated proximate chemical composition).

The particle size distribution (PSD) of both DWS and TNF, and their mixtures (10, 20 and 30% replacement level) was determined by using a MasterSizer® Laser Diffraction Particle Size Analyser (Malvern Instrument Ltd., Malvern, England), equipped with a PS 65 (dry sample). Distributions were made in triplicate and for each sample, 10–20 g of flour mixture was used. Size distribution was quantified as the relative volume of particles in size bands, presented as size distribution curves (Malvern MasterSizer Micro software v 5.40). The PSD parameters recorded included largest particle size d(0.9), mean particle volume d(0.5), smallest particle size d(10), Sauter mean diameter (D[3,2]), and mean particle diameter/volume mean diameter (D[4,3]). The Span value or measurement of the width of the size distribution, calculated from the values of standard percentiles, was complementarily reported. The wider the particle size distribution, the bigger the Span becomes. The fundamental size distribution by laser diffraction method is expressed in terms of equivalent spheres (the results are volume based), so the number distributions should only be considered as a guide of the volume distribution.

2.2. Experimental design

The significance of wheat semolina replacement by tiger nut flour at 10, 20 and 30% (w/w) was assessed through changes on the dough characteristics (texture, colour), cooking properties (water absorption index (WAI), swelling index (SI), cooking loss (%CL)) and properties of the ready-to-eat product, that is, the cooked pasta (texture, colour and sensory analysis). For this purpose, tagliatelle samples were tested, before and after cooking, for their mass, water content, dimensions, colour and mechanical properties (analysis explained below). All the measurements were made in triplicate. In addition, a sensory analysis was performed on the cooked samples, as described on section 2.8.

Wheat semolina was replaced with tiger nut flour up to 30% (w/w) to obtain pasta with more than 3% (w/w) of fiber content ("source of fiber"), according to the Nutritional Claims for Dietary Fiber Foods (Official Journal of European Commission, 2006). The fiber content was estimated considering the chemical composition of the raw materials (Table 1). The obtained values for 0, 10, 20 and 30% samples were, respectively, 0.16, 1.55, 2.94 and 4.33 g/100 g pasta.

As a second step, control and 30% samples were compared in terms of water gain kinetics during cooking. The procedure and analysis are detailed on section 2.9.

2.3. Fresh egg pasta preparation

Plain pasta (used as control, 0%) was obtained by mixing durum wheat semolina (71% w/w), pasteurized liquid egg (13% w/w) and water (16% w/w). Tiger nut flour was incorporated into the basic formula at 10, 20 and 30% replacement level (w/w). Corresponding pasta products are named henceforth as 10%, 20% and 20%, respectively. Dried (semolina/tiger nut flour) and liquid (egg/water) components were separately mixed at low speed (set 2) in a medium speed electric cooking device (Thermomix TM-31, Vorwerk Spain M.S.L., S.C., Madrid) for 45 s. The resulting blends were then kneaded for 2.5 min in the same cooking device. The Doughs were rested for 20 min inside a plastic bag in order to enable sample relaxation. Afterwards, the tagliatelle was formed by using a domestic pasta making machine (Simplex SP150, Imperia, Italia) coupled with a specific motor (A2500, Imperia, Italy). A Lamination process was performed in order to obtain a sheet of 1.30 ± 0.12 mm that was then cut into tagliatelle of 4.12 ± 0.03 mm width. Prior to cooking, the tagliatelles were rested for 10 min more in order to prevent stickiness.

2.4. Pasta cooking

The cooking trial was made in triplicate for each pasta formulation. The cooked pasta was prepared by boiling 25 g of 7-cm-long samples in deionized water (300 ml). The water volume was maintained at 90% of the initial volume by adding boiling water and covering the flasks to avoid evaporation losses. At 4 min (optimal cooking time for 100% wheat semolina pasta, as assessed by AACC method 66-50, AACC 2000), the tagliatelles were removed from the flasks, the cooking process was rapidly stopped with 50 ml of cold deionized water, and finally the samples were drained for 2 min and analysed.

2.5. Cooking properties

The water absorption index (WAI, g/g) was calculated from the mass gain and increase in water content after cooking (Eq. 1). The water content (x_w, g water/ g product) was determined according to the AACC 44-40 method (AACC 2000).

$$WAI=\frac{m_c \cdot x_{wc} - m_o \cdot x_{wo}}{m_o} \quad (1)$$

The cooking loss (amount of solid substance lost to cooking water, %CL) was determined according to the AACC approved method 16-50 (AACC 2000). After the cooking process, the cooking and rinse waters were collected in an aluminium vessel and evaporated to dryness in an air oven at 100ºC. The residue was weighed and reported as a percentage of the starting material.

The tagliatelle dimensions (thickness and width) were measured with a caliper (PCE-DCP 200N, PCE Ibérica S.L., Albacete, Spain). The swelling index (SI) was expressed as relative volume changes (%) between the uncooked and cooked samples.

2.6. Colour of dough and cooked pasta

The colour of the fresh egg tagliatelle was measured through the surface reflectance spectra obtained in a spectrocolourimeter (Minolta CM-3600D) between 400 and 700 nm (iluminant D65, 10° standard observer), using white background. From the reflectance spectra, CIEL*a*b*colour coordinates could be obtained: L* (lightness), a* (redness-greenness) and b* (yellowness-blueness). The results were expressed in terms of both chromatic magnitudes, colour saturation ($C^*_{ab} = \sqrt{a^{*2} + b^{*2}}$) and hue angle ($h^*_{ab} = \mathrm{arctg}\frac{b^*}{a^*}$), and as the total colour difference ($\Delta E = \sqrt{(L^*_{TNF} - L^*_{DWS}) + (a^*_{TNF} - a^*_{DWS}) + (b^*_{TNF} - b^*_{DWS})}$) between tiger nut pasta and wheat semolina pasta.

2.7. Mechanical properties of dough and cooked pasta

A TA.XT2 Texture Analyser (Stable Micro Systems, Godalming, Surrey, UK) was used to perform the texture profile analysis (TPA), as well as the AACC Method 16-50 (AACC 2000) on the dough (D) and cooked pasta (CP). The TPA analysis provides a significant measurement of the textural characteristics of the product (Szczesniak 2002; Olivera and Salvadori 2006) and the dough machinability (Angioloni and Dalla Rosa 2007). The settings of the experiments were the following: 50% compression, 30 mm diameter probe (flat-end aluminium compression disc), test speed 1 mm/s, 75 s gap between compressions, 5 kg load cell. Six replicates (on 1 mm width cooked pasta slices or 10 mm width dough sheet) were made for each pasta formulation. The data was processed using Texture Exponent 6.1.7 (Stable Micro Systems Software).

The AACC Method 16-50 (AACC 2000) (Gallegos-Infante et al. 2010) was performed to assess changes in pasta firmness due to cooking. Five 7-cm-long adjacent strands were cut at 0.17 mm/s until total sample deformation. Five replicates were considered for each pasta formulation.

2.8. Sensory analysis

The sensory analysis of cooked pasta, based on durum wheat semolina (control, 0%) or partially substituted with tiger nut flour at 10, 20 and 30% levels, was performed with a panel of forty untrained judges (52.5% males and 47.5% females aged 18 to 64) using a hedonic test with a five-point rating scale, as previously described by Sereewat et al. (2015). Each attribute was rated from 1 (dislike very much) to 5 (like very much). The samples were served at room temperature in white plastic dishes, randomly coded with three digit numbers. The panelists tasted approximately the same amount of each sample and mineral water was provided to the assessors to rinse their mouths between samples. The evaluated attributes were aspect, colour intensity, texture (firmness), taste intensity and overall quality.

2.9. Cooking kinetics

The cooking procedure was described on section 2.2, but analyses (mass, water content) were performed on the cooked pasta at given times (0, 60,120, 180, 240 and 300 s). Three replicates were obtained for each cooking time and for durum wheat (0%) and tiger nut (30%) pasta.

2.10. Statistical analysis

Analysis of variance (ANOVA) was carried out by using Statgraphics Plus software version 5.1. (StatPoint Technologies, Inc., Warrenton, VA) in order to evaluate the effects of partial semolina replacement by tiger nut flour on the measured parameters. The significance level was $p = 0.05$ in all cases.

3. Results and Discussion

3.1. Proximate chemical composition of raw materials

The proximate chemical composition of each raw material used for the pasta preparation (durum wheat semolina –DWS-, tiger nut flour –TNF- and pasteurized liquid egg -PLE) is summarized in Table 1. The results are similar to those reported by (Gull et al. 2015) for DWS and (Aguilar et al. 2014) for TNF. However, the fiber content evidenced in this study for DWS was lower. The partial substitution of wheat semolina by tiger nut flour in the pasta formulation may decrease its protein content but may achieve a notable enhancement of its fiber, mineral and fat contents. In addition, the use of tiger nut implies a reduction in the carbohydrate content of the fresh pasta, owing to the dilution effect of tiger nut flour, as semolina has a higher carbohydrate content than tiger nut flour.

The pasta quality and cooking properties are dependent on the protein-starch developed matrix (Brennan and Tudorica 2007). Some pasta characteristics such as firmness, cooking loss and stickiness can be associated with the pasta's protein content, gluten strength and starch composition. The incorporation of tiger nut flour in the pasta formulae -which is rich in starch, fiber and lipids, and poor in proteins- could have an effect on the protein-starch matrix force unions. On the other hand, increasing the amount of tiger nut flour improves the nutritional value of the fresh egg pasta compared to the control wheat pasta, in terms of its fiber and mineral contents. A 30% substitution level leads to a pasta with approximately 4% w/w of fiber, which can be considered in the market as a "source of fiber" product. And as reported by Cokuner et al. 2002; Linssen et al. 1988, tiger nut flour is rich in unsaturated fatty acids, especially oleic acid.

3.2. Cooking properties

Cooking loss, a measure of the amount of solids lost in the cooking water, is considered to be an important indicator of pasta quality (Gull et al. 2015). As reported by Silva et al. (2016), the pasta that features up to 6g/100g solid loss is considered quite good. Up to 8g/100g is considered regular, and above 10 g/100g is considered poor. Consequently, durum wheat and 10 and 20% tiger nut based pasta can be considered quite good (3.1, 3.9 and 4.7 g/100g, respectively). Only for the highest substitution level (30%), the cooking loss (6.1g/ 100g) was slightly higher than the limit considered for good quality pasta. Furthermore, solid losses gradually increased ($p<0.05$) with the increase in TNF levels. A similar trend has been reported for pasta products incorporating non-durum wheat ingredients such as brown rice and corn

(Silva et al. 2016), millet flour and carrot pomace (Gull et al. 2015), teff (Hager et al. 2012), insoluble dietary fiber (Aravind et al. 2012b), white and yellow beans and lentils (Wójtowicz and Moscicki 2014). The degree of starch gelatinisation and the strength of the retrograded starch network surrounding the gelatinised starch are decisive factors for the attained cooking loss (Resmini and Pagani 1983), as they can act as a binder to form a more cohesive structure with less cooking loss (Silva et al. 2016). The reduction of wheat semolina content -when it was partially substituted by tiger nut flour, with less proteins and more fat and fiber-, produces the development of a weaker gluten network in which swelled starch granules are worse entrapped. In addition, it might reduce the total accessible starch content due to the amount of fiber provided by the tiger nut flour and the reduction of amylose, which leads to a reduction in the retrograded starch content and consequently the final viscosity (Silva et al. 2016). Therefore, the loosely bound gelatinised starch is more easily leached from the product surface into the cooking water (Resmini and Pagani 1983). However, it is important to note that tiger nut flour and the conditions applied during the pasta production created a sufficiently continuous and less soluble structure, accounting for the obtained %CL values (much lower than those obtained by Silva et al (2016) or Gull et al. 2015)).

The water absorption index (WAI) was significantly higher in pasta products enriched with tiger nut flour (values ranging from 76 to 85 g absorbed water/100g) compared to durum wheat pasta (41 g absorbed water/100g). No clear links between the amount of tiger nut flour added and WAI values were found. Similar results were obtained by (Kaur et al. 2012) for pasta incorporating cereal bran, but they differed from those reported by (Gull et al. 2015) for pasta prepared with millet flour and carrot pomace. Differences in particle size distribution could affect the hydration process during cooking. As it can be observed in Table 2, the higher the level of tiger nut incorporation, the lower the mean particle diameter D[4,3] and the higher the Span value (measurement of the width of the size distribution). This non-uniform particle size distribution, in conjunction with the presence of fiber, probably inhibited the uniform hydration of the material during mixing (Gull et al. 2015). However, the smaller particle size leads to a larger surface area available for water absorption. Tiger nut flour has a smaller mean particle diameter with 90% of all particles finer than 419 μm (d(0.9), Table 2). Differences in water absorption might also be linked to differences in protein, starch, and fiber composition of flours used for pasta preparation (Wójtowicz and Moscicki 2014). Even though the protein and starch contents were lower for TNF (Table 1), the higher amount of fiber present in the tiger nut pasta -with high water holding capacity due to the high proportion of hemicellulose and lignin (Sánchez-Zapata et al. 2009)-, may have increased its WAI. In addition, disruptions in the protein matrix by fiber present in the TNF would promote water absorption and facilitate granule swelling and rupture (Kaur et al. 2012). The increase in water absorption capacity has always been associated with the increase in amylose leaching and solubility, and loss of starch crystalline structure (Gull et al. 2015). In fact, tiger nut pasta samples showed overall higher cooking loss values.

In general, the pasta increased at least twice in size, which is desirable for these products (Silva et al. 2016). Tiger nut based pasta showed greater SI values (114.8, 107.9 and 112.7 % for 10, 20 and 30% samples, respectively) than those obtained for durum wheat pasta (95.6%). No significant influence ($p<0.05$) of wheat semolina replacement by tiger nut flour could be observed. Again, the high water holding capacity of tiger nut fiber and disruptions in the gluten network (thus, higher WAI) might be responsible for the increase in the swelling index of tiger nut pasta. Kaur et al. (2012) found similar volume expansion results for cereal bran supplemented pasta. No relationship between the swelling index and water absorption index could be found, revealing that volume changes are not only due to water gain during cooking, but also to structure relaxation phenomena and cooking loss.

In fresh pasta products obtained by lamination (and not from extrusion), the gelatinisation of starch granules and water absorption occur mainly during the cooking process. Optimal cooking time (OCT) for durum wheat pasta was taken as a reference for the pasta cooking analysis; at this time, complete starch gelatinisation is reached. As the WAI, SI and %CL values of tiger nut pasta were higher, it seems that the optimal cooking time can be reduced for tiger nut pasta. OCT could not be assessed using the standard method (AACC method 66-50, AACC

2000) as the brown colour of tiger nut pasta made it difficult to visually detect complete starch gelatinisation by pressing pasta strands between two plastic plates.

3.3. Rheological properties of dough and cooked pasta

A good quality pasta product should present certain degrees of firmness and elasticity, absence of stickiness, appearance uniformity and structural integrity (Sozer et al. 2007; Edwards et al. 1995). Instrumental methods have been proved to successfully estimate the textural characteristics of pasta, which is recognized as being important for consumers and is generally accepted as the assessment on the overall quality of cooked pasta (Brennan and Tudorica 2007).

In table 3, it can be observed that the higher the percentage incorporation of tiger nut flour, the higher the dough firmness, but also the higher the loss after cooking (52.8%, 73.8%, 79.7% and 88.8% for 0, 10, 20 and 30% substitution levels, respectively). A strong correlation of decreasing firmness and percentage of tiger nut flour was obtained ($r=0.93$). This trend is in accordance with the results obtained for the cooking loss, as well as the water absorption and swelling indexes. Higher cooking losses, water contents and swelling indexes associated with higher levels of tiger nut flour in the formulation result in the lower firmness of the end product (Brennan and Tudorica 2007). Similar results were obtained for pasta incorporating carrot pomace (Gull et al. 2015), cereal bran (Kaur et al. 2012) and brown rice (Silva et al. 2016).

The TPA data for dough and cooked pasta are shown in Table 3. Increasing levels of tiger nut flour lead to decreased hardness and cohesiveness, and increased adhesiveness. This trend was more evident for dough than for cooked samples. Positive strong correlations were obtained between hardness and cohesiveness ($r=0.96$), adhesiveness and cohesiveness ($r=-0.93$) and hardness and adhesiveness ($r=-0.99$). Consequently, the use of tiger nut flour resulted in a less hard and cohesive structure, and led to a stickier product. These results indicate a very poor quality of the final product from a textural point of view. Sanguinetti et al. (2015) also observed higher values of adhesiveness for gluten-free fresh pasta based on corn and rice flours. However, these authors also found a decrease of springiness due to the absence of gluten. In this work, opposite results for tiger nut pasta were obtained as no significant differences ($p<0.05$)

could be observed in terms of springiness. These outcomes are in concordance with the firmness results if the structure-texture relationship is taken into account. Thus, the higher the level of TNF in the formulation, the more pronounced the disruption of the gluten matrix is to be expected, which causes changes not only in the firmness but also on the surface characteristics (becoming stickier, more adhesive).

Textural results evidence once again the development of a weaker protein network when non-gluten components are included. During cooking, a physical competition between the starch swelling and the properties of polymerized and polymerizing proteins determines whether the final cooked pasta is firm and elastic (when a strong protein network is formed and starch granules are entrapped in it) or rather sticky and soft (in the opposite case of significant starch swelling) (Bruneel et al. 2010). The higher presence of fiber with high affinity for water in tiger nut pasta causes water molecules to only be partially available in forming hydrogen bonds (gluten network development). As explained by Resmini and Pagani (1983), starch gelatinisation occurs towards the center of the pasta strands and rapidly, at low protein contents; prevalent starch swelling and discrete protein coagulation will be then responsible for the development of a non-continuous and sticky structure (Maningat et al. 2009).

Concerning lipid content, it is described that mono- and diglycerides of fatty acids may form complexes with amylose, thereby preventing the passage of starch into the cooking water, reducing cooking loss and stickiness (Sissons 2008). Furthermore, free lipids can interact during the dough mixing process with proteins improving the gluten network structure. However, our results revealed that tiger nut pasta samples showed overall higher cooking loss and adhesiveness values. Therefore, it seems that disruptions in the protein matrix by fiber is the main effect responsible for the observed pasta mechanical properties and cooking hydration.

3.4. Colour of dough and cooked pasta

As expected, the pasta colour was affected by the colour characteristics of the raw material included in the formulation (Table 4). The higher value of lightness (L^*) was obtained for the dough and cooked pasta based on durum wheat. With increasing levels of tiger nut flour, samples become gradually darker. This effect was evident for cooked pasta but only statistically significant ($p<0.05$) when a high amount of tiger nut flour (30% replacement level) was used. Additionally, pasta with tiger nut flour (dough and cooked product) had a brown colour, with a consequent reduction in b* and the hue angle (h^{*}_{ab}). Similar results are reported for pasta supplemented with bran (Aravind et al. 2012b), buckwheat flour (Chillo et al. 2008) or bean flour (Gallegos-Infante et al. 2010). The total colour differences between the tiger nut and wheat samples, before (ΔE^1) or after (ΔE^2) cooking (Table 4), are high enough to be visible to the naked eye (Francis and Clydesdale, 1975), as it was confirmed by the sensory evaluation. Nevertheless, this colour variation in the tagliatelle samples with respect to the durum wheat pasta may not negatively affect these pasta typologies because consumers normally associate pasta rich in dietary fiber with a darker colour (Chillo et al. 2008).

3.5. Sensory analysis

The health benefits and nutritional added value derived from tiger nut flour incorporation in pasta formulation has to be compatible with consumer satisfaction with the end product. The sensory attributes of cooked pasta products are presented in Table 5. The highest overall acceptability scores were obtained for durum wheat tagliatelle, and no significant differences ($p<0.05$) were obtained between 10, 20 and 30% tiger nut samples. The obtained results seem to support that overall acceptability depends more on visual (aspect and colour intensity) and textural characteristics -such as firmness (“al dente”)-, than on taste. In fact, stronger correlations were found with aspect ($r=0.8$), colour ($r=-0.8$) or texture ($r=0.7$) than with taste ($r=0.5$). Colour and aspect are often connected to consumers’ sensory perception of good quality and largely influence subsequent purchases. The 10% tiger nut tagliatelle rates for these sensory attributes, and also for texture, were significantly similar to those obtained for the durum wheat pasta.

A positive strong correlation between the hardness (TPA) and sensory firmness of cooked pasta ($r=0.97$) was found, revealing that instrumental analysis is useful in predicting consumers’ response to the textural characteristics of the final product.

3.6. Cooking kinetics

The cooking kinetics of the tiger nut supplemented pasta samples (30%) were analysed and compared to those obtained from durum wheat semolina (0%). The water absorption during cooking, expressed as reduced water content (dry basis) versus cooking time, is shown in Fig. 1. It is possible to observe that wheat semolina replacement by tiger nut flour induced significant ($p<0.05$) higher water content values for the same cooking time. This could be due -as explained by the water absorption indexes- to the greater fiber content with high water holding capacity of these samples. The model proposed by Peleg (1988) was used to fit the water absorption of the tagliatelle samples. It is an empirical model with two parameters, initially developed to describe rehydration curves that approach equilibrium asymptotically (Kowalska et al. 2008). Peleg's equation can be applied to model the sample water content (Eq. 1) throughout the cooking time. If the time of rehydration is long enough ($t\rightarrow\infty$), the equilibrium water content change is given by $1/k_2$.

$$X_w^t = X_w^o + \frac{t}{k_1 + k_2 \cdot t} \quad (1)$$

Where X_w^t is the sample water content at a given cooking time (g water/g dry matter), X_w^o is the initial water content (g water/g dry matter), k_1 (s*g dry matter/g water) and k_2 (g dry matter/g water) are, respectively, the first and second Peleg constants, and t is the cooking time (s). The k_1 constant is inversely related to the initial water rate absorption (Hung et al. 1993) and k_2 is inversely related to the water absorption capacity (Hung et al. 1993; Abu-Ghannam and McKenna 1997). Eq. (1) can be transformed into its linear form (Eq. 2).

$$\frac{t}{X_w^t + X_w^o} = k_1 + k_2 \cdot t \quad (2)$$

The main values for the obtained constants k_1 and k_2, regression coefficients (r^2), standard errors (SE) and equilibrium value (EV) obtained as VE = X_w^o + 1/ k_2) (Abu-Ghannam and McKenna 1997; Hung et al. 1993) are summarized in Table 6. The regression coefficients were greater than 0.9 in almost all cases, revealing the good fit of the proposed model. Analysis of variance enabled defining the observed differences in the initial water rate absorption (inverse of k_1) and equilibrium value (EV, inverse of k_2) for both pasta samples. There was not a significant influence of tiger nut flour in the formula for the initial water rate absorption, but EV was significantly higher in tiger nut supplemented pasta. The water penetration during pasta cooking is mainly related to the protein content. Starch gelatinisation takes place inwards and occurs at a fast rate at low protein concentrations. Starch changes occur during the cooking process, from the gelatinisation-hydration in the superficial layer to induced heat smelting in the center. Interactions between the starch and protein matrix are evident on the medium and superficial layers. In the center of the cooked pasta, wheat starch granules maintain its shape because of a limited water diffusion and a dense protein network (Maningat et al. 2009). As tiger nut flour is rich in fiber and starch, and poor in protein, semolina wheat partial replacement by this flour in pasta formulation may induce a faster starch gelatinisation (and thus, maximum water absorption capacity may be reached before), but the dough may take longer to rehydrate due to the presence of a significant amount of fiber. These opposite effects could explain the observed similar water absorption rates of supplemented and non-supplemented pasta samples.

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Conclusions

The significance of tiger nut flour incorporation -up to 30%- into durum wheat fresh egg tagliatelle formulae, in terms of water absorption, swelling index, cooking loss, textural properties, colour and sensory attributes was evaluated. A notable enhancement of fiber and fat contents may be achieved in tiger nut pasta. In general, the higher the substitution level, the higher the pasta stickiness, cooking loss, water absorption ratio and swelling index, and the lower the firmness, hardness and cohesiveness. These macroscopic phenomena may be due to the formation of a weaker and less elastic gluten structure. The presence of components such as tiger nut fiber and lipids may have either hindered the gluten proteins' interaction or altered the water availability for gluten hydration due to the development of a different water–solid interaction. Tiger nut fiber and the particle size distribution of tiger nut flour may be responsible for the higher water absorption ratios observed on tiger nut pasta; no significant changes on the initial water intake rates were obtained between the durum wheat and tiger nut pasta samples. From both the instrumental and sensory points of view, total colour differences between the tiger nut tagliatelle and durum wheat semolina samples, before and after cooking, were high enough to be visible to the naked eye. The obtained results seem to support the fact that the overall acceptability of tiger nut pasta depends more on visual (aspect and colour intensity) and textural characteristics (firmness) than on taste. Good relationships were found between the mechanical properties and sensory attributes of the cooked pasta.

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