1 **Role of hydrocolloids in gluten free noodles made with tiger nut flour as non-conventional powder**

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Abstract

Gluten free noodles have been made from a variety of ingredients, but very often without applying ingredients and process knowledge. Aim of this study was to build up gluten free noodles using tiger nut flour, a selection of hydrocolloids (guar gum, xanthan gum, inulin and carboxymethyl cellulose) and considering the impact of dough hydration in noodles making. Dough rheology, fresh noodles characteristics, cooking quality indicators and noodles quality after cooking were evaluated. Results showed that hydration level significantly affected dough rheology during mixing, heating and cooling, with a significant ($P < 0.05$) impact on hardness and firmness of fresh noodles and adhesiveness and firmness of cooked noodles. Hydrocolloids type significantly affected the characteristics of fresh and cooked noodles, but the extent of their effect was dependent on the hydration level applied during noodles making. In general, hydrocolloids increased dough consistency, resulting in fresh noodles with higher diameter, hardness and firmness, trend that was maintained after cooking, reducing cooking losses. In particular, gluten free tiger nut noodles made in the presence of 0.5% xanthan gum and adjusting the amount of water showed the best performance, with low cooking losses and high firmness.

Keywords: Gluten free, noodles, Tiger nut, Hydrocolloids, hydration.

1. Introduction

The design and development of gluten free (GF) foods is attracting very much attention, as a consequence of their increased consumption linked to whatever motivation (intolerances, lifestyle and so on). GF bread is the food that has prompted more extensive research trying to understand the matrixes, interactions among polymers and the impact of process conditions on the quality of the fresh bread (Matos & Rosell, 2015; Renzetti & Rosell, 2016). However, there are other widely consumed gluten free foods that are usually empirically designed by mixing gluten free ingredients without understanding their inner functionality.

Among the worldwide most consumed GF foodstuffs are noodles. They are a staple food owing to its variety, versatility, taste and price (Heo, Lee, Shim, Yoo, & Lee, 2013), representing a viable alternative for gluten intolerant patients. Noodles can be produced from various grain flours such as wheat, rice, buckwheat and corn, following three steps: raw material mixing (flour, water, salt), dough sheeting and cutting (Heo et al., 2013). Nevertheless, in the GF field, noodles are generally produced through extrusion or sheeting of a rice batter (Fu, 2008). The versatility of those technologies has stimulated the development of multitude of noodles, incorporating ingredients for nutritional enrichments, like pseudocereals and legumes (Bilgicli, 2013; Levent, 2017), or looking for healthy patterns (Levent, 2017). Lately, extensive research has been reported adding alternative raw materials that provide functional properties (Heo, Jeon, & Lee, 2014), but their role within the process requires additional understanding.

Tiger nut (*Cyperus esculentus* L.) (TN) is a specie of herbaceous plant that produces an edible sweet tuber and it is widely cultivated in Spain, Burkina Faso, Mali, Niger and Nigeria (Pascual, Maroto, López-Galarza, Sanbautista, & Alagarda, 2000). It has been used to produce a milky beverage (*orchata*) and for feeding fish and farm animals (Pascual et al., 2000). From a nutritional point of view, TN is characterized by a good amount of fiber and omega-6 fatty acids (Codina-Torrella, Guamis, & Trujillo, 2015; Sánchez-Zapata, Fernández-López, & Angel Pérez-Alvarez, 2012). These components could be play a key role in the prevention of some diseases such as coronary heart disease, colon cancer, diabetes and obesity (Martín-Esparza, Raigón, Raga, & Albors, 2018a), diabetes and obesity. For this reason, TN is attracting great interest in human nutrition. In fact, many researches tried to exploit those properties developing food applications like TN oil (Ezeh, Gordon, & Niranjana, 2014), flours and biscuits (Chinma, Abu, & Abubakar, 2010; Pascual et al., 2000) and fresh egg pasta (Albors, Raigon, García-Martínez, & Martín-Esparza, 2016). In addition, the natural absence of gluten makes TN a potentially useful raw material for

the manufacture of foods intended to consumers with specific nutritional needs. Despite its great potential, as mentioned above, the number of researches aimed to the development of TN based gluten free foods is very limited in literature, which include the use of up to 25% TN flour to improve the nutritional and functional quality of GF breads (Demirkesen, Sumnu, & Sahin, 2011) or extruded snacks mixed with cassava flour (Adebowale et al., 2017). Therefore, no previous study has been focused on developing GF noodles using TN as major ingredient.

To make GF noodles, the lack of gluten must be counteracted with ingredients that overcome the loss of extensibility. Hydrocolloids represent a group of water-soluble polysaccharides with different chemical structure widely used in the food industry as gelling agents and thickeners, emulsifiers, stabilizers, foaming agents, improvers of water retention and texture (Dickinson, 2003). Some studies have already emphasized the hydrocolloids role on GF noodles, mainly proposing the use of xanthan gum (XG), guar gum (GG) and carboxymethyl cellulose (CMC) to improve their texture and cooking quality (Srikaeo, Laothongsan, & Lerdluksamee, 2018).

The objective of this study was to build gluten free noodles applying knowledge on ingredients and processing. With that purpose, a gluten free flour or powder with described healthy properties (TN flour) was chosen, and a selection of hydrocolloids with varied chemical structure (GG, XG, inulin and two types of CMC with diverse viscosity) were evaluated. Moreover, the role of hydration level in noodles making was assessed by using two distinct hydrations: constant hydration usually applied in literature and adapted hydration depending on the food matrix requirements.

2. Materials and Methods

2.1. Materials

Milled TN was kindly granted by M6n Orxata (Alboraia, Valencia, Spain). TN powder had 8.62% moisture, 48.29% carbohydrates, 26.27% total fat, 7.67% protein, 7.31% total fiber, 1.84% ash content. GG from Cargill (Spain), XG food grade from Jungbunzlauer (Ladenburg, Germany), inulin (Fibruline® XL) from Cosucra Groupe (Warcoing, Belgium), while CMC (Methocel A15 and Methocel A4M) were generously provided by Dow Pharma & Food Solutions (La Plaine Saint Denis, France).

2.2. Noodles preparation

Commercial TN powder was ground using a laboratory mill (IKA Eurostar M 20, Staufen, Germany) equipped with a water-cooling jacket, applying 3 cycles for 10 s, with a pause of 10 s between cycles. Particle size of the resulting powder was measured by laser diffraction (Mastersizer Scirocco 2000, Malvern Instruments Ltd., Worcestershire, UK), displaying $d(0.50)$ and $d(0.90)$ of 553.06 μm , and 1337.87 μm , respectively.

For noodles making, preliminary studies were run to determine the amount of water that allowed preparing a dough with TN powder with appropriate consistency to be extruded. In a control sample TN powder and distilled water (8:2, w:w) were mixed using a laboratory mixer (IKA Eurostar 40, Staufen, Germany) for 2 min at 100 rpm. Resulting dough was then extruded using a syringe ($\varnothing$ 3 mm) and noodles were poured directly into one liter of boiling water. The water was standardized following the official method (AACC official method 66-50.01). After $\pm$ 30 s, noodles were drained and cooled at $\pm$ 25°C for 5 min before drying at 40°C for 2 hours in a vacuum oven (NÜVE EV 018, Ankara, Turkey). Noodles containing hydrocolloids were prepared adding 0.5% (w/w in solid basis) of GG, XG, I, CMC A15 or CMC A4M, following the same protocol described above to obtain those samples referred as constant hydration level. Other set of samples, named adapted water hydration, was prepared having same consistency (similar Mixolab torque during the mixing-heating-cooling cycle) than the control. The amount of water needed to reach same torque during mixing was determined in preliminary assays carried out with the Mixolab®. Three batches were prepared for each type of noodles.

2.3. Rheological behavior

Dough (75 g) prepared as previously described was placed into the Mixolab® bowl (CHOPIN Technologies, France). Rheological behavior was recorded using the protocol Chopin+, with the following settings: mixing for 8 min at 30°C, heating from 30°C to 90°C at the rate of 4°C/min, hold at 90°C for 7 min, cooling to 50°C at 4°C/min and finally held at 50°C for 5 min (Matos & Rosell, 2013). The dough consistency obtained with the control sample was used as a target consistency and the amount of water required to reach that consistency with each recipe was determined. That water absorption was applied to obtain the set of noodles referred as adapted water hydration. Parameters recorded from the plots included: consistency during mixing (Nm), minimum torque during heating stage (Nm) and maximum torque during cooling stage (Nm). Two assays were performed for each sample, and mean values calculated.

2.4. Extrusion force

The force needed to extrude the dough (8 g) through the 12 mL syringe ($\varnothing$ 3 mm) was quantified using a Texture Analyzer (TAHDI/500, TAHD Co., Stable Micro System, Surrey, UK) equipped with a load cell of 30 kg and P/36 cylinder probe (36 mm $\varnothing$) and the following settings: pre-test speed and test speed was 1 mm/s, post-test speed was 10 mm/s, and trigger force was 10 g. The maximum peak of a compression test was identified as extrusion force. Three measurement were carried out for a single dough and mean value was recorded.

2.5. Cooking quality indicators

Optimal Cooking Time (OCT) was evaluated according to AACC official method (AACC International, 2009) with some modifications. Noodles (5 g) were immersed in boiling water (60 mL), one piece of noodles (5 cm) was taken out every 30 s and squeezed between two Petri dishes to visually observe the time of disappearance of the white core (ungelatinized starch). The OCT was achieved when center core just disappears, thus complete starch gelatinization. Two measurements were performed for each sample and mean values recorded.

Cooking loss (CL) was evaluated according to AACC official method (AACC International, 2009) with some modifications. After reaching OCT, noodles were drained in a Büchner funnel and rinsed with 50 mL of distilled water for 30 s. Cooking and rinse waters were combined and the total volume annotated. An aliquot of this water (1 mL) was dried during 24 h up to constant weight in air oven (J. P. Selecta 2000210, Barcelona, Spain) at 65°C. After 1 h in a desiccator, the residue (Solid loss) was weighted and calculated CL as percentage using the Equation 1. Three measurements were performed for each sample, and mean value was calculated.

$$CL_{(g/100\text{ g})} = (\text{Solid loss}_{(g)} \times \text{Final cooking water}_{(mL)}) / (\text{Raw Noodles}_{(g)}) \times 100 \text{ [Equation 1]}$$

Drained noodles were allowed to cool down to room temperature for 10 min in a sealed Petri dish. Then, five pieces of noodles (5 cm long) were weighed and water absorption (WA) expressed in percentage was determined following equation 2:

$$WA_{(g/100\ g)} = (\text{Cooked Noodles}_{(g)} - \text{Raw Noodles}_{(g)}) / (\text{Raw Noodles}_{(g)}) \times 100 \text{ [Equation 2]}$$

Three measurements were performed for each analysis, and mean values calculated.

Five pieces of drained noodles (5 cm long) were weighed and dried for 24 h to constant weight in an air oven (J. P. Selecta 2000210, Barcelona, Spain) at 65°C. Swelling index (SI) expressed as grams of water per gram of dry noodles was determined following the procedure described by Cleary and Brennan (2006) and calculated as indicated in equation 3:

$$SI_{(g\ water/g\ dry\ noodles)} = (\text{Cooked Noodles}_{(g)} - \text{Cooked Noodles after drying}_{(g)}) / (\text{Cooked Noodles after drying}_{(g)})$$

[Equation 3]

Three measurements were performed for each sample, and the mean values were calculated.

Diameter of uncooked and cooked GF noodles was measured with a digital caliper. Five measurements were performed for each sample and mean value reported.

Color of uncooked and cooked GF noodles was measured using a Minolta Chromameter (Model CR-400, Minolta Co., Osaka, Japan) following CIELAB scale: L^* (lightness 0-100), a^* (positive values measure redness, negative values measure greenness) and b^* (positive values measure yellowness, negative values measure blueness). Each data represents the mean of five measurements.

Texture profile analysis (TPA) was carried out in a Texture Analyzer (TAHDi/500, TAHD Co., Stable Micro System, Surrey, UK) equipped with a load cell of 30 kg and P/36 cylinder probe (36 mm Ø) and with the following settings: pre-test, test and post-test speed was 2 mm/s and the trigger force was 10 g. Distance was set up at 30 mm with 75% strain and 2 s the holding time between compressions. Five strands (5 cm long) of fresh and cooked noodles were submitted to a double compression test and Hardness (g), Adhesiveness (g·s), Chewiness and Resilience were measured with the software instrument. Five replicates were evaluated for each experimental value reported.

Firmness, expressed as the maximum force (g) necessary to shear a strand of noodles, and work of shear (g·s) corresponding to the area under the curve of force/time graphic, were investigated using a Texture Analyzer (TAHDI/500, TAHD Co., Stable Micro System, Surrey, UK) as described by the official method 66-50.01 (AACC 2001). Samples were analyzed in triple and Data were calculated with the software instrument and the average of three replicates used.

2.6. Statistical Analysis

Experimental data were expressed as a mean $\pm$ standard deviation and statistically analyzed by multifactor analysis of variance (MANOVA) using Statgraphics V.7.1 (Bitstream, Cambridge, MN). Fisher's least significant differences test was used for assessment of significant differences among experimental mean values with 95% confidence.

4. Results and discussion

4.1 Rheological behavior

Mixolab® has been traditionally applied to record bread doughs performance during mixing when subjected to a heating-cooling cycle. In the present study, Mixolab® was used to record the rheology of a GF noddle dough made from TN powder. Therefore, plots (Figure 1) displayed completely different patterns than the ones observed either with gluten matrixes or non-gluten flours. Fresh doughs were directly placed into the bowl, recording initial consistency that showed a slight decay as mixing proceeds, indicating some loss of stability. A pronounced dough softening was observed during heating stage and no increase in consistency, usually attributed to starch gelatinization, was observed owing to the low amount of starch or limited amount of water. Dough consistency only exhibited a steady increase during the cooling stage.

In GF noodles, hydrocolloids are needed to provide extensibility. But, considering their diverse ability to bind water, it was assumed that water would have a crucial role in defining noodles dough consistency and the quality of fresh noodles. Nevertheless, usually constant amount of water is applied when producing rice noodles, and slightly varied when changing the flour. Considering that a non-cereal flour was used and the diverse characteristics of the hydrocolloids, dough rheology was tested applying different hydrations till reaching the same consistency in all the blends for obtaining noodles (Figure 1).

Two types of CMC were selected due to their great variation on viscosity (CMC A15 15 mPa·s and CMC A4M 4000 mPa·s). Firstly, doughs were prepared using the same amount of water, which were referred as constant hydration (Figure 1 A), and secondly, doughs were prepared adjusting the level of water to hydrate all ingredients, leading to doughs with the same consistency (same torque during mixing with a Mixolab) than the control sample, those were referred as constant consistency (Figure 1 B). The incorporation of hydrocolloids to doughs resulted in doughs with higher consistency when the level of water was kept constant (Figure 1 A), due to their water retention ability. Those differences were minimized when the water level was adapted, allowing hydrocolloids hydration, being GG followed by XG the hydrocolloids that required higher amount of water to adjust consistency (Figure 1 B). Parameters used to quantify rheological behavior are showed in Table 1, where type of dough hydration and presence of hydrocolloids were identified as main factors of variance. Statistical analysis confirmed the significant ($P < 0.05$) effect of hydration on the dough rheology during mixing, heating and cooling stages, but no significant effect was observed due to the type of hydrocolloid because differences were eliminated when constant consistency was applied. Nevertheless, the analysis of variance within the samples group with constant hydration showed a significant ($P < 0.05$) effect of hydrocolloid on the consistency (Nm) during the Mixolab® stages. When constant hydration (20 g water/100 g powder) was used for making doughs, the addition of hydrocolloids, except for inulin, significantly increased dough consistency during mixing and cooling stages with respect to control (in the absence of hydrocolloid). XG and GG were the hydrocolloids that mostly increased consistency during mixing and cooling stages, indicating their higher absorption of water. The enhancement of consistency during cooling promoted by all hydrocolloids, with exception of inulin, suggested higher interaction between hydrocolloids and leached amylose, which might indicate that gums were preferentially placed on the surrounding solution instead of being located at the external side of the granules (Rosell, Yokoyama, & Shoemaker, 2011).

To obtain a constant consistency, doughs required higher amount of water with the subsequent reduction in the torque (Nm), apart from inulin that did not affect consistency (Table 1). After adjusting water levels, no significant differences were observed due to hydrocolloids along mixing, heating and cooling stages.

Extrusion force required to obtain noodles were also evaluated, and significant differences were observed due to the hydration level and the type of hydrocolloids (Table 1). Differences within hydrocolloids type were only significant when constant hydration was applied to obtain doughs, confirming that doughs

containing XG or GG required higher extrusion force. Same findings were observed when GG was added (0 - 10%) to various flours (corn, potato, rice, and wheat) to produce extruded snacks, observing an increase of extrusion torque (Nm) with all the flours (Parada, Aguilera, & Brennan, 2011).

4.2 Quality indicators of fresh noodles

It was possible to make noodles with TN powder, despite the absence of gluten and the particular characteristics of this small tuber. Characterization of GF TN noodles was carried out at the different stages of production, including fresh noodles and their quality after cooking. Regarding fresh noodles, the statistical analysis revealed that hydration level significantly affected the luminosity of the noodles (L^*), hardness, firmness and the work of shear; conversely hydrocolloids type significantly affected all the parameters evaluated with the exception of work of shear (Table 2). Therefore, on fresh noodles, the type of hydrocolloid was crucial for producing GF noodles. Going into detailed effects, it was observed that GG, XG and CMC A4M increased the noodles diameter, independently of the amount of water used for producing them. That increase confirmed the high ability of those hydrocolloids to retain water. Color was differently affected by hydrocolloids, observing a decrease of luminosity, although only significant when hydration was adapted and in the presence of XG, GG or CMC A15. Additionally, a^* and b^* were significantly ($P < 0.05$) influenced by hydrocolloids, particularly, XG had the higher values in terms of redness, whereas GG led to lower redness and yellowness. The parameters a^* and b^* were very close to those obtained with fresh durum pasta containing TN (Martín-Esparza, Raigón, Raga, & Albors, 2018b).

Hardness and firmness were significantly affected by hydration level and hydrocolloids ($P < 0.05$) (Table 2). In general, hardness, the force necessary to attain a given deformation (Li, Dhital, & Wei, 2017), was higher in the noodles with constant hydration, after adjusting the water softer noodles were attained. When hydrocolloids were added, hardness increased especially when CMC A15 was used, independently of the hydration, and GG, but only when constant hydration was used. Thus, hydrocolloids improved the stiffness of GF noodles structure. Similar result was obtained by Padalino, Mastromatteo, De Vita, Maria Ficco, and Del Nobile (2013) that reported an increase of hardness in GF spaghetti made by corn and oat when they were separately added (2 % of GG and CMC). Firmness, the force required to cut the noodle, was higher in noodles with adapted hydration, except for those containing inulin. XG was the hydrocolloid that conferred higher firmness. Adhesiveness, the work necessary to overcome the attractive

forces between the surface of the noodle and the surface of teeth (Li et al., 2017), was significantly reduced in the presence of hydrocolloids, excepting XG when it was added without adjusting the hydration level, which led to more adhesive noodles. Likewise, Chauhan, Saxena, and Singh (2017) described the decrease of adhesiveness when 0.5% or 1% of hydrocolloids (GG, acacia gum and tragacanth gum) were added to amaranth GF pasta. Chewiness or the energy needed to make noodles in a state suitable for swallowing (Li et al., 2017) were significantly increased by all the hydrocolloids tested, but the extent of the impact was dependent on the hydration level applied to noodles. In fact, CMC A15 resulted in the highest chewiness when using constant hydration, despite its lower initial viscosity, but GG led to the highest value when adapted hydration was applied. Hydrocolloids also significantly increased the noodles resilience, except for XG when constant hydration was used. Analyzing the work required to shear, it significantly ($P < 0.05$) depended on the hydration level, samples group with constant hydration was characterized by lower results. GG, CMC A15 and CMC A4M after adjusting hydration led to noodles with the highest value in work of shear. Therefore, level of hydration significantly affected fresh noodles characteristics.

4.3 Quality indicators of cooked noodles

Generally, good quality noodles shall be characterized by low cooking loss, high firmness and absence of stickiness (Marti et al., 2013). In this study other quality indicators related to cooking have been evaluated (Table 3). The level of hydration significantly ($P < 0.05$) affected the color of the cooked noodles, and hydrocolloids affected the OCT, CL and water absorption, as well. Hydrocolloids incorporation increased significantly ($P < 0.05$) the OCT, which might be expected considering water limitation, and in consequence the delay in the starch gelatinization. Same trend was described by Kaur, Shevkani, Singh, Sharma, and Kaur (2015) when GG and XG were added (0.25% or 0.35%) to produce potato, corn and mung bean starch noodles, which has been recently explained by the protective behavior of the hydrocolloids towards starch granules that cause the increase in the gelatinization temperature onset (Pongpichaiudom & Songsermpong, 2018). On the other hand, hydrocolloids addition decreased ($P < 0.05$) the cooking loss, and those losses tended to be lower when adapted hydration was applied during the making process. The hydrocolloids improve the noodles' structure, preventing the release of solid matters into cooking water. The addition of XG allowed obtaining GF TN noodles that kept better their structure, and that effect was even greater when prepared adapting the hydration. Same action of gums on

CL has been reported for GG, CMC and XG when making organic red jasmine rice noodles (Kraithong, Lee, & Rawdkuen, 2019) and dried-naturally fermented rice noodles (Srikaeo et al., 2018). Therefore, present research shows that hydrocolloids are also able to held a tuber powder for producing noodles. The great ability of hydrocolloids to bind water was also sustained by the WA results, which were significantly ($P < 0.05$) higher, whatever hydration was applied (Table 3), except for the GG when the adapted hydration was applied. Even after adjusting the hydration, the presence of hydrocolloids promoted higher water absorption. Other authors described same results obtained with rice noodles (Srikaeo et al., 2018). The effect of hydrocolloids was evident also in the SI, indicating that hydrocolloids significantly increased the amount of bonded water to starch and proteins, leading to lower released of soluble compounds, except in the case of inulin. As mentioned above, hydration and hydrocolloids had a significant ($P < 0.05$) effect on the color parameter L^* , a^* and b^* of cooked noodles. TN tubers have a brownish color, that is maintained in TN noodles. In general, noodles made with constant hydration had higher L^* , a^* and b^* . Noodles containing inulin were brighter, with reddish and brownish tone.

Hydration type significantly ($P < 0.05$) affected the adhesiveness, resilience and firmness, and hydrocolloids type significantly affected all the texture parameters evaluated (hardness, adhesiveness, chewiness, resilience, firmness, work of shear) (Table 3). Regarding hardness, the most pronounced effect was the softening effect of GG and CMC A15, but only when constant hydration was applied; and the same trend was observed in the noodles' resilience. Hardness of cooked samples (Table 3) are in line with the values obtained for other noodles prepared with different flours, like tartary buckwheat noodles that showed hardness from 5960 g to 7780 g (Wu et al., 2017). In contrast with what was observed in fresh samples, in cooked noodles the presence of hydrocolloids increased the adhesiveness, although it was not significant in the case of inulin and CMC A15, and the former had significant effect when adjusting hydration. Consequently, gelling and starch gelatinization modified the impact of hydrocolloids on adhesiveness. Although hydrocolloids significantly affected chewiness, the effect was dependent on the type of hydrocolloids, being the impact greater when constant hydration was applied. It must be stressed the effect induced by GG, that reduced chewiness when noodles were prepared with constant hydration but when adjusting it, a significant increase in chewiness was obtained. Similarly, opposite effects were observed when adding XG depending on the hydration type applied during noodle making. XG induced a significant increase in chewiness when constant hydration, but no significant difference with the control was observed when using adapted hydration. As it was previously described with fresh noodles, firmness

during shearing was significantly affected by hydration and hydrocolloid type, but the work required to cut noodles was significantly dependent on the type of hydrocolloids. Xanthan gum was the hydrocolloid that mostly affected the performance of noodles during shearing, especially when adapted hydration was used.

5. Conclusion

Gluten free noodles could be made from TN flour, giving special attention to the amount of water used in the production process and the type of hydrocolloid added, because they play a crucial role on the dough rheology and the quality of fresh and cooked noodles. Hydration applied during noodle processing significantly affected the dough rheology during mixing, heating and cooling, but also the luminosity, hardness and firmness of fresh noodles and the color and firmness of cooked noodles. Instead, hydrocolloids type affected properties of both fresh and cooked noodles. Overall, gluten free TN noodles made with xanthan gum and adapted amount of water showed the best quality considering the lowest cooking losses obtained and its higher firmness.

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FIGURE CAPTIONS

Fig. 1 Mixolab® curves representing the rheological behavior of the noodle's doughs. A. Doughs obtained with the same hydration; B. Doughs obtained with adapted hydration level to keep constant consistency. Solid black line displays the temperature gradient applied during the rheology assessment.

Figure 1

A.

B.

457 Table 1. Thermomechanical behavior of Tiger nut doughs with constant hydration and constant consistency

Hydration	Hydration level (g/100 g)	Hydrocolloid	Mixing Consistency (Nm)				Heating Consistency (Nm)				Cooling Consistency (Nm)				Extrusion Force (g)			
Constant	20.00	None	0.71	±	0.01	ab	0.44	±	0.03	abc	0.70	±	0.02	de	5371	±	175	a
	20.00	Guar gum	0.96	±	0.01	e	0.50	±	0.01	c	0.83	±	0.00	g	6453	±	135	c
	20.00	Xanthan gum	1.01	±	0.03	f	0.43	±	0.01	ab	0.89	±	0.02	h	6516	±	23	c
	20.00	Inulin	0.73	±	0.01	b	0.47	±	0.01	bc	0.71	±	0.01	e	5246	±	53	a
	20.00	CMC A15	0.77	±	0.01	c	0.46	±	0.01	abc	0.76	±	0.01	f	5967	±	236	b
	20.00	CMC A4M	0.82	±	0.03	d	0.50	±	0.01	c	0.66	±	0.01	c	6085	±	178	b
Adapted	20.00	None	0.71	±	0.01	ab	0.44	±	0.03	abc	0.70	±	0.02	de	5371	±	175	a
	26.00	Guar gum	0.70	±	0.01	ab	0.39	±	0.01	a	0.63	±	0.01	ab	5264	±	161	a
	24.00	Xanthan gum	0.70	±	0.01	ab	0.39	±	0.05	a	0.67	±	0.02	cd	5281	±	70	a
	20.00	Inulin	0.73	±	0.01	b	0.47	±	0.01	bc	0.71	±	0.01	e	5246	±	53	a
	21.06	CMC A15	0.73	±	0.01	abc	0.44	±	0.01	abc	0.66	±	0.00	bcd	5385	±	247	a
	21.30	CMC A4M	0.69	±	0.01	a	0.42	±	0.05	ab	0.62	±	0.01	a	5125	±	58	a
P-value		Hydration	0.00				0.00				0.00				0.00			
		Hydrocolloid	0.10				0.16				0.08				0.01			

*means with different letters within the same parameter differ significantly ($P < 0.05$)

458 Table 2. Diameter, color and textural properties of fresh Tiger nut gluten free noodles

Hydration	Hydrocolloid	Diameter (mm)		Color										Firmness			
				<i>L</i> *		<i>a</i> *		<i>b</i> *		Firmness (g)		Work of Shear (g·cm)					
Constant	None	3.43 ± 0.06	a	44.40 ± 1.24	cd	5.70 ± 0.34	b	21.24 ± 0.31	de	32 ± 2	a	5.5 ± 0.4	ab				
	Guar gum	3.57 ± 0.06	c	43.55 ± 1.70	bcd	4.09 ± 0.57	a	18.45 ± 0.16	a	35 ± 1	abc	5.0 ± 0.9	a				
	Xanthan gum	3.57 ± 0.06	c	43.02 ± 1.27	bc	6.36 ± 0.51	c	21.65 ± 0.68	e	38 ± 1	abcd	5.6 ± 0.5	abc				
	Inulin	3.47 ± 0.06	ab	43.20 ± 1.79	bc	5.59 ± 0.74	b	19.33 ± 0.49	b	33 ± 7	ab	5.8 ± 0.5	abc				
	CMC A15	3.47 ± 0.06	ab	42.92 ± 1.03	abc	5.87 ± 0.41	bc	20.18 ± 0.22	c	36 ± 5	abcd	5.1 ± 1.3	a				
	CMC A4M	3.53 ± 0.06	bc	45.19 ± 0.80	d	5.46 ± 0.40	b	20.79 ± 0.46	d	38 ± 2	abcd	6.8 ± 0.4	cd				
Adapted	None	3.43 ± 0.06	a	44.40 ± 1.24	cd	5.70 ± 0.34	b	21.24 ± 0.31	de	32 ± 2	a	5.5 ± 0.4	ab				
	Guar gum	3.53 ± 0.06	bc	41.20 ± 0.40	a	5.72 ± 0.18	b	20.87 ± 0.31	d	40 ± 2	cde	6.9 ± 0.5	d				
	Xanthan gum	3.57 ± 0.06	c	42.44 ± 1.52	ab	5.70 ± 0.44	b	21.50 ± 0.30	e	44 ± 1	e	6.3 ± 1.0	bcd				
	Inulin	3.47 ± 0.06	ab	43.20 ± 1.79	bc	5.59 ± 0.74	b	19.33 ± 0.49	b	33 ± 7	ab	5.8 ± 0.5	abc				
	CMC A15	3.47 ± 0.06	ab	41.93 ± 1.41	ab	5.52 ± 0.37	b	20.11 ± 0.58	c	41 ± 3	de	7.5 ± 0.6	d				
	CMC A4M	3.53 ± 0.06	bc	43.52 ± 1.92	bcd	5.52 ± 0.37	b	19.87 ± 0.29	c	38 ± 4	bcde	6.9 ± 1.0	d				
<i>P</i> -value	Hydration	0.73		0.02		0.48		0.23		0.01		0.00					
	Hydrocolloid	0.00		0.00		0.01		0.00		0.00		0.09					
Texture profile analysis (TPA)																	
		Hardness (g)		Adhesiveness (g·s)		Chewiness (g)		Resilience									
Constant	None	8758 ± 534	a	93 ± 20	c	798 ± 144	a	0.19 ± 0.01 a									
	Guar gum	12765 ± 658	de	39 ± 4	a	2086 ± 397	cde	0.25 ± 0.01 e									
	Xanthan gum	10711 ± 559	b	114 ± 28	d	1433 ± 271	abc	0.19 ± 0.01 a									
	Inulin	11920 ± 493	c	35 ± 5	a	2020 ± 563	cde	0.23 ± 0.01 cd									
	CMC A15	13377 ± 652	e	22 ± 2	a	2495 ± 531	e	0.27 ± 0.02 f									
	CMC A4M	10447 ± 678	b	83 ± 8	bc	1918 ± 666	cde	0.22 ± 0.01 bc									
Adapted	None	8758 ± 534	a	93 ± 20	c	798 ± 144	a	0.19 ± 0.01 a									
	Guar gum	10986 ± 767	b	79 ± 12	bc	2397 ± 663	cde	0.22 ± 0.02 bcd									
	Xanthan gum	10349 ± 795	b	70 ± 7	b	1285 ± 244	ab	0.21 ± 0.01 b									
	Inulin	11920 ± 493	c	35 ± 5	a	2020 ± 563	cde	0.23 ± 0.01 cd									
	CMC A15	12190 ± 621	cd	26 ± 4	a	1837 ± 208	bcd	0.24 ± 0.02 de									
	CMC A4M	10617 ± 662	b	38 ± 4	a	2027 ± 366	cde	0.24 ± 0.01 de									
<i>P</i> -value	Hydration	0.01		0.19		0.61		0.41									
	Hydrocolloid	0.00		0.00		0.00		0.00									

*means with different letters within the same parameter differ significantly (*P* < 0.05)

460 Table 3. Quality indicators, color and textural properties of cooked Tiger nut gluten free noodles

Hydration	Hydrocolloid	Cooking quality indicators								Color					
		OCT (min)		CL (g/100 g)		WA (g/100 g)		SI (g/g)		<i>L</i> *		<i>a</i> *		<i>b</i> *	
Constant	None	4.75 ± 0.35	a	18.38 ± 0.32	f	82.12 ± 2.82	a	1.43 ± 0.08	bc	47.70 ± 1.71	cde	3.56 ± 0.44	bc	14.37 ± 0.42	a
	Guar gum	5.75 ± 0.35	b	17.96 ± 0.82	ef	110.73 ± 3.43	f	1.28 ± 0.15	a	46.31 ± 1.47	abc	4.08 ± 0.45	d	15.40 ± 0.35	b
	Xanthan gum	6.00 ± 0.00	b	13.68 ± 0.43	b	94.47 ± 2.77	cd	1.22 ± 0.06	a	48.58 ± 1.43	de	4.03 ± 0.42	d	15.58 ± 0.28	b
	Inulin	5.75 ± 0.35	b	16.52 ± 0.29	d	105.50 ± 7.15	ef	1.50 ± 0.06	c	50.25 ± 1.09	f	4.99 ± 0.10	e	17.59 ± 0.36	d
	CMC A15	5.50 ± 0.00	b	15.38 ± 0.69	c	103.45 ± 1.72	ef	1.22 ± 0.09	a	49.24 ± 1.25	ef	3.95 ± 0.44	cd	16.73 ± 0.36	c
	CMC A4M	5.50 ± 0.00	b	14.65 ± 0.95	c	93.68 ± 5.39	bc	1.22 ± 0.09	a	47.60 ± 0.52	bcd	3.91 ± 0.42	cd	17.07 ± 0.62	c
Adapted	None	4.75 ± 0.35	a	18.38 ± 0.32	f	82.12 ± 2.82	a	1.43 ± 0.08	bc	47.70 ± 1.71	cde	3.56 ± 0.44	bc	14.37 ± 0.42	a
	Guar gum	5.75 ± 0.35	b	13.06 ± 0.40	b	87.56 ± 6.75	ab	1.24 ± 0.06	a	46.05 ± 0.88	ab	3.57 ± 0.27	bc	15.36 ± 0.39	b
	Xanthan gum	6.00 ± 0.00	b	12.04 ± 0.70	a	101.37 ± 2.90	de	1.34 ± 0.08	ab	46.44 ± 0.92	abc	3.25 ± 0.30	ab	14.58 ± 0.18	a
	Inulin	5.75 ± 0.35	b	16.52 ± 0.29	d	105.50 ± 7.15	ef	1.50 ± 0.06	c	50.25 ± 1.09	f	4.99 ± 0.10	e	17.59 ± 0.36	d
	CMC A15	5.50 ± 0.00	b	17.43 ± 0.41	de	92.04 ± 2.21	bc	1.29 ± 0.02	a	45.32 ± 1.29	a	3.04 ± 0.23	a	14.40 ± 0.40	a
	CMC A4M	5.50 ± 0.00	b	14.82 ± 0.57	c	95.81 ± 0.93	cd	1.33 ± 0.04	ab	46.80 ± 0.96	abc	3.43 ± 0.38	ab	15.11 ± 0.15	b
<i>P</i> -value	Hydration	1.00		0.12		0.07		0.08		0.00		0.00		0.00	
	Hydrocolloid	0.00		0.00		0.00		0.04		0.00		0.00		0.00	
Texture profile analysis (TPA)															
		Hardness (g)				Adhesiveness (g·s)		Chewiness (g)		Resilience		Firmness (g)		Work of Shear (g·cm)	
Constant	None	6556 ± 543	cde			96 ± 6	a	905 ± 80	c	0.15 ± 0.01	b	17.7 ± 1.4	a	2.1 ± 0.4	a
	Guar gum	5375 ± 907	ab			128 ± 2	d	600 ± 187	ab	0.12 ± 0.01	a	24.0 ± 0.5	bc	3.1 ± 0.2	ab
	Xanthan gum	7205 ± 1129	e			120 ± 9	cd	2132 ± 526	e	0.14 ± 0.01	b	30.3 ± 0.6	e	4.6 ± 0.3	c
	Inulin	6744 ± 537	cde			103 ± 12	abc	832 ± 24	bc	0.14 ± 0.01	b	22.1 ± 2.5	b	2.4 ± 0.3	a
	CMC A15	5289 ± 936	a			99 ± 13	ab	507 ± 88	ab	0.12 ± 0.02	a	25.5 ± 1.3	c	2.5 ± 0.4	a
	CMC A4M	7243 ± 638	e			122 ± 9	d	981 ± 134	cd	0.15 ± 0.01	b	26.1 ± 0.5	cd	2.3 ± 0.3	a
Adapted	None	6556 ± 543	cde			96 ± 6	a	905 ± 80	c	0.15 ± 0.01	b	17.7 ± 1.4	a	2.1 ± 0.4	a
	Guar gum	7439 ± 739	e			157 ± 8	e	1261 ± 362	d	0.14 ± 0.01	b	26.4 ± 1.8	cd	2.8 ± 0.5	a
	Xanthan gum	7084 ± 227	de			148 ± 14	e	959 ± 196	c	0.14 ± 0.01	b	33.9 ± 0.6	f	3.6 ± 0.3	b
	Inulin	6744 ± 537	cde			103 ± 12	abc	832 ± 24	bc	0.14 ± 0.01	b	22.1 ± 2.5	b	2.4 ± 0.3	a
	CMC A15	5965 ± 481	abc			116 ± 10	bcd	865 ± 47	bc	0.14 ± 0.01	b	29.5 ± 3.0	e	2.5 ± 0.2	a
	CMC A4M	6199 ± 789	bcd			148 ± 17	e	999 ± 298	cd	0.14 ± 0.01	b	28.2 ± 0.4	de	3.0 ± 0.2	ab
<i>P</i> -value	Hydration	0.23				0.00		0.78		0.03		0.00		0.76	
	Hydrocolloid	0.01				0.00		0.00		0.01		0.00		0.00	

*means with different letters within the same parameter differ significantly (*P* < 0.05)

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