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BIOACTIVE CARBOHYDRATES AND DIETARY FIBRE

Effect of Psyllium fibre content on the textural and rheological characteristics of biscuit and biscuit dough

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ABSTRACT

It is well supported that a significant intake of dietary fibre reduces the risk of several chronic diseases. The development of staple foods enriched with fibre is an important contribution to a broader supply of food products with health beneficial effect. In this sense, the objective of this work is the development of biscuits enriched with Psyllium fibre.

The maximum level of Psyllium incorporation was studied. The effect of this fibre and wheat flour content on rheological behaviour and texture of the dough, and respective biscuits' texture and colour were evaluated. Psyllium incorporation was tested from 3% to 15% (w/w), and the maximum fibre incorporated in this product was 9% (w/w), due to the high water holding capacity of Psyllium (17 g/g at 25 °C) and the mechanical characteristics of dough. For higher levels of fibre incorporation the dough fails to be moulding (the idea is malleable).

1. Introduction

Regular consumption of fibre is an important factor to prevent many types of diseases and is associated with a standard balanced diet (Rosell, Santos, & Collar, 2009). The beneficial role of the dietary fibre (DF) in health and nutrition is associated with the reduction in chronic illnesses as cardiovascular disease, certain types of cancer and constipation (Lairon et al., 2005; Schaafsma, 2004). The insoluble fraction of fibres (IDF) has been related to the intestinal regulation, whereas soluble fibres (SDF) are associated to the decrease in cholesterol levels and the absorption of intestinal glucose (Rodríguez, Jiménez, Fernández-Bolaños, Guillén, & Heredia, 2006).

Psyllium is obtained from the seeds of the plant genus *Plantago*, the latter has more than 200 species. India dominates the world market, being responsible for the production of about 39,000 t of Psyllium seed each year. This represents 85% of the world market. Psyllium husk is the main product separated from the seed and the rest is usually used as animal feed. From the seed coat of Psyllium a mucilage is obtained, by mechanical milling. It is a white fibrous hydrophilic material and forms a clear colourless mucilaginous gel. Psyllium, prepared from the seed husk of *Plantago* genus contains about 80% soluble fibre and is an excellent dietary source of both soluble and insoluble fractions (Bijkerk, Muris, Knottnerus, Hoes, & de Wit, 2004). Its average composition is 23% arabinose, 75% xylose (molar basis) and traces of

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other sugars. With about 35% of non-reducing terminal residues, the polysaccharide is highly branched acidic arabinoxylan containing both (1→4) and β-(1→3) glycosidic linkages in the xylan backbone (Fischer et al., 2004). Dietary fibre Psyllium has been reported as a medicinally active gel forming natural polysaccharide, successfully used for the treatment of high cholesterol, diabetes, obesity in children, remediation of constipation, diarrhoea, inflammation bowel diseases and ulcerative colitis (Singh, 2007).

The Psyllium consumption is very popular in India, and is now widespread in the USA, mainly since the FDA approved a health claim posting that Psyllium soluble fibre is associated with the reduced risk coronary heart disease (FDA, 2012). The demand in Europe has increased in recent years. However, the intake of Psyllium in developed countries results essentially from capsules and other dietary preparations. The consumption of Psyllium as a medicine has a limiting target, and its real contribution for the general population could be amplified by the incorporation of Psyllium on common staple foods – emulsions, foams, gels, pasta and biscuits. The incorporation of Psyllium in these food products as a bioactive ingredient, can contribute to increase the commercial offer of food products enriched in special fibres, with direct benefits on health.

Psyllium husks have technological limitations, since they originate products with a high viscosity, resulting from its extremely strong water uptake and gelling capacities – each gram of Psyllium retains about 10 g of water (Kristensen & Jensen, 2011). The incorporation of Psyllium in food formula, at the levels required for health claim on the label can be great challenge (Cheng, Blackford, Wang, & Yu, 2009). Therefore, this limitation reduces the incorporation levels of Psyllium and consequently the effectiveness of the final product as a healthy promoting agent. Many physical, chemical, mechanical and enzymatic approaches have been tried to overcome this major drawback on the manufacture of the food products (Yu, Perret, Parker, & Allen, 2003 and Cheng et al., 2009). The hydrolysis of the polysaccharides, in order to decrease the water uptake may form other ingredients and intermediates with a different impact on health (Yu et al., 2003). There are USA patents about the use of Psyllium in pasta, cakes and biscuits (Bedard, Lai, Wullschleger, & Kincaid, 1995), but a pretreatment of Psyllium is applied.

Biscuits are one of the most popularly consumed bakery products widely consumed around the world, mainly resulting from their ready to eat nature, affordable cost, good nutritional quality, availability in different tastes and longer shelf life (Gandhi et al., 2001; Ajila, Leelavathi, & Rao, 2008). Several reports are available on the use of oat, wheat and rice bran as a source of dietary fibre content in bread and other bakery products (Laurikainen, Harkonen, Autio, & Poutanen, 1998; Saunders, 1990; Sidhu, Al-Hooti, & Al-Saqer, 1999; Sudha, Vetrimani, & Leelavathi, 2007).

The incorporation of solid components on the biscuit dough has serious implications on their structure and therefore there are technological limitations for the total fibre content. This limitation was previously studied for the same type of traditional biscuits used in this work, by the incorporation of vegetable fibre from different sources by Piteira, Maia, Raymundo, and Sousa (2006) and for the incorporation of *Chlorella vulgaris* biomass (Gouveia, Batista, Miranda, Empis, & Raymundo, 2007) and *Isochrysis galbana* microalgae biomass (Gouveia et al., 2008).

The present study intends to test the levels of Psyllium incorporation in the production of biscuits with no previous treatment, using whole commercial Psyllium. To attain this purpose it was carried out the rheological and textural characterisation of dough and the textural monitoring of biscuits.

2. Materials and methods

2.1. *Ingredients*

Psyllium fibre (Solgar, USA) was purchased in local market, such as wheat flour (T65), sugar, margarine, baking powder and distilled water.

Psyllium was ground and the fraction with particle size between 0.5 and 1 mm was used for all formulations.

2.2. *Biscuits preparation*

The biscuits were prepared according to a previous optimised formulation (Piteira et al., 2006), using flour (from 39% to 54%, depending on the Psyllium content), 15% sugar, 14% margarine, 16% water, 1% of baking powder and Pyllium fibre (from 3% to 15%) – all composition in a weight/weight base.

Dough was manually mixed for 5 min, sheeted with a rolling pin to a thickness of 4 mm. Then the dough was shaped and cut with a 60 mm diameter wire-cut and baked in an electrical air oven (Garbin – 23 MX-UMI, Italy), at 180±10 °C during 21 min. After cooling, biscuits were kept inside plastic bags, in sealed glass jars, at room temperature and protected from light until testing.

2.3. *Physicochemical characterisation of Psyllium and biscuits*

Dimensions of the biscuits (diameter – *D* and thickness – *T*) were evaluated using a caliper on a set of 4 biscuits for each recipe. Spread ratio (SR) was estimated by calculating the ratio *D*/*T* values.

Before the following chemical determinations, biscuits were crushed to homogenise samples.

Psyllium and biscuits were analysed for their moisture according to AOAC935.29 (1998) and ash (NP518, 1986), based on gravimetric methods. Total lipid analysis was carried out according to NP4168 (1991) and protein content was determined according the Kjeldahl, following ISO20483 (2006), using nitrogen conversion factors 6.24 for Psyllium and 5.70 for biscuits (Guo, Cui, Wang, & Young, 2008). Carbohydrate content was determined by difference to 100% of main constituents (moisture, ash, protein and fat).

Soluble, insoluble and total dietary fibre contents of Psyllium were evaluated according to AOAC 991.43 (1998) with the modifications specific for Psyllium fibre suggested by Lee, Rodriguez, and Storey (1995).

Water activity (a_w) of Psyllium and biscuits was determined in a Rotronic – Hygrolab (USA) at 20±0.5 °C.

Swelling power and solubility were accessed considering the method developed by Leach, McCowen, and Schoch (1959). This method involved a suspension of the sample (flour or Psyllium) in a known volume of water, gently stirring to keep it in suspension while incubating it at desired temperature (25, 37, 60 and 95 °C) for 30 min, centrifuging it at 10,000*g* for 10 min, and obtaining the weight of the gel, which is expressed as sediment paste per gram. Solubility of the flour is obtained by drying the supernatant at 105±1 °C and is expressed as the soluble percentage.

All analyses were carried out at least in triplicate and expressed as the mean value and standard deviation was calculated.

2.4. Texture evaluation

The texture characterisation of dough and biscuits was performed using a texturometer TA-XT plus (Stable Micro-Systems, UK). The biscuits texture was expressed in terms of firmness, obtained by a penetration test, using a cylindrical stainless steel probe of 2 mm diameter (with a load cell of 5000 g, 2 mm penetration at 0.5 mm/s crosshead speed). Firmness (N) was expressed by the ratio: positive area of the texturogram/time. This parameter can be considered as the average force necessary to the biscuit rupture, during the respective period of time. The texture evaluation of the dough was performed using a texture profile analysis (TPA) in penetration mode. The dough was moulded in an acrylic container (52 mm diameter and 24 mm height), and rested for 15 min before the test, using a 10 mm stainless steel probe plunged 10 mm at 5 mm/s. From the force versus time texturograms, parameters such as firmness and adhesiveness were calculated. Firmness was considered as the maximum resistance to the penetration of the cylinder at 10 mm depth and is recorded as the maximum force. Adhesiveness is a characteristic of sticky materials and can be defined as the resistance of the material when the probe is recessing. This parameter is recorded as a negative area and is evaluated as the work necessary to take the probe out of the material. From this test cohesiveness and springiness were also determined. Cohesiveness defines how well the structure of a product supports compression, and is measured as the ratio of the positive area of the 2nd and 1st compression cycles. Springiness is related to the height that the food recovers in the timeframe between the end of the first bite and the start of the second bite.

The measurements were conducted at 20±1 °C in a temperature controlled room and were replicated at least 8 times.

2.5. Dynamic oscillatory measurements

The rheological characterisation of dough was performed in a controlled-stress rheometer (RS-300, Haake, Germany) coupled with a UTC – Peltier system, using a serrated parallel plate (PP20 – 20 mm ∅) system with 2 mm gap. Dough was characterised by small-amplitude oscillatory shear measurements (SAOS).

After preparation, the dough rested in a container at room temperature for 20 min to promote the development of a stable structure (this aging time was previously optimised). Dough samples were transferred to the measurement instrument device, covered with a layer of paraffin oil, to prevent moisture loss and stabilised for 15 min at 20 °C. Frequency sweep tests were carried at a constant stress (in the linear viscoelastic region, previously determined for each sample: τ=20–100 Pa). Each test was performed in triplicate.

2.6. Colour evaluation

The colour measurements of the biscuits was performed instrumentally, using a Minolta CR-300 (Minolta Co., Japan) tristimulus colorimeter with standard illuminant D65 and a visual angle of 2°, calibrated using a white standard porcelain plate (L^*96.96; a*0.37; b*2.10).

The colour parameters (L*, a* and b*) were assessed by CIELAB, where L* defines the lightness (0% for black and 100% white) and a* (degree of redness or greenness: −a* – green and +a* – red) and b* (degree of yellowness or blueness: −b* – blue and +b* – yellow) are the chromaticity responsible parameters. The measurements were conducted at 20±1 °C under the same light conditions (50 mm^2 measuring area per measurement), and replicated 6 times.

2.7. Statistical analysis

All statistical treatments were performed using SPSS (v.20, IBM SPSS Statistics, New York, USA). Experimental data were compared by means analysis of variance (one-way ANOVA) and comparison of means by Kruskal-Wallis test at a significance level p=0.05 (95% confidence).

3. Results and discussion

3.1. Physicochemical characterisation of the dough ingredients

The proximate composition of Psyllium and wheat flour (Table 1) evidence that, for similar moisture content, Psyllium sample presents a much lower protein content, but higher values of ash and fibre. These results are in agreement with those found by Craeyveld, Delcour, and Courtin (2009) for chemical composition of Psyllium seed husk and with literature values referred for the wheat flours composition (e.g., Keswet, Ayo, & Bello, 2003 and Khetarpaul & Goyal, 2009).

It is important to note that Psyllium has a high proportion of soluble fibre (SDF), around 67%, and about 4% of insoluble fibre (IDF) – Table 1. Similar results were found by Yu et al. (2003): 78% for SDF and 12.4% for IDF. The importance of dietary intake of fibre with a high proportion of soluble fibre has also been recognised by Schneeman (1987).

The swelling power and solubility of Psyllium and wheat flour, at different temperatures (25–95 °C) are presented in Fig. 1(a) and (b), respectively. Study highlights the high swelling power of Psyllium in relation to the wheat flour – about 15 times higher, for all temperatures studied. According to Cheng et al. (2009) Psyllium has a water uptake capacity of 10 g/g, at room temperature, which is slightly lower than the value obtained in the present study. This difference in water retention capacity should result from the fact in the present study the Psyllium particle size is smaller.

For the wheat flour, when starch is heated in the presence of water, the granules imbibe water, swell and some amylose leaches into the solution – starch gelatinization. In the case of Psyllium increasing temperature facilitates hydration of soluble fibres, in particular 23% arabinose and 75% xylose, which contributes to an increase of swelling power. A linear increase of this parameter with increasing temperature, for both samples, is also observed. The highest values of swelling power for Psyllium, even at room temperature, may be an indicative for other food applications that do not require too much heating in order to form a gel structure. These results are in agreement with the swelling power reported for chestnut flours (Correia & Beirão-da-Costa, 2012) and rice flours (Takahashi, Miura, Ohisa, Mori, & Kobayashi, 2005). These authors also found that the swelling power of native starches increased with increasing temperature.

Regarding the solubility (Fig. 1b) it is observed that for the whole range of temperatures studied, the Psyllium solubility is higher than the wheat flour. The latter has a similar behaviour to the swelling power – a linear increase of the solubility with increasing temperature is also noticed, which is related with starch granules gelatinisation. This behaviour is related with the previous described greater interaction capacity of the starch granules with water, as the temperature increases. For the Psyllium sample a gradual variation of solubility with temperature is not obtained, probably because the solubility of this fibre depends on more complex phenomena related with the interaction of arabinoxylan with water (Fischer et al., 2004).

Table 1 – Proximate physicochemical composition of Psyllium. Data values are mean values ± standard deviation.

	Psyllium % (w/w)	Wheat flour % (w/w)
Protein	1.38 ± 0.09	9.03 ± 0.42
Total lipid	0.95 ± 0.02	1.44 ± 0.04
Moisture	12.55 ± 0.04	11.88 ± 0.04
Ash	2.25 ± 0.11	0.50 ± 0.03
Carbohydrate	82.87	77.15
Fibre	71.42	16.40
Soluble (SDF)	67.20 ± 6.62	9.91 ± 0.72
Insoluble (IDF)	4.21 ± 0.43	6.49 ± 0.29

3.2. *Physicochemical characterisation of biscuits*

The proximate composition of biscuits enriched with Psyllium from 0 to 15% (w/w) is summarised in Fig. 1. It can be noticed a slight increase of ash with the increase level of Psyllium incorporation, resulting from considerable content of minerals in the Psyllium sample (2.25% w/w from Table 1). A slight decrease of the protein content with Psyllium incorporation is also observed, resulting from the highest protein level of wheat flour (9% w/w) compared with the Psyllium fibre (1.41% w/w, from Table 1).

The moisture of the control biscuit (with no Psyllium added) is significantly higher than the Psyllium enriched formulations (4.32% w/w). The moisture content range from 1.88% to 3.27% w/w, decreasing with the increase of Psyllium content. These results are supported by the high water absorption capacity of Psyllium (about 17 g/g of water) and are also related with the variation of a_w for these formulations (Fig. 3). It is clearly noticed a reduction of water activity with an increase in Psyllium, which could lead to a longer shelf life for the biscuits enriched with fibre.

Ajila et al. (2008) obtained similar results for the incorporation of mango peel in biscuits. Similar increase in water absorption was also reported when bran from different cereals was incorporated into flour (Barber, Barber, & Martinez, 1981; Pomeranz, Shogren, Finney, & Bechtel, 1977; Sudha et al., 2007). Increased absorption of water resulting from the incorporation of fibre, is mainly due to the interaction between hydroxyl groups of polysaccharide macromolecules present in the fibre, and water, through hydrogen bonding (Chaplin, 2003; Dikeman & Fahey, 2006; Rosell, Rojas, & Benedito de Barberr, 2001). In the Psyllium fibre the hydrogen bonds are mainly established by arabinose and xylose molecules (Temudo et al., 2008).

Since the fat content of wheat flour (1.44% w/w) is within the same order of magnitude of the Psyllium lipid content (0.95% w/w), there are no significant differences in biscuits lipid content, for different levels of fibre incorporation, nor for the control.

The effect of the replacement of wheat flour by Psyllium, in terms of the shape characteristics of the biscuits is expressed in terms of the spread ratio (SR) – Fig. 4. An increase in SR with higher Psyllium content is observed, which means an increase of the ratio between diameter and

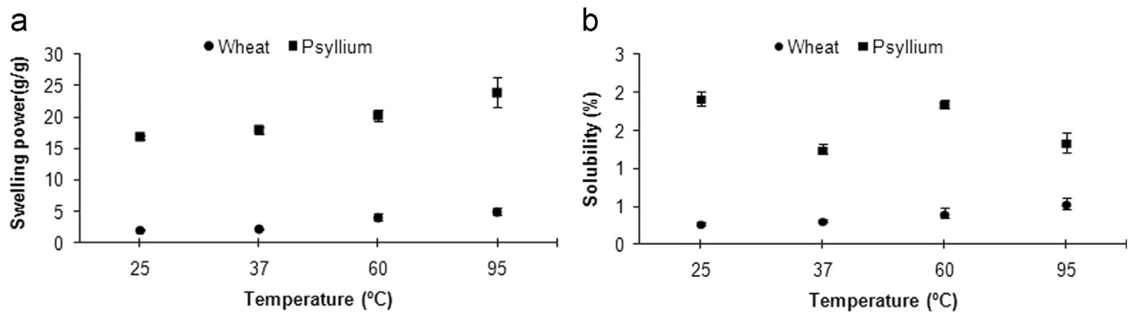

Fig. 1 – Swelling power (a) and solubility (b) of wheat flour and Psyllium at different temperatures (25 °C, 37 °C, 60 °C and 95 °C).

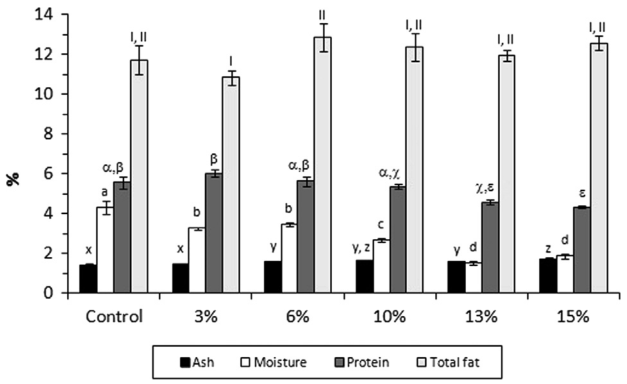

Fig. 2 – Proximate physicochemical composition of biscuits with different Psyllium and wheat flour content (Control to 15% of Psyllium). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

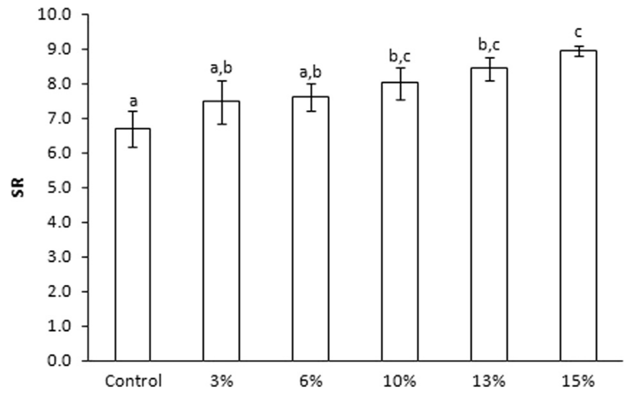

Fig. 4 – Spread ratio of biscuits with different Psyllium and wheat flour content (Control to 15% Psyllium). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

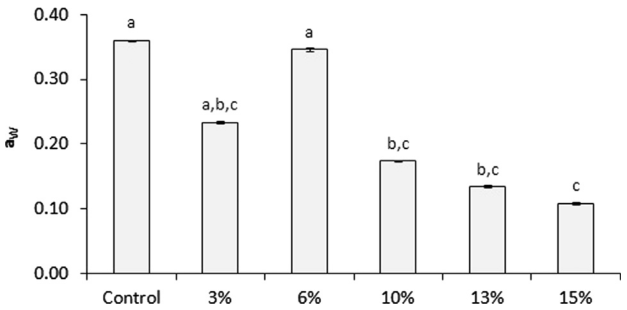

Fig. 3 – Water activity (a_w) of biscuits with different Psyllium and wheat flour content (Control to 15% Psyllium). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

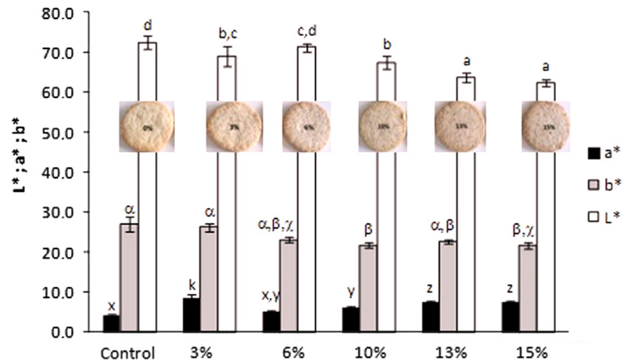

Fig. 5 – L^*, a^* and b^* colour values of biscuits with different Psyllium and wheat flour content (Control to 15% Psyllium). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

thickness of the biscuit. In practice, the biscuits enriched with Psyllium become more splayed, with a lower retention of the original shape (Fig. 5).

The impact of fibre incorporation on the biscuits' shape depends on the type of fibre. Ajila et al. (2008) observed a decrease in diameter and thickness of biscuits with the addition of 15 and 20% mango peel and justified it as a dilution of gluten effect. Fustier, Castaigne, Turgeon, and Biliaderis (2009) also reported some contradictory data reported in the literature, on the influence of protein content on cookie spread – Gaines (1991) showed a negative impact of the protein on spread, while Nemeth, Williams, and Bushuk (1994) found no correlation between cookie diameter and protein content.

The gradual substitution of wheat flour by Psyllium reduces the free water in the dough structure that may be responsible for the insufficient hydration of proteins and their conversion into a properly developed gluten network. As a result, the starch granules embedded in the protein matrix may not be changed during cooking as confirmed by Flint, Moss, and Wade (1970).

Thus, increasing the fibre content is related to a difficulty in maintaining the structure of the biscuit, corresponding to an increase of the SR values.

3.3. *Colour properties*

The effect of Psyllium incorporation on the biscuits' colour is an important factor to determine their consumer acceptability. It is found that increasing the content of Psyllium implies a significant decrease in L^* (biscuits become darker), the one which is associated with an increase in b* and a* (yellow component decreased and red component increased).

The darkening of the biscuits as a result of the incorporation of fibre was verified by several authors as Sudha et al. (2007) and this effect can result from a more pronounced non-enzymatic browning when wheat flour is replaced by fibre with different sugar composition. In addition, Psyllium, as well as several other fibres, is darker than wheat flour.

3.4. *Texture evaluation of biscuits*

The texture results of biscuits with Psyllium incorporation from 3% to 15% (w/w) are shown in Fig. 6. Biscuits with 3 and 6% w/w of fibre have significantly ($p<0.05$) higher firmness. The biscuits with higher content of fibre (13 and 15% w/w) have firmness values similar to the control (with no Psyllium addition). In fact, it is found that for these Psyllium concentrations, the biscuits become difficult to shape and have a substantial change in texture, with a negative impact on the sensory assessment. Psyllium content over 10% (w/w) brings technological constraints, and this limitation is especially induced by the rheological characteristics of dough with high levels of fibre incorporation, as result the dough can no longer be moulded.

Zhou et al. (2013) studied the addition of distinct amounts of konjac glucomannan (KGM) to low-protein wheat flour in noodles, concluding that KGM addition affect cooked starch granule structure and gluten network development. In general, for the addition of low concentrations of KGM, a strengthening of the gluten network was observed resulting in an increase in water retention capacity of gluten, despite the lower total protein content. However, for higher levels of incorporation, KGM interferes in the formation of gluten network, with a negative impact on noodles texture.

A similar effect was observed by Tudorica, Kuri, and Brennan (2002) for polysaccharides from different sources (pea fibre, inulin and guar), concluding that the negative effect on the formation of the gluten network depends on the type of polysaccharide and its levels.

According to the results of Fig. 6, it can be expected that up to 6% of Psyllium there is a positive effect on the strengthening of gluten network. By contrast, at higher concentrations, the network formation is adversely affected. This may justify the lower values of firmness (Fig. 6) and also the lower water activity of biscuits (Fig. 3) obtained for Psyllium contents between 10% and 15% (w/w).

Due to the limitation found for production of biscuits with levels of incorporation greater than 10% (w/w) of Psyllium, subsequent studies have been conducted with concentrations below this threshold.

The replacement of wheat flour by Psyllium entails a reduction in the capacity of the gluten development, as already mentioned, which can be related with a decrease in biscuits' firmness for the highest contents of fibre incorporation (10, 13 and 15%). For these cases, the biscuits enriched with Psyllium show a significantly ($p<0.05$) decrease of protein content with the increase of fibre incorporation (Fig. 2) and a consistently reduction of firmness. This behaviour was reported by several authors – Fustier et al. (2009) observed that cookie's firmness increased with the increase of protein level. Saha et al. (2011) also reported that the firmness of cookies increased with the increase of wheat flour content. For the lower levels of Psyllium incorporation, the reduction in protein content is balanced by an increased content of highly branched soluble arabinoxylan, which should contribute to reinforcing the biscuits structure, becoming less evident the effect of the protein content reduction. Regarding firmness results, it is clearly evident that there is a limit on the level of Psyllium incorporation – 10% (w/w). From this level there are no benefits in terms of texture, and there are great difficulties in processing of biscuits. The existence of limits to the fibre incorporation on biscuits is referred by other authors – Ajila et al. (2008) also referred 10% (w/w) as the upper limit of mango fibre incorporation in biscuits.

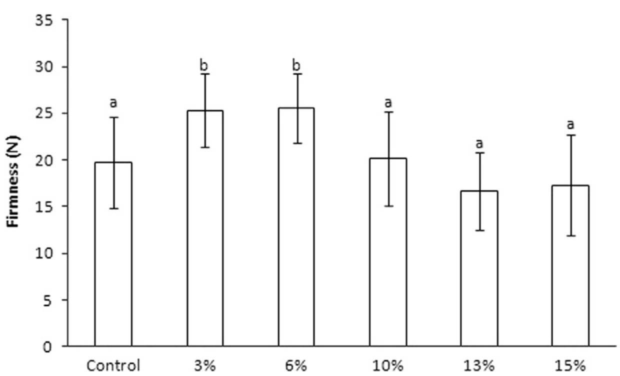

Fig. 6 – Firmness values of biscuits with different Psyllium and wheat flour content (Control to 15% Psyllium). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

3.5. *Texture characterisation of dough*

The impact of dough formulation on its texture properties was evaluated, according to the formulations summarised on Table 2, with different proportions of wheat flour and Psyllium.

The evaluation of the texture properties of the dough obtained with 50% wheat flour and Psyllium enrichment (Fig. 7) shows that all texture parameters considered are significantly influenced by the Psyllium content. Thus, the increase of fibre content leads to an increase of the dough firmness, paralleled by an increase of its adhesiveness and a less marked increase of springiness and a decrease in cohesiveness (0.482 N for 3% P compared with 0.248 N for 9% P). The results also reveal that firmness is the texture property that provides a more appreciable variation with the fibre addition. For the same amount of flour (50% w/w), the gradual addition of fibre involves the formation of biscuits with a more compact structure. This results in strengthening of the structure due to the presence of highly branched soluble arabinoxylan polymer, constituent of Psyllium, that can promote interaction between these polysaccharides and proteins (Sudha et al., 2007). The reduction in the free water content in biscuits enriched with fibre also reinforces this aspect, as it was reported by Sudha et al. (2007).

The effect of increasing the content of flour, for two levels of Psyllium incorporation (4 and 6% w/w) can be observed in Fig. 8.

A significantly ($p<0.05$) increase of dough firmness with the increasing content of wheat flour is observed, independently of the amount of Psyllium added. Adhesiveness also significantly increases with the flour content, being more evident for the highest level of incorporation of fibre (6% w/w). For the lower level of fibre incorporation, cohesiveness decreases with increasing the content of flour.

In relation to springiness there are no significant changes, for all combinations of flour and Psyllium studied. In this set of experiments, for each Psyllium concentration, an increase of wheat flour content is essentially related with an increase in the protein content of the formulation. There are very few reports concerning the role of gluten in biscuit-making (Saha et al., 2011). However, there are evidences that an increasing of protein content, resulting from the increase of wheat flour,

Table 2 – Dough formulations with different proportions of wheat flour and Psyllium. Water content was adjusted up to 100% (w/w).

(%)				
Psyllium	Wheat flour	Margarine	Sugar	Baking powder
3.0	50.0	14.0	15.0	1.0
4.0	49.0			
4.0	52.0			
6.0	48.0			
6.0	50.0			
9.0	50.0			

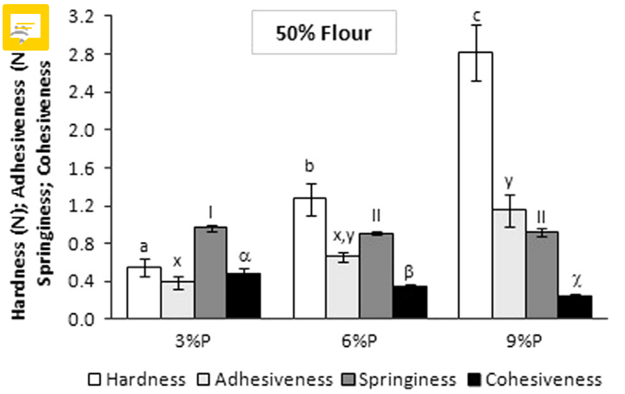

Fig. 7 – Texture of dough formulations with 50% Flour: 3% P; 6% P and 9% Psyllium. Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

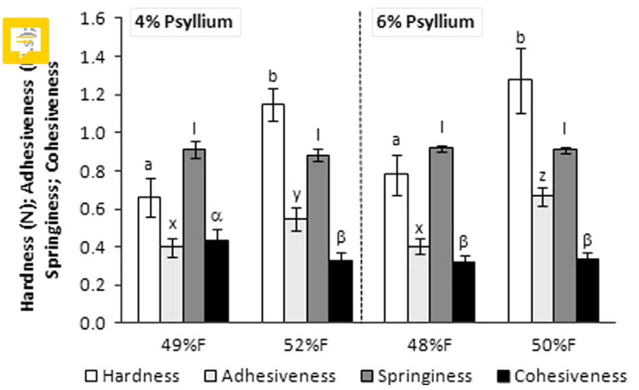

Fig. 8 – Texture of dough formulations with 4% Psyllium (49% F and 52% F) and 6% Psyllium (48% F and 50% F). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

leads to a more intensive development of the gluten network, increasing the magnitude of the texture parameters, especially firmness and adhesiveness (Ajila et al., 2008).

3.6. *Dynamic oscillatory measurements of dough*

Generally, the dough composition affects the development of the gluten network during mixing, which may be reflected in the viscoelastic parameters of the dough (Pedersen, Kaack, & Adler-Nissen, 2001; Pedersen, Kaack, BergsØe, & Adler-Nissen, 2005).

The rheological behaviour of dough was studied for the six formulations summarised in Table 2. Results from frequency sweeps (Fig. 9) show that G' is always higher than G'' and both moduli increase with increasing frequencies, reflecting that at higher frequencies the dough behaves more like a liquid. This result agrees with Pedersen and co-authors (Pedersen et al., 2001, 2005). As it was indicated for texture, there are two factors that may contribute to a higher degree of the dough structure: the high protein content – which favours the gluten formation – and the high levels of soluble fibre – which promotes the establishment of interaction between proteins and polysaccharides.

Taking this in account, it can be observed that the mechanical spectra with higher magnitude of G' and G'' are obtained for the formulations with both higher levels of flour and Psyllium.

To quantify the impact of different combinations of flour and Psyllium on the elastic moduli, it is represented in Figs. 10 and 11 the variation of G' with dough composition, at three frequency values (0.01, 1 and 10 Hz) obtained from the respective mechanical spectra.

Comparing the values of G' for the formulations with 50% flour (Fig. 10), it is found that the increase of Psyllium content is associated with an increased degree of dough structure, which results in an increase of G' values, for the three frequencies considered. This behaviour is markedly noticed for the highest Psyllium concentration (9% w/w). Addition of Psyllium may reduce the interactions between glutenins and gliadins during gluten development, but this effect should be overcome by its strong water uptake, the possibility of establishment of interactions between the arabinose and xylose molecules and by the interaction of these polysaccharides and proteins.

The increase of the wheat flour content for both Psyllium concentrations (4 and 6% w/w) did not induce significant ($p>0.05$) increase of G' values, for the three frequencies considered (Fig. 11). These results reinforce the previous observation, that the effect of Psyllium in structuring the dough overlaps the effect of wheat flour, for the proportions range studied.

Several authors have reported the adverse effect of the fibre addition on the dough structure of biscuits expressed in terms of the reduction in the viscoelastic properties, especially when the insoluble fraction of fibre is very high, as noted Saha et al. (2011).

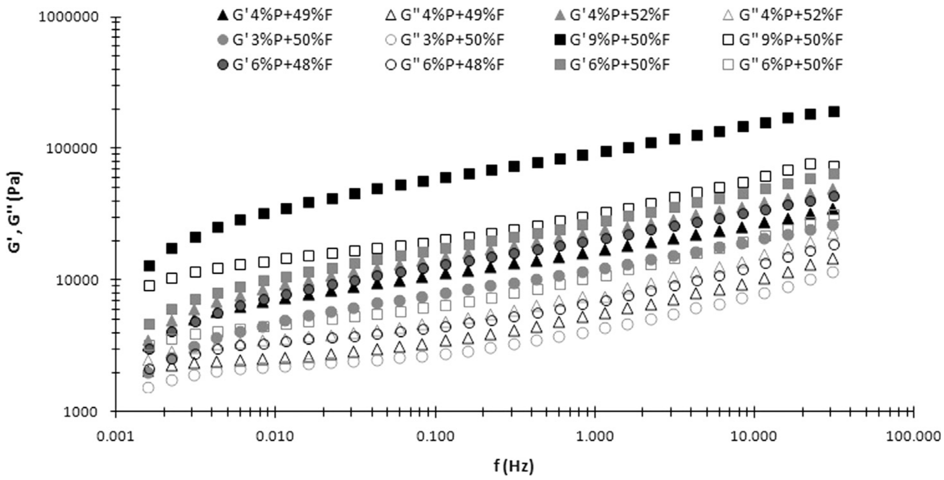

Fig. 9 – Frequency sweeps of six dough formulations: 4% P+49% F; 4% P+52% F; 3% P+50%; 9% P+50% F; 6% P+48% F; 6% P+50% F (P – Psyllium and F – Wheat flour).

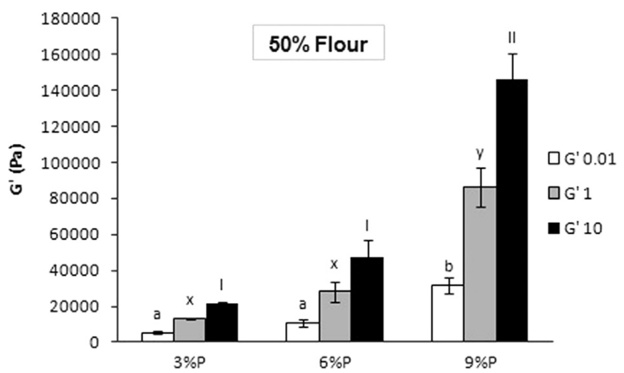

Fig. 10 – G′ at 0.01 (□), 1 (■) and 10 Hz (■) of dough with 50% flour and different Psyllium incorporation (3%, 6% and 9% Psyllium). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

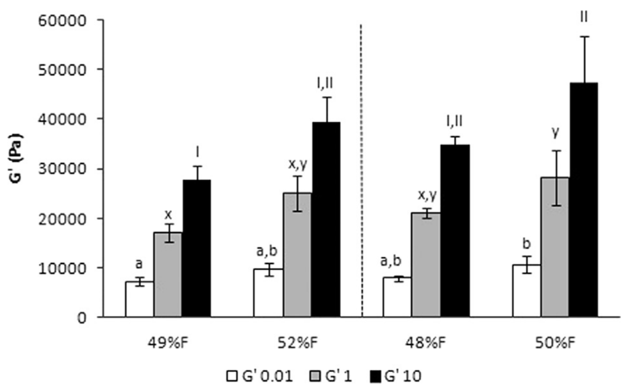

Fig. 11 – G′ at 0.01 (□), 1 (■) and 10 Hz (■) of dough with 4% Psyllium (49% and 52% Flour) and 6% Psyllium (48% and 50% Flour). Different superscript letters in the same parameter are significantly different at the $p<0.05$ level.

4. Conclusions

The production of biscuits enriched with Psyllium husks can be considered as an alternative way to include this health promoter fibre in human nutrition. The biscuits obtained have a colour and texture with high potential for commercial exploration.

As a result of the high water absorption capacity of Psyllium, the maximum fibre incorporated in this type of biscuits is about 9% (w/w). For high levels of fibre incorporation, the dough fails to be moulding. This limitation is especially induced by the rheological characteristics of dough.

It is found that the rheological properties of the dough are highly dependent on fibre content, as the texture of the resulting biscuits.

It is necessary to improve technological developments which increase levels of incorporation of Psyllium, namely the incorporation of other ingredients that allow inhibition of absorption of water.

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