Research Article

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Effect of different fibers on dough properties and biscuit quality

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Abstract

BACKGROUND: This study forms part of a broader project aimed at understanding the role of fibers from different sources in high-fat, high-sugar biscuits and at selecting the best fibers for biscuit quality. The main purpose of this work was to understand the rheological and structural properties involved in fiber-enriched biscuit dough. High-amylose corn starch (RSII), chemically modified starch (RSIV), oat fiber (OF) and inulin (IN) were used at two different levels of incorporation (6 and 12 g) in dough formulation. The influence of fiber on the properties of biscuit dough was studied via dynamic rheological tests, confocal microscopy and spreading behavior. Biscuit quality was assessed by width/thickness factor, texture and surface characteristics, total dietary fiber and sensory evaluation.

RESULTS: Main results indicated that IN incorporation increased the capacity of dough spreading during baking and thus improved biscuit quality. OF reduced dough spreading during baking and strongly increased its resistance to deformation. RSII and RSIV slightly affected the quality of the biscuits. Sensory evaluation revealed that the panel liked IN-incorporated biscuits as much as control biscuits.

CONCLUSION: The increase in total dietary fiber modified dough behavior and biscuit properties, and the extent of these effects depended on the type of fiber incorporated.

Supporting information may be found in the online version of this article.

Keywords: dough; rheology; dietary fiber; cookie/biscuit quality; sensory evaluation

INTRODUCTION

Short dough biscuits, characterized by high fat, high sugar content and low amount of water, do not require development of gluten for manufacture. They are usually made with soft wheat flour with low protein quantity. However, in Argentina, the biscuit industry uses flour obtained from bread wheat, since soft wheat cultivars are not available. In the absence of more appropriate varieties for biscuit production, flours from low-quality bread wheat are used, with specific additives incorporated and changes made in the manufacturing process to minimize the formation of gluten.[1]

The modification made in dough formulation impacts not only on texture, flavor and quality parameters but also on the dough, generating technological problems in its processing, in addition to loss of consumer acceptance.

In the processing of short dough biscuits, dough is the intermediate product between flour and biscuits, and its rheological behavior is of considerable importance in the manufacture as it influences the processability and quality of biscuits. Dough rheology plays a key role in biscuit production, since this process includes unit operations such as mixing, extrusion, sheeting, relaxing and stamping. Molders, the most extensively used technology for short dough biscuits, can handle relatively dry and crumbly dough, though a much softer dough consistency is needed for other types. For rotary molded biscuits, a critical balance must be sought between the stickiness of the dough and the adhesive nature of the extraction band of the molder.[2] Further knowledge of the rheological properties of biscuit doughs is needed in order to predict their behavior.

The refining of whole grains involves a process that results in the loss of vitamins, minerals and dietary fiber. Most refined grains are enriched with iron, thiamin, riboflavin, niacin and folic acid before being further used as ingredients in food. This restores some, but not all, vitamins and minerals that were removed during the refining process. One of the suggested strategies involves the replacement of refined grains by whole grains. A further strategy consists of the development of enriched food with higher fiber content, reaching levels at which the beneficial effects can be appreciated.[3]

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Dietary fiber is defined as the component of plant cells that resists digestion and absorption in the human small intestine, undergoing partial or total fermentation in the large intestine.[4] Dietary fiber can be classified as soluble (oligosaccharides, pectins and β-glucans) or insoluble (cellulose, hemicellulose and lignin) according to its solubility in water.[5] Since fiber does not intervene directly in human basic metabolic processes, health benefits have been largely described, including, but not limited to, heart disease risk reduction, certain types of cancer, diabetes, obesity, prevention of constipation and stimulation of beneficial growth of colonic microflora.[6,7] These effects are attributed to the ability of the fiber to increase the viscosity in the gut and thus control glucose and lipid metabolism.[8]

Resistant starches have been recently proved to serve a physiological function similar to that of dietary fiber.[9] Resistant starch is divided into four fractions: RSI (type I), RSII (type II), RSIII (type III) and RSIV (type IV). RSII resists enzyme digestion because of its certain granular form, and RSIV is a chemically modified starch, forming bonds other than α-(1 → 4) or α-(1 → 6).[10]

Inulin is a polyfructose consisting of linear chains of D-fructose β-(1 → 2)-linked molecules, terminated or not by a glucose residue, with a degree of polymerization (DP) ranging between 10 and 25.[11]

Oat fiber is an insoluble fiber that contains β-glucans, linear polymers composed of glucosyl residues linked via a mixture of β-(1 → 4) and β-(1 → 3) linkages.[12]

Knowledge of the influence of fibers on rheological properties is essential for the development of good quality products. The most serious technological drawbacks related to the rheological properties of dough include problems with adhesion to work surfaces and changes in shape, color, density and texture of the baked product. These modifications prove inconvenient in the production process and in sensory aspects of the product, both visual and flavor.[13]

The aim of the present research was to analyze the effect of the incorporation of various commercial dietary fibers from different sources on the formulation of biscuits to understand the rheological and structural properties involved in fiber-enriched biscuit dough and quality.

MATERIALS AND METHODS

Materials

All-purpose wheat flour (protein 104 g kg^{-1}, moisture 119 g kg^{-1}, ash 6.2 g kg^{-1} (dry basis), gluten 234 g kg^{-1}, Alveograph deformation energy (W) = 260 and tenacity/extensibility ratio (P/L) = 2.89, and falling number 545 s) was used. Inulin (IN) (Orafti® HP) with DP above 23 was obtained from Orafti Food Ingredients (São Paulo, Brazil). Resistant starch type II (RSII) (Hi-maize 260, National Starch) and resistant starch type IV (RSIV) (Novelose 480, National Starch) were supplied by Gelfix SA (Buenos Aires, Argentina). RSII is a high-amylose maize starch, while RSIV is defined as a phosphated distarch phosphate, a crosslinked high-amylose maize starch. Oat fiber (OF) (Canadian Harvest® Oat Fibers 200/58 Series, USA) was supplied by Saporiti SA (Buenos Aires, Argentina).

Fiber hydration properties

The fiber and resistant starch samples used and the biscuit samples were analyzed for moisture (AACC method 44-01).[14] In order to determine the water-soluble fraction (WSF) and water retention capacity (WRC) of the fibers, samples (1.000 ± 0.001 g) were hydrated with 30 mL of distilled water for 18 h at 25 °C, after stirring in a vortex, in a conical tube. Centrifugation for 30 min at 2000 × g was then performed (Centrifugal Sorval RC-5, Thermo Scientific, Waltham, MA, USA). The hydrated solid (residue) and the supernatant were quantitatively separated. Both the supernatant and the hydrated fiber (residue) were weighed and dried at 105 °C (until constant weight), then the dry residues were weighed to obtain the values of WRC (g water g^{-1} dried residue of hydrated solid) and WSF (g soluble solids from supernatant kg^{-1} fiber). Three replicates were maintained for the study.

Preparation of biscuit dough

Biscuits were obtained according to Serial *et al.*[15] Fiber and starch samples were incorporated at two levels, 6 g (IN6, OF6, RSII6, RSIV6) and 12 g (IN12, OF12, RSII12, RSIV12), with 39 and 33 g (instead of 45 g) of wheat flour respectively being used.

Dynamic rheological measurements

A controlled stress rheometer (RHEOPLUS/32, Anton Paar, Germany) was used in the oscillatory tests. It was equipped with a 25 mm parallel plate geometry. A dough sample was obtained with a cylindrical biscuit cutter and placed on the lower plate. The upper plate was lowered until the final gap (2 mm), and the excess dough protruding from the edge of the plate was carefully trimmed. Dehydration was prevented by adding low-viscosity silicone around the plate edges. The sample was rested for 5 min before measurements were conducted.

The linear viscoelastic region was analyzed by a strain sweep at a frequency of 10 Hz or an angular frequency (ω) of 62.83 rad s^{-1} at 25°C. The linear viscoelastic region was determined to be up to 0.1% strain, and a target strain of 0.05% was used in all experiments. A frequency sweep was performed in the range 0.05–100 rad s^{-1} at 25 °C and 0.05% strain.

Temperature scans were performed to investigate the main transformations in the dough undergoing heating. After equilibration at the initial temperature of 25 °C for 5 min, the sample was heated at a rate of 4 °C min^{-1} to the final temperature of 100 °C. This heating rate was chosen to emulate the baking process of biscuits. During heating, the sample was sheared at a frequency 10 Hz and a strain of 0.05%. A static force of 500 mN (optimum determined in preliminary test) was applied to allow the upper plate to be in contact with sample during the temperature scan.

Two fresh samples of dough were measured and dough elaborated at least in duplicate to ensure reliable results. Results were expressed in terms of storage modulus (G'), loss modulus (G'') and tanδ (G''/G').

Dynamic diameter measurements

In order to monitor changes in biscuit dimensions during baking, videos were taken during baking using a digital camera (DSC-W320, Sony, Tokyo, Japan). Four biscuits were considered in each trial. A calibrated metal bar was used in each test as a dimension reference. Images were stored in AVI format. The AVI files obtained were analyzed by ImageJ software (National Institutes of Health, Bethesda, MD, USA) to obtain biscuit diameter, thickness and spread rate at 30 s intervals after calibration of the image using the metal reference. Two parameters were determined from these profiles: maximum diameter of biscuit pieces reached during baking (MD) and biscuit set time (ST). Biscuit ST was defined as the time at which the biscuit reaches its maximum spread during baking. Four biscuits of each cooking batch and three batches were measured to ensure reliable results. The MD and ST values presented are the average of all biscuits measured of each sample.

Biscuit evaluation

Width/thickness factor

Six biscuits were obtained for each batch, from which four (the most homogeneous ones) were selected to determine this parameter. The width/thickness factor (W/TF) was calculated as the ratio between the diameter (D) and thickness (T) of four biscuits taken at random.[16] Biscuits were elaborated in triplicate to ensure reliable results.

Biscuit texture

The breaking strength was measured by the triple-beam snap technique using an Instron 3342 universal testing machine (Norwood, MA, USA) with a load cell of 500 N. The base gap of the two support beams was adjusted to 36 mm. Each biscuit was centered on the base, and the travel distance of the blade was 35 mm; pre-test and speeds were 0.5 mm s^{-1}. The average value of four replicates from three independent batches during production was determined. Two parameters were assessed: deformability modulus (Def), defined as the time elapsed until the structure breaks, and breaking stress (σ), calculated as[17]

$$\text{breaking stress} = \left(3 \times \text{peak force} \times \text{span width}\right) / \left[2 \times \text{cookie length} \times (\text{cookie height})^2\right]$$

Characteristics of biscuit surface

Biscuit surface was analyzed by the degree of surface cracking. TIF images were analyzed with an image analyzer (ImageJ, National Institutes of Health). Color images were converted to 8 bit 256 gray-level images. Images were segmented and analyzed. A circle of 40 mm diameter was taken from the center of the biscuit and evaluated for each image. The threshold Rényi entropy method[18] was applied for image segmentation and a binary image was obtained, where pixels with a gray level higher than that of the threshold will be associated with crack regions, while the remaining pixels will be associated with biscuit surface. The biscuit feature chosen was the crack area/total area ratio (degree of surface cracking). The average value of four replicates from three independent batches during biscuit production was determined.

Total dietary fiber and inulin contents

Defatted biscuit samples were dried at 70 °C overnight and milled for total dietary fiber content determination (AACC method 32-05).[14] Results were expressed as g dietary fiber kg^{-1} biscuit. To determine the inulin content of biscuits, an anion exchange high-performance liquid chromatography (HPLC) method following extraction of inulin was used.[19] Results were expressed as g inulin kg^{-1} biscuit. All analyses were done in duplicate.

Sensory evaluation

The eight biscuit samples (consisting of two rounds of four samples each) were evaluated by a panel of 14 assessors (ten females and four males aged between 25 and 55 years) having knowledge and experience in sensory descriptive analysis, which included techniques and practice in attribute identification and terminology development. The panel evaluated the samples using a seven-point scale, where the reference value (control sample) was in the middle of the scale (3.5 points). A whole biscuit of each sample was served in a plastic container coded with a random three-digit number. Water was used for rinsing the palate between samples. The test was carried out 24 h after baking. Six attributes were analyzed: hardness (force required to compress and break the biscuit structure with the molars), crispness (sound perceived when the biscuit structure breaks when compressing with the molars), sweetness (sweet taste perceived during chewing), palatability (fat sensation perceived on the palate after swallowing), chewiness (number of times it is necessary to chew a piece of biscuit to reduce it to a consistency suitable for being swallowed) and grain properties (perceived granules during chewing). Sensory instructions are detailed in 'Supporting information'.

A consumer test was carried out with the 12 g enriched biscuits in order to acquire knowledge of the panel preference for texture and flavor. The panel was the same for both tests. They assessed the order of liking, including the control, assigning a number to each sample, where 1 was the least liked and 5 the most liked. The resulting number for each sample was the mean value of the score assigned by each judge.

Statistical analysis

The data obtained were statistically treated by variance analysis, while means were compared by Fisher's least significant difference (LSD) test at a significance level of 0.05. Correlation between variables was determined via Pearson's coefficient. These tests were carried out using INFOSTAT statistical software (Universidad Nacional de Córdoba, Córdoba, Argentina).

RESULTS AND DISCUSSION

Fiber properties

Hydration properties of the fibers were analyzed. IN and OF retained more water (3.75 ± 0.11 and 2.90 ± 0.10 g water g^{-1} solids respectively) than commercial native wheat starch (1.12 ± 0.06 g water g^{-1} solids) and wheat flour (1.25 ± 0.02 g water g^{-1} solids). RSII (1.46 ± 0.0 g water g^{-1} solids) and RSIV (1.39 ± 0.04 g water g^{-1} solids) had values similar to those of commercial native wheat starch and wheat flour (Fig. 1).

IN showed the highest WSF and WRC values. OF, RSII and RSIV showed low values of WSF (<19 g soluble solids kg^{-1} fiber). OF had higher WRC than resistant starches but lower WRC than IN.

Scanning electron microscopy (SEM) images of the structure and shape of the raw materials are detailed in 'Supporting information'. Wheat flour particles formed aggregates of diverse size and heterogeneous distribution. The distribution of IN was more homogeneous (particle size ~100 μm). OF showed a scaly and irregular shape and length, with large pieces of fiber distinguishable between smaller and heterogeneous aggregates. Both resistant starches showed a spherical shape with particles of ~10 μm diameter. RSII showed more a homogeneous distribution than RSIV.

Effects of fiber addition on dough rheological properties

The distribution of ingredients in biscuit dough was investigated by confocal laser scanning microscopy (CLSM) on 12 g fiber samples ('Supporting information'). Micrographs showed a bicontinuous system, where two phases were found, a fat phase (continuous phase) and a non-fat phase, composed of sucrose syrup binding flour/starch particles. RSII and RSIV dough seemed to have a larger amount of starch granules, and these samples and control dough showed a similar distribution of phases. OF and IN had a more developed non-fat phase. OF fluoresced in red when stained with Rhodamine B, therefore it seems reasonable to find a larger non-fat phase. IN did not show dying, hence the differences in micrographs were ascribed to a change in phase distribution. The non-fat phase

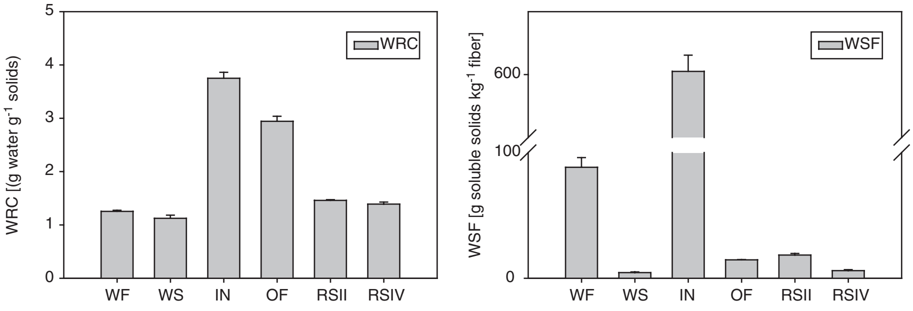

Figure 1. Water retention capacity (WRC) and water-soluble fraction (WSF) of wheat flour (WF), wheat starch (WS) and fibers. IN, inulin; OF, oat fiber; RSII, resistant starch type II; RSIV, resistant starch type IV.

seemed to be less homogeneous, forming bigger aggregates of protein and starch granules than those of control dough.

Figure 2 shows the average mechanical spectra of biscuit dough pieces produced with 12 g of replacement (6 g replacement was not included to make the figures clearer). Storage modulus (G') values were always higher than those of loss modulus (G''), indicating the prevalence of elastic over viscous properties, a typical response of a crosslinked polymer network. The evolution of both moduli was roughly the same in all samples: an increase in G' and G'' with frequency was observed in all cases, but maintaining the predominant elastic character. However, G'' showed larger increases at higher frequencies. These results indicated that the recovery of the stressed dough network was a slow process, i.e. the network was not completely elastic, as pointed out by Agyare *et al.*[20]

Regarding tanδ, the general profile showed a significant decrease in the values between 0.05 and $\sim$10 rad s^{-1}, which is related to a larger increase in G' over G'', indicating the system shift toward elastic properties at lower frequencies. At higher frequencies, tanδ increased in all samples, denoting a more viscous behavior.

IN and both RSII and RSIV at 6 and 12 g of addition did not produce significant differences in G' and G'' compared with the control, whereas OF significantly increased these parameters, showing the highest moduli when added at 12 g (Table 1). These results indicated that OF dough had a higher elastic behavior than control, IN, RSII and RSIV doughs. OF6 resulted in intermediate curves between the control and OF12 (results not shown).

In all cases, tanδ values did not show significant differences compared with the control or with each other.

Insoluble β-glucans of oat non-starchy polysaccharides have a high fraction of β-(1 $\rightarrow$ 4) linkages that facilitate hydrogen bonding between polymer chains and with water molecules as well. It has been suggested that non-starchy polysaccharides from oat can influence water distribution and dough viscosity by trapping water, since they cannot enter the dough aqueous phase owing to their low solubility. A similar behavior was described for water-unextractable arabinoxylans.[21,22]

Both RSII and RSIV had a water retention capacity similar to that of flour and lower than that of OF, in agreement with lower values of both G' and G'.

Despite greater solubility and capacity for water retention (Fig. 1), IN incorporation did not change the dough viscoelastic behavior at 25 °C. Peressini and Sensidoni[23] studied the addition of different types of inulin samples to bread dough. They showed that the storage modulus gradually increased and tanδ decreased with increasing levels of IN, which contributed to the overall dough elasticity and strength. They also noted that the polymerization degree of IN was important to determine the extent of change in linear viscoelastic properties of dough. When viscoelastic behavior was evaluated at constant water absorption (54.2%), the storage modulus of ST-inulin (average DP of 10) samples was lower than that of the control. The authors suggested a diluent action of the dough when ST-inulin was added. However, the opposite behavior was found for high-performance (HP) inulin (average DP of 23); at any given moisture level, HP-inulin showed higher elasticity and solid-like behavior than the control sample. The authors suggested the formation of elastic networks due to inulin–inulin interaction. In another study, Wang *et al.*[24] proposed interactions between inulin and gluten to explain the fiber effect on dough.

In our study, biscuit dough was obtained with minimal mixing and low water content, resulting in a short dough with minimal if any gluten development. It is thought that IN can partially enter the dough aqueous phase and can also be part of the solid matrix. IN as part of the dough aqueous phase can contribute to increasing the volume, which may reduce the dough consistency. At the same time, IN as part of the solid matrix can compete with other flour constituents for available water, increasing the dough consistency. The net result of these effects was no significant change in the viscoelastic properties of dough with IN at room temperature compared with control dough.

In order to evaluate dough viscoelastic behavior during heating, temperature sweeps from 25 to 100 °C were carried out in all samples (Fig. 3). Three major zones could be differentiated in the general profile of control dough. These profiles are consistent with those of previous temperature sweep studies in biscuit dough.[25] In the first zone, between 25 and 50 °C, a rapid decrease in G' and G'' due to fat melting and sugar solubilization was observed. In the second zone, between 50 and 75 °C, the consistency decreased slightly with increasing temperature. Finally, between 75 and 100 °C, the behavior of G' and G'' was dependent on the dough formulation, i.e. these values showed a slight increase or followed the same tendency as the second zone.

OF dough showed the highest resistance to deformation throughout the entire assay. In addition, a slight decrease in both moduli was observed in the second zone, and, in the third zone, G'' continued to decrease while G' remained constant. Again, this behavior suggested a high capacity of OF to trap water, increasing the system viscosity.

RSII and RSIV doughs showed no significant differences compared with control dough in the first and second zones; however, from 75 °C to the end, both showed a more pronounced increase in G' and G'' than that of the control. Resistant starches had similar water absorption to that of wheat flour, and both RSII and RSIV typically do not gelatinize.[26] Therefore more water seemed to be

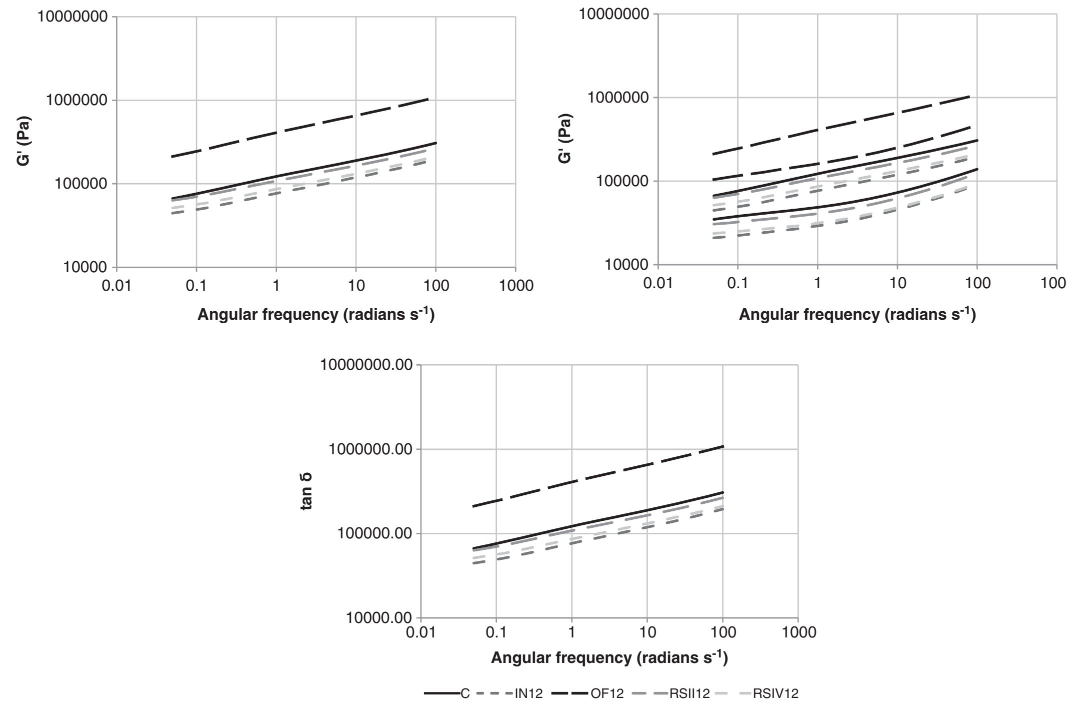

Figure 2. Effect of fiber addition on storage modulus (G') and loss modulus (G'') during frequency sweep. C, standard formulation; IN, inulin; OF, oat fiber; RSII, resistant starch type II; RSIV, resistant starch type IV; 12 indicates the amount of fiber (g) added to the formulation.

Table 1. Dough rheological parameters at 25 °C and 1 Hz ($\omega = 6.28$ rad s^{-1})

Sample	G' (kPa)	G'' (kPa)	tanδ
C	171c	65c	0.378a
IN6	144cde	55cd	0.389a
IN12	149cde	55cde	0.368a
OF6	281b	108b	0.383a
OF12	586a	222a	0.379a
RSII6	134cde	51def	0.380a
RSII12	107e	40f	0.372a
RSIV6	113de	42ef	0.369a
RSIV12	119de	42def	0.356a

Values in the same column with a common letter are not significantly different ($P > 0.05$). C, standard formulation; IN, inulin; RSII, resistant starch type II; RSIV, resistant starch type IV; OF, oat fiber; 6 and 12 indicate the amount of fiber (g) added to the formulation.

available for wheat starch swelling, increasing the dough viscosity at high temperatures.

Both G' and G'' of IN-enriched dough decreased from 25 to ∼40–45 °C and then remained relatively constant until the end of the second zone, where both moduli decreased, remaining slightly above the control values throughout the whole assay. A similar behavior has been found by other researchers in frequency sweep assays with HP-inulin.[27,28]

Dough samples showed a maximum value of tanδ between about 44 and 48 °C (Fig. 3, Table 2). This behavior indicated a more liquid-like behavior of the matrix due to fat melting and sugar solubilization. The maximum tanδ value was shifted to lower temperature (43.2 °C) when IN was incorporated (45.7 °C for control dough), showing a faster increase from viscous to elastic behavior which may be related to IN water solubility, since an extra increase in the volume of the water phase can be achieved as a consequence of IN incorporation. OF and resistant starches did not significantly change the temperature of the maximum tanδ values. OF and IN showed lower tanδ maximum values and OF had the lowest values, indicating the lowest liquid-like behavior during heating. Resistant starches did not change the maximum tanδ values significantly.

These results are in agreement with those reported by Serial *et al.*[15] In their study, the effect of IN and OF (at 12 g of flour replacement) was analyzed by nuclear magnetic resonance (NMR). The incorporation of IN and OF rendered the same T2 distribution as that in control dough at ambient temperature. However, as the temperature increased, OF significantly affected the most mobile water population. This water population split into two populations with different T2 values with increasing temperature. The splitting temperature decreased slightly for IN (∼47 °C for IN and ∼49 °C for control) and increased significantly for OF (∼59 °C). The authors suggested that the phase with high mobility, together with the melting of the fat, provides the necessary lubrication for the dough's effective expansion during baking.

Effects of fiber addition on dough spreading behavior and biscuit quality

Figure 4 shows the effect of fiber addition on diameter changes during baking (each curve was obtained by averaging all assays in each sample). The general profile showed that biscuit diameter increased fast during the first minutes of baking. From about 5 to 6 min (102–104 °C), until the end of the baking process, biscuit pieces showed a slight shrinkage in diameter. The general curve shape followed the same trend and they presented similar slopes, i.e. spread rates, even though different maximum values were found.

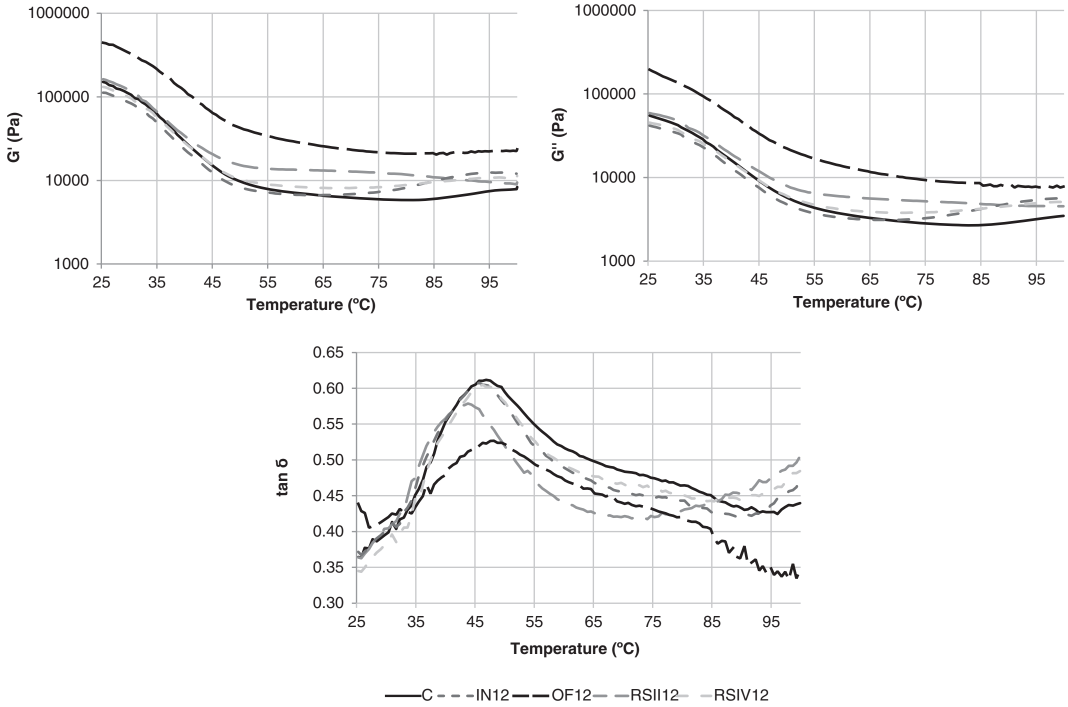

Figure 3. Effect of fiber addition on storage modulus (G') and loss modulus (G'') during temperature sweep. C, standard formulation; IN, inulin; OF, oat fiber; RSII, resistant starch type II; RSIV, resistant starch type IV; 12 indicates the amount of fiber (g) added to the formulation.

Table 2. Maximum $\tan\delta$ (Max $\tan\delta$) and temperature at which it occurs (T max $\tan\delta$) during temperature sweep

Sample	T max $\tan\delta$ (°C)	Max $\tan\delta$
C	46.63 ± 0.81cd	0.615 ± 0.016d
IN6	44.28 ± 1.46ab	0.596 ± 0.007c
IN12	43.95 ± 1.58a	0.580 ± 0.006b
OF6	46.65 ± 0.49cd	0.567 ± 0.006b
OF12	48.20 ± 0.00d	0.528 ± 0.005a
RSII6	46.00 ± 0.42bcd	0.599 ± 0.008cd
RSII12	45.70 ± 0.00abc	0.608 ± 0.007cd
RSIV6	46.30 ± 0.00cd	0.608 ± 0.000cd
RSIV12	46.60 ± 0.42cd	0.605 ± 0.002cd

Values in the same column with a common letter are not significantly different ($P > 0.05$). C, standard formulation; IN, inulin; RSII, resistant starch type II; RSIV, resistant starch type IV; OF, oat fiber; 6 and 12 indicate the amount of fiber (g) added to the formulation.

In general, biscuit height increased linearly until reaching a maximum, and then collapsed (results not shown). OF, RSII and RSIV significantly decreased the MD reached during baking compared with the control (Table 3). The MD of IN biscuit pieces showed no statistical differences from the control, probably because of the high error associated with the methodology used to obtain the values, although IN12 exhibited the highest value.

The highest ST was found for IN12, while the lowest was related to OF12, both showing significant differences from control dough. The rest of the samples had values between 3.80 and 4.60 min and did not show statistical differences.

W/TF values ranged from 4.37 to 6.78 (Table 3). In agreement with previous results, the lowest and highest values were obtained with OF and IN respectively. Biscuit thickness was more affected than biscuit diameter by the inclusion of fibers. IN12 decreased biscuit thickness by ∼20% but increased biscuit diameter by ∼8% compared with the control.

RSII did not affect W/TF ($P > 0.05$), while RSIV12 reduced W/TF and increased biscuit thickness. On the other hand, IN significantly increased W/TF (by 11 and 36% when used at 6 and 12 g of replacement respectively), indicating better quality parameters of the biscuits.

The cracking area fraction (CAF) indicates the degree of surface cracking on biscuits (Table 3). IN12 showed the highest CAF, followed by IN6, while the lowest values were for biscuits made with OF. Slade *et al.*[29] associated the cracking pattern with the degree of collapse at the end of baking and therefore with biscuit thickness. In this work, a negative correlation between CAF and biscuit thickness and a positive correlation with W/TF ($P < 0.05$) were found.

The snapping/bending test measures the force needed to bend and snap brittle foods such as biscuits and crackers. Biscuit hardness depends primarily on the strength and dimensions of samples.[17] In relation to biscuit breaking stress (σ), addition of IN gradually decreased this parameter, reaching a reduction of ∼47% compared with the control when 12 g of IN was incorporated. On the other hand, 12 g of OF addition increased σ (∼23%). The modulus of deformability (Def) followed the same trend as that of σ, indicating a decrease and an increase in brittleness for OF and IN respectively. Resistant starches also decreased σ compared with control samples; however, no significant changes were observed for Def.

The low values of σ, Def and thickness found for IN biscuits indicated that they broke without significant deformation, showing a high degree of brittleness. On the other hand, OF biscuits, having high values of σ, Def and thickness, underwent a process of bending plus deformation and breaking during the three-point break

Table 3. Effect of fiber addition on dough spread parameters and biscuit quality

Sample	MD (cm)	ST (min)	W/TF (cm/cm)	D (cm)	T (cm)	CAF	Def (seg)	σ (Pa)
C	6.54a	4.30bc	4.97c	5.61cd	1.13b	2.59c	2.03bc	77.24d
IN6	6.18ab	4.50abc	5.53b	5.80b	1.05c	7.74b	1.20a	51.39ab
IN12	6.56a	5.20a	6.78a	6.06a	0.90d	9.76a	1.20a	56.19b
OF6	5.62cd	4.20bc	4.37d	5.35e	1.22ab	2.48c	3.23d	76.65d
OF12	5.51d	3.00d	4.39d	5.19f	1.18ab	1.91cd	3.03d	95.76e
RSII6	6.05b	4.50abc	5.11bc	5.65c	1.10bc	3.15c	1.88b	66.58c
RSII12	5.85bc	3.80c	4.51cd	5.51cd	1.23ab	2.89c	1.87b	57.14b
RSIV6	5.90bc	4.30bc	5.14bc	5.57cd	1.08bc	2.85c	2.22c	64.87c
RSIV12	5.80bc	4.60abc	4.46d	5.50d	1.23ab	2.89c	2.12bc	46.07a

Values in the same column with a common letter are not significantly different ($P > 0.05$). MD, maximum diameter reached during baking; ST, set time; W/TF, width/thickness factor; D, biscuit diameter; T, biscuit thickness; CAF, cracking area fraction; Def, modulus of deformability; σ, breaking stress; C, standard formulation; IN, inulin; RSII, resistant starch type II; RSIV, resistant starch type IV; OF, oat fiber; 6 and 12 indicate the amount of fiber (g) added to the formulation.

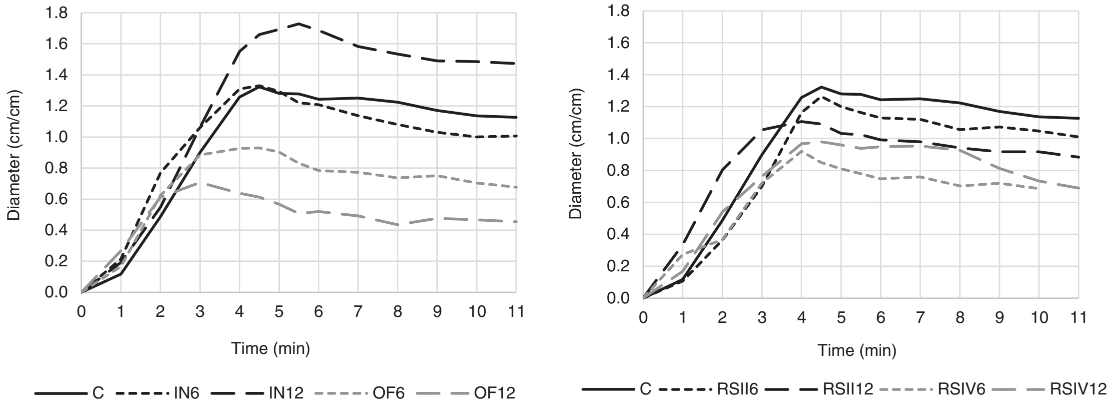

Figure 4. Effect of fiber addition on development of biscuit diameter during baking. Diameter is expressed as diameter ratio (diameter at time/initial diameter). C, standard formulation; IN, inulin; OF, oat fiber; RSII, resistant starch type II; RSIV, resistant starch type IV; 6 and 12 indicate the amount of fiber (g) added to the formulation.

technique, which increased total breaking force and decreased brittleness.

Biscuit moisture was determined and ranged between 56.3 g kg^{-1} for control and 49.7 g kg^{-1} for RSIV12 biscuits; however no significant differences were found among samples.

During the first part of the baking process, fat melts and sucrose dissolves progressively, increasing the system fluidity. The biscuit spreads during baking until the point at which the viscosity suddenly increases. Consequently, the final biscuit diameter is controlled by the rate of expansion in the oven, which depends on dough viscosity and set time (when the biscuit stops spreading).[22,30]

The increase in viscosity was related to the flour proteins, because starches do not gelatinize. According to Doescher and Hoseney,[31] during heating, the dough flows until the protein undergoes an 'apparent' glass transition at T_g, thereby gaining mobility that allows it to swell and form a continuous phase or network. As a result, the water mobility decreases and the dough viscosity increases, stopping spreading. On the other hand, Slade *et al.*[32] suggested that biscuit dough actually does not 'set,' but proposed that poor quality biscuit flours exhibit elastic expansion followed by elastic shrinkage, due to a protein film network. This has elastic properties and first expands upon heating and then shrinks above T_g. In any case, an extra increase in viscosity caused by the addition of hydrophilic substances such as fibers produces lower dough fluidity and biscuit diameter and higher biscuit breaking stress.

The improving effect of IN may be related to the extra lubrication factor described by Serial *et al.*[15] Moreover, this extra lubrication factor is in agreement with the shift to lower temperature of the tanδ peak (the highest viscous to elastic behavior) during temperature sweep, since a more lubricated dough should have a more liquid-like behavior. These changes in the viscoelastic behavior may be related to two physicochemical events. The first involves the extra increment of the volume of the sugar/water phase as a consequence of IN incorporation in the dough aqueous phase. The second, related to the particular conformation of IN molecules, allows the formation of bond areas where a large amount of water is enclosed. It is suggested that when wheat flour is partially replaced by IN, more water is retained by this oligosaccharide, which, in turn, could reduce starch swelling and decrease dough viscosity.[23]

Sensory evaluation

Table 4 and Figs 5 and 6 show the sensory evaluation results. Biscuits including IN presented the highest and those including RSIV12 and OF12 the lowest sensory hardness values, while the rest of the samples did not show significant differences.

Regarding crispness, only OF biscuits showed statistical differences from the control, presenting lower values. IN biscuits did

Table 4. Sensory attributes of fiber-enriched biscuits

Sample	Hardness	Crispness	Sweetness	Palatability	Chewiness	Grain properties
Control	3.50 ± 0.00bc	3.50 ± 0.00cde	3.50 ± 0.00abc	3.50 ± 0.00ab	3.50 ± 0.00a	3.50 ± 0.00ab
IN6	3.89 ± 0.59cd	3.59 ± 0.18cde	3.92 ± 0.70cd	3.81 ± 0.93ab	3.62 ± 0.91a	3.30 ± 1.24ab
IN12	4.62 ± 0.47d	4.04 ± 0.31e	4.49 ± 0.99d	3.50 ± 1.29ab	3.64 ± 1.23a	3.43 ± 1.21ab
OF6	3.11 ± 0.87ab	2.89 ± 1.07b	3.38 ± 0.77abc	3.62 ± 1.05ab	3.48 ± 1.17a	3.32 ± 0.78ab
OF12	2.81 ± 1.22a	2.25 ± 0.62a	3.19 ± 1.03ab	3.21 ± 0.99a	3.11 ± 1.08a	3.26 ± 1.34ab
RSII6	3.08 ± 0.88ab	3.75 ± 1.08de	3.78 ± 0.93bc	3.77 ± 0.92ab	3.15 ± 1.23a	3.82 ± 1.33b
RSII12	3.55 ± 0.62bc	3.94 ± 0.74e	3.32 ± 1.16abc	3.20 ± 0.84a	3.19 ± 0.67a	3.75 ± 0.63b
RSIV6	3.01 ± 1.03ab	3.30 ± 0.89bcd	3.78 ± 1.04cd	4.08 ± 1.06b	3.36 ± 0.91a	3.53 ± 0.76ab
RSIV12	2.69 ± 0.92a	2.97 ± 0.72bc	3.00 ± 0.75a	3.19 ± 0.99a	3.02 ± 1.03a	2.94 ± 0.91a

Values in the same column with a common letter are not significantly different ($P > 0.05$). C, standard formulation; IN, inulin; RSII, resistant starch type II; RSIV, resistant starch type IV; OF, oat fiber; 6 and 12 indicate the amount of fiber (g) added to the formulation.

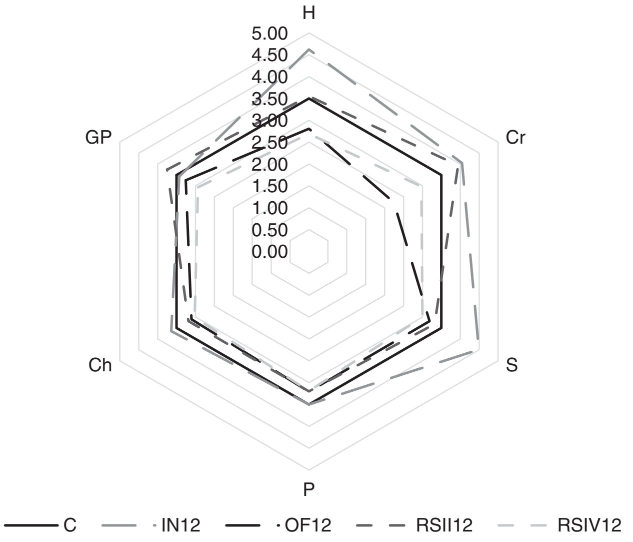

Figure 5. Attributes of sensory evaluation of fiber-enriched cookies. H, hardness; Cr, crispness; S, sweetness; P, palatability; Ch, chewiness; GP, grain properties; C, standard formulation; IN, inulin; OF, oat fiber; RSII, resistant starch type II; RSIV, resistant starch type IV; 12 indicates the amount of fiber (g) added to the formulation.

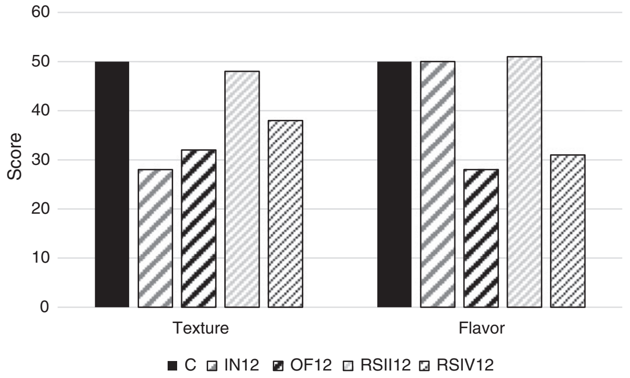

Figure 6. Consumer test preference of texture and flavor. C, standard formulation; IN, inulin; OF, oat fiber; RSII, resistant starch type II; RSIV, resistant starch type IV; 12 indicates the amount of fiber (g) added to the formulation

not show significant differences from the control; however, they presented the highest crispness values. The low and high sensory hardness values of OF and IN biscuits respectively were related to their low and high brittleness, as previously described for OF and IN biscuits, respectively.

Sucrose content was constant in all formulations, however, IN12 biscuits were perceived as sweeter than control biscuits. This may be related to partial degradation of IN during baking.

No statistical differences were found in palatability, chewiness and grain properties among samples.

The consumer test showed differences in biscuit texture, where the favorite was the control, closely followed by RSII12 (Fig. 6). Regarding flavor, IN12 and RSII12 reached the same score as the control, indicating that, in addition to perceiving differences in sweetness, judges liked IN biscuits as much as control biscuits.

Biscuit total dietary fiber content

Control biscuits (without fiber addition) showed low contents of total dietary fiber (TDF) (13.0 ± 0.2 g kg^{-1}). Products formulated with 12 g of OF or IN presented the highest values of TDF (OF12, 126.8 ± 0.3 g kg^{-1}; IN12, 110.9 ± 0.8 g kg^{-1}), followed by those formulated with 12 g of resistant starches (RSIV12, 107.5 ± 03.8 g kg^{-1}; RSII12, 99.4 ± 3.2 g kg^{-1}). As expected, 6 g fiber biscuits exhibited intermediate values between 12 g and control biscuits.

A food is considered as a source of dietary fiber when having 0.3 g kg^{-1} or when fulfilling 10% of daily reference value per serving; and as high in dietary fiber when having 0.6 g kg^{-1} or when fulfilling 20% of daily reference value per serving.[33] Considering a nutrient reference value for dietary fiber of 25 g day^{-1}, two servings of biscuit represent between 3.3 g (RSII6) and 7.3 g (OF12), equivalent to 13 and 29% of daily reference value (considering one serving as 30 g) respectively.

CONCLUSIONS

Fiber changed dough rheological properties, biscuit quality and nutritional characteristics. The extent of the effects depended on the type of fiber used and the level of flour substitution. Oat fiber addition had negative effects on dough spreading behavior, and resistant starches RSII and RSIV slightly altered these parameters. Inulin imparted particular characteristics to biscuit dough that allowed the piece to spread longer, since a faster increase from viscous to elastic behavior of dough occurred before and during baking.

The results obtained in this study are expected to help in the development of high-fiber formulations that improve dough spreading and hence biscuit quality, with consumer acceptability, without introducing significant changes in its rheological properties, which is of great importance in large-scale production.

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SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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