



Jerusalem artichoke tuber flour as a wheat flour substitute for biscuit elaboration



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ARTICLE INFO

Keywords:

Jerusalem artichoke
Nutritionally differentiated flours
Fructooligosaccharides
Inulin
Healthy cookies

ABSTRACT

Jerusalem artichoke produces underground tubers which accumulate fructans, mainly inulin, which can be regarded as functional dietary fiber. In the present work, flour from Jerusalem artichoke (JA) was obtained and this product resulted in a source of inulin (48.97 ± 3.40 g/100 g dry base, db) and phenolic compounds (272 ± 22 mg gallic acid equivalents/100 g). Total protein and fat content in JA flour was 4.27 ± 0.02 and 0.53 ± 0.01 g/100 g db, respectively. The glass transition temperature (T_g) of the flour, which is a critical parameter that determines the storage temperature of this product, was determined by thermal analysis. The flour remained thermally stable up to 190 °C, which limits the baking temperature. Biscuits were formulated from a mixture of flours from wheat (WF), amaranth (AF) and JA (JAF). The baking condition (150 °C, 15 min) was selected based on the color and texture attributes of the baked products. The percentage of substitution of the wheat flour was limited by the sensory characteristics of the biscuits obtained. The formulation containing 8% AF, 17% JAF and 75% WF exhibited the higher rate of acceptance, resulting a healthier alternative, with lower energy content than traditional wheat flour-based biscuits.

1. Introduction

Diabetes is a chronic disease characterized by elevated levels of blood glucose due to an insufficient insulin production or to the inefficiency of the insulin produced. The WHO informed that the estimated prevalence of diabetes in the adult population worldwide was 422 million in 2014, compared to 108 million in 1980 (WHO, 2016). Added to this problem, a high incidence of overweight and obesity, particularly in children and young people, constitutes a relevant health concern since these conditions, among other health problems, predispose to diabetes.

Helianthus tuberosus L., commonly known as Jerusalem artichoke, produces fibrous roots with short rhizomes that end in underground caulinar tubers, which accumulate fructans, mainly inulin. The plant has four main uses: horticultural, fodder, bioethanol production, and inulin extraction (Rébora, 2008). Fructooligosaccharides (FOS) and inulin resist the hydrolysis by enzymes from the human digestive tract, thus behave as functional dietary fiber (non-digestible carbohydrates that show beneficial physiological effects on humans) and act as prebiotics. According to Rao (1999), a daily intake of inulin can effectively

increase the number of beneficial bacteria in the colon. Furthermore, FOS and inulin consumption entails a hypoglycaemic effect, being suitable for diabetic persons. These dietary fiber components have been accepted as GRAS ingredients by the FDA since 1992.

Sweet cookies are one of the most commonly consumed snacks worldwide, and are tightly linked to obesity rate increase, particularly in children (Carnell, Benson, Gibson, Mais, & Warkentin, 2017), due to their high input of saturated fat, added refined sugar and polysaccharides to the diet (Shriver et al., 2018). The main contributor to the complex carbohydrate content of commonly consumed cookies is wheat flour (WF). The partial substitution of WF with flours with higher nutritional quality may reduce the impact of these snacks in overweight and obesity problems, especially in toddlers. In this sense, several studies have been performed on partial substitution of WF using non-traditional flours that allowed obtaining biscuits with enhanced nutritional value and adequate attributes of color, texture, and acceptability (Inglett, Chen, & Liu, 2015; R.; Kaur & Kaur, 2018; Sharma & Gujral, 2014). Besides its beneficial health effects, the inulin from JAF would contribute to other desirable technological characteristics such as good water-holding capacity and gel texture properties (Luo et al., 2017).

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<https://doi.org/10.1016/j.lwt.2019.03.082>

Received 30 November 2018; Received in revised form 25 March 2019; Accepted 26 March 2019

Available online 28 March 2019

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Amaranth flour (AF), for its part, is a high-value food ingredient due to its protein content and equilibrated balance of essential amino acids, which has been used for partially substituting wheat flour to enhance the nutritive value of low-gluten bakery and other products (Chauhan, Saxena, & Singh, 2015; M.; Kaur, Sandhu, Arora, & Sharma, 2015).

The objective of this work was to develop and characterize the flour obtained from Jerusalem artichoke tubers and to formulate nutritionally enhanced and sensory acceptable sweet cookies by partial substitution of wheat flour with the obtained JAF and AF as inulin and protein sources, respectively.

2. Materials and methods

2.1. Plant material and flour elaboration

Jerusalem artichoke tubers (JAT) from white skin variety were cultivated at the Engineering and Agroindustrial Science College (FICA, UNSL, Villa Mercedes, San Luis, Argentina, 33°40' S 65°28' W). The crop was planted in September 2017 and tubers were harvested in June 2018.

JAT were washed with tap water and brushed to partially remove tuber skins. Tubers were then cut into ~2 mm slices and dried at 60 °C in an electric oven with convection (Exoterm, Argentina), until constant weight was achieved. Dried slices were then ground and passed through a 60-mesh sieve to obtain the JA flour (JAF).

2.2. Chemical composition of Jerusalem artichoke tubers and Jerusalem artichoke flour

2.2.1. Proximate composition

Moisture and ash contents were determined gravimetrically. Total moisture was measured by drying the samples at 105 °C until constant weight and ash content was determined after complete incineration of the samples at 550 °C (AOAC, 1990). Results were expressed as g per 100 g. Lipid content was quantified gravimetrically on JAF (dried at 105 °C) after eight successive extractions with n-hexane in a Soxhlet apparatus. Protein content was determined by the Kjeldahl method using 6.25 as total nitrogen-to-protein conversion factor. Acid detergent fiber was determined on JAF following the protocol 973.18c of the AOAC (1990). This fraction correspond to the residue remaining after digesting the sample with H₂SO₄ and cetyl trimethylammonium bromide at 100 °C for 1 h. Results were expressed as g/100 g on dry basis (db).

2.2.2. Estimation of the inulin content in Jerusalem artichoke flour

For inulin quantification, flour samples (10 g) were extracted with water (1:16 w/v) at 75 °C for 90 min with constant stirring. Samples were then filtered and the solid was subjected to other two extractions under the same conditions. The three filtrates were collected and deproteinized by addition of Ca(OH)₂ up to pH 11 and centrifuged to remove the precipitated proteins. Then, H₃PO₄ (80%) was added reaching pH 8 (Li et al., 2015). The deproteinized extract was later divided into two equal parts: one was used for the quantification of reducing sugars by the Somogyi-Nelson method ($\lambda = 590$ nm), utilizing a UV-1800 model spectrophotometer (Shimadzu, Kyoto, Japan). This value corresponds to the free fructose (FF) in the sample. The other part of the deproteinized extract was submitted to acid hydrolysis with 0.05 mol/L for 40 min in a boiling water bath, and the released fructose was quantified by the Somogyi-Nelson method. This value corresponds to total fructose (TF).

Inulin content (I) was calculated by the following equation:

$$I = k (TF - FF)$$

where k is a constant equal to 0.995, used when the degree of polymerization of the inulin is unknown (Saengkanuk, Nuchadomrong, Joghloy, Patanothai, & Srijaranai, 2011).

2.2.3. Jerusalem artichoke flour mineral composition

JAF was analyzed for its Na, K, Mg, Ca and Fe contents. In brief, samples were incinerated at 550 °C and 0.05 g of ashes from the respective sample were mixed with 5 mL of HNO₃ 50% (v/v), vigorously mixed, filtered, and analyzed by atomic absorption spectrometry using an AA-6800 Shimadzu (Shimadzu Corporation, Kyoto, Japan) equipment. Results were expressed as mg/100 g (db).

2.2.4. Quantification of total phenolic compounds in Jerusalem artichoke flour and Jerusalem artichoke tubers

JA tubers were hand peeled, and the removed skin and the peeled tuber (flesh) were chopped into small pieces. Phenolic compounds were extracted from 0.2 g of the samples (JAF, JAT peel and JAT flesh) with 4 mL of acidified methanol (HCl:methanol:water 1:80:10) according to Kaur, Singh, and Kaur (2017). Total phenolic compounds were quantified spectrophotometrically at 725 nm using the Folin-Ciocalteu reagent. Results were expressed as mg of gallic acid equivalents (GAE) per 100 g db.

2.2.5. Thermal analysis of Jerusalem artichoke tubers and Jerusalem artichoke flour

Thermogravimetric analysis of samples was performed in a TG-DTA Shimadzu 60 (Shimadzu Corporation, Japan) equipment. JAF and JAT samples (10 mg) were analyzed under N₂ atmosphere (20 mL/min). The heating range varied from 30 to 600 °C at a rate of 10 K/min. Likewise, thermal properties of JAF were determined by DSC according to López, García, and Zaritzky (2008), using a Q100 equipment (TA Instruments, New Castle, Delaware, USA) with a quench-cooling accessory, under a N₂ atmosphere (20 mL/min). Approximately 10 mg of JAF aqueous suspensions (20 g/100 g) were weighed into aluminum pans. Heating range varied from 10 to 130 °C at 10 K/min. In the case of first order transitions, the onset (To), peak (Tp) and end temperature (Tc) (°C), as well as the associated enthalpy (ΔH) (J/g of dry sample) were calculated. For both TGA and DSC measurements, samples were analyzed in duplicate.

2.3. Biscuit formulation and elaboration

Biscuits were formulated using different degrees of substitution of wheat flour (WF) with Jerusalem artichoke flour (JAF) and amaranth flour (AF). WF:JAF:AF proportions assayed as well as the nomenclature used are described in Table 1. Cookies were elaborated by mixing 100 g of the respective flour blend with butter (30 g), eggs (30 g), stevia-based sweetener (2.4 g), guar gum (3 g), ammonium bicarbonate (3 g), sodium bicarbonate (1 g), and cream of tartar (1 g). Ingredients were mixed until a homogeneous dough was formed, then rolled out to a 2 mm thick sheet, cut into 2 cm diameter circular pieces, and cooked in an electric oven (Atma Grill, Atma, Buenos Aires, Argentina). Two different cooking conditions were assayed for each formulation: 6 min at 180 °C and 15 min at 150 °C.

2.4. Biscuit quality attributes

2.4.1. Texture properties

Biscuit texture was evaluated through a compression and penetration test using the “Volodkevich Bite Jaws” probe. Measurements were

Table 1
Flour blends used in biscuit formulations and their nomenclature.

Nomenclature	Wheat flour (WF, %)	Jerusalem artichoke flour (JAF, %)	Amaranth flour (AF, %)
0WF	0	66	34
25WF	25	50	25
50WF	50	34	16
75WF	75	17	8
100WF	100	0	0

Table 2
Proximate chemical composition of Jerusalem artichoke flour.

Chemical component (db)	Jerusalem artichoke flour (JAF)
Moisture (g/100 g)	7.82 ± 0.32
Protein (g/100 g)	4.27 ± 0.02
Fat (g/100 g)	0.53 ± 0.01
Ash (g/100 g)	5.27 ± 0.04
Acid detergent fiber (ADF, g/100 g)	3.95 ± 0.01
Fe (mg/100 g)	2.0 ± 0.3
Na (mg/100 g)	23.3 ± 1.5
K (mg/100 g)	280.5 ± 3.0
Mg (mg/100 g)	11.0 ± 0.6
Ca (mg/100 g)	25.7 ± 1.4

Reported values correspond to the means ± standard deviation.

performed in a TAXT2i Texture Analyzer (Stable Micro Systems Ltd Godalming, Surrey, UK) fitted with a 250 N load cell. Product firmness (maximum force in Newtons exerted when compressing 20% the sample), the energy required to penetrate the sample (area under the force curve, in N mm) and the crunchiness (number of peaks which

represented variations in force higher than 0.02 N) were evaluated according to [Doporto, Sacco, Vifia, and García \(2017\)](#). The informed results correspond to the average of at least ten determinations.

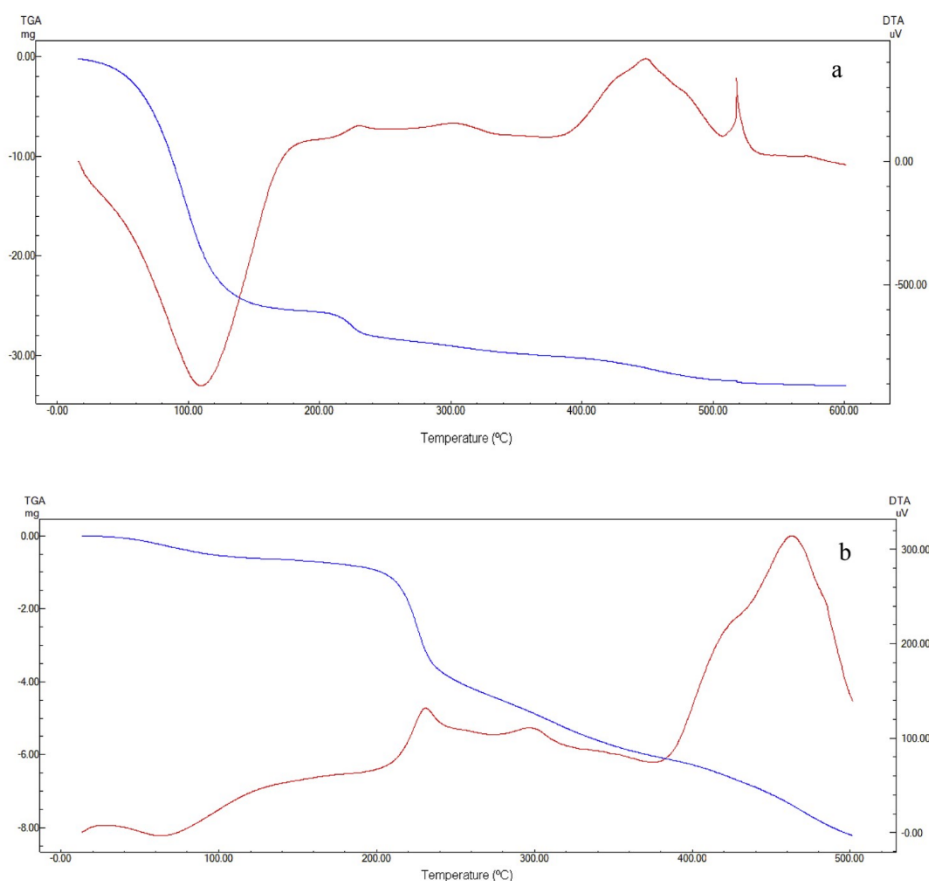
2.4.2. Surface color

Surface color of the biscuits was measured using a Chroma Meter CR 400 (Konica Minolta Sensing Inc Osaka, Japan): Lightness (L^*), red-green coordinate (a^*), and blue–yellow coordinate (b^*) from the CIE scale were registered. Color measurements were expressed as the total color difference (ΔE) referred to the color coordinates (a_0^* , b_0^* , L_0^*) of the control cookies formulated with only wheat flour, according to the following expression:

Reported values correspond to the average of at least ten determinations for each cookie formulation and cooking condition.

2.4.3. Sensory analysis

A sensory analysis was carried out using a semi-structured hedonic scale to evaluate the acceptability by attributes of the cookies formulated with the substituting flours (25, 50 and 75% wheat flour), baked at 150 °C for 15 min (selected condition). A total of 51 potential



Sample	Weight loss (%)			
	First range (20–190°C)	Second range (190–340°C)	Third range (340–500°C)	Residue
JAT	75.71±0.06	9.82±0.03	3.25±0.01	11.18±0.10
JAF	9.21±1.46	45.38±0.42	25.85±1.36	19.47±2.27

Fig. 1. TGA thermograms of a) Jerusalem artichoke tubers (JAT) and b) derived flour (JAF). Weight loss associated to the peaks observed during thermal analysis is shown in the insert table.

Table 3
Quality attributes of biscuits formulated with partially substituted wheat flour.

Baking condition	Biscuits nomenclature ^a	Moisture content (%)	Surface color				Texture		
			L*	a*	b*	ΔE	Area (N mm)	Maximum force (N)	Force peaks number
150 °C 15 min	0WF	10.4 ± 0.1 ^a	47.8 ± 0.5 ^a	8.2 ± 0.6 ^c	15.8 ± 0.4 ^{bc}	23.4 ± 0.8 ^c	119.6 ± 60.5 ^f	41.1 ± 5.5 ^f	12.1 ± 4.1 ^{de}
	25WF	13.4 ± 1.2 ^{ab}	49.5 ± 0.6 ^b	6.8 ± 0.3 ^c	14.4 ± 0.9 ^a	22.8 ± 1.0 ^d	170.6 ± 14.3 ^e	27.7 ± 2.6 ^c	11.5 ± 3.6 ^{cd}
	50WF	12.5 ± 1.0 ^{ab}	52.4 ± 0.5 ^c	7.3 ± 0.2 ^{cd}	15.4 ± 0.6 ^b	19.9 ± 0.7 ^c	90.4 ± 13.2 ^e	16.2 ± 2.5 ^d	16.2 ± 4.3 ^f
	75WF	10.8 ± 0.2 ^a	61.2 ± 0.2 ^d	5.2 ± 0.4 ^b	19.2 ± 0.7 ^d	11.1 ± 0.6 ^a	60.2 ± 9.8 ^e	11.7 ± 2.0 ^c	24.9 ± 2.5 ^e
	100WF	14.7 ± 0.05 ^b	68.1 ± 0.2 ^e	7.6 ± 2.2 ^d	27.5 ± 1.5 ^e	–	80.1 ± 12.8 ^d	13.6 ± 2.8 ^c	14.7 ± 4.4 ^{ef}
180 °C 6 min	0WF	18.1 ± 0.8 ^c	47.2 ± 0.5 ^a	5.0 ± 0.2 ^b	14.4 ± 0.3 ^a	31.2 ± 1.1 ^h	51.5 ± 6.7 ^{bc}	9.2 ± 1.2 ^b	10.6 ± 3.0 ^{de}
	25WF	23.3 ± 3.9 ^d	49.2 ± 3.0 ^b	5.3 ± 0.5 ^b	14.6 ± 0.3 ^a	28.5 ± 1.5 ^g	50.6 ± 6.5 ^{bc}	9.4 ± 0.8 ^b	7.7 ± 2.0 ^{bc}
	50WF	19.1 ± 0.6 ^c	53.2 ± 0.5 ^c	5.0 ± 0.9 ^b	16.1 ± 0.6 ^c	25.4 ± 0.8 ^f	35.6 ± 4.7 ^a	6.4 ± 0.6 ^a	7.4 ± 2.8 ^a
	75WF	18.8 ± 0.6 ^c	60.4 ± 1.1 ^d	4.3 ± 0.6 ^a	19.3 ± 0.2 ^d	17.8 ± 1.0 ^b	37.4 ± 5.34 ^a	7.0 ± 0.9 ^a	6.3 ± 2.2 ^{ab}
	100WF	18.1 ± 0.3 ^c	73.5 ± 2.1 ^f	5.0 ± 1.1 ^b	31.2 ± 0.7 ^f	–	45.3 ± 8.0 ^b	9.1 ± 1.4 ^b	6.4 ± 3.3 ^{ab}

^a Biscuits nomenclature is described in Table 1. Reported values correspond to the means ± standard deviation. Different letters in the same column indicate significant differences ($p < 0.05$).

consumers evaluated biscuit color, texture, taste, aroma and overall acceptability according to a box-scale (1–5) anchored in the following steps: 1 = “dislike very much”, 3 = “indifferent” and 5 = “like very much”.

2.4.4. Biscuit proximate composition

The biscuits selected for sensory analysis were characterized with respect to moisture, ash, protein and fat content.

2.5. Statistical analysis

Data was analyzed by a one-way analysis of variance at a significance level of $p < 0.05$ followed by a Fisher's Least Significant Difference Test ($p < 0.05$). Results were subjected to Principal Components Analysis (PCA) and Cluster Analysis (CA). Data was analyzed using the Infostat software v2011 (Di Rienzo et al., 2011).

3. Results and discussion

3.1. Jerusalem artichoke tubers and Jerusalem artichoke flour chemical composition

JAT moisture content was 73.10 ± 1.52 g/100 g db. Moisture values higher than 60 g/100 g are associated with high transportation costs, short shelf life, and reduced market margin (Chandrasekara & Josheph Kumar, 2016). Thus, JAF obtaining is an alternative to reduce these inconveniences. JAF yield was 22.5 g JAF/100 g JAT, similar to those obtained by Rincón, Araujo de Vizcarrondo, Carrillo de Padilla, and Martín (2000) from ñame (*Dioscorea alata*) tubers and Doporto, Mugridge, García, and Viña (2011) from ahípa (*Pachyrhizus ahípa*) roots. Results from chemical analyses performed on JAF are shown in

Table 2 and were in the range of those reported by Bach, Clausen, and Edelenbos (2015).

Afoakwah et al. (2015) analyzed the chemical composition of JAF obtained by oven-drying the tubers at 60–70 °C for 5 h and found similar values for ash content (7.39 g/100 g db). Likewise, ash and fat contents found in the present work were in the range reported by Rubel, Pérez, Genovese, and Manrique (2014) for lyophilized JAT. However, the protein contents reported by Afoakwah et al. (2015) (10.88 g/100 g db) and Rubel et al. (2014) (9.75 g/100 g db) were significantly higher than those found in the present work (Table 2).

The analyzed minerals from JAF (Table 2) resulted lower in quantity but similar in distribution than that reported by other authors (Afoakwah et al., 2015; Judprasong, Archeepsudcharit, Chantapiriyapoon, Tanaviyutpakdee, & Temviriyankul, 2018). Potassium was widely the most abundant mineral in JAF, exhibiting more than twice the concentration found in a well-recognized source of potassium like banana (El-Mahdy, Youssef, & Eissa, 2018), but lower than that found in other flours such as chickpea (Saha, Chakraborty, Sehgal, & Pal, 2015). Potassium was followed in abundance by calcium and sodium, but these latter are present in concentrations approximately ten times lower than K. Particularly, JAF would not represent a significant contribution of magnesium or iron to the diet (Table 2).

Total phenolics were quantified in JAF and separately in JAT flesh and skins. Results were expressed as mg equivalent of gallic acid (GAE) per 100 g of sample on dry basis. Regarding phenolic content, the tuber skin had 511 ± 11 mg GAE/100 g while the flesh contributed with only 49.6 ± 0.3 mg GAE/100 g. Takeuchi and Nagashima (2011) reported a similar ratio between phenolics from the skin and the flesh (10:1), although the reported values (82.3 ± 30.6 and 8.0 ± 0.5 mg GAE/100 g, respectively) were markedly lower than those from the present work.

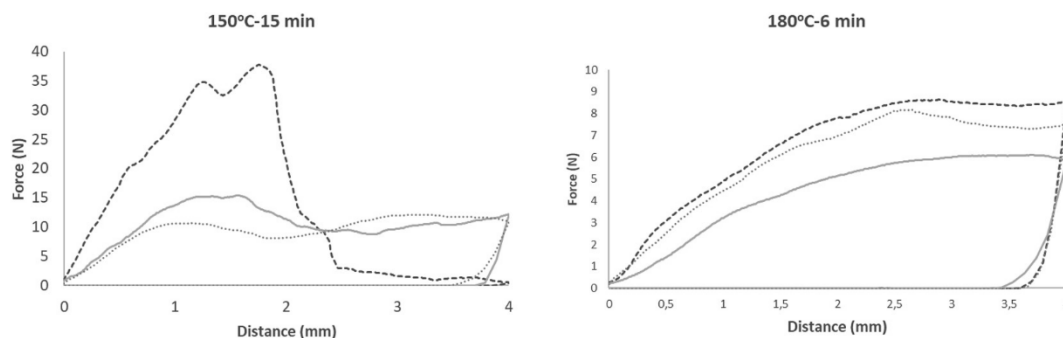


Fig. 2. Textural profile of biscuits containing 0, 50 and 100% of wheat flour (WF) obtained at two different baking conditions (150 °C for 15 min and 180 °C for 6 min).

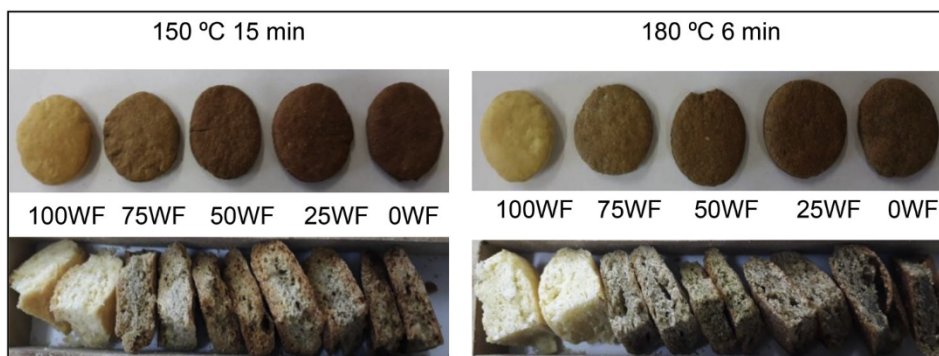


Fig. 3. Biscuits formulated with partially substituted wheat flour obtained at the two different baking conditions assayed. Biscuits nomenclature is described in Table 1.

JAF obtained from processed tubers, where tuber skin was partially removed by brushing, exhibited phenolic levels of 272 ± 22 mg GAE/100 g. Thus, maintaining certain portion of the skin may enhance the content of potentially bioactive compounds in the flour, although the use of unpeeled tubers would impair some undesirable characteristics, such as dark color and bitter taste.

The estimated amount of inulin from JAT was 85.03 ± 4.20 g/100 g db and 22.80 ± 1.13 g/100 g wb, similar to the contents found by Rubel et al. (2014) and Saengkanuk et al. (2011), and among the highest values reported for this tuber, which are in the range of 75.8–84 g/100 g db (Johansson et al., 2015). The elevated content of inulin of the tubers used in this study was attributed to the harvesting time, which was 60 d after plant flowering, in agreement with the results obtained by Kocsis, Liebhard, and Praznik (2007).

The concentration of inulin in JAF was 48.97 ± 3.40 g/100 g db, which represents a 57% of the content in the JAT. This drastic reduction in the amount of inulin could be attributed to a thermal degradation of the carbohydrate during drying of the tubers. Kays and Nottingham (2008) reported inulin contents in JAT in the range of 7–30 g/100 g wb, and around 50 g/100 g db for JAF, similar to the values found in the present work.

3.2. Thermal analysis

JA tubers and derived flour thermal properties were evaluated by TGA and DSC. Fig. 1 shows the characteristic TGA thermograms obtained. In order to carry out the analysis, three temperature ranges were selected. The first range comprises from 20 to 190 °C where the main event is water loss, as expected, more evident in the tuber thermogram than in the flour (Fig. 1 a and b). The second range (190–340 °C) can be associated to the decomposition of carbohydrates, mainly inulin, as well as peptides. The third temperature range covers from 340 °C to 500 °C and in this region, thermal events are attributed to oxidation of organic matter (pyrolysis).

The results suggest that the flour derived from JAT is thermally stable up to 190 °C, which conditions the cooking temperature of the derived baked products. Similar results were reported by Afoakwah et al. (2015) on the basis of DSC and TGA results for Jerusalem artichoke powders obtained by oven or freeze drying.

DSC assays conducted on JAF, showed an endothermic event at 49.2 ± 0.3 °C with an onset peak temperature of 37.3 ± 1.0 °C and an enthalpy associated of 3.99 ± 0.73 J/g (db). Similar results were informed by Apolinário et al. (2017) working on inulin extracted from *Agave sisalana*. Besides, Leone, Colman, Schnitzler, Ellenderson, and Masson (2014) and Ganguly, Roy, and Moulik (2015) observed other endothermic events at 165–170 °C associated to inulin melting.

A second order transition was also observed in the present work. The glass transition temperature took place within the range of 32.07–35.60 °C and was located at 34.25 ± 0.23 °C. Chiavaro,

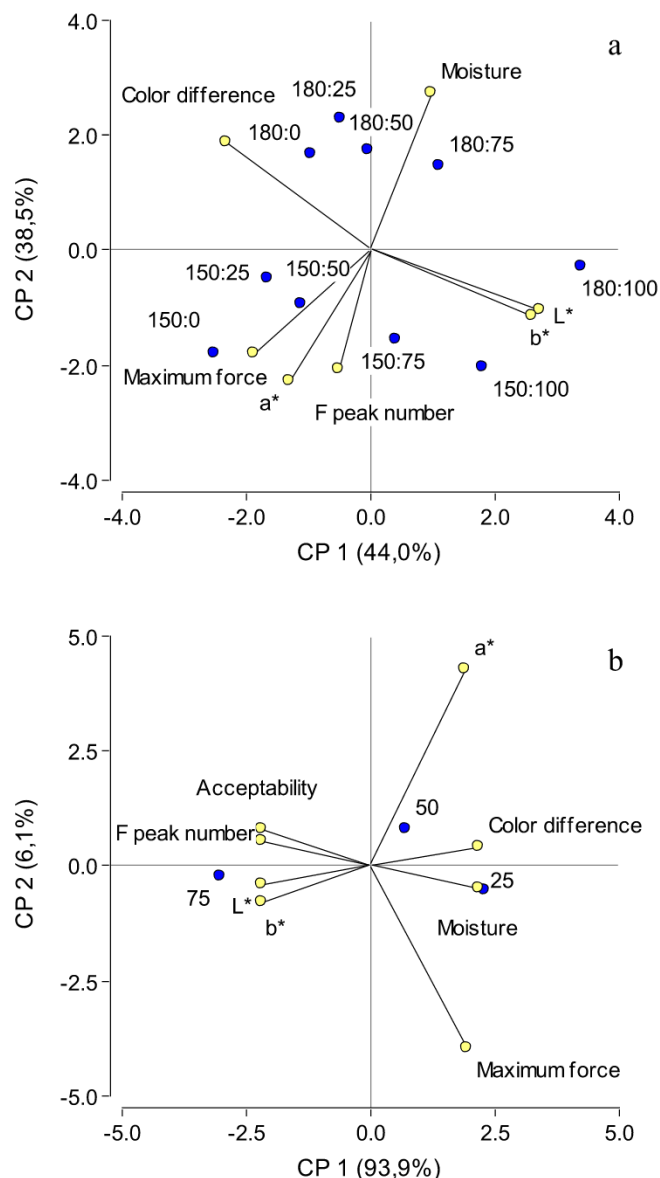


Fig. 4. Principal component analysis (PCA) of a) quality attributes of biscuits formulated with partially substituted wheat flour obtained at the two baking conditions assayed and b) quality attributes and sensory acceptability of biscuits formulated with partially substituted wheat flour baked at 150 °C for 15 min.

Vittadini, and Corradini (2007) reported for Raftilose[®], Tg values in the temperature range of 44.7 ± 0.5 – 55.5 ± 0.6 °C and observed a progressive increase in this parameter with increasing molecular weight. Panchev, Delchev, Kovacheva, and Slavov (2011) informed a Tg within the range of 51–55 °C for Jerusalem artichoke inulin. The botanical source of inulin has a significant effect on the glass transition temperature, with higher values for that extracted from chicory (Ronkart, Deroanne, Paquot, Fougnes, & Blecker, 2010). Besides, Kawai, Fukami, Thanatukorn, Viriyarattanasak, and Kajiwara (2011) demonstrated that inulin Tg was also affected by sample moisture content and crystallinity. Leyva-Porras et al. (2017) analyzed Tg values for inulin with different DP and informed that it was located in the range of 99 to –38 °C for high DP inulin and 105 to –28 °C for lower DP, varying the water activities of samples from 0.05 to 0.9. These results clearly show that as the DP increase, the Tg range is widened and shifted toward lower temperatures. The knowledge of this parameter is critical since storage temperatures above the Tg induce physicochemical changes, such as sticking, collapse, caking, agglomeration, loss of volatiles, browning and oxidation.

3.3. Biscuit analyses

Considering Jerusalem artichoke does not represent a good source of proteins, the substitution of wheat flour with JAF would result in a lower quality product regarding to the technological and nutritional characteristics that proteins provide to the biscuits. As pointed out by Antoniewska, Rutkowska, Pineda, and Adamska (2018), the increasing use of amaranth as food ingredient relays on its high nutritional value, since it is a good source of lysine-rich proteins: 5.96 g/16 gN, twice higher than that in wheat flour (Inglett et al., 2015). Thus, for biscuit

formulations, the substituting mixed flours contained twice the amount of JAF than AF to reduce, at least partially, the detrimental effect that would ensue from diminishing the amount of wheat proteins in the quality of the biscuits, by maintaining the total amount of proteins above 8% in all cases.

The gelatinization temperature of the starch present in whole amaranth grain flour was reported to be 67.9 °C (Srichuwong et al., 2017), similar to that of wheat starch, therefore the temperature for baking was established above this value and below 190 °C, as determined by TGA. Thus, two cooking conditions were evaluated: 150 °C for 15 min, and 180 °C for 6 min.

The moisture content of the baked products obtained from the first baking condition resulted half of that observed for the second one (Table 3). Fig. 2 shows the evident effect of baking condition on the textural profile of biscuits containing 0, 50 and 100% WF. Moisture content was directly related to the textural characteristics of the biscuits, with lower moisture leading to products with higher maximum force, crunchiness and area under the curve (Table 3). As observed in Table 3 lower degrees of substitution led to unchanged or slightly lower peak area and maximum force while higher degrees of substitution increased both parameters for the biscuits baked at 150 °C for 15 min. The biscuits baked at 180 °C for 6 min followed a similar trend but the changes were slight compared to those baked at lower temperature. Čukelj et al. (2017) reported that biscuit hardness was significantly higher for whole-meal wheat biscuits compared to those from white wheat, due to its higher amount of fiber. The degree of substitution of whole-meal wheat with different cereal flours and flaxseed flour reduced the hardness of the biscuits but it remained higher than that of the white wheat biscuits (Čukelj et al., 2017). In the present work, the increment in the biscuit hardness with increasing substitution degree of

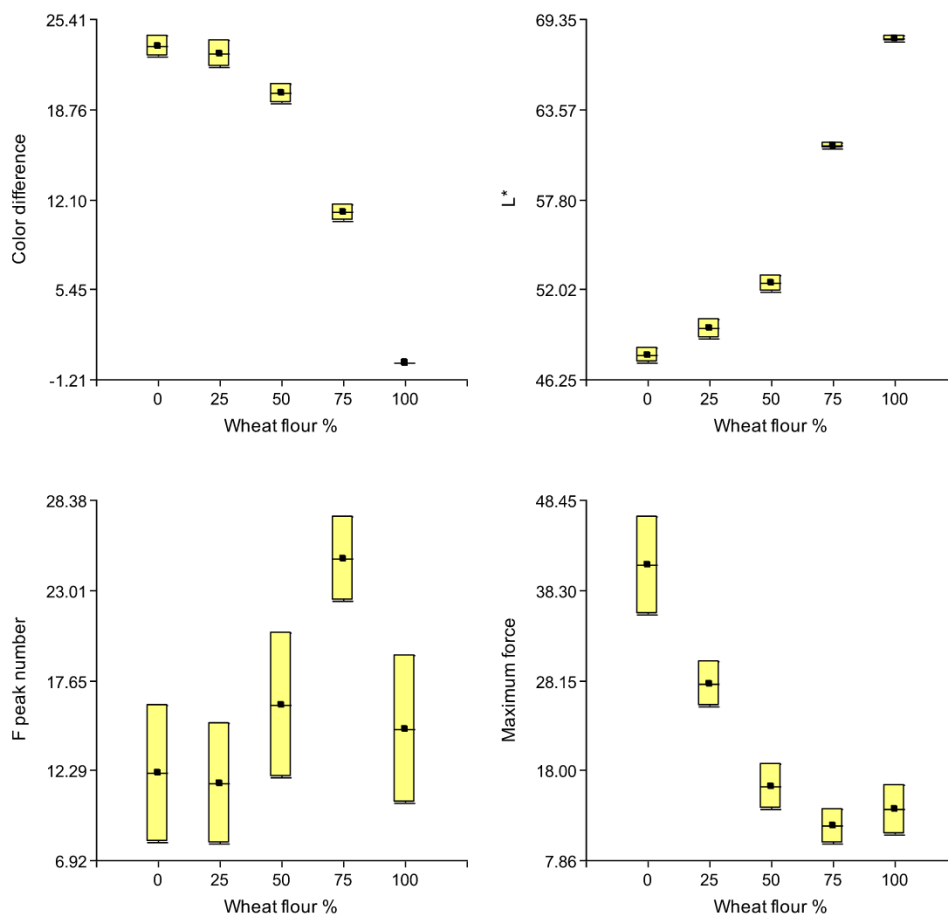


Fig. 5. Box-plots graphics of quality attributes of biscuits formulated with partially substituted wheat flour baked at 150 °C for 15 min.

the wheat flour was attributed to the raise in the amount of JAF, since partial replacement of wheat flour with JAF was reported to increase cookies hardness [Lee, Kim, Lee, and Yoon \(2016\)](#), and this was attributed to the contribution of dietary fiber (inulin) from JAF. Conversely, the partial substitution of wheat flour with amaranth flour has been reported to reduce cookies hardness ([Chauhan, Saxena, & Singh, 2016](#); [Sindhuja, Sudha, & Rahim, 2005](#)), but considering amaranth is a minor component in the substituting mixed flours it is expected that the predominant effect would be that of the JAF.

As a general trend, the higher the substitution of the wheat flour with JAF + AF, the higher the difference in the color parameters L^* and b^* of the biscuits with respect to the control with 100% wheat flour, regardless of the baking condition ([Table 3](#), [Fig. 3](#)). This darkening effect of cookies was previously reported when wheat flour was partially substituted with Jerusalem artichoke flour ([Lee et al., 2016](#)).

Although a^* and b^* values (5.42 ± 0.04 and 20.96 ± 0.13 , respectively) reported by [Kaur et al. \(2017\)](#) for nutritious cookies made with 30% raw flaxseed flour and 70% wheat flour were similar to those found in the present work ([Table 3](#)), L^* values (47.05 ± 0.02) were significantly lower than those reported for the formulation with 25% JAF + AF assayed in this work.

The results of PCA for moisture content, color and textural parameters of biscuits prepared from composite flour blends are shown in [Fig. 4a](#). The first (CP1) and second (CP2) principal components described 44% and 38.5% of the variance, respectively. CP1 could be

associated to the wheat flour content in the biscuit while CP2 is related to the baking condition. The loading plot of the two principal components ([Fig. 4a](#)) provided information about several correlations between measured biscuit attributes. As expected, CP1 is linearly correlated with L^* (0.94) and b^* (0.90) while it shows a negative correlation with maximum force (-0.65) and color differences (-0.80). In the case of CP2, it is linearly correlated with moisture content (0.88) and negatively related to a^* (-0.73) and force peak number (-0.67).

The baking condition of 150 °C-15 min was selected for further analyses because increased the crunchiness (number of peaks) and browning (a^*) of the final product.

[Fig. 5](#) shows the box-plot for textural and color attributes for biscuits cooked at 150 °C-15 min, showing the evident effect of wheat flour percentage. As expected, L^* was increased at higher wheat flour contents, while color differences and maximum force were decreased. Particularly, biscuit crunchiness was maximum for the biscuits containing 75% wheat flour. A similar trend was found for the hardness of wheat-jering flour composite cookies, which increased almost 100% with rise of jering seed flour supplementing levels ([Cheng & Bhat, 2016](#)). Contrarily, [Kaur et al. \(2017\)](#) observed that a high level of flaxseed flour substituting wheat flour gradually decreased the hardness and fracturability of nutritious cookies, which became softer.

Since the addition of fructans may affect the sensory attributes of food products ([da Silva & Conti-Silva, 2018](#); [Volpini-Rapina, Sokei, & Conti-Silva, 2012](#)), the biscuits obtained by the selected baking

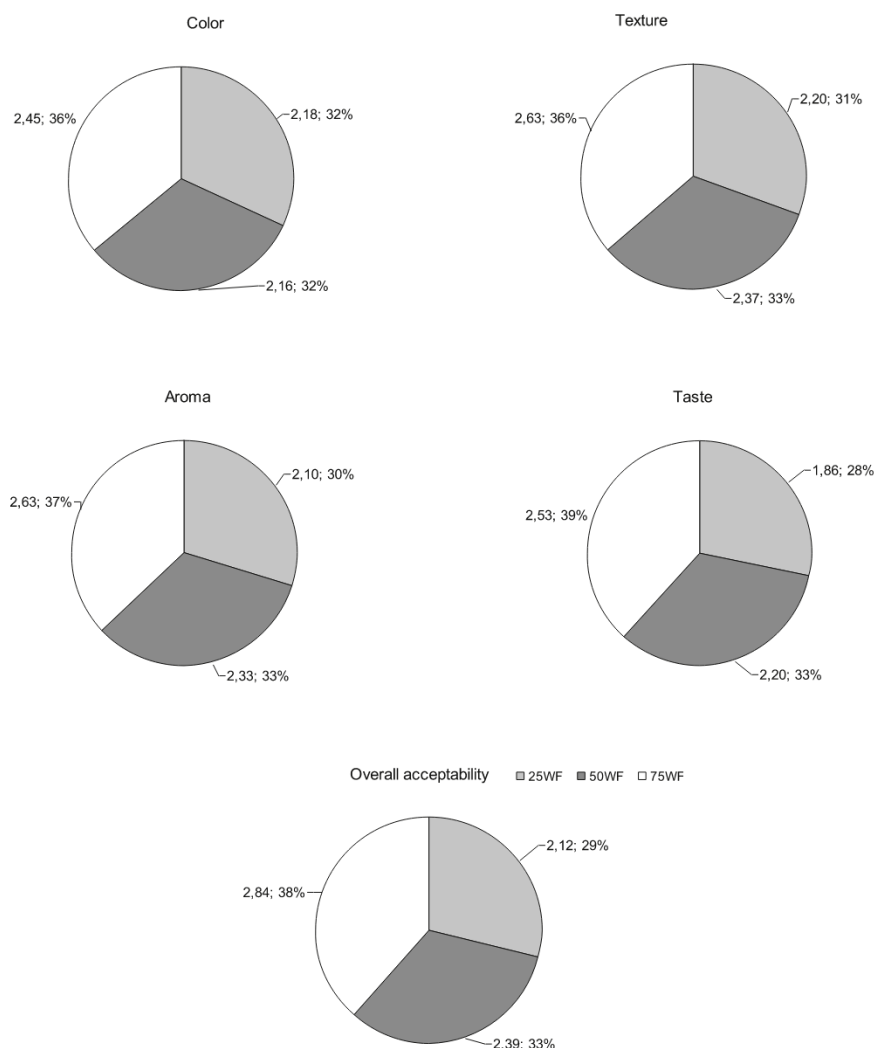


Fig. 6. Sensory evaluation of biscuits formulated with partially substituted wheat flour obtained at 150 °C for 15 min. The reported values correspond to the percentage (%) obtained for each score. Biscuits' nomenclature is described in [Table 1](#).

condition were evaluated by a sensory panel. The obtained results are shown in Fig. 6. As observed, consumers preferred cookies with lower JAF + AF substitution percentage. Cookies with 75% of substitution were rated as acceptable (score = 3) by a 61% of the panelists, while a 70.7% and an 83.8% considered acceptable those with a 50 and 25% of substitution with JAF + AF, respectively. General acceptability and flavor were the most affected parameters by the degree of substitution (Fig. 6). This was attributed to the characteristic flavor of JAF, which can be perceived even at low substitution values. No significant differences ($p < 0.05$) were observed in the scores for color, texture and aroma among the samples. In this sense, da Silva & Conti-Silva, (2018) formulated partially substituted gluten-free chocolate cookies with inulin/oligofructose and rice flour. The authors stressed that the product formulated with 25% substitution of rice flour showed similar overall acceptance and purchase intention than both the control and a commercial cookie. Formulations with higher substitution percentages (50 and 75% of rice flour replacement) exhibited lower sensory scores, results which agree with those obtained in the present work.

PCA was also performed in order to interrelate quality attributes and sensory scores. Fig. 4b shows that the total variance can be explained considering two principal components, and that CP1, which can be associated to wheat flour content, allowed to explain the 93.9% of the total variance. This analysis summarizes the previously detailed results, indicating a strong influence of wheat flour content in the biscuit quality attributes and overall acceptability.

Finally, the chemical composition of the selected biscuit formulation (25% JAF + AF) was determined, exhibiting a moisture content of $10.8 \pm 0.2\%$, $11.4 \pm 0.6\%$ protein, $24.1 \pm 2.1\%$ total fat and $2.40 \pm 0.04\%$ ash content (on dry basis). The carbohydrate content was 51.3%, which led to a maximum estimated caloric content of 440.7 kcal/100 g. This value is lower than that reported for generic, butter and “María” cookies which range between 479 and 484 kcal/100 g (BEDCA, 2018).

4. Conclusions

Jerusalem artichoke flour resulted an interesting food ingredient due to its high content of prebiotics (inulin) and phenolics, which may be used as a wheat flour substitute to increase the nutritional quality of baked products.

The flour exhibited a Tg of 34.25 °C and resulted stable up to 190 °C, from which inulin degradation processes begin, thus this is the maximum temperature for baking. The biscuits cooked at 150 °C for 15 min provided better textural and color properties than 180 °C for 6 min. The cookies formulated with 8% AF, 17% JAF y 75% WF had the better score in the sensory panel, representing an alternative to the traditional wheat flour-based biscuits, with enhanced nutritional value and lower caloric content.

Conflicts of interest

None.

Acknowledgements

Authors acknowledge to the financial support provided by Universidad Nacional de San Luis, PICT 2015-0921 and PICT 2015-3249 (ANPCyT), and PIP 0555 2013–2015 (CONICET).

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