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Research Article

Effect of Maize Starch Substitution on Physicochemical and Sensory Attributes of Gluten-Free Cookies Produced from Nixtamalized Flour

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Nixtamalized corn flour (NCF) has a good dietary fiber profile that makes it an alternative to produce gluten-free cookies because upon hydration and mixing it yields a cohesive and machinable dough. In order to improve the texture and acceptance of cookies, five different experimental treatments were devised and compared with a cookie made with refined wheat flour. A waxy native maize or pregelatinized cross-linked starches in concentrations of 5% and 10% were evaluated. Results showed that the spread factor, diameter, and thickness of the different types of cookies were not statistically different ($p > 0.05$). With the exception of the control and cookies made with 10% waxy starch which were rated with lower scores, the rest of the treatments were not significantly different in terms of sensory attributes. The texture of cookies evaluated by panelists related to the objective texture was determined with the texture analyzer. Cookies made from the composite flour containing 10% pregelatinized cross-linked were softer or had lower maximum positive force after 5 days of storage. This particular gluten-free cookie contained 65% more dietary fiber compared to the wheat flour counterpart and had the best sensory attributes among all treatments including the cookie made with refined wheat flour.

1. Introduction

Today foods are intended not only to satisfy hunger and to provide necessary nutrients for humans but also to prevent nutrition-related diseases and improve physical and mental well-being. Functional foods are quiet remedy. To develop functional foods, professionals are always exploring the abilities of different food ingredients/crops [1]. In recent years there has been an increasing interest in production of gluten-free foodstuffs. The gluten-free products market represents one of the most prosperous markets in the field of food and beverages in the immediate future. However, the nutritional quality and sensory properties of these products are important aspects to consider [2].

On the other hand, the traditional nixtamalization (alkaline cooking) process which produces a hydrated tortilla dough (masa) has been modified to produce convenient and functional dehydrated nixtamalized corn flour (NFC) [3]. The pregelatinized, shelf stable, and convenient NFC is rehydrated and blended to obtain a cohesive dough consisting of starch polymers (amylose and amylopectin) mixed with partially gelatinized and intact granules, endosperm parts, and lipids. All these components form a heterogeneous complex matrix within a continuous aqueous phase. These doughs are sheeted and cut or formed to produce tortilla discs that are further baked [4]. From a nutritional point of view, the nixtamalization process makes the pericarp fragile, lowering the content of insoluble dietary fiber. However, it also increases the amount and availability of calcium and niacin [5]. Starch gelatinization is incomplete because the starch granules are within endosperm cells and exposed to very limited amounts of water during the cooking and steeping operations. Grinding of nixtamal releases some starch granules from the endosperm and disperses some starch polymers from swollen and partially gelatinized starch granules. Rapid drying of masa causes further starch gelatinization and reorientation of starch polymers because remaining crystalline areas of starch act as a nuclei for further starch associations [3].

Among bakery products, cookies are most significant because they are widely consumed as snacks by children and adults. Cookies hold an important position within the snack food category due to variety in taste, crispiness, and digestibility. These are popular among all age groups especially among children. Commercially available cookies are prepared from refined wheat flour that is nutritionally inferior to whole wheat flour [6]. The popularity of cookies is mainly due to their ready-to-eat nature, convenience, and their amenability for fortification with functional ingredients.

Starch takes a special position in many types of foods because it affects texture, viscosity, gel formation, adhesion, binding, moisture retention, film formation, and product homogeneity. It has been used as food additive mainly in soups, sauces and gravies, bakery goods, dairy confectionery, snacks, batters, and coatings [7]. Composition and structure of starch affect its properties and functions. A waxy starch (99% or more amylopectin) has lower rate of retrogradation, slows starch gel formation after cooking and cooling, and produces a cohesive and sticky pastes which are used as stabilizer and thickener [8]. On the other hand, modification of starch is carried out to enhance the positive attributes and eliminate the shortcomings of the native starches [7]. Pregelatinization is one of the physical methods used for modification of starches. These modified starches are commonly used as thickeners in many food products and applications [9]. Cross-linking is one of the most widely used technologies to improve long texture of foods [10].

Upon hydration and blending, the gluten-free NFC yields a cohesive and machinable dough that should be explored in bakery products. Previous research [11, 12] has shown that NFC based cookies not only have the gluten-free nature but also are an excellent option to enhance both protein content and quality and nutraceutical profile. However, to our knowledge there are not previous investigations looking at the production of gluten-free NFC based cookies supplemented with different types of modified starches. Therefore, the specific objective of this research was to determine the chemical, physical, textural, and sensorial properties of NFC cookies supplemented with native waxy corn starch or cross-linked pregelatinized corn starch.

2. Materials and Methods

2.1. Flours Characterization. The water absorption (WAI) and water solubility (WSI) indexes were obtained according to Anderson et al. [13] using (1) for WAI and (2) for WSI:

$$\mathrm{WAI} = \frac{\text{g precipitate}}{\text{gr dry sample}}, \tag{1}$$

$$\mathrm{WSI} = \frac{\text{g soluble solids}}{\text{g dry sample}} \times 100. \tag{2}$$

The relative viscosities of the water suspensions of maize masa flours were determined using a Rapid Visco Analyser, RVA (StarchMaster, Perten, Warriewood, Australia) according to Fernández-Muñoz et al. [14].

2.2. Preparation of Cookies. Five different gluten-free NCF based-cookie formulations were prepared and compared with a refined wheat flour based counterpart. The experimental gluten-free treatments mainly differed in the substitution of different modified starches which were added to enhance machinability and improve cookie properties (Table 1). All raw materials except lactic acid and water were placed in a dough bowl and blended for 3 minutes at slow speed until a complete incorporation was achieved. Then, lactic acid and water were incorporated and mixed into a homogenous dough at low speed for 4 min. Then, the resulting dough was laminated with a rotatory cylinder (0.5–0.6 cm thickness) and cut with a 6.5 cm diameter circular mold. The formed cookies were placed onto a greased baking sheet and baked in a convection oven (Electrolux EOG 601 X Gas single oven) set at 170°C for 13 min. Cookies were allowed to cool down for 10 minutes before packaging in polyethylene bags.

2.3. Characterization of Cookies. Cookie diameter, thickness, and spread factor were determined following the AACC method 10-50D proposed by Hussain et al. [6]. Instrumental evaluations for compression texture were conducted using the Texture Analyzer (TA XTPlus, Stable Micro Systems, USA). The texture analyzer was equipped with a cylindrical probe and the settings of the test were assay velocity of 1 mm/s and a distance of 5 mm. Results of the mean of maximum force and area under the curve for each formulation at days 0, 1, and 5 after baking and storage at room temperature were reported. Crust color of cookies was measured using a Minolta colorimeter (model CM-600D). L, a^*, and b^* values were determined on the Hunter Lab color space, where L = 100 (white), L = 0 (black), $+a$ = red, $-a$ = green, $+b$ = yellow, and $-b$ = blue. Cookies moisture was determined using approved method 44-15A [15]. Dietary fiber was assayed using a commercial kit of Megazyme ([15] approved method 32-45.01).

2.4. Sensory Analysis. Hedonic tests were performed for each cookie formulation. A 1–9 scale was used, where 1 and 9 were the least and most accepted values, respectively. Thirty untrained panelists between 19 and 38 years old evaluated flavor, flavor intensity, texture, and general score of each sort of cookie. The statistical software JMP 5.0 was used to analyze the data with ANOVA procedures to determine whether there were statistically significant differences among means. Comparative sensory results were expressed in a radar chart.

Table 1: Formulations employed to produced wheat flour based (control) and nixtamalized corn flour cookies supplemented with different types and concentration of starches.

Ingredient	Treatment					
	Control	1	2	3	4	5
All-purpose refined wheat flour	100					
Nixtamalized corn flour		100	95	90	95	90
Waxy corn starch		—	5	10	—	—
Pregelatinized cross-linked Corn starch		—	—		5	10
Brown sugar	56.75	56.75	56.75	56.75	56.75	56.75
Vegetable shortening	27.24	27.24	27.24	27.24	27.24	27.24
Water	24.97	24.97	24.97	24.97	24.97	24.97
Dextrose	13.62	13.62	13.62	13.62	13.62	13.62
Sodium bicarbonate	1.14	1.14	1.14	1.14	1.14	1.14
Salt	0.91	0.91	0.91	0.91	0.91	0.91
Guar gum	0.91	0.91	0.91	0.91	0.91	0.91
Lactic acid	0.02	0.02	0.02	0.02	0.02	0.02

3. Results and Discussion

3.1. Flour Characterization. Table 2 shows RVA profiles, water absorption (WAI), and water solubility indexes (WSI) for nixtamalized corn composite flours. As expected, the composite flours with starches improved WSI in all cases. A low WSI implies a greater degree of associative forces among starch granules. In case of treatments 2 and 3, the addition of waxy starch practically devoid of amylose enhanced the formation of a tridimensional network without affecting water solubility [16]. The higher WSI values of composite flours or treatments 4 and 5 supplemented with pregelatinized starches can be attributed to the macromolecular disorganization and the degradation of starch during thermal treatment [9]. In all experimental treatments, the WSI and WAI values are typical for a pregelatinized NFC flour [17]. The RVA values for the NCF (treatment 1) were similar to values reported by Chávez-Santoscoy et al. [11]. As expected, treatments 2 and 3 containing waxy starch showed lower final viscosity compared to flours supplemented with cross-linked pregelatinized starches (treatments 4 and 5). Rheological/pasting behavior of starch is governed by amylose content, granule size distribution, granule volume fraction, granule shape, granule-granule interaction, and continuous phase viscosity [18]. When starch granules swell, the amylose inside the granules leaches out simultaneously forming a three-dimensional network [16] Chemical modifications of starches are aimed towards changes in the rheology and pasting properties. Composite flours supplemented with cross-linked pregelatinized (treatments 4 and 5) starches showed higher peak viscosity and higher final viscosity compared to the unsupplemented NFC (treatment 1). The supplementation with pregelatinized cross-linked starch reinforced the hydrogen and chemical bonding that acted as bridges between starch molecules. As a result these starches were more resistant to high temperature, low pH, and high shear [10]. Pineda-Gómez et al. [17] concluded that the use of different kinds of corn starches affect peak viscosity values.

3.2. Cookies Physicochemical Characteristics. Results showed that the spread factor, diameter, and thickness of the different types of cookies were not statistically different (Table 2). Color is a very important parameter in judging properly baked cookies since it not only reflects the suitable raw material used for the preparation but also provides information about the formulation and quality of the product [6]. Statistical analysis for values of L^*, a^*, and b^* of the NCF based cookies (treatment 1) and the other four experimental treatments containing starches showed significant differences ($p < 0.05$). The control and treatment 5 cookies presented the highest and lowest L values, respectively. The wheat flour or control cookies were the reddest and yellowest. Among the experimental treatments, the composite flour containing 10% waxy starch (treatment 3) produced the darkest (lowest L value), reddest and yellowest cookies. Crust color in bakery products containing high amounts of reducing sugars is mainly attributed to both nonenzymatic Maillard and caramelization reactions. Both mechanisms are enhanced by thermal treatments such as the ones employed during baking. Maillard reactions occur between amino acids and reducing sugars under a suitable temperature that normally needs to be above 50°C and it can be stimulated when moisture diminishes. The Maillard reaction efficiency depends upon various factors including chemical conformation of proteins, amino acid residues, and presence of reducing sugars and of complex carbohydrates such as starch [19].

All cookies contained moisture contents ranging from 4.6 to 6.1. The NCF cookies that contained the cross-linked starch contained the highest moisture. According to Adedokun and Itiola [20] pregelatinized starches have a greater ability to swell and retain water compared to regular starch after heating. Dietary fiber values were significantly higher for all nixtamalized corn flour cookies treatments (5.9 to 6.5%) compared to cookies produced from refined wheat flour (3.9%). The heat treatment employed during baking and starch retrogradation after cooling promoted the interaction of starch with other components (protein, lipids, or itself)

Table 2: Water absorption (WAI) and solubility (WSI) indexes, rapid viscoamylograph (RVA) profile, physicochemical parameters, and color values of control and nixtamalized corn flour supplemented with different amounts and types of starches.

	Control	Treatment[1]				
		1	2	3	4	5
Parameter in flour						
WAI	0.94 ± 0.01	4.33 ± 0.18	3.10 ± 0.06	3.61 ± 0.06	3.44 ± 0.44	4.14 ± 0.43
WSI	5.4 ± 0.14	4.21 ± 0.28	4.89 ± 0.71	5.51 ± 0.78	7.36 ± 0.71	8.28 ± 0.31
Peak viscosity (cP)	2931 ± 19	1835.0 ± 29.7	1884.5 ± 27.6	1844.5 ± 29.8	2253.0 ± 26.5	2056.0 ± 12.7
Peak time (min)	7.02	6.47	6.87	7.00	6.93	7.02
Hold (cP)	2025.66 ± 20.1	1664.5 ± 23.1	1682.0 ± 22.6	1680.5 ± 21.9	1842.0 ± 18.5	2077.5 ± 16.4
Final viscosity (cP)	3375.66 ± 4.04	2759.4 ± 16.9	2901.5 ± 3.54	3384.0 ± 18.4	3525.6 ± 5.96	4275.5 ± 24.7
Parameter in cookies						
Diameter (cm)	6.83 ± 0.07	6.53 ± 0.06	6.71 ± 0.09	6.71 ± 0.11	6.54 ± 0.05	6.54 ± 0.07
Thickness (cm)	0.53 ± 0.05	0.59 ± 0.09	0.65 ± 0.09	0.65 ± 0.09	0.51 ± 0.07	0.51 ± 0.05
Spread factor	128.12	111.11	103.83	103.83	127.59	127.64
Color						
L	50.34 ± 0.39	61.91 ± 1.39	58.83 ± 1.39	54.97 ± 3.66	59.55 ± 1.83	65.52 ± 1.81
a	11.14 ± 0.30	6.55 ± 0.58	7.79 ± 0.44	8.56 ± 0.68	7.10 ± 0.65	6.69 ± 0.41
b	29.47 ± 0.39	26.11 ± 1.23	26.41 ± 0.85	27.65 ± 1.08	25.01 ± 0.87	26.24 ± 0.65
Moisture (%)	4.61 ± 0.04	5.97 ± 0.06	5.17 ± 0.06	5.41 ± 0.06	5.83 ± 0.04	6.06 ± 0.06
Dietary fiber (% db)	3.94 ± 0.27	5.91 ± 0.21	6.38 ± 0.22	6.40 ± 0.29	6.16 ± 0.27	6.52 ± 0.27

[1]Treatment 1 = 100% nixtamalized corn flour, treatment 2 = 95% nixtamalized corn flour + 5% waxy corn starch, treatment 3 = 90% nixtamalized corn flour + 10% waxy corn starch, treatment 4 = 95% nixtamalized corn flour + 5% pregelatinized and cross-linked corn starch, treatment 5 = 90% nixtamalized corn flour + 10% pregelatinized and cross-linked corn starch, and control = wheat flour.

making starch less accessible to enzymatic hydrolysis [21]. According to Pellegrini and Agostoni [22] most gluten-free bakery goods provide low quantities of total dietary fiber. This is attributed to the high use of refined starches or flour that contains low fiber contents in the gluten free formulations. The gluten-free NCF based cookies produced herein are considered as a good source of dietary fiber. The consumption of 100 gr of these cookies can provide about one quarter of the daily dietary fiber requirement for adults.

3.3. Textural Shelf-Life. All cookies had differences in textural parameters at day 0 and after storage at room temperature for 1 or 5 days (Table 3). Fresh cookies of treatment 4 or made with the control wheat flour had the lowest and highest force values, respectively. This implies that the control wheat based cookie was the toughest and most brittle whereas the NCF cookie containing 5% pregelatinized cross-linked starch was the softest. These parameter are closely related to the chewiness and mouth feel. As expected, the cookie texture parameters changed significantly during 5 days of storage at room temperature. The penetration force and work area of the wheat control cookie slightly decreased after 5 days of storage whereas the force of all NCF cookies except treatment 5 increased after 5 days of storage. These notorious differences are attributed to differences of gluten-starch interaction in wheat or NCF flours and the rate of starch retrogradation [23]. In case of tortilla this phenomenon is very important. Campas-Baypoli et al. [21] report that during tortilla storage there is an important loss of apparent amylose and important increase in resistant starch that are correlated with tortilla staling. Although it is well known that regular starches have higher rate of retrogradation, the high amylopectin or waxy corn starch also contributes to the retrogradation phenomena. According to Park et al. [24] this reassociation of short branch chains of amylopectin affects long-term rheological properties and promotes structural changes. On the other hand, fat forms one of the basic components of a cookie formulation and is present at relatively high levels (Table 1). Fat imparts desirable eating qualities and contributes to texture of the product. The lipids play a critical role in starch phase transitions affecting rheological and morphological properties. Amylose-lipid complexes affect starch thermal transitions and retrogradation [25]. However, pregelatinaized cross-linked starch used in treatments 4 and 5 improved textural parameters because cross-linking reinforced the hydrogen bonds in the granule with bonds that acted as bridges between starch molecules. As a result, the cross-linked starches are resistant to high temperature and improve viscosity and textural properties compared to native counterparts [10].

3.4. Sensory Analysis. With the exception of the control and cookies of treatment 3, the rest of the treatments were not significantly different in terms of sensory attributes. This could be explained because the formulations contained significant amounts of shortening and sugars. It is known that shortening and sugars play a critical role because they greatly affect flavor, sweetness, mouth feel, and texture. The radar chart depicted in Figure 1 shows that cookies of treatment 3 scored significantly lower in overall acceptance. The acceptance of cookies of treatments 2 and 3 which contained waxy starch was rated significantly lower by panelists compared to the other

Table 3: Comparison of objective texture parameters of regular wheat cookies with nixtamalized corn flour cookies supplemented with different amounts and types of starches and stored at room temperature for 5 days.

Treatment[1]	Day 0		Day 1		Day 5	
	Maximum positive force (kg)	Positive area (kg·s)	Maximum positive force	Positive area	Maximum positive force	Positive area
Control	4.47 ± .66	7.16 ± .77	5.20 ± .97	2.98 ± .71	3.00 ± .43	2.05 ± .88
1	2.45 ± .64	2.58 ± .36	3.99 ± .62	5.33 ± .80	4.17 ± .86	2.89 ± .89
2	3.32 ± .62	2.62 ± .41	4.91 ± .61	1.55 ± .36	5.17 ± .45	1.78 ± .34
3	2.38 ± .49	1.98 ± .52	3.47 ± .63	1.97 ± .80	4.28 ± .72	1.61 ± .73
4	1.00 ± .21	6.99 ± .61	4.11 ± .61	1.49 ± .24	4.79 ± .41	2.85 ± .89
5	2.15 ± .60	0.93 ± .19	2.34 ± .71	2.12 ± .86	2.39 ± .50	0.99 ± .28

[1]Treatment 1 = 100% nixtamalized corn flour, treatment 2 = 95% nixtamalized corn flour + 5% waxy corn starch, treatment 3 = 90% nixtamalized corn flour + 10% waxy corn starch, treatment 4 = 95% nixtamalized corn flour + 5% pregelatinized and cross-linked corn starch, treatment 5 = 90% nixtamalized corn flour + 10% pregelatinized and cross-linked corn starch, and control = wheat flour.

experimental treatments. The texture of cookies evaluated by panelists related to the objective texture determined with the texture analyzer (Table 3). Cookies made from the composite flour of treatment 3 were harder or had higher maximum positive force at day 5. The crust colors for cookies of treatments 4 and 5 were not significantly different but differed significantly when compared to the rest of the treatments. Flavor had different levels of acceptability among treatments, resulting in significant differences between the two types of starches. The amount of starch added did not significantly affect taste but changed the overall acceptability scores. The wheat flour and treatment 3 cookies were perceived by panelists as less sweet. The most accepted cookies were the ones manufactured from treatments 4 and 5, followed by the gluten-free cookie made with NCF (treatment 1). The worst rated cookies were produced from treatments supplemented with the waxy starch. Cookies of treatment 4 were rated with the highest acceptability or overall score by consumers followed by counterparts of treatment 5. Therefore, the addition of cross-linked and pregelatinized starch used in treatments 4 and 5 yielded gluten-free cookies with the highest level of sensory acceptability even better compared to cookies made from refined wheat flour.

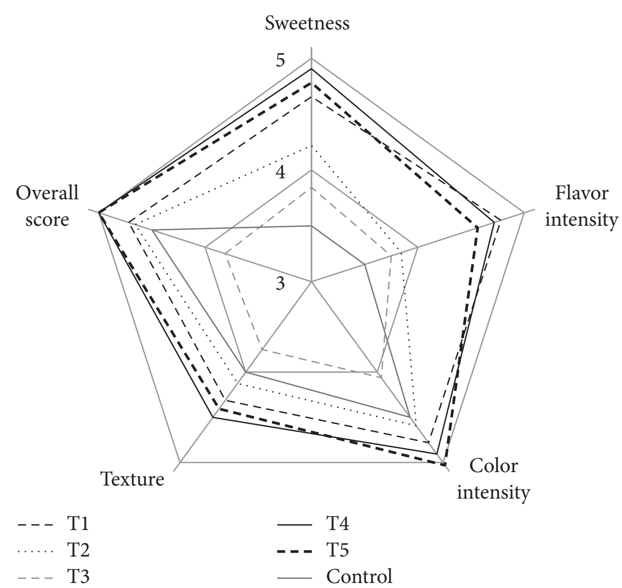

Figure 1: Comparison of the sensory acceptance of cookies made with nixtamalized corn flour mixed with different types and amounts of starches with regular wheat cookies. Treatment 1 = 100% nixtamalized corn flour, treatment 2 = 95% nixtamalized corn flour + 5% waxy corn starch, treatment 3 = 90% nixtamalized corn flour + 10% waxy corn starch, treatment 4 = 95% nixtamalized corn flour + 5% pregelatinized and cross-linked corn starch, treatment 5 = 90% nixtamalized corn flour + 10% pregelatinized and cross-linked corn starch, and control = wheat flour.

4. Conclusions

Cookies prepared by mixing 90% NCF and 10% pregelatinized starch (treatment 5) yielded the best gluten-free items. These cookies contained 65% more dietary fiber compared to the control cookies made with refined wheat flour. Objective textural data showed that it contained a softer texture that it was maintained during 5 days of storage at room temperature. The general acceptance sensory data indicated that treatments 4 and 5 supplemented with cross-linked starch produced the best sensory acceptance in every evaluated parameter, contrary to treatments 3 and the control. This study clearly indicates that gluten-free cookies formulated with nixtamalized corn flour and supplemented with cross-linked modified starch could be considered as a low cost alternative to a conventional cookie manufactured from refined wheat flour.

Competing Interests

The authors declare that they have no competing interests.

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