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Evaluation of bread made from composite wheat-sweet potato flours

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Abstract

Wheat flour was replaced with 5-20% sweet potato flour (SPF) prepared from solar dried slices of an orange flesh Mexican cultivar (cv Nylon) and the physical properties of the dough and bread were studied. Crust and crumb color and appearance and bread porosity were evaluated by a sensory panel. On a dry weight basis, the SPF was composed of 7.4% protein, 1.6% fat, 13.7% crude fiber, 1.9% ash, 40.6% reducing sugars, 35.2% N-free extract, and 17 mg/100 g carotenoids, and 81.5% of the flour had a particle size of 0.149 mm or less. As SPF percentage increased, water absorption capacity and firmness of bread increased, while farinograph and alveograph indices (*P*, *L* and *W*) and specific volume decreased. Water absorption capacity was highly correlated with L, specific volume and firmness. Developing time predicted 96.5% of the variability in firmness. Dough stability was highly correlated with alveograph parameters and inversely correlated with firmness. High negative correlation was found between extensibility, *L*, and firmness. Physical and sensory analyses showed that substitution of wheat flour with 5-10% sweet potato flour yielded acceptable doughs and breads. All sensory properties (except crust color) differed significantly between control breads and those supplemented with 15 and 20% SPF. All breads with SPF differed from control breads in porosity.

Introduction

Sweet potato (*Ipomoea batatas* L.) ranks third in world root and tuber crop production after potato and cassava (127 million metric tons, FAO, 2004) and is generally recognized as being an underutilized nutritious food (Woolfe, 1992; Bovell-Benjamin, 2007; Rodriguez-Amaya *et al*., 2011). It is commonly consumed fried, grilled, baked, boiled or steamed, and the manufacture of sweet potato purees, flours and starches broadens its possibilities for utilization (De Ruiter, 1978).

Proximal composition, granular characteristics, and viscoelastic, pasting and other functional properties have been studied in sweet potato (Akubor, 1997; Collado *et al*., 1997; Fasina *et al*., 2003). The starch granules have round, polygonal, spherical and oval forms with size ranging from 3.4-24.1 µm. Sweet potato starches exhibit different crystalline patterns (A and C or mixtures), amylose content varies from 8.5 to 38%, the onset of gelatinization is 56-79°C, pasting temperature is 66-86°C and water binding capacity varies from 66 to 212% (Tian *et al*., 1991; Collado and Corke, 1997; Zhang and Oates, 1999; Chen *et al*., 2003; Jangchud *et al*., 2003; Osundahunsi *et al*., 2003). Colors of the peel and pulp can be combinations of white, yellow, orange or purple. The yellow and orange colors are due to carotenoids, mainly β carotene (2.9-150.6 µg/g), precursor of vitamin A (Collado *et al*., 1997; Rodrigues-Amaya *et al*., 2011).

On a fresh weight basis, Mexican varieties of sweet potato provided 103 kcal/100 g of energy, and had 24% carbohydrates, 2.9% fiber, 23 mg/100 g vitamin C and 204 mg/100 g potassium (Muñoz de Chávez *et al*., 1992). Sweet potato is low in fat (1-3% dry weight) and although low in protein content (3-5% dry weight), PER value is near that of casein (Walter *et al*., 1984; Dansby and Bovell-Benjamin, 2003). The dry weight composition of white fleshed sweet potato roots from Trinidad was 64-92% starch, 3-3.8% protein, 0.48-0.62% fat, 4.05-3.15% reducing sugars, 0.92-1.57% fiber and 1.58-1.69% ash (Sammy, 1970). Akubor (1997) reported the proximal composition of an African sweet potato flour as 2.5% ash, 0.3% fat, 2.1% protein, 2.8% crude fiber, 87.3% carbohydrate and 360 calories. Mean values for the composition of flours from 44 sweet potato genotypes grown in Mexico were 71.7% starch, 11.3% total free sugar, 3.9% protein, 0.6% fat, 1.89% ash and 10.3% fiber (Collado *et al*., 1997).

To reduce wheat imports in developing countries and/or to improve nutritive value of bakery products, studies have been conducted on the use of composite

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flours, which consist of blending wheat flour with flours from other cereals, oilseeds, legumes or tubers. Numerous reports describe aspects of the total or partial replacement of wheat flour by sweet potato pulp, flour or starch to produce bakery and confectionary products, noodles and breakfast cereals (De Ruiter, 1978; Abdel-Baki *et al.*, 1980; Hathorn *et al*., 2008; Palomar *et al*., 1981; Chandra-Shekara and Shurpalekar, 1983; Bauchamp de Caloni, 1989; Wanjekeche and Keya, 1995; Collado and Corke, 1996; Chen *et al*., 2002; Dansby and Bovell-Benjamin, 2003; Greene and Bovell-Benjamin, 2004; Oluwalana *et al.*, 2012).

Sammy (1970) reported that sweet potato substitutions of 15% in bread and 20-30% in pastries showed no deleterious effects, but there was some improvement in baking characteristics using 1% glyceryl monostereate or glyceryl monopalmitate. Collins and Abdul Aziz (1982) prepared baked and steam-cooked doughnuts replacing wheat flour by 7 to 21% sweet potato flour and puree. Texture and specific volume were affected, but overall sensory quality was not reduced. Incorporation of 15% sweet potato flour in bread produced good loaf volume and crust and crumb characteristics (Collado *et al*., 1997). Among several products made with mashed sweet potato, bread obtained an acceptable score in overall quality (Bauchamp de Caloni, 1989).

The objective of the present study was to further characterize the effects of partial replacement of wheat flour by sweet potato flour (SPF) on dough and bread properties. It is desirable that the substitution of SPF in bread not change significantly dough and bread characteristics. The sweet potato flour was prepared from roots of an orange flesh high yielding variety common in central Mexico.

Materials and Methods

Sweet potato flour preparation and analysis

Sweet potatoes cv. Nylon, with violet skin and orange flesh, were obtained at harvest from a grower in Vistahermosa, Michoacán, Mexico. The unpeeled roots were washed, thinly sliced (1.4 mm thickness) and dipped in 1% $NaHSO_3$ for 30 sec. Treated slices were drained and dried in batches of 3000 g in a single layer solar dryer (2.5 m^2 useful area) with a polyethylene plastic window. The highest dryer temperature was 65°C at midday and less than 8 hours were required to dry the slices from 74% to a final average 7.6% moisture content. Slices were held in containers with desiccant until milled.

The dried slices were milled (Tecator cyclon mill, Cyclotec model) using a no. 100 sieve (0.149 mm diameter). Particle sizes were determined by passing the resultant flour through no. 60, 80 and 100 sieves. Moisture, fat, crude fiber, protein, reducing sugars and ash contents of the flour were determined by AOAC methods 925.10, 920.39C, 962.09E, 920.87, 939.03, and 923.03, respectively (AOAC, 1999). Nitrogen-free extract, assumed to be mostly starch, was computed by difference. Total carotenoids were determined by the method described by Ahmed and Scott (1962).

Physical characteristics of dough

Composite flours were prepared by blending all-purpose wheat flour (13% moisture, 8.7% protein and 0.57% ash) with sweet potato flour. In one set of tests, composite flours consisted of 0, 2.5, 5, 7.5, 10, 12.5, 15 or 20% sweet potato flour. In other tests, replacement percentages were 0, 5, 10, 15 or 20. Farinograph (Brabender) values for developing time, stability and water absorption capacity were derived from a 15 min mixing curve for 50 g of flour and sufficient distilled water to give a maximum dough consistency centered on the 500 BU line (AACC method 54-21, 2000). Alveograms were obtained on a Chopin instrument using the methodology described by the manufacturer with 250 g flour portions for 26 min to measure tenacity or overpressure (*P*), elasticity (*G*), extensibility (*L*), and work (*W*). The height (*H*), length (*L*) and area under the curve (*S*) were measured on each alveogram. Maximum overpressure (P) was calculated by the formula $P = H \times 1.1$. Deformation energy (W) was computed by the formula $W = S \times 6.54$.

Baking tests

Baking tests were conducted with a modified straight dough procedure (AACC method 10-10B, 2000). Four loaves were prepared in each lot with the following baking formula: 300 g flour or composite flour (14% moisture), 15 g sugar, 20.1 g shortening, 10.5 g compressed yeast, 3 g salt and 180 mL water. The dough was mixed for 4 min, raised for 30 min, punched for 5 min, and raised for another 30 min. The dough was divided, punched again for 5 min, rounded and molded. Then it was placed in baking pans and allowed to rise for 60 min at 30°C. Loaves were baked for 10 min at 250°C.

Bread evaluation

Loaves were removed from pans and placed on wire racks to cool for one hour. Weight and volume (by rapeseed displacement) were determined, and specific volume was calculated as volume/weight. Two slices (2.2 cm thickness) were cut from the center of each loaf for firmness measurement (Instron Universal Testing Machine model 1132) with a cylindrical flat disk (3.6 cm diameter). Measurement conditions were: 5 cm/min crossed-head speed, 50 cm/min and 2 kg full scale load. The force to compress the bread slices 25% were averaged from 4 replicates per treatment. For sensory evaluation, thirty eight untrained panelists evaluated crumb and crust color, firmness and porosity of the breads in a paired preference test, using five point scales, where 1 = unsatisfactory (serious defects), 2 = minimally acceptable (obvious defects), 3 = satisfactory (noticeable but acceptable deviation), 4 = good (minimal deviation) and 5 = very good (expectations of quality fully met).

Statistical analysis

Data are based on averages from 3 or 4 measurements per determination. Pearson regression coefficients were calculated for farinograph and alveogram parameters, as well for specific volume and loaf firmness, using Windows 95 Excel program. A two-tailed test was used to determine significance levels of the correlation coefficients (O'Mahony, 1986).

Sensory data scores were analyzed by analysis of variance with mean separation by LSD (P < 0.05).

Results and Discussion

Flour milling and composition

About 81.5% of the milled material passed through no. 100 sieve indicating a particle size less than 0.149 mm. The distributions of the SPF through sieve numbers 60, 80 and 100 were 9.4, 3.9 and 5.1%, respectively. The SPF contained 7.6% water, and on a dry weight basis was 7.4% protein, 1.9% ash, 1.6% fat, and 13.7% crude fiber, with 40.6% reducing sugars, 35.2% N-free extract, and 17 mg% carotenoids. The SPF has higher levels of protein, fat, ash, crude fiber and reducing sugars than those reported by Sammy (1970) for sweet potato varieties from Trinidad. However, values were similar to those of other sweet potatoes, except for the lower protein and fat concentrations (Collado *et al*., 1997; Jangchud *et al*., 2003). The carotenoid content was similar to that of other orange flesh cultivars studied by Picha (1985), but more than twice the content in the Mississippi Red cultivar used by Hathorn *et al.* (2008). The SPF had a high reducing sugar content, which imparted a characteristic sweet flavor, noted also by other authors (Oluwalana *et al*., 2012). The relatively low drying temperature of the solar dryer likely enhanced β-amylase activity in the root slices (Walter *et al*., 1976; Houvet, 1986). The enhanced activity would contribute to the relatively high sugar and low N-free extract (presumably starch) contents of the SPF.

Table 1. Farinograph and alveograph properties and bread quality from composite wheat-sweet potato flours (cv Nylon). Data are the average of 3 determinations.

Parameter	Sweet potato flour (%)				
	0	5	10	15	20
Water absorption capacity (mL/100 g)	57.6	57.7	58.2	58.9	59.3
Developing time (min)	2.0	2.0	1.7	1.6	1.4
Stability (min)	5.2	3.4	2.4	1.9	1.6
Overpressure, P (mm)	90	60	59	55	51
Elasticity, G (mL)	18.1	16.1	12.5	--	--
Extensibility, L (mm)	64	50	29	21	15
P/L	1.55	1.32	2.24	2.88	3.74
Work, W (10^3 ergs/g)	248.8	117.7	78.5	52.3	39.2
Firmness (g-f)	147.7	178.7	219.7	264.1	320.3
Specific volume (cm^3/g)	4.04	4.07	4.10	3.78	3.55
Slice area (% control)	100.0	105.0	102.0	93.4	85.2

Physical properties of dough

Farinograph and alveogram data of wheat and composite flours are summarized in Table 1. Increasing SPF substitution resulted in a small increase in water absorption capacity. This is expected because of the higher swelling capacity of tuber starches (Collado and Corke, 1997). The commercial wheat flour farinograph (control) was typical of a medium strength wheat class (D'Appolonia and Kunerth, 1990). The farinographs of the composite wheat-sweet potato flour doughs had short developing time and low stability, characteristics of types I and II doughs (FAO, 1971). SPF incorporation at 10 and 20% decreased the dough developing time by 15 and 30%, respectively. With the same substitution levels, dough stability was reduced by 54 and 69%, respectively. These results are due to the decrease in wheat gluten and the increase in the SPF starch and are similar to results in other studies on tuber starch incorporation in bread dough (Kim and De Ruiter, 1968; Seyam and Kidman 1975; Yáñez *et al*., 1981; Chandra-Shekara and Shurpalekar, 1983; Hathorn *et al*., 2008).

Addition of SPF resulted in a more marked reduction in alveogram than farinograph parameters except P/L ratio which increased 2.4 times at 20% substitution compared to non-substituted dough (Table 1). Overpressure or index of resistance to dough elongation (*P*) decreased 33% with only 5% SPF, but with further addition, declined gradually to a value of 57% reduction with 20% SPF substitution. Dough extensibility (*L*) and dough strength or deformation energy of dough (*W*) were reduced 55 and 68.5%, respectively at 10% sweet potato flour replacement. Dough elasticity (*G*) could only be measured in dough with up to 10% SPF.

Bread evaluation

Specific loaf volume was the same or slightly higher with 2.5, 5, 7.5 or 10% SPF (data not shown

Table 2. Correlation coefficients of farinograph and alveogram dough properties and bread quality attributes (specific volume and firmness) of composite wheat-sweet potato flours (cv Nylon).

Parameter	Developing time	Stability	P	L	W	P/L	Specific Volume	Firmness
Water abs.	0.26	-0.02	-0.73	0.94*	-0.81	-0.42	-0.92*	0.99**
Dev. time	--	0.89*	0.74	0.96**	0.83	-0.98**	0.82	-0.98**
Stability		--	0.95*	0.98**	0.99***	-0.80	0.64	-0.91*
P			--	0.87*	0.98**	-0.64	0.52	-0.80
L				--	0.94*	-0.90*	0.72	-0.95*
W					--	-0.73	0.58	-0.86
P/L						--	-0.90*	0.97**
Spec. vol.							--	-0.88*

***, **, * = significant at $P<0.001$, $P < 0.01$ and $P < 0.05$, respectively.

Table 3. Sensory evaluation of breads prepared from composite wheat-sweet potato flours (cv Nylon). A score of 5 = very good and a score of 1 = unsatisfactory. Data are based on evaluations from 38 untrained panelists.

Sweet potato flour replacement (%)	Crust Color	Crust Appearance	Crumb Color	Crumb Firmness	Crumb Pore uniformity
0	4.9	4.9	4.8	4.9	4.8
5	4.4	4.1	4.2	4.3	3.3
10	3.9	3.8	3.8	3.8	2.9
15	3.8	3.3	3.3	3.3	2.4
20	3.6	2.9	2.9	2.9	2.0
LSD.05	0.3	0.3	0.3	0.3	0.3

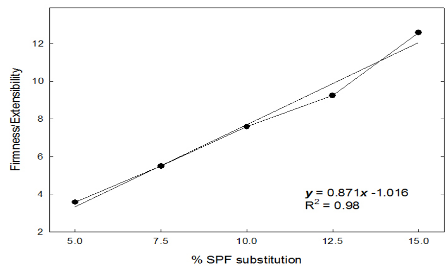

Figure 1. The relationship between the ratio bread firmness: dough extensibility in composite wheat-sweet potato flours (SPF).

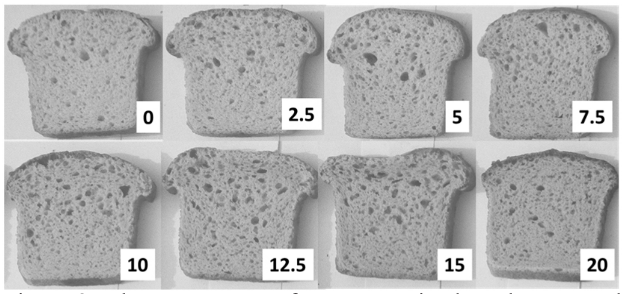

Figure 2. The appearance of representative breads prepared from wheat-sweet potato composite flours. The numbers indicate the % replacement with sweet potato flour.

for first set of tests; Table 2 for subsequent testing), then decreased with 12.5 (data not shown), 15 or 20% (Table 3) substitution. Similar results were reported in breads made from 5-20% sweet potato flour (Sammy, 1970; Tapang and del Rosario, 1977; Collins and Abdul Aziz, 1982; Hathorn *et al*., 2008, Oluwalana *et al*., 2012) as well as in breads made from wheat flour-tuber starches (Kim and De Ruiter, 1968; Seyam and Kidman, 1975; Yáñez *et al*., 1981; Chandra-Shekara and Shurpalekar, 1983). Slice area was similar or slightly higher with 5 or 10% SPF compared to the area of control loaves (Table 1). Firmness consistently increased with SPF substitution as previously reported by Collins and Abdul Aziz (1982). Bread was 48 and 116% firmer at 10 and 20% SPF replacement, respectively (Table 1).

Relationships among farinograph, alveogram, and bread quality parameters

A high correlation was found between percent SPF and bread firmness: dough extensibility ratio ($r = 0.98$, $P < 0.01$; Figure 1). The correlation coefficients of farinogram, alveogram values and bread properties (specific volume and firmness) are summarized in Table 2. High significant correlations were found between water absorption capacity and extensibility (L) ($r = 0.935$, $p < 0.05$), between water absorption capacity and specific volume ($r = -0.916$, $p < 0.05$) as well as between water absorption capacity and bread firmness ($r = 0.988$, $p < 0.01\%$). Water absorption capacity predicted 83.9% of the variability in specific volume and 97.6% of firmness variation. Developing time was highly and positively correlated with dough stability ($r = 0.893$, $p < 0.05$) and L ($r = 0.961$, $p < 0.01$) and inversely correlated with P/L ratio and bread firmness ($r = -0.98$, $p < 0.01$). Development time could predict 96.5% of the variability in firmness. Significant positive correlations were found between dough stability and alveogram values, except P/L and a negative correlation coefficient was found with firmness ($r = -0.906$, $p < 0.05$). Only 82.2% of the variability of this bread property was predicted from dough stability. Overpressure *P* was only highly correlated with W ($r = 0.984$, $p < 0.01$) and *L* ($r = 0.872$, $p < 0.05$). Regression coefficients between *L* and *W* was high and positive ($r = 0.943$, $p < 0.05$); between *L* and *P/L* ratio as well as firmness they were high and negative ($r = -0.898$ and -0.951, respectively, $p < 0.05$). *L* caused 90% of the variability in firmness. *W* was not correlated with *P/L* ratio, specific volume and firmness. *P/L* ratio was inversely correlated with specific volume ($r = -0.904$, $p < 0.05$) and positively and highly with firmness ($r = 0.971$, $p < 0.01$). Coefficients of variation in these characteristics were 81.2% and 94.2% and were predicted from *P/L* ratio. As expected, a negative correlation was found between specific volume and firmness ($r = -0.88$, $p < 0.01$).

Sensory evaluation

Sensory evaluation data are shown in Table 3 and the appearance of slices from representative loaves in Figure 2. The color of all bread crusts was qualified as good by panelists. At 20% SPF replacement, bread color was satisfactory, but slightly darker than in control bread. Appearance, crumb color and firmness were good to satisfactory (15 and 20% SPF). Significant differences ($p < 0.05$) in all sensory attributes (except crust color) were found between control and bread supplemented with 15 and 20% SWP (Table 3). All breads with SPF differed from those of the non-substituted wheat breads in porosity ($p < 0.05$). Pore uniformity was regular to poor with 5 to 20% SPF. Some cells of these breads were open and irregularly sized and shaped (Figure 2). Sammy (1970) and Tapang and Del Rosario (1977) reported even crumb and fine grain in breads with up to 15% sweet potato flour replacement. Greene and Bovell-Benjamin (2004) reported significant sensory differences with SPF substitutions of 50 to 65%. Other than porosity, the sensory results in the present study are in agreement with those reported by Sammy (1970), Tapang and Del Rosario (1977), and Aniedu and Agugo (2010). Oluwalana *et al.* (2012) reported that a 10% SPF substitution was preferred based on the textural properties of the bread.

Conclusions

This study aimed to substitute SPF in bread so that dough and bread characteristics were essentially unchanged. Water absorption capacity slightly increased with the addition of sweet potato flour (SPF) (solar dried slices from cv Nylon, orange flesh) to wheat bread flour. Addition of SPF generally resulted in decreased farinograph and alveogram parameters, except *P/L* ratio which increased. Bread firmness increased with increased SPF addition. Bread slice area was not reduced until 10% SPF replacement. Dough stability produced high and positive correlations with developing time (*P*) and extensibility (*L*), but was negatively correlated with *P/L* ratio and bread firmness. Extensibility is a good index for developing time, *W*, *P/L* ratio and firmness. Also *P/L* ratio appears to be a suitable index for evaluation of bread-making potential of wheat and sweet potato composite flours due to its high and negative correlation with specific volume and positive correlation with firmness. From the perspective of physical dough and bread properties, SPF addition to the extent of 5% yielded acceptable doughs and breads. Based on sensory properties, wheat flour replacement with 10% SPF yielded good quality breads.

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