Fermented Sorghum as a Functional Ingredient in Composite Breads

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ABSTRACT

Whole sorghum flour was fermented (a five-day natural lactic acid fermentation) and dried under forced draught at 60°C, and evaluated for its effect on sorghum and wheat composite bread quality. In comparison with unfermented sorghum flour, fermentation decreased the flour pH from 6.2 to 3.4, decreased total starch and water-soluble proteins, and increased enzyme-susceptible starch, total protein, and the in vitro protein digestibility (IVPD). Fermentation and drying did not decrease the pasting temperature of sorghum flour, but slightly increased its peak and final viscosity. In comparison with composite bread dough containing unfermented sorghum flour, fermented and dried sorghum flour decreased the pH of the dough from 5.8 to 4.9, increased bread volume by ≈4%, improved crumb structure, and slightly decreased crumb firmness. IVPD of the composite bread was also improved. Mixing wet fermented sorghum flour directly with wheat flour (sourdough-type process) further increased loaf volume and weight and reduced crumb firmness, and simplified the breadmaking process. It appears that the low pH of fermented sorghum flour inactivated amylases and increased the viscosity of sorghum flour, thus improving the gas-holding capacity of sorghum and wheat composite dough. Fermentation of sorghum flour, particularly in a sourdough breadmaking process, appears to have considerable potential for increasing sorghum utilization in bread.

Sorghum is potentially suitable for use in composite flours (De Ruiter 1978; Dendy 1992). Sorghum flour can have a definite advantage over maize and other tropical cereals in composite flours because of its bland flavor and white color in tanplant types (Rooney et al 1997). However, due to its high starch gelatinization temperature and low water-holding capacity, sorghum flour tends to give a drier, more gritty, and firmer texture to breads and biscuits made with sorghum and wheat composite flours (Munck 1995; Rooney et al 1997).

We have shown that the simple, traditional technology of malting can ameliorate these adverse sorghum flour characteristics and improve its composite breadmaking quality (Hugo et al 2000). Fermentation is also a simple, traditional technology with the potential to improve the composite breadmaking quality of sorghum flour. In Ethiopia, lactic acid fermentation is applied in the making of the traditional sorghum or tef flour *injera*, a semi-leavened bread (Murty and Kumar 1995). By decreasing the pH to values as low as 3.4 (Chavan and Kadam 1989), lactic acid fermentation of sorghum could, as in rye and wheat sourdough, bring about desirable changes in flour quality. The sourdough process improves rye and wheat breadmaking quality essentially because low pH controls the solubility and swelling power of pentosans and partly inactivates amylases (Brümmer and Lorenz 1991; Seibel and Brümmer 1991).

The low pH of fermented sorghum flour has also been reported to partly inactivate amylases, especially α- and β-amylase (El Tinay et al 1979) and to increase, although slightly, the solubility of cellulose and hemicelluloses (El Tinay et al 1979; Susheelamma and Rao 1979) and proteins (Kazanas and Fields 1981). Fermentation pH also increases the pasting viscosity of sorghum starch (Wanink et al 1994), presumably as a result of preferential breakdown of damaged starch where the fermentation pH is optimal for α-amylase activity. The aim of this study was to determine the effect of fermentation of sorghum flour on the functional and nutritional quality of sorghum and wheat composite bread.

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MATERIALS AND METHODS

Flours

A white, tannin-free sorghum from Mozambique was cleaned and milled with a hammer mill fitted with a 1-mm screen (Alpine, Augsburg, Germany) and then with a pin mill (Alpine). The wheat flour used was "Favorita" a commercial bread flour produced by Companhia Industrial da Matola, Maputo, Mozambique. The wheat flour had a protein content of 12.9% (N × 5.7) and ash of 1.9%, db, a water absorption of 63%, and mixogram mixing times of 3.0 and 2.8 min for peak time and stability to mixing, respectively. The particle size distribution of the flours was determined by sieving flour (50 g) for 10 min with a Ro-tap shaker using standard sieves with sieve apertures of 500, 212, 180, and 75 µm. The percentage of each fraction was determined from the weight of overs on each sieve. The particle size distribution of sorghum flour was >95% <212 µm and >5% <75 µm, whereas the particle size distribution of wheat flour was >98% <212 µm and >32% <75 µm. Thus the sorghum flour was slightly coarser than the wheat flour but still within the acceptable range for wheat flour.

Fermentation of Sorghum Flour

Milled sorghum (15 kg) was weighed into a large stainless vessel and mixed with tap water at a ratio of 1:1.4 (grain to liquid) (Mosala and Taylor 1996). The mixture was inoculated with a natural inoculum, which had been prepared from a previous fermentation and maintained through back-slopping, as described by Taylor and Taylor (2002). The contents were stirred, covered with aluminum foil, and allowed to ferment at room temperature (≈25°C) for five days. The pH and titratable acidity (TA) were measured during the period of fermentation. TA was determined as milliliters of 0.1*M* sodium hydroxide (NaOH) required to raise the pH of a 100-g sample to pH 6.3.

At the end of the fermentation period, the fermented material was transferred to aluminium pans. Each aluminium pan contained a thin layer (≈0.5 cm thick) of the fermented material, which was dried in a forced draught oven set at 60°C. The drying time varied between 24 and 30 hr. After drying, the fermented and dried material was remilled as described above and stored at 10°C. The dry matter losses due to fermentation and drying were ≈4%, within the range of 1.4–8.2% for one to five days of natural fermentation, respectively, reported by Kazanas and Fields (1981).

A second batch of fermented sorghum flour was prepared by mixing in buckets, in duplicate, the milled sorghum (1 kg/bucket) with tap water (1:1.2, grain to liquid) and fermenting as described above. However, whereas the content of one bucket was dried at 60°C as described above, the contents of the other bucket was not dried.

Flour Analyses

Flour pasting properties were determined using a Rapid Visco Analyser (RVA 3D, Newport Scientific, Narrabeen, Australia). Flour (4 g, 14% moisture) was suspended in 25 mL of distilled water and heated. The temperature profile used was heat from 25 to 91°C in 8 min, hold at 91°C for 10 min, cool to 50°C in 9 min.

The RVA parameters measured were pasting temperature (temperature at which paste viscosity starts to increase), peak viscosity (maximum hot paste viscosity), holding strength (the trough at minimum hot paste viscosity), and final viscosity (viscosity after cooling to 50°C and holding the temperature) (Batey et al 1997).

Flour moisture, protein, and optimum absorption were determined according to Approved Methods 44-15A, 46-12, and 54-21, respectively (AACC 2000). Soluble nitrogen was determined by Approved Method 46-23, except that the protein content was estimated by converting nitrogen to protein (N × 6.25). In vitro protein digestibility (IVPD) was determined by pepsin hydrolysis, as described by Hamaker et al (1987), using Sigma pepsin (cat. P-7000 with 543 units of activity/mg). Total starch (TS) and enzyme susceptible starch (ESS) were determined using an α-amylase and amyloglucosidase (Novo BAN 480L and AMG 300L, respectively, Enzymes SA, Benmore, South Africa) hydrolysis method (Taylor 1992). The color of flour was determined by measuring the energy reflectance of the sample, using an Agtron M-35 process analyzer spectrophotometer (Filper Magnuson, Reno, NV), where 0 is black and 90 is white, set in red color mode.

Breadmaking

Bread was produced using the formulation wheat flour (70%), sorghum flour (30%), water (63%), active dried yeast (1%), salt (2%), sugar (1%), ascorbic acid (20 ppm), and fat (1%), based on flour weight, by a straight-dough process. The dough was mixed to optimum development for 15–20 min with a spiral mixer, rested for 15 min, divided into 950-g pieces, molded, and placed in baking pans. The dough was proofed for 50 min, at 40°C and 95% rh, and baked at 230°C for ≈30 min.

The same formulation and baking procedure was used to produce bread with wet fermented sorghum flour (sourdough type process), except that the fermented sorghum flour, which already contained ≈60% water, was added directly when mixing the dough. The dough was divided into 500-g pieces, molded, and placed into proportionally smaller baking pans.

Bread Analyses

Moisture content of breads was determined using the two-stage air-oven method, Approved Method 44-15A (AACC 2000). Bread volume was determined by rapeseed displacement. Specific volume was calculated from the volume and weight of bread. Crumb firmness was determined by measuring the force required to compress bread slices using the Instron universal testing machine (Approved Method 74-09, AACC 2000). The instrument was fitted with a 28-mm diameter cylinder probe. The crosshead speed was 100-mm per min. Samples were prepared, allowed to cool to ambient temperature for ≈2 to 3 hr, and then wrapped in polyethylene bags and stored in ambient conditions (≈25°C) until required for testing. Measurements of crumb firmness began 4 hr after baking day 0, and thereafter at one-day intervals until the third day. Consumer sensory evaluation of bread samples made with sorghum grain flour (30%), fermented and dried sorghum flour (30%), and boiled sorghum malt flour (Hugo et al 2000) was performed. The testing methodology was based on liking and preference ranking test (Jellinek 1990), with slight modifications to suit semi-illiterate consumers. The panel members (62) were women, all residents of the community of Mmotla, near Pretoria, who were familiar with sorghum foods.

Statistical Analyses

All analyses were repeated at least twice. The data were analyzed by one-way analysis of variance and significance was measured at the 5% level using a computer program (StatSoft, Tulsa, OK). The significance of liking judgments and the degree of ranking preference were determined using the "Roessler Table for Paired Preference Test" (Stone and Sidel 1993) and the "Table of Rank Total" (Kramer 1963), respectively.

RESULTS AND DISCUSSION

Effect of Fermentation and Drying on Flour Properties

With fermentation, the pH of sorghum flour decreased from 6.2 to 3.4, with a concomitant increase in TA from 0.9 to 11.9 mL (Table I). Typically, with inoculated sorghum flour fermentations values of pH 3.5 and TA ≈ 10 are attained after two days at room temperature, and thereafter the decrease in pH and increase in TA are slower. (Taylor and Taylor 2002). The low pH of fermented sorghum flour has been attributed mainly to the formation of lactic acid (Hamad and Fields 1979; Chavan and Kadam 1989). The color of the fermented and dried sorghum flour was slightly but significantly ($P < 0.05$) lighter compared with unfermented sorghum grain flour. Low pH brightens anthocyanin pigments by increasing methylation (Von Elbe and Schwartz 1996).

Fermentation and drying decreased the starch content of sorghum flour by ≈2.8 percentage points, but increased the ESS content significantly, from 1.6 to 10.5%, whereas it increased the total protein and decreased the water-soluble proteins (as a % of total proteins) by 0.5 and 5.2 percentage points, respectively (Table I). In inoculated sorghum flour fermentations, water-soluble proteins are lowest after two days, and thereafter increase slightly (Taylor and Taylor 2002). The IVPD of sorghum flour also increased from 35.3 to 52.7%. The maximum increase in IVPD is generally attained after two days of fermentation (Taylor and Taylor 2002). The decrease in starch and water-soluble protein of sorghum flour with fermentation has been attributed to utilization of the products of starch and protein hydrolysis by the fermenting microflora (El Tinay et al 1979). However, the slight but significant increase in total protein can simply be due to a decrease in total carbohydrates. According to Taylor and Taylor (2002), the increased IVPD of fermented sorghum flour, with a subsequent decrease in water-soluble proteins, can be attributed to structural changes in the sorghum storage proteins (prolamins and glutelins). These modifications, apparently brought about by rapid lowering of the pH, make the storage proteins of sorghum more accessible to pepsin attack.

TABLE I
Effect of Fermentation and Drying on Properties of Sorghum Flour

Bread Ingredient	pH	Color (Agtron)	Titratable Acidity (mL)	Starch (%)	ESS[a] (%)	Protein (%)	Soluble Protein (%)	IVPD[b] (%)
Sorghum grain flour	6.2a[c]	8.4b	0.9b	68.3a	1.6b	12.3b	1.6 (13.1a)[d]	35.3b
Fermented and dried sorghum grain flour	3.4b	8.7a	11.9a	65.5b	10.5a	12.8a	1.0 (7.9b)	52.7a

[a] Enzyme susceptible starch, expressed as % of total starch.
[b] In vitro protein digestibility, expressed as % of total protein.
[c] Values followed by the same letter in the same column are not significantly different ($P > 0.05$).
[d] Soluble protein as a percentage of total protein.

Drying the fermented sorghum flour at elevated temperature could have increased its ESS content. Heating of carbohydrates at low pH causes random depolymerization, that is breakage of glucosidic bonds of the starch molecules (BeMiller and Whistler 1996). Ahamed and Ramanathan (1988) and Wanink et al (1994) have reported the inactivation of both grain and bacterial amylases with the low pH of fermented sorghum flour. Thus, the increase in the ESS could not be due to amylase action.

Pasting properties of sorghum flour before and after fermentation and drying are presented in Fig. 1. Fermentation and drying did not change the pasting temperature of sorghum flour which remained at ≈71°C but increased, although slightly, the peak viscosity (from 129 to 143 RVA units), holding strength (from 84 to 85 RVA units), and final viscosity (from 213 to 238 RVA units) of the flour. The flour Falling Number (data not tabulated) increased from 507 to 560, indicating a slight increase in the pasting viscosity of the flour with fermentation and drying. It appears that inactivation of the amylases had occurred. However, it is not clear whether inactivation was due to low pH, as suggested by Wanink et al (1994), or due to thermal denaturation with drying at 60°C, or both low pH and thermal drying.

The absence of browning of the fermented and dried sorghum flour, as evident from that fact that it was lighter than the unfermented flour (Table I), can be explained by the absence of simple sugars and water-soluble proteins after a five-day fermentation. During fermentation, the fermenting bacteria utilize the simple sugars, water-soluble proteins, and amino acids (El Tinay et al 1979; Chavan and Kadam 1989; Taylor and Taylor 2002). Therefore, the Maillard type of browning reaction, which occurs between reducing sugars and proteins or amino groups (BeMiller and Whistler 1996), could not occur.

Breadmaking Properties of Fermented Sorghum Flour

Fermenting and then drying the sorghum flour did not change the water requirement of sorghum flour but decreased the pH of sorghum and wheat dough from 5.8 to 4.9, increased the bread volume from 2,998 to 3,117 cm^3, and slightly increased the weight and the moisture content of breads (Table II). The increased volume of bread made with fermented and dried sorghum flour can be attributed to an improvement of the gas-holding capacity of sorghum and wheat composite dough caused by the increased viscosity of the fermented and dried flour (Fig. 1). An increase of dough viscosity results in improvement of the gas-holding capacity of wheat dough (Gan et al 1995). The slight increase in loaf weight indicates also a slight improvement in the water-holding capacity of sorghum and wheat dough with fermentation and drying of the sorghum flour. In rye and wheat sourdoughs, the low pH increases the swelling power of pentosans, thus increasing the moisture content of breads (Seibel and Brümmer 1991). The decreased crumb firmness of the breads made with fermented sorghum flour (fermented and dried and sourdough-type process) can be attributed to the increased volume and improved crumb structure of these breads. The low pH of rye and wheat sourdough contributed to a more cohesive and staling resistant crumb by inactivating the amylases (Seibel and Brümmer 1991). Siljeström et al (1988) and Seibel and Brümmer (1991) also reported that low pH represses the activity of intrinsic amylases in sourdough. Therefore, the low molecular weight dextrins, which have been reported to prevent staling of bread by interfering with crystallization of starch (Martin and Hoseney 1991), cannot account entirely for the decreased crumb firmness of bread made with fermented and dried sorghum flour.

A comparison between the breads made with fermented and dried sorghum flour, the unfermented sorghum grain flour, and boiled sorghum malt flour (Fig. 2), shows that the bread made with fermented and dried sorghum flour had the highest loaf volume, improved crumb structure, and lighter crumb color. In contrast, bread made with boiled sorghum malt flour, as described by Hugo et al (2000), had smaller loaf volume, denser crumb, and darker color. Attempts to increase the level of fermented and dried sorghum flour in the composite to 50% gave bread with poor loaf volume and poor crumb structure (data not shown).

Heating and drying fermented sorghum flour obviously increases energy costs and takes time. As an alternative to drying, sorghum and wheat composite bread was prepared by mixing the wet fermented sorghum flour slurry directly with the wheat flour, as in the rye or wheat sourdough process (Seibel and Brümmer 1991).

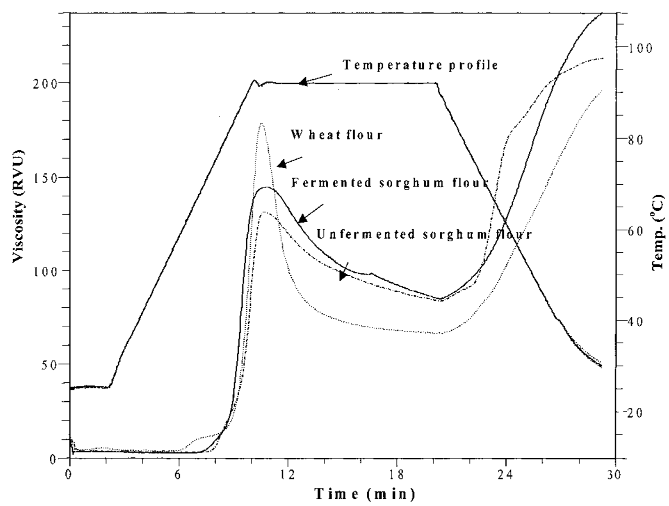

Fig. 1. Pasting profiles of sorghum grain flour, fermented, and dried sorghum grain flour and wheat flour (11.9% solids content).

TABLE II
Breadmaking Properties (dmb) of Composite Breads with Sorghum, Fermented and Dried Sorghum, and Fermented Sorghum (sourdough process)[a,b]

Bread Ingredient	pH of Dough	Loaf Vol. (cm^3)	Loaf Weight (g)	Specific Vol. (cm^3/g)	Crumb Firmness[c] (g)	Moisture (%)	Total Protein (%)	IVPD[d] (%)
Wheat flour (100%)[c]	5.9a	4,008a	835c	4.8a	11.5c	42.6a	13.2a	74.8a
		(2,133)	(429)	(5.0)	(10.3)	(43.4)	(nd)[e]	(nd)
Sorghum grain flour (30%)	5.8a	2,998d	855b	3.5d	24.1a	38.2c	12.5c	64.0c
		(1,598)	(450)	(3.6)	(22.6)	(38.5)	(nd)	(nd)
Fermented and dried sorghum	4.9b	3,117c	860a	3.6c	20.6b	39.0b	12.9b	68.0b
grain flour (30%)		(1,816)	(424)	(4.3)	(20.1)	(39.7)	(nd)	(nd)
Fermented sorghum grain flour	4.1c	3,295b[f]	867a	3.8b[f]	nd	nd	nd	nd
(30%) (sourdough process)		(1,875)	(433)	(4.3)	(16.6)	(41.3)	(nd)	(nd)

[a] Values followed by the same letters in the same column are not significantly different ($P > 0.05$).
[b] Dough loaves 950 g; in parentheses, dough loaves 500 g.
[c] One-day crumb firmness.
[d] In vitro protein digestibility, expressed as % of total protein.
[e] Not determined.
[f] Values recalculated to dough loaves 950 g.

TABLE III
Sensory Evaluation of Fermented and Dried and Nonfermented Sorghum and Wheat Composite Breads

Bread Ingredients (dmb)	Panelists Liking Bread (n = 62)	Rank Sum of Sample[a,b]
Sorghum grain flour (30%)	47	111a
Fermented and dried sorghum grain flour (30%)	38	136b
Whole boiled sorghum malt flour (30%) (Hugo et al 2000)	53	86c

[a] Rank sum of the sample = ∑(number of panelists × the respective rank position). Lower rank sum indicates the better-liked sample.
[b] Values followed by the same letters in the same column are not significantly different ($P > 0.05$).

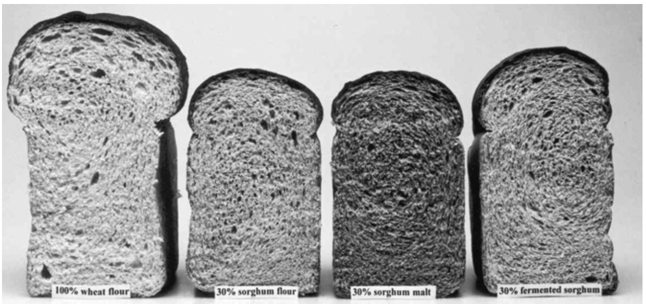

Fig. 2. Effects of malting and fermentation on the volume, crumb structure, and color of sorghum and wheat composite breads (950-g dough loaves). Left to right: wheat flour (100%); sorghum grain flour (30%); whole boiled sorghum malt flour (30%) (Hugo et al 2000); fermented and dried sorghum grain flour (30%).

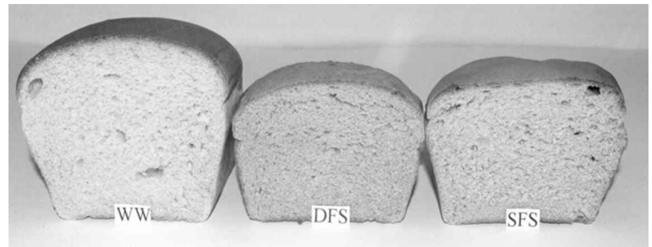

Fig. 3. Effects of fermented sorghum flour on the volume, crumb structure, and color of sorghum and wheat composite breads (500-g dough loaves). Left to right: WW, wheat flour (100%); DFS, fermented and dried sorghum grain flour (30%); SFS, fermented sorghum grain flour (sourdough process) (30%).

As shown in Table II, the sourdough process significantly increased the volume, weight, and moisture content of the bread and decreased the one-day crumb firmness compared with fermented and dried sorghum flour. The slightly higher weight of bread made with fermented sorghum flour by the sourdough process indicates that a decrease occurs in the water-holding capacity of fermented sorghum flour with heating and drying. This adverse effect of heating and drying on the breadmaking quality of fermented sorghum flour was probably due to protein and carbohydrate condensation reactions (Damodaran 1996). Such reactions could bring about structural changes in the flour polymers that interfere with swelling power and solubility. This is supported by the fact that the composite bread made by the sourdough process not only had a higher volume than the bread made with fermented and dried sorghum, but had a more open crumb structure and a lighter crumb color (Fig. 3).

Protein Quality of Sorghum and Wheat Composite Breads

As also shown in Table II, breadmaking with fermented and dried sorghum flour improved the protein quality of sorghum and wheat composite bread. Although the total protein of composite bread increased only slightly, the IVPD increased significantly. This indicates that the dry process of baking retains more of the benefits of fermentation on sorghum protein digestibility than are retained in traditional wet cooking (Taylor and Taylor 2002). This is important because fermentation of sorghum flour can also be used to improve the nutritional quality of sorghum and wheat composite bread.

Sensory Evaluation

Although the composite bread made with fermented and dried sorghum flour had a higher volume and a softer crumb compared with bread made with unfermented sorghum grain flour, consumer panel members liked it less and preferred it less (Table III). Panel members liked and preferred more the bread made with boiled sorghum malt flour, which had a lower bread volume, a softer crumb, and a fine malt flavor compared with the bread made with fermented and dried sorghum flour (Hugo et al 2000). Apparently, they did not like the very sour taste of the bread made with fermented and dried sorghum flour. This suggests that a shorter fermentation time to a slighter higher pH and lower TA could improve the acceptability of fermented sorghum-wheat composite bread. Based on data on inoculated sorghum flour fermentations from Taylor and Taylor (2002) a fermentation time of two days would probably be adequate.

CONCLUSIONS

Natural lactic acid fermentation of sorghum flour increases the bread volume, decreases the crumb firmness, and improves the protein digestibility of sorghum and wheat composite bread, apparently by lowering the pH of sorghum flour. Natural lactic acid fermentation, particularly if the fermented flour is applied in a simple sourdough breadmaking process, appears to have considerable potential for increasing the utilization of sorghum flour in bread.

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