1. GENERAL INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench), is an indigenous African cereal which is well adapted to low-rainfall and drought-prone climates prevailing over much of the semi-arid regions of Africa and Asia (Hulse, Laing and Pearson 1980). In these regions, sorghum is particularly important in that it will yield a crop under conditions of endemic drought and less fertile soil, where maize fails (Dendy 1993; Osmanzai 1993). It is estimated that about 90% of the world sorghum area and 70% of its production, lies in developing countries, mainly in Africa and Asia (Anonymous 1996). Much of the crop is grown by small-scale farming households operating at the margins of subsistence. In more developed countries such as Australia, Mexico and the United States, sorghum production is intensive, with wide use of fertilizers and improved seeds, but there it is used mainly as feed grain (Anonymous 1996).

In terms of both production and area planted, sorghum is ranked the world's fifth most important cereal, after wheat, rice, maize and barley (Anonymous 1996). World production in 1996/97 was approximately 64 millions tons (FAO 1997), which was about 3% of the world cereal production. Asia and Africa each accounted for 25-30% of total production. Worldwide, the consumption of sorghum as human food is estimated in approximately 27 millions tons per year, almost the entire amount being in Africa and Asia (Anonymous 1996).

Statistical documentation on sorghum production, trade and utilization generally understates its importance to developing countries, especially in the drier and more marginal areas of semi-arid tropics of Africa and Asia. In these areas, sorghum is the main staple food, constituting the major source of energy and protein for millions of people (Osmanzai 1993). According to Dendy (1995) sorghum represents about 70% of the total cereal produced in West Africa, 30% in East Africa and 10% of Southern Africa. In these regions, whole grain sorghum or processed into flour is consumed in a variety of forms, including flat unleavened breads, thin and thick porridges, boiled rice-like products and fermented alcoholic and non-alcoholic beverages (Rooney, Kirleis and Murty 1986).

Worldwide there are good prospects for the expansion of sorghum production. Global warming and growth of world population will require that more marginal and less fertile lands be used for food production (Taylor and Dewar 2001). It is predicted that globally sorghum production will grow at 1.2 percent per year, from 64 million tons to reach 74 million tons by the year 2005, with an 15% increase in its food use globally, and a 39% increase in its food use in Africa (Anonymous 1996).

In Southern Africa, the production of sorghum is increasing (FAO 1997). Although, there is a lack of a consistent supply of good quality grain for commercial processing (Taylor and Dewar 2001), sorghum varieties with good nutritional and food processing properties are available, from among advanced material of the SADC/ICRISAT, Sorghum, Millet Improvement Program (Obilana 1997). Roller milling technologies for production of sorghum flour with quality comparable to that of other cereals have been developed (Gomez 1993). However, the image of sorghum as “poor people’s food” has led to avoidance by upper and middle class consumers. In addition, due to government subsidies, wheat is often cheaper than locally grown sorghum, which means that sorghum products cannot compete economically with wheat products (Rooney, Waniska and Subramanian 1997). Also, traditional sorghum foods do not generally suit urban consumers. Urban consumers want food products that deliver convenience, taste, texture, color, and shelf-stability at an economical cost (Rooney et al 1997). Consequently, sorghum is consumed as a staple food in the rural areas, whereas in urban areas the consumption of wheat products increases (Dendy 1993).

In fact, it is estimated that in 1996/97 developing countries imported 134 million tons of wheat (FAO 1997). The international wheat price by 1997 was US$180 per ton. Therefore, it can be seen that about US$24 billion of wheat is imported annually by developing countries to make wheat food products. This is a large drain on these countries foreign exchange, which causes problems to their economy and food production.

The image of sorghum as "poor people's food" can be overcome. High-value sorghum products that are attractive and more socially acceptable must be developed. According to Rooney et al (1997) the best strategy for developing a high-value, convenient and shelf-stable sorghum product is to use identity-preserved grains to produce upscale and niche market (supermarkets) products that can be priced slightly lower than imported products. The targets should be middle class and wealthy urban consumers who will pay for convenience, acceptable taste and texture, to generate sufficient profits to allow the development of the industry. It is also important to develop sorghum products using low-input technologies.

It is also a fact that the development of technologies to produce added-value sorghum food products is far behind that of other major cereals (Taylor and Dewar 2001). Even now, the quantity of sorghum used by commercial food industries is small. The major commercial use of sorghum in Southern Africa is in the industrial brewing of traditional opaque beer. However, very little is used to make yeast-leavened bread. Bread is a generally accepted, ready-to-eat, shelf-stable, convenience food, which can potentially be produced from sorghum flour.

For bread production, the problem is that sorghum does not have the visco-elastic dough making property of wheat. To produce yeast-leavened bread, for both technological and consumer acceptance reasons, sorghum flour can only be partly substituted for wheat flour (De Ruiter 1978). Composite flours are potentially important to those developing countries, which due to climate and soil conditions cannot grow wheat with good bread-making properties. Those countries are, however, better able to produce sorghum and other local crops, which can be milled and added to wheat flour to extend the use of the imported wheat supply (Hulse et al 1980).

Through the "Composite Flour Programme" of the Food and Agriculture Organization of the United Nations (FAO), according to De Ruiter (1978), remarkable achievements have been made in the formulation and development of feasible bread-making technologies for sorghum and wheat composite breads (reviewed by Dendy 1992; Taylor and Dewar 2001). However, sorghum flour tends to give a drier and gritty (sandy) texture to sorghum and wheat composite breads (Munck 1995). These characteristics seem to undermine the use of sorghum in bread-making. It is generally accepted that it is the corneous endosperm of sorghum, which adversely affects the bread texture (Munck 1995). Therefore, modifications to the bread-making properties of sorghum flour must be made.

Malting and fermentation are simple technologies widely used in Southern Africa to produce a large variety of traditional foods and beverages from sorghum (Chavan and Kadam 1989a,b). Although the main purposes of malting and fermentation are the synthesis and activation of hydrolytic enzymes and the acidification of food to improve its taste, respectively, both processes result in significant hydrolytic modifications on the grain components. These modifications seem to affect functional properties of sorghum flour as well as to improve its nutritional quality. Therefore, it is possible that malting and fermentation of sorghum can enable sorghum and wheat composite breads with improved characteristics to be produced. If successful, such breads are likely to improve the acceptability of sorghum in the urban areas in developing countries and contribute to a decrease in wheat importation for bread-making.

2. OBJECTIVES

The objectives of this study were:

- To determine how malting modifies grain sorghum constituents with respect to bread-making quality.
- To determine how fermentation modifies grain sorghum constituents with respect to bread-making quality.
- To examine malted and fermented sorghum as ingredients in composite wheat bread.
- To determine the causes of changes in bread-making quality of sorghum brought about by malting and fermentation.

3. GENERAL LITERATURE REVIEW

3.1. Sorghum structure and composition

Before examining what researchers have done to improve the bread-making quality of sorghum, it is valuable to compare the structure and composition of sorghum and wheat grains, with respect to bread-making quality.

3.1.1. Structure of sorghum and wheat grains

The sorghum grain (Figure 1) is generally spherical, ranging 2-5 mm in width and 8-50 mg in weight (Kent and Evers 1994), and comprises 8% pericarp (presumably pericarp plus the seed coat), 10% germ and 82% endosperm (Hoseney 1994). The wheat grain (Figure 2) is oval shaped and pointed on the opposite side of the germ, averages about 8 mm in length, weighs about 35 mg and comprises about 5% pericarp, 2.5-3.5% germ and the remainder endosperm (Hoseney 1994). Unlike sorghum, its most striking morphological characteristic is a longitudinal crease on the ventral side (opposite side of the germ) (Kent and Evers 1994). The crease, which extends nearly to the center of the grain makes separation of the bran from the endosperm difficult. Therefore wheat can only be milled with good yield through roller milling (Hoseney 1994). Grains that do not have a crease, like sorghum, can alternatively be milled through decortication or attrition milling, followed by reduction of the endosperm particles with a hammer, pin or a roller mill (Hoseney 1994).

The pericarp of sorghum is relatively thick (Rooney and Miller 1982), and is more friable than that of wheat grain. This unique feature of the sorghum grain can be related to the fact that sorghum, unlike other cereals, contains some starch granules in its mesocarp (Earp and Rooney 1982). The friable nature of the pericarp of sorghum adds problems to the milling of sorghum (Taylor and Dewar 2001). These problems are often compounded as thicker sorghum pericarps tend to pulverize during roller milling, thus contaminating the flour (Perten 1977).

The starchy endosperm of sorghum differs remarkably from the starchy endosperm of wheat in that a single sorghum grain comprises both a hard or corneous outer area and a soft or floury inner area. The relative proportion of corneous to floury endosperm areas varies among sorghum varieties (Rooney and Miller 1982).

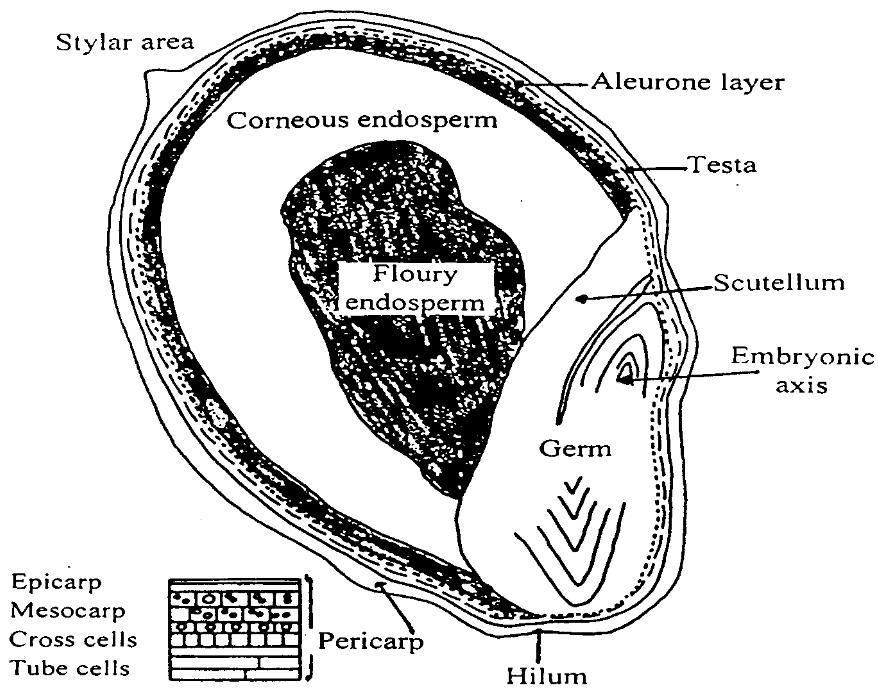

Figure 1. Longitudinal section of the sorghum grain. Source: Rooney and Miller (1982).

In wheat, the starchy endosperm is either hard (corneous) or soft (floury) (Hoseney 1994). There is a clear difference between hard and soft wheats, which may be the result of selection; hard wheats (bread wheats) have been selected for higher water absorption. The resulting particle size of the flour and its amount of damaged starch is related to endosperm hardness (Hoseney 1994; Kent and Evers 1994).

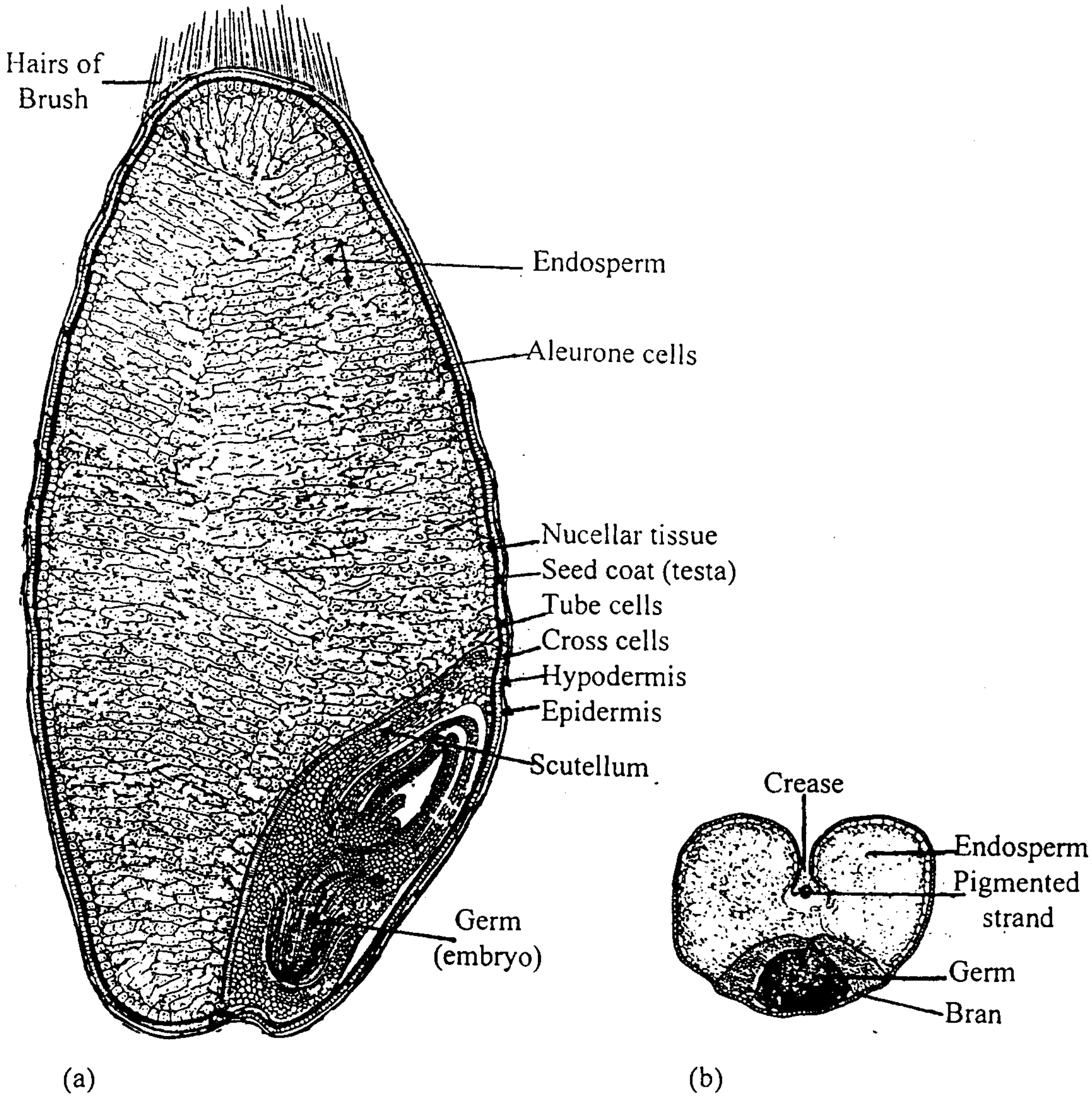

Figure 2. The wheat grain. (a) Longitudinal section. (b) Cross section showing the crease region. Modified from Hoseney (1994).

This is a reflection of the fact that the bonds between the endosperm components, mainly starch and protein, are hard to break in the corneous endosperm and weaker in the floury endosperm (Hoseney 1994). Related to endosperm hardness, Rooney and Miller (1982) have pointed out that the grittiness of sorghum flour is due to intact peripheral and corneous endosperm cells.

Another distinctive structural difference between sorghum and wheat grain is the germ. The germ of sorghum is relatively large (10% of the total grain), and is deeply embedded inside the endosperm (Rooney and Miller 1982). This feature makes it extremely difficult to remove. In contrast, the germ of wheat grain is relatively smaller (2.5-3.5 % of total grain) and it protrudes from the wheat kernel (Hoseney 1994).

3.1.2. Composition of sorghum and wheat grains

3.1.2.1. Starch

The gelatinization temperature range of sorghum starch, 68-78°C, is much higher than that of wheat (58-64°C), rye (57-70°C) and barley (51-60°C), but it is only slightly higher than that of maize (62-72°C) (Hoseney 1994). This similarity to the gelatinization temperature range of maize starch appears to be partly, related to the size of the starch granules. The starch granules of sorghum and maize which average about 20 µm in diameter have a 50% of gelatinization at about 67°C; whereas, wheat, like barley and rye, which have two types of starch granules: large (25-40 µm) and small (5-10 µm) granules, have a 50% loss of birefringence at about 53°C (Hoseney 1994). Other research studies have attributed the higher gelatinization temperature range of sorghum to the presence of insoluble protein and pentosans in sorghum starch isolates, which may compete with starch while becoming highly hydrated (Wankhede, Deshpand, Gunjal, Bhosale, Patil, Gahilod and Walde 1989). The gelatinization temperature of sorghum may require changes in process when using sorghum in bread-making (Taylor and Dewar 2001). It appears that the adverse factors, grittiness, dryness and high firming ratio of sorghum and wheat composite breads (as reviewed by Munck 1995) can be related in part to the high gelatinization temperature of sorghum, in addition to a lower water holding capacity of sorghum flour. It has been demonstrated that starch gelatinization is the main factor in structuring the bread crumb (Rotsch 1954), and that cereals starches that gelatinized at temperatures higher than that of wheat starch have poorer bread-making characteristics, compared to rye and barley starches which gelatinized around the same temperature as wheat (Hoseney, Finney, Pomeranz and Shogren 1971). This leads to the hypothesis that the sorghum flour to be used in bread-making may have to be processed in the way that its starch gelatinization temperature decreases.

Sorghum starch is less soluble than wheat or other cereal starches (Jackson, Waniska and Rooney 1989). It appears that the solubility of sorghum starch can only be achieved by physically damaging the granules (Glennie 1987). The low solubility of sorghum starch can be related to the fact that starches from the peripheral and, to some extent, from the corneous endosperm of sorghum are embedded in a dense mixture of protein bodies and matrix. This mixture is difficult to remove so as to gain access to the starch granules during processing (Rooney and Miller 1982).

3.1.2.2. Proteins

The protein content of sorghum ranges from 7 to 14 % (Taylor, Schüssler and Van der Walt 1984); somewhat lower than that of wheat which ranges between 8 and 18% (Kent and

Evers 1994). Also, the molecular weight of kafirins, the storage proteins of sorghum are lower, varying between 16 and 28 kDa (Shull, Watterson and Kirleis 1991). Various oligomers of kafirins varying in molecular weight between 100 and 150 kDa may be found in sorghum flour (El Nour, Peruffo and Curioni 1998). However, these oligomers are still small compared to the glutenins of wheat. In wheat, both gliadins and glutenins constitute the storage proteins (Hoseney 1994). Gliadins are single chained proteins with a molecular weight of about 40 kDa, whereas glutenins consist of a variety of cross-linked proteins, varying in molecular weight from about 100 kDa to several thousand kDa, with an average molecular weight of about 3000 kDa (Hoseney 1994).

Unlike sorghum, the storage proteins of wheat (gliadin and glutenin) are unique in that when hydrated they form strong, cohesive and visco-elastic dough (Hoseney 1994). Sorghum proteins, when hydrated, bind to starch through a three-dimensional network and do not promote cohesion of the meal particles (Wall and Paulis 1978). It is generally accepted that the high molecular weight glutenins are responsible for the elastic functional property of gluten (Shewry, Halford and Tatham 1992). Schofield (1986) postulated that the essential features of the glutenin subunits were terminal α-helices and central regions of many β-turns, which were capable of much extension when tension is applied to the polymer, and can regain their folded conformation when the tension is released. Thus the presence of repetitive β-turn structures on the high molecular weight glutenins result in gluten elasticity (Kent and Evers 1994). Gliadins, which consist in monomeric proteins which either lack cysteine (ω-gliadin) or have only intra-chain disulfide bonds (α- and γ-gliadins) (Shewry and Tatham 1997), are significant in providing cohesiveness of gluten, through their tendency to become involved in hydrogen bonding.

A further protein quality problem of sorghum is that compared to other cereals, the prolamins of sorghum, kafirins, become significantly less digestible when sorghum is cooked during food processing (Axtell, Kirleis, Hassen, D'Croz Mason, Mertz and Munck 1981; Hamaker, Mertz, Kirleis and Axtell 1986). The problem of the digestibility of sorghum protein has been associated with the amount of cross-linked kafirin (Hamaker, Kirleis, Butler, Axtell and Mertz 1987). According to Hoseney (1994), about 31%, compared to 17% cross-linked zein in maize.

3.1.2.3. Non-starch polysaccharides

Non-starch polysaccharides of cereal grains consist of the cell walls components, cellulose arabinoxylans (also often referred as pentosans) and β-glucans (Fincher and Stone 1986; Kent and Evers 1994). Cellulose is composed of D-glucose units linked β-(1-4). According to Hoseney (1994) it is water-insoluble and not degradable by the enzymes of human digestive tract. It constitutes about 30% of the pericarp but is almost absent (less than 0.3%) in the endosperm cell walls.

Arabinoxylans consist of β-(1-4)-D-xylan linked backbone to which single α-L-arabinofuranose residues are attached randomly to the xylan (Kent and Evers 1994). Arabinoxylan contribute about 70% of total non-starch polysaccharides of cereal grains and 30% of the total non-starch polysaccharides of the starchy endosperm (Fincher and Stone 1986; Shogren, Hashimoto and Pomeranz 1987). They are partly extractable in water. The water-extractable "water-soluble" arabinoxylan have a high water absorbing capacity (Kent and Evers 1994). They are linear molecules while those of the water-unextractable "water-insoluble" fraction are highly branched. Beta-glucans, specifically D-glucans, are predominantly water-extractable. The total content of β-glucans in rye grain is 1-2% (Saastamoinen, Plaami and Kumpulainen 1988) and that of barley grain varied from 4.3 to 11.3% (Bhatty 1992). The presence of β-glucans in the sorghum endosperm has been identified (Woolard, Rathbone and Novellie 1976; Earp, Doherty, Fulcher and Rooney 1983).

Sorghum grain contains about 7.9% non-starch polysaccharides of which about 4.1% are pentosans (Serna-Saldivar and Rooney 1995). Less than 20% were water-extractable (Verbruggen, Beldman, Voragen and Hollemans 1993), with the remaining water-unextractable pentosans, being hardly degraded by non-starch polysaccharide hydrolases such as arabinofuranosidase, endoxylanase and α-glucuronosidase (Verbruggen, Beldman and Voragen 1995). Several researchers (Bach Knudsen and Munck 1985; Verbruggen et al 1993) have reported that sorghum pentosans consist of glucuronoarabinoxylans, which are highly substituted arabinoxylan (arabinose/xylose=0.9) containing considerable amounts of 4-O-methylated D-glucoronic and D-galacturonic acid. The soluble fraction is predominantly (1-3), (1-4)-β-D-glucans (Verbruggen et al 1993).

The non-starch polysaccharide content of wheat grain is approximately 5%, of which about 1.5% occur as water-extractable pentosans (Shogren et al 1987). Wheat pentosans comprise predominantly arabinoxylan with small quantities (about 0.1%) of esterified ferulic acid, and (1-3),(1-4)-β-D-glucans (Eliasson and Larsson 1993; Rybka, Sitarski and Raczynska-Bojanowska 1993). Wheat flour contains approximately 2% pentosan (Shogren et al 1987). In contrast, the endosperm cell walls of rye grain consist of arabinoxylan and the β-glucans, gluco- and galactomannans (Meuser and Suckow 1986). They account for about 7-11% of grain weight, of which 2% are β-glucans (Saastamoinen et al 1988). About 30-50% of the total rye pentosans are water-extractable (Meuser and Suckow 1986). Rye flour (4-7% pentosan) contains roughly three times more water-soluble pentosans, than does wheat (Vinkx, Van Nieuwenhove and Delcour 1991).

Rye and wheat pentosans, both water-soluble and water-insoluble types, improved bread volume and cell uniformity (Hoseney 1984a) and the resistance of bread to staling by reducing the rate of starch retrogradation (Kim and D'Appolonia 1977a). Pentosans are reported to improve the water-holding capacity of dough (Bushuk 1966), gas retention and the gluten extensibility (Hoseney, Finney, Shogren and Pomeranz 1969), essentially by three mechanisms: 1) Increased water-binding capacity which leads to an increased dough viscosity, and hence increased bulk rheological properties of the starch-protein matrix of dough (Jelaca and Hlynka 1971, 1972; Sarker, Wilde and Clark 1998); 2) Oxidative gelation between aromatic residues of proteins and the ferulic acid esterified to the arabinoxylan, under the catalytic action of peroxidase (Hoseney and Faubion 1981; Izydorczyk, Biliaderis and Bushuk 1990; Vinkx et al 1991); and 3) Formation of polysaccharide-protein complexes, through arabinoxylan-mediated cross-linking between adsorbed proteins (Dickinson 1993) which, due to a combination of bulk viscosity and surface effects, stabilize and prevent coalescence of air cells in bread dough (Sarker et al 1998).

The differences in composition and structure between sorghum and wheat and rye pentosans may have important consequences when sorghum is used in bread-making. For example, Hahn and Rasper (1973) found that water-soluble non-starch polysaccharides of sorghum (1%) were the only ones, compared to that of wheat and millet, to decrease, although slightly, the rheological properties of dough and the bread volume, whereas; the water-insoluble non-starch polysaccharides of all grains decreased almost equally the bread volume. Although no reason was given for that effect, a probable explanation can be that the water-soluble pentosans of sorghum, which instead of ferulic acid are richer in uronic acid (Verbruggen et al 1993), do not have the same dough improving effect as the water-soluble pentosans of wheat and millet. It appears that a certain modification, leading to an increase of the water-soluble pentosans of sorghum may be relevant in improving the dough and the bread-making quality of sorghum flour.

The endosperm cell walls of sorghum, unlike barley, are not substantially degraded during germination (Aisien 1982; Glennie, Harris and Liebenberg 1983; Glennie 1984). However, although the endosperm cell walls of sorghum persist during malting, there have been reports on changes in the composition. EtokAkpan (1993) found that although the total pentosans decreased, the content of water-soluble pentosans increased. Glennie (1984) and Ogbonna and Egunwu (1994) reported a slight decrease on the water-soluble pentosan; whereas, Verbruggen et al (1993) reported a certain reduction in the degree of substitution of arabinoxylans together with breaking up of cross-links within polysaccharides and proteins.

3.2. Milling of sorghum for bread-making

Because of the structural similarities between sorghum and maize, except for sorghum's smaller size and spherical shape, most processing technologies applied to maize have been applied to sorghum (Hoseney 1994). The problems associated with processing of maize, such as the existence of a proportionally large germ (10-14% of the grain), the relative friability of the pericarp, compared to wheat, and the occurrence of both, hard and soft endosperm areas within the same kernel, are also common to sorghum. The proportionally large germ, about 3.4% in sorghum compared to 2.1% of wheat, results in high fat content flour when sorghum is milled without degerming (Hoseney 1994). High fat content in the flour leads to problems with rancidity.

As pointed out by Hahn (1969) when sorghum is milled the same way as wheat, by straight roller milling, the pericarp which is more friable than that of wheat, breaks into small pieces which contaminated the endosperm flour. Maxson, Fryar, Rooney and Krisnaprasad (1971) reported that sorghum varieties with corneous endosperm and thin pericarp are preferred for mechanical milling as they give higher flour yield with a good separation of bran, germ and endosperm parts.

Dendy (1992) pointed out that the desired sorghum flour for making composite breads is clean, fine, free from specks of colored bran, compatible in color with wheat flour and as low in fiber content as possible. Thus, to produce such flour it is required that the bran (pericarp, seed coat and aleurone layer) and the germ be removed, preferentially with minimal loss of the endosperm.

According to Rooney and Serna-Saldivar (1990) a highly refined sorghum flour is produced by tempering and decorticating the grains using mills with abrasive disks or carborundum stones, and tempering again and degerming using impact grinders or pin mills. After the grain fractions are separated by sieving and gravity separation, the endosperm pieces are tempered again and roller milled with wheat milling equipment. High extraction flours (90% yield) and low extraction flours (70%) are produced.

According to Schmidt (1992) the most widely used decortication machines for removal of bran of sorghum is the PRL (Prairie Research Laboratory)-dehuller.

According to Taylor and Dewar (2001) recent developments in sorghum milling have been made in South Africa using small roller mills with 2 or 3 pairs of rollers, plus a vibrating screen sieving device. The top pair are coarse fluted "break", the second pair finer break rolls and the third pair (if present) are smooth "reduction" rolls. These roller mills have a capacity of 500 kg/hour. Best results are obtained when the grain is pre-conditioned to 16% moisture. This milling process has consistently given finer and more refined flour of higher extraction rate, and lower fat, ash and tannins contents than the products of decortication followed by hammer milling (Hammond 1996). A major development in this roller milling process is the incorporation of reduction rolls, thus providing simple means of producing fine flour from sorghum which is suitable for use in bread-making (Taylor and Dewar 2001). However, the resulting particle size and starch damage may not be significant to prevent grittiness of the flour.

Particle size analysis of the roller milled sorghum flour showed that the yield of particles < 600 µm ranged between 75-79% (Hammond 1996); whereas, the standard granularity required for wheat (bread) flour is that 98% of the flour pass through a 212 µm sieve (Kent and Evers 1994). There are no reports on damaged starch content of roller milled sorghum flour. In wheat, the amount of mechanically damaged starch produced during milling is greater for hard than soft wheats. Damaged starch influences a flour's ability to absorb water as well as the gassing power of the flour, since only damaged granules are susceptible to amylases at temperatures below gelatinization (Kent and Evers 1994).

According to Hoseney (1994) the value of damaged starch in wheat flour may be 2-3%:

3.3. Use of sorghum in traditional bread-making

Sorghum flour is used to produce traditional fermented types of flat bread such as Injera (from Ethiopia), a thin flat bread (about 6 mm thick), spongy, with a honeycomb-like structure (Gebrekidan and Gegrehiwot 1982); Kisra (from Sudan), a thin pancake-like, with no holes and supple in texture (Ejeta 1982); and Dosai (from Southern India) which is a slightly crisp yet flexible thin pancake made from a mixture of sorghum and black gram (Rooney et al 1986).

According to Gebrekidan and Gebrehiwot (1982) for Injera production, whole sorghum flour is mixed with about 40% water and an inoculum, usually a starter from a previous batch, which contains a combination of yeast and lactobacilli. The mixture is kneaded into a dough, which is fermented overnight (12-17 h) or longer (up to 72 h), depending on the sourness desired. Then about 10% of the fermented dough is mixed with water and cooked (boiled to gelatinize starch). After cooling, this is added to the remaining dough and water. The resulting batter is allowed to undergo vigorous fermentation for 2 h, then is poured in a thin layer onto a hot griddle, covered and steam baked for 2-3 min.

The production of Kisra and Dosai, involves mixing whole sorghum flour (mixed with black gram for Dosai) with a starter, usually saved from the previous batter, and water in a 9:2:1 ratio respectively, to form a paste. This paste is left to stand fermenting for approximately 12-24 h, by which time it develops a sour taste. Before baking, this batter may be diluted to a thin batter by the addition of more water, and then spread in a thin layer over a hot griddle and baked for 30 sec (Ejeta 1982; Rooney et al 1986).

Sorghum dough, unlike wheat dough, is neither cohesive nor elastic; consequently it cannot produce high specific volume types of bread. In processes such as that developed for Injera some cohesiveness is achieved by cooking part of the flour or by mixing the flour with boiling water (Desikachar and Chandrashekar 1982). This is to gelatinize some of the starch. In addition, flour of very fine particle size is used, which improves the water absorption of the flour.

Traditional sorghum fermented flat breads with good quality have been produced. However, a problem lately is that urban consumers have a relatively easy access to inexpensive wheat breads, which are also better preferred presumably due to their spongy crumb structure.

3.4. Improving the bread-making quality of sorghum flour

The approaches taken in research to improve the bread-making quality of sorghum can be divided into three different categories: 1) compositing with wheat, 2) addition of chemical additives and 3) creation of a viscous, cohesive dough.

3.4.1. Compositing sorghum with wheat flour

This approach concerns the use of sorghum flour plus wheat flour to make bread. The aims of this approach have been to establish the maximum percentage of sorghum flour that can be blended with wheat flour, and finding, in the process, the manufacturing technology to achieve these goals (De Ruiter 1978). This must, however, be achieved without causing major changes in the bread quality.

Concerned with the fact that when sorghum flour is added to wheat flour, regardless of the amount of sorghum flour used, the resulting mixture "composite" will behave like a bread flour with less favorable bread-making characteristics (De Ruiter 1978), the most important technological development in this approach has been the use of the mechanical dough development process, the "so-called Chorleywood process (CBP)", to make bread from composite flours. The mechanical dough development process (MDDP) was specially developed to enable the use of weak wheat flour to produce pan bread. It applies intense mechanical energy to develop the flour into dough within 3-4 minutes, thus eliminating the bulk fermentation (Kent and Evers 1994). However, it requires specialized high speed mixers, the use of oxidizing agents such as ascorbic acid, potassium bromate or azodicarbonamide, and fat of high melting point to strengthen the gluten after mixing.

Pringle, Williams and Hulse (1969) produced stronger dough and higher loaf volume from composites containing 40% sorghum flour, using the CBP, rather than the traditional bulk fermentation process. They used a wheat flour with a protein content of 16% and an oxidizing system of 175 ppm potassium bromate and a level of energy input of 40 kJ per kg of dough (as recommended in the CBP), plus 0.1% of glycerol monostearate (GMS) to prevent bread staling. Similar results with sorghum, millet and maize composite flours were achieved through mechanical dough development using sheeting rollers of progressively narrower gap size (Bushuk and Hulse 1974). Loaf-size pieces of dough, after a short bulk fermentation of 30 min, were passed through a setting of rolls (4.9, 4.8 and 4.0 mm), given a short proof of 10 min and then sheeted again between rolls 9, 5 and 3 mm prior to molding, panning, proofing and baking.

3.4.2. Addition of chemical additives

This approach concerns the addition of chemical additives, so-called dough improvers, to enable the percentage of sorghum flour in the composite to be increased, without necessitating considerable adjustments in the manufacturing procedures. Such substances may include oxidizing agents, surfactants and hydrolytic enzymes.

3.4.2.1. Oxidizing agents

Oxidizing agents have been found to be of great importance for making good quality bread with composite flours. Potassium bromate and ascorbic acid (each at 50 mg/kg flour) enabled a good quality bread to be produced, using a relatively low quality flour blended with 25% maize flour (Ballschmieter and Vlietstra 1963). A conventional mixer was used and 1% fat was added. The bread produced was comparable to bread made with 100% wheat flour without oxidants nor fat added. Bushuk and Hulse (1974) made similar findings using a variety of different composite flours, including sorghum and millet.

The role of oxidizing agents is an oxidation of the cysteine sulfhidryl or thiol (-SH) groups present in wheat gluten (Kent and Evers 1994). As a result the thiol groups are no longer available to participate in interchange reactions with disulfide (-S-S-) bonds in the gluten protein. This reaction releases the stress in dough, and consequently the dough tightens (extensibility of dough is reduced) (Kent and Evers 1994). Alternatively, it is suggested that oxidation of sulfhidryl groups lead to formation of new disulfide bonds, which increase the dough rigidity (Hoseney 1994). Oxidizing agents used in the baking industry include ascorbic acid and azodicarbonamide, and formerly potassium bromate.

3.4.2.2. Surfactants

Surfactants (including emulsifiers) improve the bread-making quality of sorghum and wheat composite breads. Pringle et al (1969) found that the replacement of shortening with 1% (flour basis) of a 20% GMS emulsion improved the quality of composite breads. Bushuk and Hulse (1974) reported that the addition of 0.5% sodium stearoyl-2-lactylate (SSL) to composite flours containing 30-40% of sorghum or maize flour, increased loaf volumes. According to Breyer and Walker (1983) emulsifiers of high hydrophilicity were generally more effective in improving the loaf volume and crumb softness of sorghum and other wheat containing composite breads than mono-, di-glycerides or SSL. In contrast, concerning the bread-making quality of sorghum flour and cassava starch composites, Hugo, Waniska and Rooney (1997) investigated a number of different dough improvers such as SLL, calcium stearoyl-2-lactylate (CSL), GMS and succinylated monoglycerides (SMG) and found that the addition of 1% shortening and 1% SMG gave the largest increase on the loaf volume, crumb softness and resistance to staling.

The surfactants or emulsifiers used in the baking industry include CSL, SSL and mono- and di-acetyl tartaric esters of mono- and di-glycerides of fatty acids, which are collectively referred as DATEM. They are amphiphilic in nature, having both a hydrophilic and lipophilic (hydrophobic) component and have the effect of reducing surface tension at interfaces. The specific dough improving effect of emulsifiers appears to be due to them reducing repulsion charges between gluten molecules, causing these to aggregate (Stauffer 1996). Improved aggregation between gluten molecules appears to be of particular importance in composite flours as the wheat gluten has been diluted (Taylor and Dewar 2001). In wheat flour dough, surfactants act as dough strengtheners, helping the dough withstand mechanical abuse during processing, and as anti-staling agents, i.e. reducing the degree of starch retrogradation. Surfactants are used at levels of about 0.5% on flour weight (Hoseney 1994).

Addition of fat in a specific prepared form also appears to be useful. Rajapaksa, Eliasson and Larsson (1983) have reported on bread with about the same volume as the corresponding wheat bread, being produced from a 1:1 wheat/rice, and a 1:1 sorghum/wheat flour mixture with 2% (w/w) of lipids added in the form of a liposomal dispersion (lipid vesicles prepared by ultrasonication).

3.4.2.3. Hydrolytic enzymes

Enzymes such as amylases, proteinases and pentosanases (also referred as arabinoxylanases or hemicellulases) are increasingly being used to modify the components of wheat flour, in order to improve their functional baking qualities (Si 1997). Although no reports were found on the use of enzymes to improve the bread-making quality of sorghum and wheat composite breads, it appears that enzymatic modification of sorghum flour could improve its baking quality.

Malt (barley or wheat malt) and microbial α-amylase have been used in bread-making to provide fermentable sugars, mainly maltose, for yeast; therefore to improve loaf volume. These enzymes have also been found to reduce the staling of breads. Martin and Hoseney (1991) demonstrated that the anti-staling effect of added α-amylase was due to low molecular weight dextrins (DP 3-9) interfering with the cross-linking (hydrogen-bonding) between starch and proteins. However, these authors also pointed out that any improvement giving a larger bread volume and more uniform crumb structure also contributed to softer bread. Si (1997) has reported on the availability of a bacterial maltogenic α-amylase for anti-staling which affected neither volume nor crumb structure. Its anti-staling mechanism was by retarding starch retrogradation. According to Hebeda, Bowles and Teague (1990) bacterial maltogenic enzymes can degrade both amylose and amylopectin at the gelatinization temperature producing mainly α-maltoses.

Proteinases and peptidases are present in malt and, although in smaller amounts, in the flour. Their effect in baking is usually masked by the greater effect of amylases (Kent and Evers 1994). Both proteinases and peptidases have been added to high-protein flour that is "too strong", to increase its extensibility and give higher bread volume (Hoseney 1994). However, peptidases may be important in producing organic nitrogen that is utilized by yeast during fermentation.

Pentosanases cleave glycans in the backbone chain of the pentose sugar polymer. Typical pentosanases are β-D-galactanases, β-D-mannases, and β-D-xylanases (Dekker 1979). Among them, xylanases of fungal origin are the most used in bread-making. Two types are the most recognized: debranching endoxylanases that free L-arabinose from arabinoxylans and arabinoglucuronoxylans and non-debranching xylanases (L-arabinose not released during hydrolysis). Both types are able to attack glucuronoxylans and unsubstituted (1-4)-β-D-xylans.

The true mechanism of xylanases in bread-making has not been clearly elucidated. According to Si (1997) two distinct mechanisms have been reported: 1) that the use of pentosanases increased gluten coagulation, and 2) that xylanase increased the gluten strength. However, in both mechanisms the rheological properties of the gluten, i.e., dough machinability (dough stability) and oven spring improved resulting in larger bread volume.

A pure xylanase with single activity, therefore far more active against xylan than the traditional pentosanase preparations, has become available (Si 1997). This enzyme has the advantages that lower dosage is needed and has less risk of possible interference from side activities. However, pentosanases and xylanases at too high levels can cause extensive degradation of wheat pentosans, thereby destroying the water-binding capacity of the wheat pentosans. The result is dough stickiness.

3.4.3. Creating a viscous, cohesive dough

This approach concerns the production of bread from sorghum without the use of wheat flour, so called "wheatless" bread. There were two possibilities: one of adding water binding substances such as gums as the gluten substitutes, and a second one involving modification to the bread-making procedure, such as the "custard process", to allow sorghum dough to become viscous and expand during fermentation (Taylor and Dewar 2001).

Rotsch (1954) made a very important contribution to these approaches, demonstrating that any gel-forming substance can perform the function of both the starch (structuring the bread crumb) and gluten (imparting gas retention property) in gluten-free flours. Jongh (1961) demonstrated that through the addition of GMS it was possible to produce a yeast-leavened bread-like product with just starch. Jongh postulated that the emulsifier attracts the starch granules to each other, causing them to aggregate. Such aggregation gave the dough sufficient cohesiveness for retention of the fermentation gas. Following this work, researchers have investigated various additives as possible aids in making breads from non-wheat flours. Hart, Graham, Gee and Morgan (1970) examined a wide range of gums, pectins and surfactants in the making of non-wheat breads, studying sorghum bread. They found that of the thickening substances examined, 4000 centipoise methyl cellulose at an addition rate of 4%, was most effective. It increased gas retention, prevented the loaf from collapsing and gave a larger loaf volume. GMS plus methyl cellulose gave a finer, but weaker crumb structure. These authors also demonstrated that the problems of lack of consistency and elasticity, and failure to raise, encountered when using sorghum dough without additives, could be minimized by increasing the amount of water to 50-60% (based on flour weight). However, although the resulting batter could rise upon fermentation, the loaves collapsed during baking.

Casier, De Paepa, Willens, Goffings and Wappen (1977) reported that rye pentosans, at an addition rate of 3-4%, improved the volume and resistance to staling of breads made from sorghum and millet flours. They postulated that rye pentosans increased the viscosity of dough, hence improving the flexibility of the gas cell walls and enabling a much greater expansion.

The use of GMS, methyl cellulose or rye pentosans as replacement for gluten, appears to be a very successful approach for making bread from sorghum flour. However, the obvious drawback for most developing countries, is that these substances would have to be imported.

Taking another approach, Satin (1988) demonstrated that mixing sorghum flour with gelatinized cassava starch, increased dough cohesiveness and strengthened the gas cell walls. Cassava starch seems uniquely effective for this purpose as on gelatinization it produces a gel with much greater cohesion than the starches of cereals and other tubers (De Ruiter 1978). The probable reason that cassava starch is particularly effective is that it contains a higher ratio of amylose to amylopectin (1:5) than most cereal starches (Wheatly and Chuzel 1993). Concerning the functionality of sorghum starch in relation to bread-making, Hugo et al (1997) found that the loaf volume of sorghum flour-cassava starch bread, was related to the amylose content of sorghum flour.

3.4.4. Problems with these approaches

The major problem with compositing sorghum with wheat flour to make bread seems to be the limited proportion of sorghum flour that can be used in the composite. Dendy (1992) has pointed out that bread of acceptable quality could be made with up to 30% of sorghum flour incorporated to a reasonably strong wheat flour (over 12% protein). This is provided that the sorghum flour is fine, bran-free and compatible in color with wheat flour. As reviewed by Taylor and Dewar (2001), this high level of substitution, may be unrealistic. Such a high level of incorporation of sorghum flour can only be achieved when strong wheat flour of high protein content plus dough improvers are used in well-controlled laboratory bakeries. The reality is that in many developing countries, the available wheat is frequently the soft type with low protein content. Also, dough improvers are not available and commercial baking is poorly controlled (Randall, Wessels and Traut 1995). An additional problem is that it appears that highly refined sorghum flour can only be obtained using roller milling (Taylor and Dewar 2001). The implementation of roller milling technology has been limited to wheat in most developing countries.

The obvious problem with the use of the CBP, for developing countries, is that specialized high-speed mixers have to be used and oxidizing systems would have to be imported. The same applies to the use of water binding substances such as GMS, methyl cellulose or rye pentosans to produce sorghum wheatless breads, as these substances would also have to be imported. In the sense that cassava starch would not constitute an expensive import in most sorghum producing countries the sorghum flour-cassava starch approach seems the more successful one. However, these breads staled faster than wheat bread and have a rigid consistency more similar to cake than bread (Hugo et al 1997). These breads would probably not withstand competition with wheaten bread.

Modification of sorghum grain components, particularly starch, protein and non-starch polysaccharides seems to be an appropriate approach to improve the functional properties of sorghum flour in relation to bread-making. Simple technologies such as malting and fermentation could possibly be used to modify the composition and properties of sorghum starch, protein and non-starch polysaccharides.

3.5. Modification of sorghum grain structure and composition by simple technologies

Malting and fermentation are two of the oldest and most simple and economical methods of producing and preserving foods. Sorghum is malted and fermented for preparation of many traditional foods and beverages (reviewed by Chavan and Kadam 1989a,b).

3.5.1. Malting

Malting is a specially controlled form of germination (and drying), of cereal grains which produces hydrolytic enzymes and modifies the original grain structure and components (Kent and Evers 1994). Malting is important in cereal processing. Malt enzymes, otherwise not present in the original grain, modify the grain components and when added to a cereal-based product, these enzymes are required to similarly hydrolyze the starch, protein and non-starch polysaccharides of the product. These modifications increase the susceptibility of the sorghum products to hydration, cooking and digestion.

3.5.1.1. Development of hydrolytic enzymes

The most important hydrolytic enzymes in cereal grains are amylases, proteases and β-glucanases, as the products resulting from their activity affect the functional and nutritional quality of cereal products. Germinated sorghum has been found to develop α- and β-amylase and carboxypeptidase in the scutellum; whereas endo-(1-3)-β-glucanase, pentosanase, limit dextrinase and endo-protease developed in the starchy endosperm (Aisien, Palmer and Stark 1983; EtokAkpan and Palmer 1990). Although β-amylase activity is generally low in malted sorghum, some sorghum cultivars develop β-amylase in significant levels (Palmer 1989; Aniche and Palmer 1990).

3.5.1.2. Modification of starch, proteins and non-starch polysaccharides

Starch

Amylolytic degradation of starch in germinating sorghum grain occurs more extensively in the floury endosperm than in the corneous endosperm (Glennie et al 1983). Bhise, Chavan and Kadam (1988) found that malting decreased the starch content of sorghum and increased the content of soluble sugars. This modification was attributed to dextrinization and solubilization of starch molecules by the grain amylases.

Protein

Malting of sorghum has been reported to decrease the content and the cross-linking of sorghum prolamins, while increasing the albumin fraction (Wu and Wall 1980). Taylor (1983) reported that during germination, sorghum prolamins were degraded directly into small peptides and free amino acids, thus increasing the content of soluble proteins. Malting has also been reported to increase the content of essential amino acids, particularly lysine and methionine (Wang and Fields 1978), and to increase the digestibility of sorghum proteins (Bhise et al 1988). Several researchers have also observed that during germination the protein matrix was first to be hydrolyzed and the protein bodies were degraded later (Glennie et al 1983; Palmer 1989).

Non-starch polysaccharides

Malting has been reported to cause very limited modification on the endosperm cell walls of sorghum (Glennie et al 1983; Palmer 1989). Although no significant change in the content of sorghum pentosans occurred during malting, a slight increase (about 2.0%) of the water-soluble pentosans was observed (EtokAkpan 1993). In apparent contradiction, Verbruggen et al (1993) observed no change in the arabinoxylan content or composition.

3.5.1.3. Use of malt in bread-making

Milled barley malt has been used as a diastatic supplement for bread flours with low natural diastatic activity (Kent and Evers 1994). Barley malt has been added to wheat flour, at a rate of 0.2-0.3%, to provide some fermentable sugars, so improving yeast activity, and consequently improving the bread volume. Malt enzymes, particularly amylases, can reduce crumb firmness by means of volume and crumb improvement (Si 1997). The use of malt as source of amylases appears to have a slight problem in that other enzymes such as proteases, β-glucanases and lipases can also be present. This gives a limited control of the enzymatic activity of malt in the dough.

Sorghum malt apparently has never been used in bread-making. Sorghum malt, unlike barley malt, generally contains low levels of β-amylase (Dufour, Mélotte and Srebrnik 1992; Taylor and Robbins 1993). Beta-amylase is an exoenzyme that sequentially cleaves maltose units from the non-reducing end of the starch molecule (Hoseney 1994). Since the production of maltose, a fermentable sugar, is a major objective of adding malt to bread dough, sorghum malt would appear to be less suited than barley malt for use as a diastatic supplement in bread-making. However, sorghum malt could be used as an ingredient in composite bread-making. Although, most reports on sorghum malting are related to its possible utilization in the brewing industry, the structural and compositional modifications occurring in the grain during malting may be advantageous for production of sorghum flour with improved nutritional and functional quality.

3.5.2. Fermentation

Fermentation often involves the controlled souring of a food product by naturally occurring lactic acid bacteria (Chavan and Kadam 1989b). Fermentation of sorghum has been found to improve starch and protein availability (Kazanas and Fields 1981), to increase essential amino acids content (Wu and Wall 1980; Kazanas and Fields 1981) and to prevent the growth of pathogenic bacteria by decreasing the pH of food (Hamad and Fields 1979).

Several factors have been found to contribute to the effect of fermentation on the nutritional quality of sorghum. Higher fermentation temperature (35-37°C) more rapidly decreased the pH of sorghum and produced the highest improvement of nutritional value of sorghum, whereas; available lysine and methionine increased more when sorghum was fermented at 25°C (Au and Fields 1981). The fermenting microflora are also important in that some lactic acid bacteria such as *Lactobacillus plantarum* do not possess amylolytic activity (Akinrele 1970; Adeyeye and Beckley 1986).

3.5.2.1. Development of hydrolytic enzymes

The amylolytic activity of fermented sorghum is quite insignificant. Amylolytic enzymes, specially α- and β-amylase, of both the grain and microorganisms, become inactivated at low pH (El Tinay, Abdel Gadir and El Hiadi 1979), the pH of optimal activity of these enzymes being 5.2-5.4 (Seibel and Brümmer 1991). This leaves bacterial proteolytic enzymes (Tongnual, Nanson and Fields 1981) and other non-starch hydrolases as the most active enzymes in fermented cereal products.

3.5.2.2. Modifications of starch, protein and non-starch polysaccharides

Starch

The major effects of fermentation on sorghum starch appear to be a decrease in starch content and paste viscosity and an increase in starch availability. Tongnual et al (1981) attributed the increase in starch availability to microbial proteolytic activity, which freed the starch. A decrease in starch content, of about 3% after a 5-days fermentation period with concomitant decrease of soluble sugars was attributed to microbial utilization of released sugar as a ready source of energy (El Tinay et al 1979; Chavan and Kadam

1989a). Banigo, DeMan and Duitschaever (1974) found that fermentation of maize meal to pH 3.4, increased gelatinization temperature and the time to reach it from 73° to 78°C and from 30 to 33 min, respectively, by simply increasing the concentration of undamaged starch in the fermented meal.

Protein

Fermentation increases the protein content of sorghum (1-2%), mainly due to loss of dry matter, particularly carbohydrates (Au and Fields 1981; Kazanas and Fields 1981; Chavan, Chavan and Kadam 1988). Fermentation also increases significantly the water-soluble proteins, free-amino acids and the content of limiting amino acids such as lysine and methionine (Chavan et al 1988). These changes have been attributed to the presence of proteolytic bacteria (Au and Fields 1981), and to the fact that bacteria synthesize amino acids from metabolic intermediates during growth cycle (Au and Fields 1981; Tongnual et al 1989). Fermentation is also beneficial to the protein of sorghum, as it reduces the particularly high level of disulfide bonds of the sorghum prolamin fraction (Abdel Moneim and El Tinay 1995).

Non-starch polysaccharides

Fermentation of sorghum has been found to decrease significantly the non-starch polysaccharide content (El Tinay et al 1979; Kazanas and Fields 1981). This decrease has been attributed to the partial solubilization of cellulose and hemicelluloses by microbial enzymes.

3.5.2.3. Use of fermentation in bread making

The sourdough process as used in most of Europe and certain parts of the United States, is primarily a sponge-and-dough system in which a natural lactic acid fermented dough (sour or starter dough) is used, to improve the bread-making quality of both rye and/or wheat flour (Seibel and Brümmer 1991). The sour or starter dough is prepared by allowing a rye or wheat dough to stand for several hours (usually 8-24 h), at 23°-26°C, to induce a natural lactic acid fermentation (Brümmer and Lorenz 1991), or alternatively the dough can be inoculated with a culture of multiform lactic acid bacteria and allowed to ferment for a shorter period (Brümmer 1991). The matured sourdough is then mixed with the remaining flour and other dough ingredients such as salt and sugar, to obtain the final dough which is used to make the bread (Drews and Seibel 1976). The desirability of a sour depends upon the flavor produced and the gassing obtained (Hoseney 1994). In general, the gas-producing ability of sours is low compared to that of commercial yeast, so the proof time of sourdough bread is often long, about 5 to 8 h.

Lactic acid fermentation is the most important metabolic reaction involved in sourdough process (Seibel and Brümmer 1991). It can be controlled by adjusting the temperature and the yield of dough. Warm and fast increasing doughs give raise to higher formation of lactic acid, while cool and firm doughs reduce the production of lactic acid and produce almost the same amount of acetic acid. However, under anaerobic conditions or by the addition of yeast, both warm and cool doughs can produce ethanol and carbon dioxide.

Although the sourdough process enhances the volume, the taste and flavor of bread and improves mold resistance in both rye and wheat sour breads (Brümmer and Lorenz 1991; Seibel and Brümmer 1991), it does not have the same function in rye as is wheat bread

(Brümmer and Lorenz 1991). In rye bread the acidification of the dough is absolutely essential to produce bread of good quality, whereas; in wheat, sourdough affects mainly the taste and aroma of bread. According to Seibel and Brümmer (1991) the sour (acidic) condition reduces the solubility and the swelling power of rye pentosans, as well as it partly inactivates amylases, consequently controls the water absorption of the dough, the baking process and crumb formation.

Other uses of sourdough include the production of organic wholemeal wheat or rye breads, as yeast cannot be used in the production of organic bread, and to offset slight sprout damage of wheat and rye (Seibel and Brümmer 1991).

3.6. Conclusions

From the several approaches taken in research to improve the bread-making quality of sorghum flour (compositing with wheat, addition of chemical additives and creation of a viscous, cohesive dough), it is clear that to produce a good quality yeast-leavened bread from sorghum, at an acceptable cost, sorghum flour has to be composited with wheat flour. However, the problem of the poor bread-making quality of sorghum remains in that sorghum flour tends to give a drier, more gritty and firmer texture to sorghum and wheat composite breads.

The gritty and firmer texture of sorghum and wheat composite breads can be related to the high gelatinization temperature of sorghum starch, and to a lower water holding capacity of sorghum flour. The high starch gelatinization temperature and its low solubility can be related to the fact that starches from the peripheral and corneous endosperm of sorghum are embedded in a dense mixture of protein bodies and matrix which difficult the access to the starch granules during processing.

This can mean that the right approach has not been taken. The possible role of grain components, specifically starch, protein and non-starch polysaccharides, not yet well studied in relation to the bread-making quality of sorghum flour, may be significant in improving the functional bread-making properties of sorghum. Therefore, the present study investigates the use of the simple technologies of malting and fermentation to improve the bread-making quality of sorghum.

During malting, structural and compositional modifications such as dextrinization and solubilization of starch molecules, increased content of water-soluble non-starch polysaccharides, and increased content of soluble and digestible proteins, are expected to occur in the grain. During natural fermentation, however to a lesser extent than malting, the grain components undergo similar hydrolytic modifications. A decrease of pH (acidification) accompanies these modifications. Low pH in fermented sorghum flour may inhibit the amylase activity of the flour, and influence the solubility and the swelling power of pentosans, therefore improving the viscosity of sorghum and wheat dough.

The probable role of increasing the water-soluble fractions of grain components could be an increased bulk viscosity of sorghum and wheat dough and consequently a greater stabilization of the gas cell. Dextrinization of starch molecules is particularly expected to decrease the grittiness and the staling rate of sorghum and wheat composite bread.

The fact that the non-starch polysaccharides of sorghum are predominantly the "water-insoluble" glucuronoarabinoxylan, and that of wheat and rye are arabinoxylans of both the "water-soluble" and "water-insoluble" type, suggestes that a certain modification, leading to an increase of the water-soluble pentosan in sorghum, may be relevant in improving the sorghum dough and bread quality. Rye pentosans, particularly the water-soluble pentosans, have been found to improve dough functionality, essentially by increasing the water-binding capacity and dough viscosity, due to oxidative gelation and the formation of polysaccharide-protein complexes.

Improving the protein digestibility of sorghum and wheat composite breads will also be addressed. It is expected that malting and fermentation by improving the protein digestibility of sorghum flour, improve also the nutritional quality of sorghum and wheat composite bread.

4. CHAPTER I

EFFECT OF MALTING TIME ON THE MODIFICATION OF SORGHUM GRAIN PROTEIN

ABSTRACT

To determine the optimal malting time to obtain high protein modification with minimal dry matter losses, 5 sorghum cultivars, NK283, PAN8564, KAT369, Shaka and Local White, were malted for up to 8 days. The total and water-soluble proteins, the *in vitro* protein digestibility (IVPD) and the free amino nitrogen (FAN) of sorghum malts, as well as the dry matter losses, both due to respiration activity and to roots and shoots removal, increased with malting time. The maximum protein modification, which included the increase of total and water-soluble proteins and IVPD, by 2.8, 3.8 and 17.2 percentage points, respectively, and the increase of FAN by 182 mg/100 g, was obtained with 8-days malt of Local White. However, the optimal malting time for bread-making appears to be 6-days, because these malts gave high levels of protein modification with dry matter losses lower than the obtained with 8-days. The IVPD of 6-days malts was positively correlated to diastatic power (r=0.77), FAN (r=0.62) and water-soluble proteins (r=0.43).

INTRODUCTION

Sorghum is a major food crop in the arid and semi-arid tropics (Dendy 1993). In these regions, almost the entire production of sorghum is consumed in the form of traditional products (Rooney, Kirleis and Murty 1986) and as brewing material for traditional opaque beer (Novellie 1977; Dewar and Taylor 1993). There has been a growing interest in the use of sorghum to produce new, convenient and shelf-stable products, for example bread (Rooney, Waniska and Subramanian 1997). However, the lower protein digestibility of sorghum, after cooking (Axtell, Kirleis, Hassen, D'Croz Mason, Mertz and Munck 1981; MacLean, Lopez de Romana, Placko and Graham 1981; Hamaker, Kirleis, Mertz and Axtell 1986), and the gritty nature of sorghum endosperm (Desikachar 1975; Munck 1995), seem to be the major constraints on sorghum utilization.

The problem of the lower protein digestibility of cooked sorghum, compared to other grains, is attributed to inaccessibility of α-kafirin to proteolysis (Oria and Hamaker 1995; Oria, Hamaker and Shull 1995). It has been suggested that β- and γ-kafirins, which are located predominantly at the periphery of the protein bodies, become highly cross-linked during cooking (Kirleis 1990; Hamaker, Kirleis, Butler, Axtell, and Mertz 1987; Rom, Shull, Chandrashekar and Kirleis 1992), hence, rendering the α-kafirin located in the center of the protein bodies less accessible to enzyme attack.

Because during germination of sorghum, the protein body degradation occurs through surface pitting (Glennie, Harris and Liebenberg 1983; Taylor, Novellie and Liebenberg 1985), β- and γ- kafirins are degraded most (Mazhar and Chandrashekar 1993). Therefore, malting of sorghum can be used to overcome the problem of the poor protein digestibility of sorghum based food products. Moreover, malting of sorghum has been reported to enhance overall the nutritional qualities of sorghum (Wang and Fields 1978; Wu and Wall 1980; Bhise, Chavan and Kadam 1988; Chavan and Kadam 1989), to promote the development of enzymes which hydrolyze the prolamins and glutelins of sorghum (Taylor 1983; Subramanian, Sambasiva-Rao, Jambunathan, Murty and Reddy 1995) and to increase the protein content of sorghum, simply due to an increase in dry matter loss during germination (Wu and Wall 1980).

The content of water-soluble protein and the *in vitro* protein digestibility (IVPD) of the sorghum grain have also been reported to increase with malting time (Bhise et al 1988; Chavan and Kadam 1989; Subramanian et al 1995). However, prolonged malting time results in significant loss in grain weight (Novellie 1962; Pathirana, Sivayogasunderam and Jayatissa 1983; Morrall, Boyd, Taylor and Van der Walt 1986).

Malting consists of steeping, germination and subsequent drying of grains. Optimal malting conditions (steeping and germination time, temperature, moisture availability and aeration) for production of sorghum malt with optimal quality for brewing (in terms of diastatic power, free amino nitrogen and hot water extract) have been investigated (Dewar, Taylor and Berjak 1997a). Steeping the grain for 20-24 h at 25-30°C with air rest periods, followed by germination for 4-5 days at 25-30°C and 95-100% relative humidity, and drying at 50°C, produced malt with improved enzyme activity (Ratnavathi and Bala Ravi 1990; Dewar, Taylor and Berjak 1997a,b; Morrall et al 1986).

It is possible that the modifications of sorghum proteins, with malting, for example the increase of total and water-soluble proteins and the increase of the protein digestibility of sorghum flour, may improve both the bread-making and the nutritional property of sorghum flour. The water-soluble components of wheat flours improve the bread volume by increasing the viscosity of the dough and hence the gas-holding capacity of dough (Gan, Ellis and Schofield 1995). However, because the desired sorghum malt for food use should have higher protein and starch digestibility with minimum loss in dry matter (Bhise et al 1989), the malting conditions for sorghum to be used in bread-making needed to be optimized.

The objective of this investigation was to determine the changes in the protein quality (content, solubility, free amino nitrogen and digestibility) with malting time and to optimize the malting time for sorghum intended for bread-making.

MATERIALS AND METHODS

Grain

Five tannin-free sorghum cultivars: Local White, KAT369, NK283, PAN8564 and Shaka, all from the 1996 season, were obtained in three different countries: Local White and KAT369 (white color) from Kenya, NK283 and PAN8564 (red color) from South Africa and, Shaka (white color) from Mozambique. The cultivars exhibited a wide range of kernel characteristics and protein contents. The grains were characterized for pericarp color and thickness and endosperm texture, as described by Rooney and Miller (1982) (Table I-1). Thousand-kernel weight (TKW) was determined by weighing 100 randomly selected unbroken grains and multiplying the result by 10. Test weight, a measure of grain bulk

Table I-1. Kernel characteristics, protein content and Germinative Energy of sorghum grains

Sorghum grain	Pericarp color	Pericarp thickness	Endosperm texture[1]	Pigmented testa	Test weight (g/hl)	Thousand kernel weight (g/1,000-kernels)	Protein content (%)[3]	Germinative Energy (%)
NK283	Red	Thick	3	No	76.0c	27.6c[2]	6.9c	98.3a
PAN8564	Red	Thin	4	No	76.6c	27.2c	7.3c	98.3a
KAT 369	White	Thick	3	No	77.6b	35.3a	9.8b	81.7d
Local White	White	Thick	4	No	72.4d	23.8d	10.7a	84.0c
Shaka	White	Thin	2	No	80.4a	32.9b	10.8a	97.3b

[1] Subjectively rated on a scale of 1 to 5, where 1= corneous and 5=floury.

[2] Values in the same column with different letters differ significantly from each other ($p<0.05$).

[3] Dry weight basis. Protein = (Nx6.25).

density was determined according to the USDA Federal Grain Inspection Service method (FGIS) (1988), except that the hectoliter weight was measured.

Malting of grains

Steeping

Samples of cleaned sorghum (500 g) were pre-washed, spin-dried for 1 min at 300 g in a domestic spin drier, placed in perforated nylon bags and steeped in running tap water with a cycle of 3 h wet, 1 h dry, for 24 h (Morrall et al 1986). After steeping, the grains were spin-dried (1 min) at 300 g to remove excess surface-held water.

Germination

The steeped grain was germinated in a water-jacketed incubator (Forma Scientific Marrieta, USA), set at 28°C and 100% relative humidity. Samples were germinated for 2, 3, 5, and 7 days. Twice daily, the bags were removed from the incubator; the grains were turned (to avoid meshing of the roots and shoots) and immersed for 10 min in tap water. Following the short steep, the grains were spin dried (1 min) and returned to the incubator.

Drying

After the pre-determined germination time the grains were removed from the incubator and dried in a forced draught oven at 50°C, for 24 h. Before analyses, malts and berries (malts with roots and shoots removed) were milled for two 30 s periods in a "beater type" water cooled coffee mill (Janke and Kunkel, Staufen, Germany).

Analyses

Germinative Energy

Germinative Energy (GE) was determined in petri dishes (100 grains each) lined with Whatman No. 4 filter paper. Water (4 ml) was added, and the dishes were placed in a incubator at 28°C, close to 100% relative humidity. Grains that developed roots and shoots were counted at 24, 48 and 72 h intervals (Essery, Kirsop and Pollock 1955).

Malting losses

Malting loss was estimated by calculating the thousand-kernel weight (TKW) of dried malts, and comparing it with the TKW of dry grain, as described by Novellie (1962). To estimate the malting losses due to roots and shoots, a 100 g sample of each malt was polished as described by Morrall et al (1986) and the contribution by weight, of roots and shoots to the whole malt was determined.

Diastatic power (DP)

DP, the joint α- and β-amylase activity of malts was determined according to the standard test method for determination of the diastatic power of malts prepared from sorghum including bird-proof varieties, and millet (SABS Method 235) (South African Bureau of Standards 1970), except that water was used as the extractant. The results were expressed as sorghum diastatic units (SDU)/g dry weight malt.

Free α-amino nitrogen (FAN)

FAN, the amount of small peptides and free amino acids, was determined according to the method of Morrall et al (1986) and expressed as mg FAN/100 g dry weight malt. Samples of malt (125 mg) were extracted with 5 ml 5% (w/v) trichloroacetic acid at room temperature by vortex mixing for three 15 s periods over 30 min. The extracts were centrifuged at 4,500 x *g* for 10 min to obtain clear supernatants. Samples (100 µl) were then subjected to the European Brewery Convention (EBC) ninhydrin assay. The results were expressed as mg FAN/100 g dry weight malt.

Protein

Nitrogen was determined using the Kjeldahl method, boric acid modification (Approved Method 46-12A, American Association of Cereal Chemists 1983). Protein was calculated from N x 6.25 and includes also free amino nitrogen and other reduced nitrogenous compounds.

Water-soluble protein

Water-soluble-protein was determined according to the Official Method Ba 11-65 of the Association of Official Analytical Chemists (1995). Exactly 2 g of sample was suspended in 200 ml water and extracted for 2 h in a shaking water bath set at 37°C and filtered using Whatman No. 4 filter paper. The extract, 5 ml was determined for nitrogen content according to the Kjeldahl method described above.

Protein digestibility

IVPD was determined by pepsin (Sigma P-2000, activity 120 units/mg of protein) hydrolysis, as described by Hamaker et al (1987). Flour samples (200 mg) were suspended in 35 ml enzyme solution (1.5 g pepsin/l 0.1 M KH_2PO_4 buffer; pH 2.0) and the resultant mixture was incubated for 2 h at 37°C in a shaking water bath. Following centrifugation, the residue was dried at 50°C, digested, and assayed for nitrogen content (Approved

Method 46-12A), American Association of Cereal Chemists (1983). Protein digestibility was calculated by subtracting residue nitrogen from total nitrogen, dividing by total nitrogen, and multiplying by 100.

Moisture

Moisture content of each sample was determined following the air-oven method (Approved Method 44-15A), American Association of Cereal Chemists (1983).

Statistical Analysis

All analyses were made at least in triplicate. Data were subjected to a one-way analysis of variance. The level of significant difference was measured at the 5% level using the StatSoft (1995) computer program.

RESULTS AND DISCUSSION

Malting characteristics of sorghums

In South Africa, where large quantities of sorghum are malted for use in sorghum beer brewing, the malting quality of sorghum grains for brewing is specified in terms of Germinative Energy (GE) higher than 90%, diastatic power (DP) minimum 28 SDU/g and free amino nitrogen (FAN) higher than 110 mg FAN/100 g (Dewar, Joustra and Taylor 1993). The DP of malts is the measure of joint activity of α- and β-amylases and FAN is the result of the protease activity of malts (Taylor 1983).

In the view of that, NK283, PAN8564 and Shaka, with GE ranging between 97.3 and 98.3% (Table I-1) would be considered cultivars of potentially good malting quality, whereas Local White and KAT369 with GE of 84.0 and 82.7%, respectively, would not be suitable for commercial malting. It should be mentioned that the DP of the malts increased with malting time, reached a maximum at 4-6 days and then decreased (Figure I-1), whereas the FAN of the malts increased continuously throughout the malting time (Figure I-2). Thus, PAN8564 with a GE of 97.3, a DP maximum of 32 SDU/g and FAN maximum of 122 mg/100g would be the only grain to meet South African standards for malting. NK283 with a GE of 98.3%, a DP maximum of 27 SDU/g and FAN maximum of 135 mg/100 g would still be suitable for commercial malting, whereas Shaka, with a DP maximum of 19 SDU/g, would not be suitable for commercial malting, despite of a GE of 98.3%.

The highest malt FAN values, 199 and 181 mg/100 g, respectively, were obtained with Local White and Shaka (Figure I-2), which had the highest protein contents (Table I-1). This indicates that grains with the highest protein contents gave malts with highest FAN, regardless of their GE. It seems also that with the exception of Shaka, which with a GE of 97.3% gave a low DP of 19 SDU/g, grains with a higher GE, such as PAN8564 and NK283, gave the highest DP, 32 and 27 SDU/g, respectively, as would be expected. The positive and significant correlation between the DP and FAN of 6-days malts (r=0.62) (Table I-2), can be explained with both, the DP and FAN, increasing with germination time.

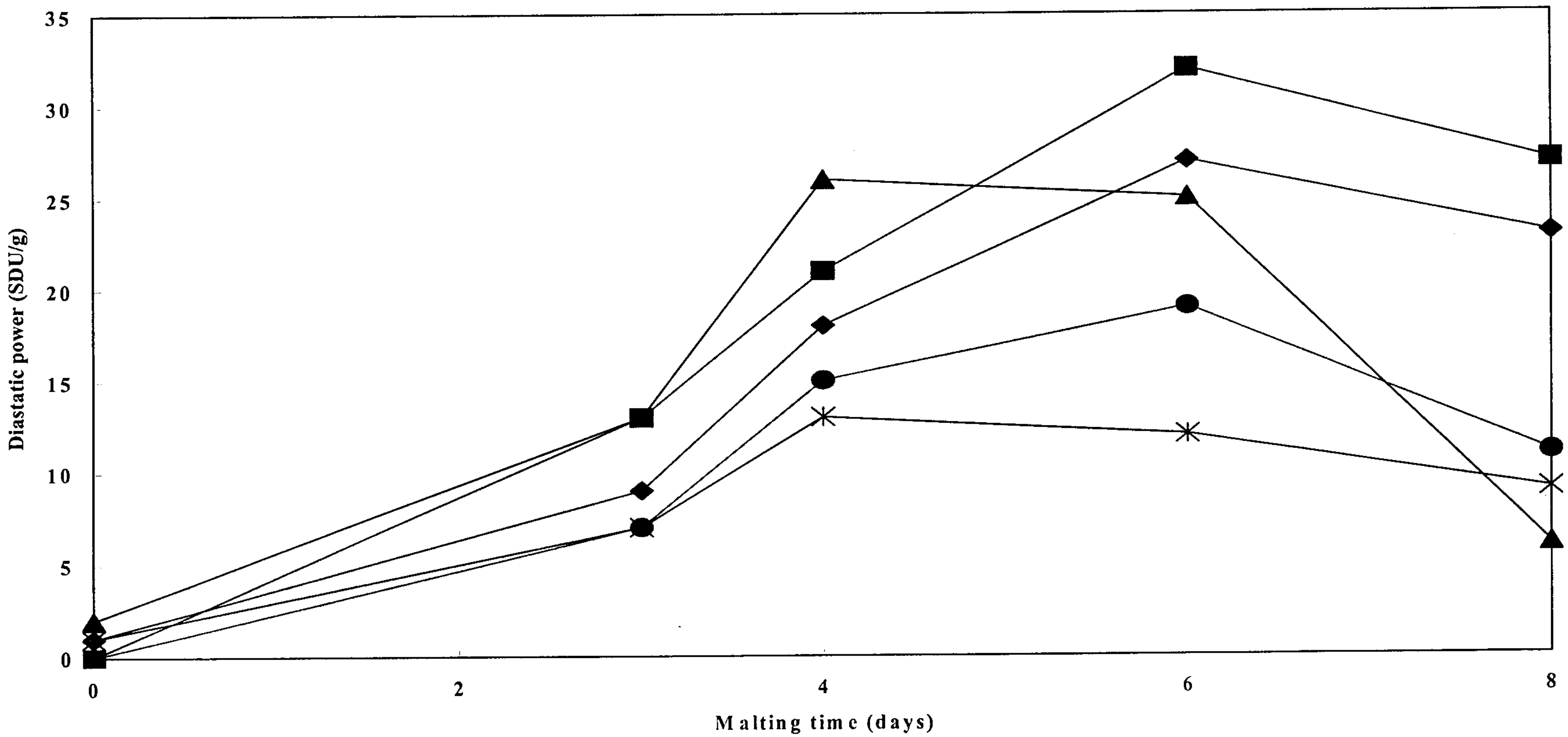

Figure I-1. Effect of malting time on the diastatic power (DP) of sorghum malts: (◆) NK283, (■) PAN8564, (✶) KAT369, (▲) Local White, and (●) Shaka.

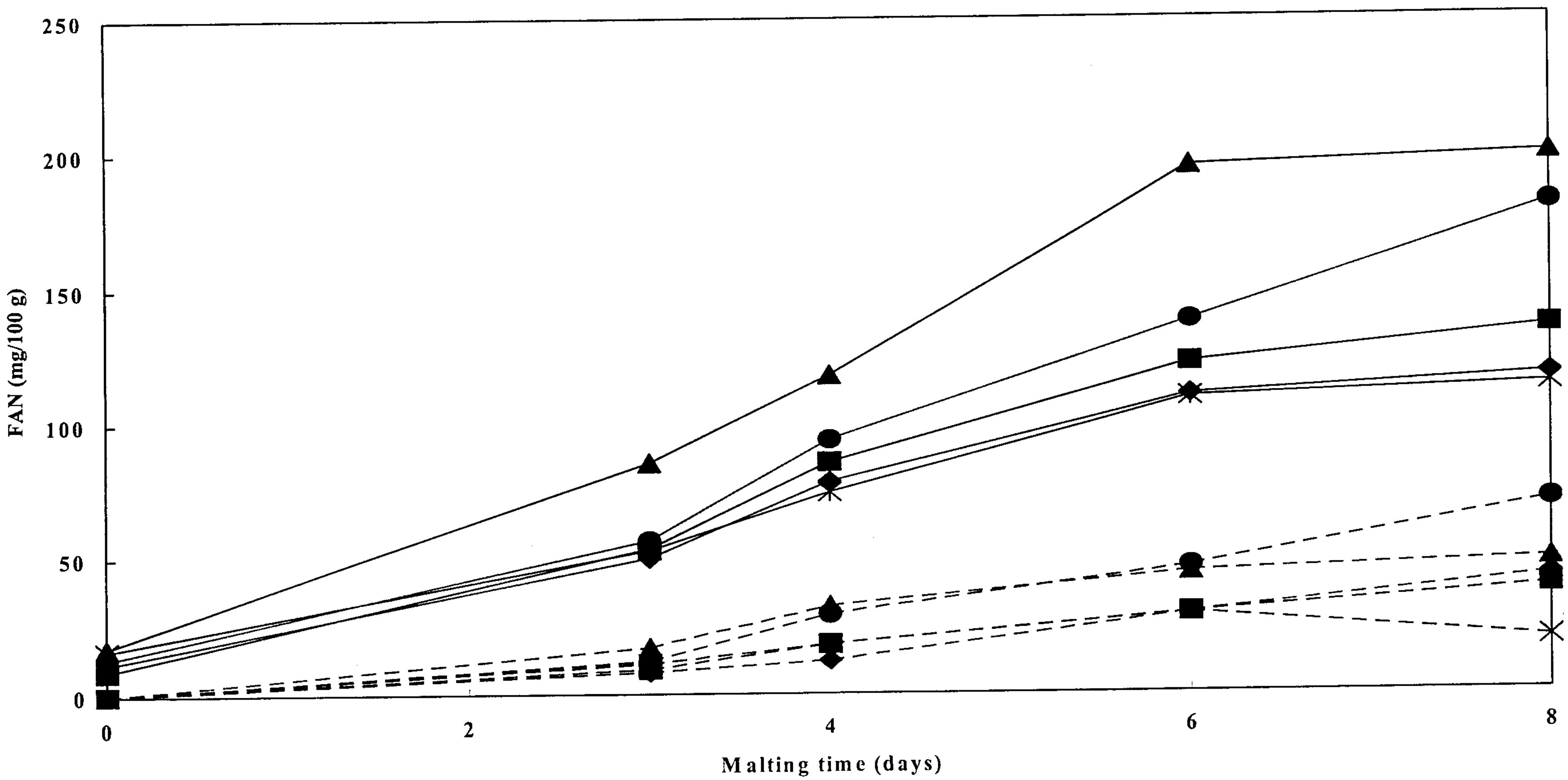

Figure I-2. Effect of malting time on the free amino nitrogen (FAN) of whole malts (T) and roots and shoots (R-S) of sorghum malts: —(◆)NK283 (T), —(■) PAN8564 (T), —(✶) KAT369 (T), —(▲) Local White (T), —(●) Shaka (T), ---(◆) NK283 (R-S), ---(■) PAN8564 (R-S), ---(✶) KAT369 (R-S), ---(▲) Local White (R-S), and ---(●) Shaka (R-S).

Table I-2. Correlation analysis between the properties of 6-days sorghum malts

Variables	Days	Totprot	IVPD	Soluprot	FAN	DP	DML(R-S)
Totprot	0.35*[a]						
IVPD	0.71*	0.14					
Soluprot	0.66*	0.59*	0.43*				
FAN	0.89*	0.54*	0.65*	0.83*			
DP	0.64*	0.06	0.77*	0.28	0.62*		
DML(R-S)	0.90*	0.29	0.68*	0.61*	0.78*	0.61*	
DML-R	0.94*	0.55*	0.59*	0.77*	0.90*	0.46*	0.83*

[a] Pearson correlation coefficients. All values marked with * are significant at $p < 0.05$.

[b] Days, malting time; Totprot, total protein; IVPD, *in vitro* protein digestibility; Soluprot, water-soluble protein; FAN, free amino nitrogen; DP, diastatic power; DML-R, dry matter losses due to respiration; and DML(R-S), dry matter losses due to removal of roots and shoots.

The FAN of roots and shoots of sorghum malts (Figure I-2) also increased with malting time. On the 8th day of malting the roots and shoots contributed between 17 and 38% of total FAN of malts. The roots and shoots are known to be a rich source of malt FAN relative to their weight, compared to total grain weight (Dewar et al 1997b). Taylor (1983) has indicated that during malting of sorghum, much of the protein and non-protein nitrogen resulting from the protein degradation in the kernel is transferred to the roots and shoots of germinating grains.

Changes in total and water-soluble protein

Both the total and the water-soluble protein in the sorghum grains increased with malting time (Figure I-3). The total protein of grains which ranged between 6.9 and 10.8%, increased between 1.3 and 2.8 percentage points with 8 days malting (Figure I-3). The water-soluble proteins of ungerminated grains ranged between 1.8 and 2.0% and increased up to 5.8%, with 8-days malting (Figure I-3). In KAT369, PAN8564 and Shaka, the water-soluble protein initially decreased and later increased. According to Wang and Fields (1978) and Wu and Wall (1980), an initial decrease of the water-soluble components, including proteins can be attributed to leaching of water-soluble nutrients, during steeping. Grains of Local White and Shaka had the highest protein contents, 10.7 and 10.8%, respectively, and had the highest increase of both the total and the water-soluble proteins. The malts with lowest protein contents, PAN 8564 and NK283, 6.9 and 7.3% respectively, had the lowest increase of both the total and the water-soluble proteins.

The increase of the protein content of sorghum grains, with malting time, has been attributed to dry matter losses, particularly due to loss of carbohydrates, occurring due to

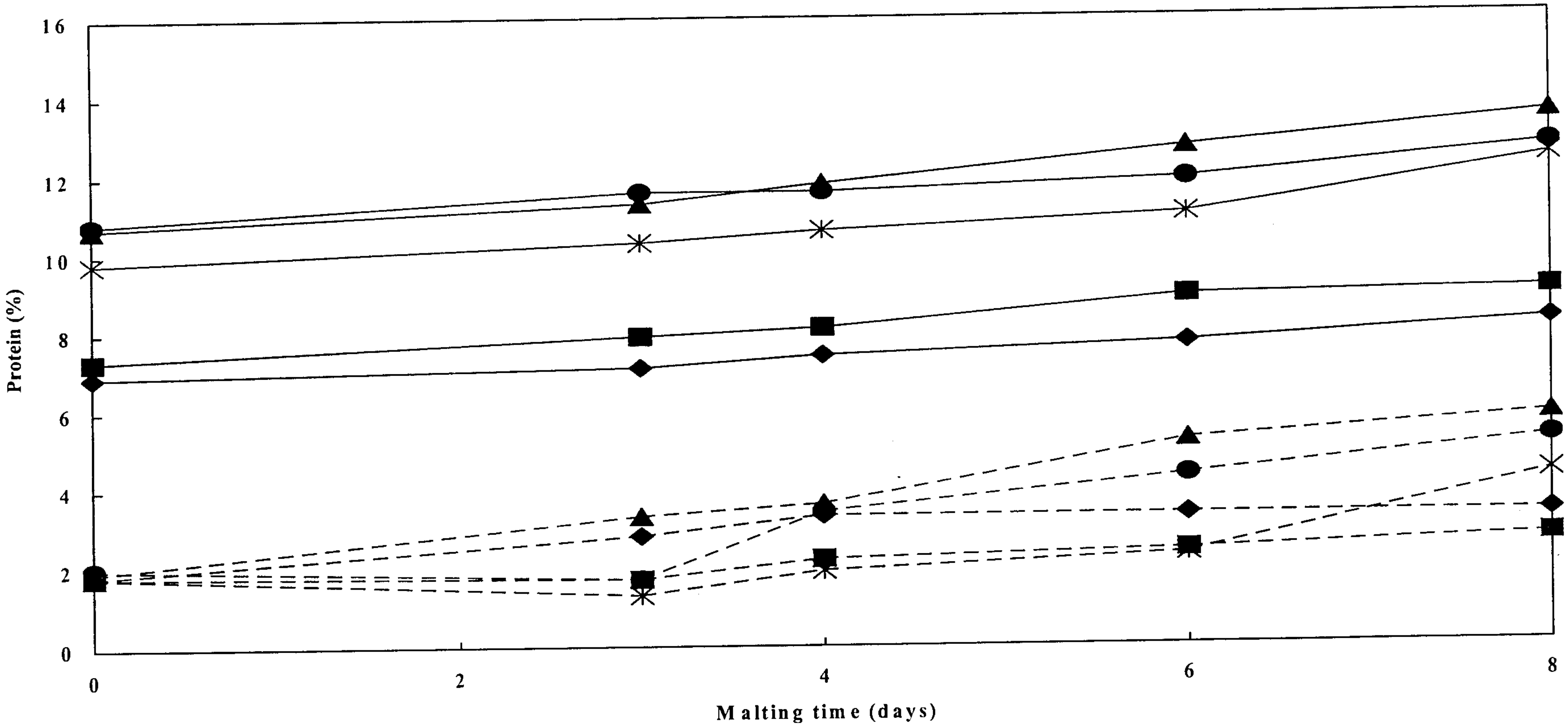

Figure I-3. Effect of malting time on the total protein (T) and water-soluble protein (S) of sorghum malts: —(◆) NK283 (T), —(■) PAN8564 (T), —(✶) KAT369 (T), —(▲) Local White (T), —(●) Shaka (T), ---(◆) NK283 (S), ---(■) PAN8564 (S), ---(✶) KAT369 (S), ---(▲) Local White (S), and ---(●) Shaka (S).

respiration of germinating grains (Wu and Wall 1980; Chavan and Kadam 1989). The increase of water-soluble protein, with malting time, has been attributed to a partial hydrolysis of storage proteins by endogenous proteases produced during malting (Wu and Wall 1980; Taylor 1983; Taylor et al 1985; Mazhar and Chandrashekar 1993; Subramanian et al 1995).

Water-soluble protein and FAN of sorghum malts were positively and significantly correlated with the protein content of grains (r=0.59 and r=0.54, respectively). The correlation between DP and water-soluble proteins (r=43) was also significant. Working on the effect of malting on the extractability of sorghum proteins, Subramanian et al (1995) found a positive and significant correlation between DP and water-extractable proteins. However, Okolo and Ezeozu (1996) reported a poor correlation between protein degradation and DP, even though alkaline steeping increased the solubilization of the storage proteins of sorghum.

Changes in *in vitro* protein digestibility of malted grains

The IVPD of sorghum grains increased up to the 6th day of malting, and then very slightly decreased (Figure I-4). The IVPD of ungerminated grains ranged 48.4 and 56.8%. By the 6th day of malting, the IVPD increased to between 60.6 and 68.1%, giving absolute increases of IVPD varying between 10.6 and 17.2 percentage points. The highest increase occurred with Local White, followed by PAN8564 with only 11.5 percentage points. Bhise et al (1988) also reported that malting increasing the protein digestibility of sorghum.

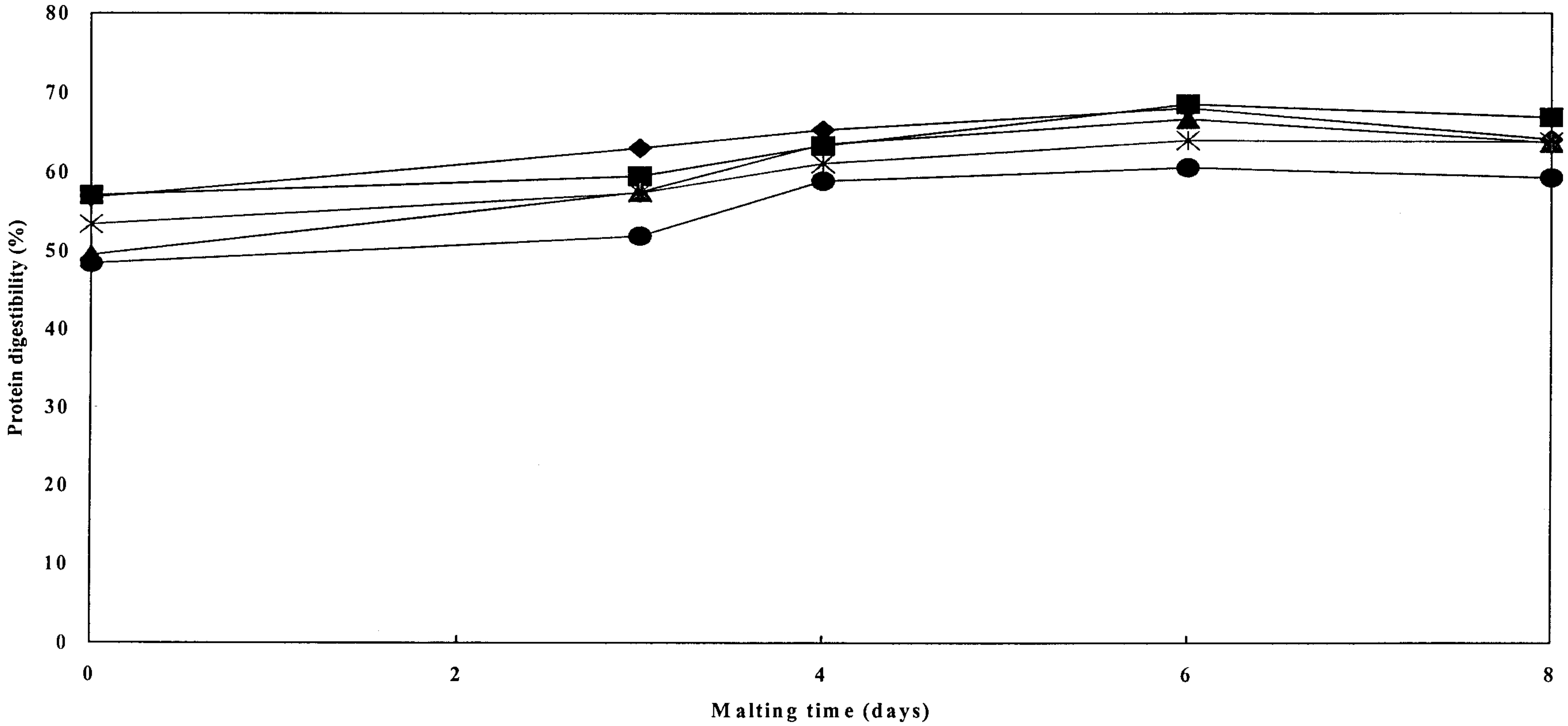

Figure I-4. Effect of malting time on the *in vitro* protein digestibility of sorghum malts: (◆) NK283, (■) PAN8564, (✶) KAT369, (▲) Local White, and (●) Shaka.

In this study the IVPD of sorghum malts was positively and significantly correlated with DP (r=0.77), water-soluble protein (r=0.43) and FAN (r=0.65) (Table I-2). The poor correlation between IVPD and total protein can be attributed to a decrease of IVPD from the 6th day of malting. However, it is not clear why the IVPD of sorghum malts decreased from the 6th day of malting. It might be that with longer malting time the cellulosic cell walls of the roots and shoots prevented the hydrolysis by the pepsin of the protein residues (FAN) transferred to the roots and shoots during germination of grains. According to Raven and Johnson (1992) the cells of primary plant body are characterized by thick cellulosic cell walls, which are often coated by a thick layer of cuticle.

The increase of the water-soluble proteins, FAN and IVPD of sorghum malts, and presumably of sugars as a result of degradation of carbohydrates, which occurs during malting (Von Holdt and Brand 1960), may be important in improving the nutritional properties of sorghum. However, a balance between the optimum concentrations of soluble proteins and soluble sugars need to be standardized, to avoid excessive browning of baked sorghum products (Bhise et al 1988), as well as to avoid excessive loss of viscosity in porridge products.

Malting losses during germination of grains

Dry matter losses due to both respiration activity of grains and roots and shoots removal increased with germination time (Figure I-5). On the 8th day of malting the dry matter losses due to respiration ranged between 17.6 and 24.4% and the dry matter losses due to roots and shoots removal ranged between 6.1 and 13.0%. These losses were in the ranges found by Novellie (1962) and Pathirana et al (1983). The highest losses due to respiration

Figure I-5

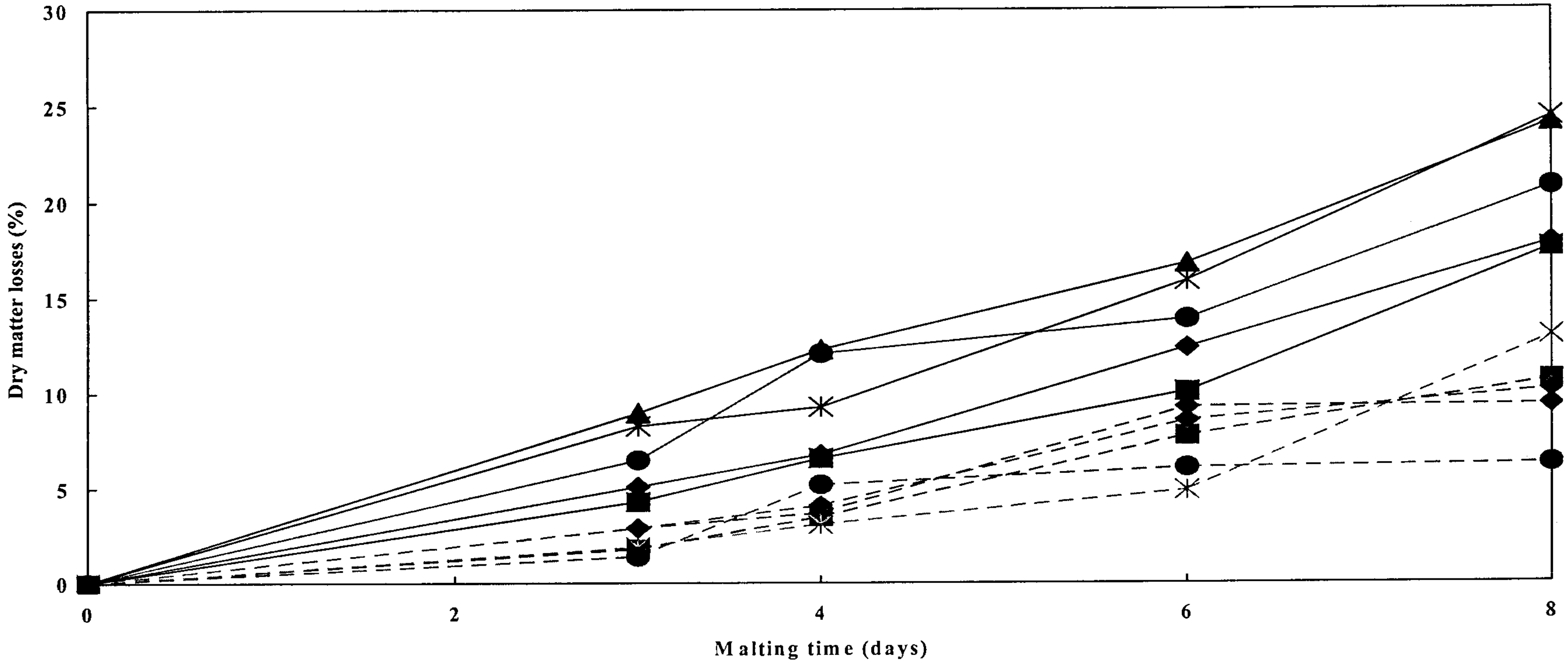

Figure I-5. Effect of malting time on the dry matter losses due to respiration (R) and roots and shoots (R-S) of sorghum malts: —(◆) NK283 (R), —(■) PAN8564 (R), —(✶) KAT369 (R), —(▲) Local White (R), —(●) Shaka (R), ---(◆) NK283 (R-S), ---(■) PAN8564 (R-S), ---(✶) KAT369 (R-S), ---(▲) Local White (R-S), and ---(●) Shaka (R-S).

were 24.4% KAT369, 24.1% Local White and 20.8% Shaka. Cultivars NK283 and PAN8564, with 17.9 and 17.6% losses respectively, had the lowest respiration losses, even though the GE and the DP of these sorghums were the highest.

Malting losses for sorghum malt for food use can be entirely attributed to leaching of soluble materials from the grain during steeping and to oxidation of substances during germination (Pathirana et al 1983). It should be noted that for sorghum beer brewing, the roots and shoots of malts are not normally removed prior to milling them (Novellie 1962).

Novellie (1962) and Beta, Rooney and Waniska (1995) found a positive correlation between germination and malting losses and germination and DP of sorghum malts. Beta et al (1995) also indicated that germination was also positively correlated with dry matter losses due to roots and shoots. The results of this study, with the exception of Shaka, suggest that the higher the GE of grains, the lower the losses due to roots and shoots removal, and the higher the DP of malts the lower the losses due to respiration activity. However, this relationship may simply be because NK283 and PAN8564, the two South African malting grains, and KAT369, have been selected for high GE, high DP and lower malting losses.

In view of the fact that malting losses due to respiration can be minimized with shorter germination time (Pathirana et al. 1983; Morrall et al 1986) and that protein modification of sorghum increased with malting time, a nutritionally improved sorghum malt flour suitable for bread-making has to be selected on the basis of high protein modification and low dry matter losses. Therefore, a 6-days malt of Local White, with levels of total and water-soluble protein, FAN and IVPD, and malting loss midway between those of the 4th and 8th days, appears most suitable for bread-making. Local White has also the advantage that it is white and has predominantly a floury endosperm. The thick pericarp, although bad in industrial milling of sorghum, would not be a disadvantage with malt, since malt is friable anyway.

CONCLUSIONS

Total and water-soluble protein, FAN and IVPD, as well as the dry matter losses of sorghum grains increase with malting time. FAN and IVPD of sorghum malts are positively and significantly correlated with DP of malts. The highest improvement of the protein quality of sorghum grains, i.e., the highest increase in total and water-soluble protein, FAN and IVPD of sorghum malts, was obtained with cultivar Local White. The optimal malting time for sorghum to be used in bread-making appears to be 6-days, since 8-days malts tend to have a decreased IVPD and excessively high dry matter losses, and 4-days malts have a rather low protein modification.

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4. CHAPTER II

EFFECT OF MALTING SORGHUM ON COMPOSITE SORGHUM AND WHEAT BREAD-MAKING QUALITY

ABSTRACT

To alleviate the adverse effects (grittiness and high crumb firmness) caused by the inclusion of sorghum flour in composite breads, sorghum grain was malted. Four different heat treatments were investigated: drying the malt at high temperatures (from 50°C to 150°C), stewing, steaming and boiling, before drying the malt at 80°C. Malting decreased the pasting temperature of sorghum to values approaching those of wheat flour, but the paste viscosity was very low. Increasing the malt drying temperature inactivated the amylases but gave malts of darker color and bitter taste. Stewing, steaming and boiling the malt before drying, almost completely inactivated the amylases, and increased the enzyme susceptible starch content and the pasting viscosity of malt flours. Malting and boiling also increased the total protein but decreased the in vitro protein digestibility (IVPD) of sorghum flour. Bread made with boiled malt flour (30%) had a slightly decreased protein content, similar IVPD, an improved crumb structure, crumb softness, water holding capacity and resistance to staling, as well as a fine malt flavor, compared to the bread made with grain sorghum flour (30%). Consumers panel members preferred the malted sorghum composite bread to bread made with grain sorghum flour.

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INTRODUCTION

Composite breads are breads made from blends of wheat and nonwheat flours (Dendy 1992). Those flours are advantageous to developing countries because they reduce wheat imports and enable the use of locally grown grains. Sorghum is an important cereal crop grown in many developing countries that is potentially suitable for use in composite flours.

Much attention has been given to using sorghum in composite breads. Composite flours containing 30% sorghum produce stronger dough and higher loaf volume with the mechanical dough development process (Chorleywood process) than with the traditional bulk fermentation process (Pringle, Williams and Hulse 1969). Good quality bread can also be produced with mechanical dough development process, using sheeting rollers (Bushuk and Hulse 1974). Dough additives including potassium bromate (20 ppm), glycerol monostearate (0.5%), and sodium stearoyl lactylate (0.4-1.0%), enable the level of sorghum flour to be increased from 10% to 25% (Haridas Rao and Shurparlekar 1976). Dendy (1992) concluded that a reasonably strong wheat flour, preferably over 12% protein (N x 5.7) can make good quality bread with up to 30% sorghum, provided that the sorghum flour is clean, fine and low in fiber.

Although the use of sorghum flour in composite bread appears promising in terms of loaf volume and crumb structure, its use in bread-making may not be straightforward. The starch gelatinization temperature range of sorghum (68-78°C) is high compared to that of wheat (58-64°C) (Hoseney 1994). This factor and a lower water holding capacity (WHC) of sorghum flour may be responsible for the grittiness, dry mouthfeel, and higher firming ratio of sorghum composite breads (Munck 1995). The role of gelatinized starch in bread-making has been evaluated. Starch gelatinization was the main factor in structuring the bread crumb (Rotsch 1954). By gelatinization, starch becomes flexible and takes water from gluten, a process that helps gluten to set and become rigid (Kent and Evers 1994). Cereal starches that gelatinized at temperatures higher than wheat starch had poorer baking characteristics, while, rye and barley starches, which gelatinized around the same temperature as wheat, were nearly equal to wheat starch in bread-making (Hoseney, Finney, Pomeranz and Shogren 1971). Also, according to De Ruiter (1978) the bread-making quality of cassava starch is explained by the gel produced on gelatinization of cassava starch, whose gel possesses far greater cohesion than do gels of grain starches and most other tuber starches.

Therefore, if sorghum is to be used in composite flours to produce acceptable bread, it should be processed in a way that it lowers starch gelatinization temperature and increases water holding capacity. This study was conducted with the hypothesis that such conditions could be achieved by malting sorghum and heat-treating the malt to promote biochemical modifications in the starch and non starch components of the grain. Modifications of the protein of sorghum grain with malting and baking were also evaluated.

MATERIALS AND METHODS

Materials

A white, tannin-free Kenyan sorghum variety, Local white, was used. The grain had an intermediate endosperm texture, a test weight 72 kg/hl, and a good germinability (Germinative Energy of 84%). The wheat flour used was ‘Favorita’, a commercial bread flour produced by Companhia Industrial da Matola (CIM), Maputo, Mozambique. The flour was of particle size distribution >97% < 212 μm and > 60% > 75 μm and had a protein content of 12.9% (N x 5.7) and ash 1.9%, dry basis, and a water absorption of 63%, and its mixogram mixing times were peak time, 3.0 min and stability to mixing, 2.8 min.

Malting procedure

Exactly 500-g lots of cleaned sorghum were pre-washed, spin-dried for 1 min at 300 x g, placed in perforated nylon bags and steeped for 24 h in aerated, running tap water at 28-30°C (Morrall, Boyd, Taylor and Van der Walt 1986). After steeping, the grains were spin dried (1min) to remove excess surface-held water. Then, the steeped grain was germinated for five days in an incubator set at 28°C, 95% relative humidity (RH). Twice daily, the bags were removed from the incubator, and the grains were turned (to avoid meshing of the roots and shoots) and immersed for 10 min in tap water. Following the short steep, the grains were spin dried (1 min) and returned to the incubator.

Heat treatments of sorghum malts

After six days from the beginning of steeping, green malts were dried at 50, 80, 100, 120, or 150°C, in a forced-draught oven. The drying times varied from 4 h for malts dried at 150°C to 24 h for malts dried at 50°C. A second batch of sorghum was malted and subjected to three different wet treatments (stewing, steaming and boiling) before drying the malt at 80°C. In stewing, green malt was placed in drying pans, covered with aluminum foil, and placed in a forced-draft oven set at 80°C. After 4 h, the aluminum cover was removed and the malt was dried (4-6 h). In steaming, the green malt was placed in a perforated pan over a pan containing water and steamed for 4 h, then dried as above. In boiling, the green malt was placed in a pan with excess water and boiled for 20 min. At the end of 20 min, the malt was removed from the pan, excess water was drained, and the malt was dried, as above.

Milling of grain and malts

Cleaned grain and whole malts (malts with the external roots and shoots) were milled with a hammer mill fitted with a 1 mm screen and then with a pin mill. The particle size distribution of the sorghum flours was >95% < 212 μm and > 80% > 75 μm. Thus the sorghum flours were slightly coarser than the wheat flour used, but still within the normal range for wheat flour.

Flour analyses

A Rapid Visco Analyser (RVA) 3D instrument (Newport Scientific Pty Ltd., Narrabeen, Australia) was used to determine pasting properties of flours and malts. Flour (4 g, 14% moisture content) was suspended in 25 ml distilled water. The suspension was heated from 25 to 95°C in 5 min, held at 95°C for 5 min, cooled to 50°C in 5 min and held at 50°C for 5 min. The RVA parameters measured were pasting temperature (the temperature at which paste viscosity starts to increase), peak viscosity (the maximum hot paste viscosity), holding strength (the trough at the minimum hot paste viscosity), and final viscosity (the viscosity after cooling to 50°C and holding the temperature) (Batey, Curtin and Moore 1997).

Flour moisture was determined using the air-oven method (Approved Method 44-15A), American Association of Cereal Chemists (AACC) (1983). Protein was determined using the crude protein, Kjeldahl method, boric acid modification (Approved Method 46-12A) (AACC1983). Soluble nitrogen was determined using the Association of Official Analytical Chemists (AOAC), Official Method Ba 11-65 (1995), except that the protein content of extracts was determined by converting the nitrogen values to protein (N x 6.25). The *in vitro* protein digestibility (IVPD) was determined by pepsin hydrolysis, as described by Hamaker, Kirleis, Butler, Axtell and Mertz (1987). Optimum water absorption was determined using the Farinograph method (Approved Method 54-21A) (AACC 1983). Total starch (TS) and enzyme susceptible starch (ESS) were determined using an α-amylase and amyloglucosidase hydrolysis method (Taylor 1992). Falling Number values were determined using the Falling Number determination method (Approved method 56-81B) (AACC 1983). Diastatic power, the joint α- and β-amylase activity of malts was determined according to standard test method for determination of the diastatic power of malts prepared from sorghum including bird-proof varieties, and millet (SABS Method 235) (South African Bureau of Standards 1970), except that distilled water was used as the extractant. All determinations were repeated at least twice.

Bread-making

Bread was produced using the formulation: wheat flour (70%), sorghum flour (30%), water (63% and 75% for plain and malted sorghum flour, respectively), active dried yeast (1%), salt (2%), sugar (1%), ascorbic acid (20 ppm) and fat (1%). 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 of (275 by 100 by 105 mm). The dough was proofed for 45-50 min, at 40°C and 95% RH and baked at 230°C for 30 min. Bread volume was determined by rapeseed displacement. Specific volume was calculated from the volume and weight of bread.

Crumb firmness

Crumb firmness was determined by measuring the amount of force required to compress bread slices using the Instron UTM (Approved Method 74-09, AACC 1983). The instrument was fitted with a 28-mm-diameter cylinder probe. The crosshead speed was 100 mm/min. Samples were prepared and cooled to ambient temperature for 3-4 h. After cooling, samples were wrapped in polyethylene bags (35-µm thickness). The loaves were then stored in baskets, in ambient conditions (about 20°C) until required for testing. Measurements of crumb softness began 4 h after baking for day 0, and thereafter at one-day intervals until the third day.

Sensory evaluation

Bread samples, containing whole sorghum grain flour (30%), whole boiled sorghum malt flour (30%) and fermented whole sorghum grain flour (refer to Chapter III) were evaluated. The consumer testing methodology was based on liking and preference ranking test (Jellinek 1990), with slight modifications to suit semi-illiterate consumers. The panelist (62) were women, all local resident of the community of Mmotla, near Pretoria.

Statistical Analysis

Analysis of variance was determined using the StatSoft (1995) computer program. The significance of the number of liking judgements (Basker, 1988), 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

Flour properties

Pasting temperature, peak viscosity, holding strength, final viscosity and the Falling Number values of sorghum flour; were much higher than that of wheat flour; whereas the diastatic power and ESS of sorghum flour were lower than that of wheat flour (Table II-1). Notable was the substantial rise in viscosity on cooling (final viscosity) of sorghum flour.

Table II-1. Starch and amylase properties of sorghum grain, sorghum malt, and heat-treated sorghum malt flours

Flour	Pasting temperature (°C)	Peak viscosity (SNU)[2]	Holding strength (SNU)[2]	Final viscosity (SNU)[2]	ESS (% of total starch)	Falling Number (FNU)[2]	Diastatic power (SDU/g)[2]
Wheat flour	63[1]e	2015b	800b	2775b	8.4e	345a	4.5e
Sorghum flour	72a	2267a	1743a	5733a	0.6f	507b	0.3f
Malt dried at							
50°C	64e	80i	0g	76e	16.0d	62c	38.9b
80°C	63e	98h	48f	80e	17.1d	62c	22.6c
100°C	64e	123g	40f	79e	19.7d	62c	14.4d
120°C	64e	483c	265d	655d	18.8d	79d	0.9f
150°C	66d	483c	175e	457e	17.4d	79d	0.3f
Stewed malt	70b	450d	255d	650d	40.4c	62c	4.7e
Steamed malt	68c	367e	325c	725c	73.4b	62c	1.0f
Boiled malt	66d	315f	333c	610d	87.0a	62c	0.5f

[1]Values followed by the same letter in the same column are not significantly different (P <0.05).

[2]SNU, Stirring number units; FNU, Falling Number units (the higher the FNU, the lower the α-amylase activity); and SDU, sorghum diastatic units.

Malting decreased the pasting temperature, peak viscosity, final viscosity and the Falling Number values of sorghum flour, and substantially increased the content of ESS and diastatic power (Table II-1). The pasting temperature of sorghum decreased to values approaching that of wheat flour. The decrease in pasting temperature of sorghum with malting can be explained by the biochemical modifications occurring in the grain during germination. Glennie, Harris and Liebenberg (1983) reported that, during germination, hydrolytic enzymes progressively degrade the starch and the protein in the endosperm by pitting rather than by surface erosion. This process of modification, which hydrolyzes starch and proteins into dextrins, glucose, and amino acids, renders the starch in the malt easier to gelatinize, consequently decreasing the pasting temperatures and paste viscosity.

Increasing the drying temperatures of malt reduced diastatic power, increasing the paste viscosity of sorghum. Wet heat-treating (stewing, steaming and boiling) the malt virtually inactivated diastatic activity and increased the ESS content and the paste viscosity of sorghum malt. However, drying the malt at 100°C and at higher temperatures, and wet heat treating, increased the pasting temperatures of sorghum malt to values slightly higher than that of wheat flour, but still lower than that of sorghum flour. Boiling produced the highest ESS content, as boiling gelatinized the starch, and almost totally inactivated diastatic power of sorghum malt. Wet heat-treatments also reduced the breakdown viscosity of sorghum, with boiling producing malt with the lowest breakdown viscosity. Breakdown viscosity is determined as peak viscosity minus holding strength (Batey et al 1997). Breakdown viscosity gives an indication of hot paste stability. The smaller the breakdown viscosity, the higher the paste stability, presumably due to starch gelatinization. Paste stability of sorghum malts increased with increased amounts of gelatinized starch (ESS).

Falling Number values, did not substantially increase with the drying temperatures of malts nor with wet heat treating the malts. This suggests that, under the test conditions, malt flour was rapidly liquefied due to dextrinization of starch during germination, and not due to α-amylase activity in the malt flour, which would almost certainly be inactivated at high drying temperature and with wet heat treatments.

The low viscosity of malt dried at 50 to 100°C (hot air method) suggests that the grain dried slowly and, hence gradually reached the amylase inactivation temperatures, thus promoting hydrolysis of starch and other grain components; whereas, with boiling and other wet heat treatments, the heat penetrated the grain faster, rapidly inactivating the amylases.

Bread-making properties of sorghum flour and heat-treated sorghum malt flours.

The substitution of wheat flour with 25% sorghum malt flour gave smaller bread volume than sorghum flour (Table II-2). Malt dried at 50°C had a deleterious effect on the bread volume, presumably due to the high amylase activity of the malt. High α- and β-amylase in bread flour is detrimental to bread quality because starch dextrinization results in reduced water holding capacity, weak dough, and sticky crumbs (Kent and Evers 1994). Increasing the drying temperatures of malts slightly improved the volume of breads. However, an informal sensory evaluation of the breads revealed that the bread made with malt dried at 80°C had acceptable appearance and flavor, whereas breads made with malt dried at higher temperatures had unacceptable dark color and a bitter taste. The dark color and the bitter taste are attributed to Maillard reactions, which are accelerated at higher temperature (BeMiller and Whistler 1996).

Table II-2. Volume and specific volume of composite breads containing sorghum grain, sorghum malt and heat-treated sorghum malt flours

Bread ingredients	Loaf volume (cm^3)	Specific volume (cm^3/g)
Wheat flour (100%)	3567a[2]	4.8a
Sorghum flour[1]	2708b	3.4b
Malt dried at 50°C[1]	1776h	2.2e
80°C[1]	1875g	2.3e
100°C[1]	1858g	2.3e
120°C[1]	2067e	2.6d
150°C[1]	2067e	2.6d
Stewed malt[1]	2038f	2.5d
Steamed malt[1]	2188d	2.7d
Boiled malt[1]	2350c	2.9c

[1]Recipes contained sorghum (25%) and wheat flour (75%).

[2]Values followed by the same letter in the same column are not significantly different (P <0.05).

Wet heat treatment of malts improved the bread characteristics, with boiled malt giving the highest loaf volume and the highest loaf specific volume (Table II-2). The doughs made with wet heat-treated malts had higher water requirements, with stewed, steamed, and boiled malt requiring 66, 70 and 75% of water, respectively. The doughs made with conventionally dried malts required 62-64% of water, while the dough prepared with sorghum flour required 62%. It was observed that breads containing sorghum malts had higher loaf weight, suggesting a better water-holding capacity than the dough containing sorghum flour. The fact that boiled malt gave the largest loaf volume suggests that complete inactivation of amylases and a higher content of gelatinized starch in the malt are major factors responsible for the satisfactory bread-making qualities of sorghum malts.

Baking trials to optimize the bread-making procedure with boiled malt flour were undertaken. Increasing the mixing time of dough from 15 to 20 min, and the proofing time from 45 to 50-55 min, improved the volume, specific volume and crumb structure of composite bread. The level of sorghum in the composite flour could also be increased.

Sorghum flour and boiled sorghum malt flour at both levels, 30 and 50%, had adverse effects on the volume, crumb structure, and color of composite breads (Figure II-1). However, with 30% sorghum flour and 30% boiled sorghum malt flour, the bread volume increased to 2998 and 2888 cm^3, respectively, compared to the volumes of 2708 and 2325 cm^3 of bread made with 25% sorghum flour and 25% boiled sorghum malt flour, respectively, before optimizing the baking procedure. Though the volume of bread made with sorghum flour was slightly higher than the volume of bread made with boiled sorghum malt flour, the specific volumes of those breads were almost the same, 3.5 and 3.4 cm^3/g, respectively. Increasing the level of sorghum flour and boiled sorghum malt flour to

Figure II-1. Effect of sorghum and sorghum malt flour on the volume and crumb structure of sorghum and wheat composite breads. From left to right, breads made with 100% wheat flour, 30% sorghum flour, 30% sorghum malt, 50% sorghum flour and 50% sorghum malt.

50% reduced the bread volumes to 2040 and 1745 cm^3, respectively. The specific volume of those breads was also reduced to 2.4 and 2.1 cm^3/g, respectively. The level of 50% sorghum had a notable negative effect on the crumb structure of bread made with sorghum flour, and on the volume of bread made with boiled sorghum malt flour.

The crumb structure of bread made with sorghum flour collapsed on account of a reduced capacity of the dough to retain the carbon dioxide produced during fermentation. The crumb of bread made with boiled sorghum malt flour (50%) was very dense, almost not developed. This could be explained by the fact that 50% boiled sorghum malt flour gave tough and sticky dough, with poor visco-elastic properties, even though 10% extra water had been added. There was no visual evidence of carbon dioxide escape; such as pitting on the surface of the loaves. It is suggested that the dough was too tough to expand greatly. The reduced bread-making potential of wheat flour upon partial substitution with nonwheat flours is attributed to a reduced capacity of the gluten network to slow down the rate of carbon dioxide diffusion (Hoseney 1984a).

Sorghum flour or boiled sorghum malt flour at 30% was found to be the maximum level that could be used in the composite with wheat flour of 12.9% protein, and with ascorbic acid (20 ppm) as the dough improver. Though the volume of bread made with 30% boiled sorghum malt flour was slightly lower, it was observed that this bread was more moist and had a better crumb structure than the bread prepared with 30% sorghum flour.

The slightly smaller volume of bread made with boiled sorghum malt flour can be explained as follows: high dextrinization and gelatinization of starch, which was found in boiled sorghum malt flour, decreases dough strength and dough gas-holding capacity, consequently decreasing the bread volume (Kent and Evers 1994). On the other hand, a higher amount of non-starch polysaccharides in the malt, particularly the water-insoluble fraction, could have reduced the gas-holding capacity of dough, because malt was milled with the roots and the shoots included. The moistness of the bread made with boiled sorghum malt flour, was attributed to the higher water-holding capacity of doughs, which was due to the high amount of gelatinized starch in the malt flour. The improvement of the crumb structure in bread made with boiled sorghum malt flour is explained by the fact that free starch granules, which resulted from the malting process, gelatinized more rapidly and completely than starch in flour particles (De Ruiter 1978). That view is in agreement with that of Rotsch (1954), who also found the degree of gelatinization to be the major factor in determining crumb cohesion.

Crumb firmness as function of storage time and the amount of sorghum

Softness is one of the most important textural properties of bread for consumer acceptance. Bice and Geddes (1949) concluded that firmness and crumbliness are related closely to the organoleptic assessment of staleness. Therefore, if wheat and sorghum composite breads are to be produced, it is necessary that they have a soft crumb and a low firmness over storage time.

The initial crumb firmness and the changes in crumb firmness over three days of storage time are presented in Figure II-2. Bread made from 100% wheat flour was the softest and had the lowest rate of firming. The bread made with boiled sorghum malt flour (30%) was softer and more resistant to firming than the bread made with sorghum flour. Bread made from 50% boiled sorghum malt flour was also softer and had a lower firming rate than the bread made with 50% sorghum flour.

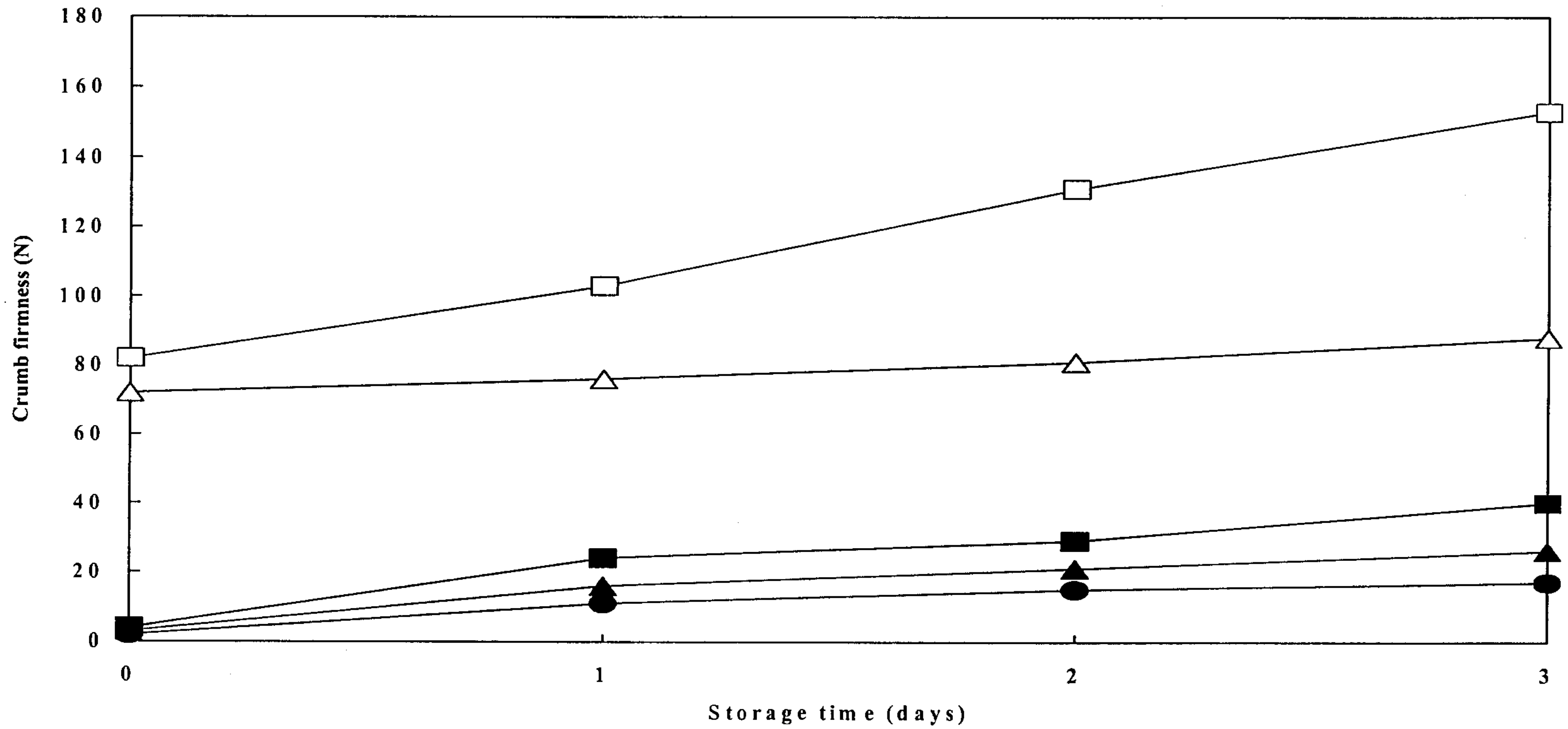

Figure II-2. Crumb firmness of wheat and sorghum composite breads as a function of storage time and level of sorghum ingredient. (●) Wheat flour (100%), (▲) sorghum malt flour (30%), (■) sorghum grain flour (30%), and (Δ) sorghum malt flour (50%) and (□), sorghum grain flour (50%).

The increase of bread firmness, due to increase in crumb rigidity with the storage time, is attributed to starch retrogradation (Lineback and Rasper 1988). Bread with high crumb moisture appears significantly fresher than bread with low moisture content (Bechtel and Meisner 1954; Kulp and Ponte 1981). Maleki, Hoseney and Mattern (1980) concluded that the moisture content of bread affects the absolute softness but not the staling rate. In those studies, the rate of bread staling was related to the protein quality of the flour.

Several authors have investigated the contribution of protein, starch, and non starch polysaccharides on the moisture retention and shelf life of wheat bread (Maleki et al 1980; Martin and Hoseney 1991). The later authors demonstrated that low molecular weight dextrins (DP 3-9) are responsible for the anti-firming effect in bread. Dextrins of that particular size interfere with the cross links (hydrogen bonds) between starch and proteins and thus prevent staling.

Protein quality of sorghum and wheat composite breads

It seems that malting modified the protein of sorghum flour by increasing the total and the water-soluble protein and greatly increasing the IVPD of sorghum flour whereas boiling cancelled out the increase in water-soluble proteins and IVPD of sorghum flour brought about by malting, and more than reversed the IVPD of whole sorghum grain (Table II-3).

The improving effect of malting on the protein quality of sorghum flour has been discussed (Chapter I). The decrease in the water-soluble proteins of sorghum malt, with boiling, can be partly attributed to leaching into the boiling water. However, much of the decrease in IVPD due to boiling can be attributed to the increase in the levels of cross-linking of the prolamins of sorghum, which occurs with cooking (Hamaker et al 1987).

Table II-3. Protein quality of sorghum grain, sorghum malt, boiled sorghum malt flour, wheat flour and sorghum and wheat composite breads

Samples	Total Protein[1] (%)	Soluble Protein[1] (%)	*In vitro* Protein digestibility (%)
Flours			
Sorghum grain flour	10.7d[2]	1.6c	45.3c
Sorghum malt	12.7b	5.7a	68.7b
Boiled sorghum malt flour	12.0c	1.6c	24.0d
Wheat flour	12.9a	3.2b	74.0a
Composite breads			
Sorghum grain flour (30%)[3]	12.2c	1.6c	64.0c
Boiled sorghum malt flour (30%)[3]	12.6b	2.3a	64.8b
Wheat flour (100%)[3]	13.0a	1.8b	74.8a

[1]Dry basis

[2]Values followed by the same letter in the same column and group are not significantly different (P <0.05).

[3]Bread ingredients.

The composite bread made with boiled sorghum malt flour was only significantly higher in water-soluble protein but the total protein and the IVPD were almost similar compared to bread made with whole sorghum grain flour. The similarity between the IVPD of these breads seems to suggest that, unlike boiling, the drier process of baking, did not decrease the IVPD of sorghum. It is also notable that the bread-making process decreased the water-soluble proteins of wheat flour but caused no major changes on the IVPD of bread. The IVPD of wheat bread was higher compared to sorghum and wheat composite breads.

Sensory evaluation of composite breads

Bread prepared with boiled sorghum malt flour was significantly more liked than the bread prepared with whole sorghum grain flour (Table II-4, $p<0.05$) and fermented whole sorghum grain flour (Chapter III). Consumer panel members apparently preferred the bread prepared with malt flour because it was more moist and had a fine roasted malt flavor.

CONCLUSIONS

Boiled sorghum malt flour (30%) can be successfully used as a partial replacement for wheat flour in pan bread. Bread prepared with sorghum malt flour was softer, more resistant to firming of the crumb, and had a better taste and chewing quality and a similar protein digestibility, compared to bread made with sorghum flour. Malting and boiling decreased the pasting temperature and increased the water-holding capacity of sorghum flour. Complete inactivation of amylases and a higher content of gelatinized starch in the malt appear to be the major factors responsible for the useful bread-making qualities of boiled sorghum malt.

Table II-4. Sensory evaluation of sorghum and wheat composite breads

Bread ingredients	Panelists liked bread	Rank sum of Sample[1]
Sorghum grain flour (30%)	47	111a[2]
Sorghum malt flour (30%)	53	86b

[1]Rank sum of the sample = $\sum$(number of panelists x the respective rank position). Lower rank sum indicates the better-liked sample.

[2]Values followed by the same letter in the same column are not significantly different (P <0.05).

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4.CHAPTER III

EFFECT OF FERMENTATION OF SORGHUM FLOUR ON THE COMPOSITE SORGHUM AND WHEAT BREAD-MAKING QUALITY

ABSTRACT

Whole sorghum flour was fermented (a 5-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. Fermentation and drying decreased the pH of sorghum flour 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. Fermented and dried sorghum flour decreased the pH of the dough, from 5.8 to 4.9, increased the bread volume by about 4%, improved crumb structure and slightly decreased the crumb firmness. The IVPD of sorghum and wheat composite bread also improved. Mixing wet fermented sorghum flour directly with wheat flour (sourdough-type process) further increased loaf volume and reduced crumb firmness, and simplified the bread-making 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.

INTRODUCTION

Sorghum is potentially suitable for use in composite flours (De Ruiter 1978; Dendy 1992). Sorghum flour has also a definite advantage over maize and other major tropical cereals, in composite flours, because of its bland flavor and white color (Rooney, Waniska and Subramanian 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).

Fermentation is a simple technology with the potential to improve the bread-making quality of sorghum flour. By decreasing the pH of sorghum to values as low as 3.4 (Chavan and Kadam 1989), fermentation of sorghum flour could possibly, as in rye and wheat sourdough, be used to improve its bread-making quality. The sourdough process improves rye and wheat bread-making 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), consequently improving the functional bread-making properties of pentosans and starch.

The low pH due to fermentation of sorghum flour has also been reported to partly inactivate amylases, specially α- and β-amylase (El Tinay, Abdel Gadir and El Hidai 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). Additionally, fermentation has been found to increase the pasting viscosity of sorghum starch, apparently as a result of preferential break down of damage starch (Wanink, Van

Vliet and Nout 1994). The aim of this study was to determine the effect of fermentation of sorghum flour on the bread-making, sensory and nutritional quality of sorghum and wheat composite bread.

MATERIALS AND METHODS

Flours

A white, tannin-free sorghum from Mozambique was cleaned and ground with a hammer mill fitted with a 1 mm screen and then with a pin mill. The particle size distribution of sorghum flour was >95% <212 µm and >60% > 75 µm. 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 x 5.7) and ash of 1.9%, dry basis, 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 wheat flour was >95% <212 µm and >80% > 75 µm. Thus the sorghum flour was slightly coarser than the wheat flour, but still within the normal range for wheat flour.

Fermentation of sorghum flour

The 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 aluminium foil and allowed to ferment at room temperature (about 25°C) for 5 days. The pH and tritratable acidity (TA) were measured during the period of fermentation. TA was determined as ml of 0.1M sodium hydroxide (NaOH) required to raise the pH of 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, about 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 h. After drying, the fermented and dried material was remilled as described above and stored at 10°C.

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

Flour analyses

Flour pasting properties were determined using a Rapid Visco Analyser (RVA) 3D instrument (Newport Scientific, Narrabeen, Australia). Flour (4 g, 14% moisture content) was suspended in 25 ml distilled water and heated. The temperature profile used was: heat from 25 to 95°C in 5 min, hold at 95°C for 5 min, cool to 50°C in 5 min and hold at 50°C for 5 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, Curtin, and Moore 1997).

Flour moisture was determined using the air-oven method (Approved Method 44-15A), American Association of Cereal Chemists (AACC) (1983). Protein was determined using the crude protein Kjeldahl method, boric acid modification (Approved Method 46-12A) (AACC 1983). Soluble nitrogen was determined using the Association of Official Analytical Chemists (AOAC) Official Method Ba 11-65 (1995), except that the protein content of extracts was determined by converting the nitrogen values to protein (N x 6.25). The *in vitro* protein digestibility (IVPD) was determined by pepsin hydrolysis, as described by Hamaker, Kirleis, Butler, Axtell and Mertz (1987). Optimum water absorption was determined using the Farinograph method (Approved Method 54-21A) (AACC 1983). Total starch (TS) and enzyme susceptible starch (ESS) were determined using an α-amylase and amyloglucosidase 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, USA) set in red spectral. The higher the reading the lighter the sample, were 0 is black and 90 is white. All determinations were repeated at least twice.

Bread-making

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. The dough was mixed to optimum development for 15 to 20 min with a spiral mixer, rested for 15 min, divided into 950 g pieces, moulded and placed in baking pans of (275 x 100 x 105 mm). The dough was proofed for 50 min, at 40°C and 95% RH and baked at 230°C for approximately 30 min.

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

Bread analysis

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 1983). 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 about 2 to 3 h, and then wrapped in polyethylene bags and stored in ambient conditions (about 25°C) until required for testing. Measurements of crumb firmness began 4 h after baking for 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, Rooney and Taylor 2000) was done. 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 Analysis

A one-way analysis of variance (ANOVA) was determined. The level of significance was measured at 5% level using the StaSoft (1995) computer program. The significance of liking judgements 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

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, with fermentation (Table III-1). 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). Apparently, the color of the fermented and dried sorghum flour was slightly, but significantly (<0.05) lighter compared to unfermented sorghum grain flour (Table III-1) due to the low pH. Low pH brightens anthocyanins pigments by increasing methylation (Von Elbe and Schwartz (1996).

Fermentation and drying decreased the starch content of sorghum flour by about 2.8 percentage points but increased significantly the ESS content, from 1.6 to 10.5%, whereas it increased the total protein and decreased the water-soluble proteins (as a % of total proteins) by 1.1 and 5.8 percentage points, respectively. The IVPD of sorghum flour also increased from 35.3 to 52.7%. 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 increase of the IVPD of fermented sorghum flour, with a subsequent decrease in water soluble proteins, can be

TABLE III-1. Effect of fermentation and drying on the properties of sorghum flour

Bread ingredient	pH	Color (Agtron)	Titratable acidity (ml)	Starch (%)	ESS[1] (%)	Protein (%)	Soluble protein (%)	IVPD[2] (%)
Sorghum grain flour	6.2a[3]	8.4a	0.9b	68.3a	1.6b	12.3b	1.6 (13.1a)[4]	35.3b
Fermented and dried sorghum flour	3.4b	8.7b	11.9a	65.5b	10.5a	12.8a	1.0 (7.9b)	52.7a

[1] ESS, enzyme susceptible starch, expressed as % of total starch

[2] IVPD, *in vitro* protein digestibility, expressed as % of total protein

[3] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

[4] Soluble protein as a percentage of total protein

attributed to structural changes in the sorghum storage proteins (prolamins and glutenins). These modifications, apparently brought about by rapid lowering of the pH, make the storage proteins of sorghum more accessible to pepsin attack.

Heating and drying the fermented sorghum flour could have increased the ESS content of sorghum flour. Heating of carbohydrates at low pH causes a random depolymerization, i.e., breakage of glycosidic bonds of the starch molecules (BeMiller and Whistler 1996). Several researchers (Ahamed and Ramanathan 1988; Wanink et al 1994) have reported the inactivation of both, the grain and the bacteria amylases, with low pH of fermented sorghum flour. Thus, the increase in the ESS of fermented sorghum flour could not be due to amylase action.

Pasting properties of sorghum flour before and after fermentation and drying are presented in Figure III-1. Fermentation and drying did not change the pasting temperature of sorghum flour but increased, although slightly, the peak viscosity, holding strength and final viscosity of sorghum flour. The Falling Number values (data not shown) increased from 507 to 560 FNU, indicating a slight increase of the pasting viscosity of sorghum flour with fermentation and drying. It appears that inactivation of the amylases have occurred. However, it is not clear whether due to low pH, as suggested by Wanink et al (1994) or due to thermal denaturation with drying at 60°C.

The absence of browning of the fermented and dried sorghum flour can be explained by the unavailability of simple sugars and water-soluble proteins after a 5-days fermentation. During fermentation, the fermenting bacteria utilize the simple sugars, water-soluble

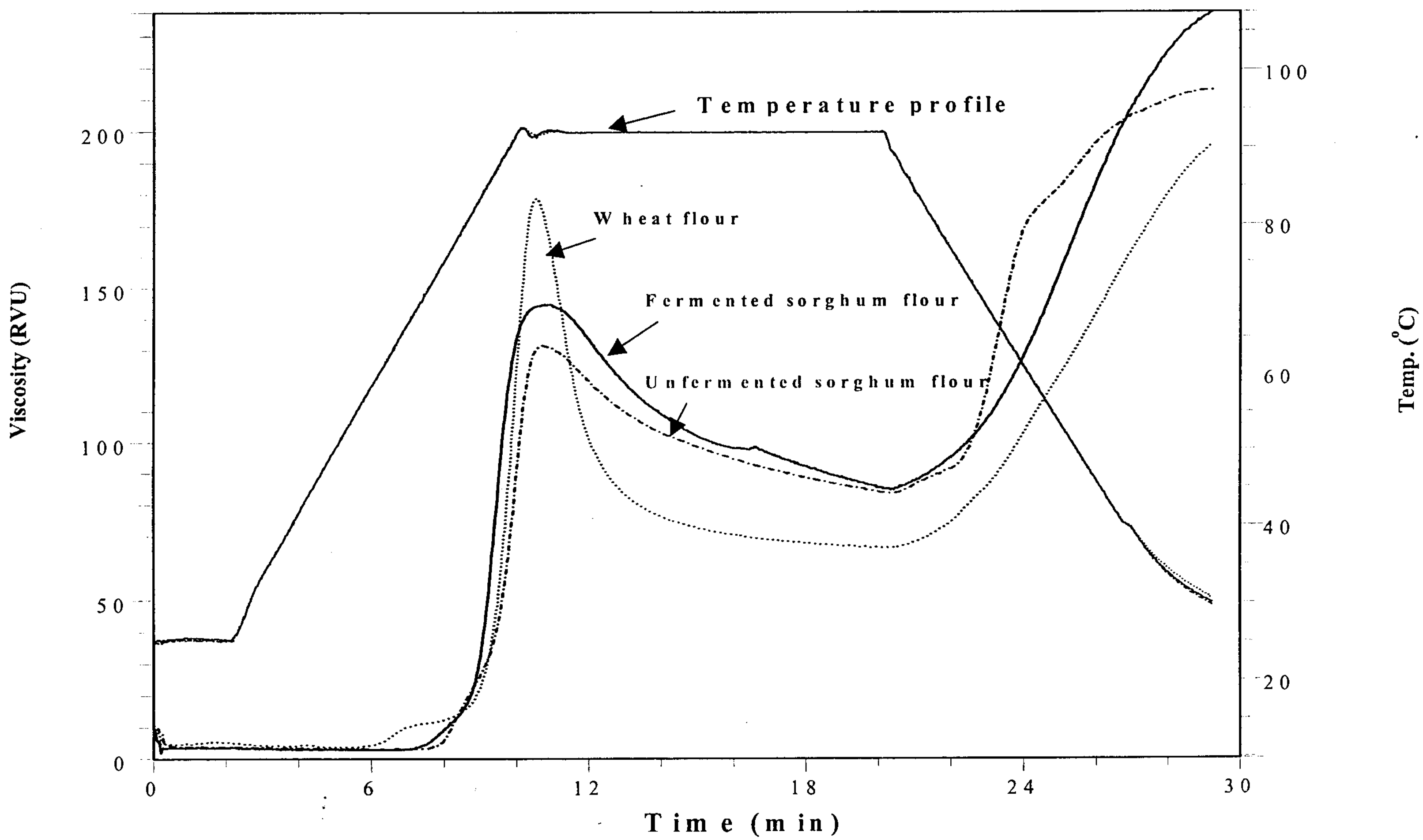

Figure III-1. Pasting properties of sorghum grain flour, fermented and dried sorghum grain flour and wheat flour.

proteins and amino groups (El Tinay et al 1979; Chavan and Kadam 1989). Therefore, the Maillard type of browning reaction, which occurs by heating sugars, with the involvement of proteins or amino groups (BeMiller and Whistler 1996), could not occur.

Bread-making properties of fermented sorghum flour

Fermented and dried sorghum flour (30%) decreased the pH of sorghum and wheat dough from 5.8 to 4.9, did not change the water requirement of sorghum flour but increased the bread volume from 2998 to 3117 cm^3, and slightly increased the weight of breads (Table III-2a). The increased volume of bread made with fermented and dried sorghum flour can simply be attributed to an improvement of the gas-holding capacity of sorghum and wheat composite dough. Probably, the increased viscosity of fermented and dried sorghum flour (Figure III-1) contributed to the increase of the viscosity of sorghum and wheat composite dough, and hence to the increase of its gas-holding capacity. Increase of dough viscosity results in improvement of the gas holding capacity of wheat dough (Gan, Ellis and Schofield 1995). The slight increase in loaf weight indicates a slight improvement on the water-holding capacity of sorghum and wheat dough with fermentation and drying of 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).

A comparison between the bread made with fermented and dried sorghum flour (30%) and the bread made with sorghum grain flour and boiled sorghum malt flour (Figure III-2) shows that the bread made with fermented and dried sorghum flour had the highest loaf volume and improved crumb structure, and the lighter crumb color, whereas the bread made with boiled sorghum malt flour (Hugo et al 2000) had the smaller loaf volume, the

TABLE III-2a. Water requirement and pH of dough and volume, weight and specific volume of composite breads containing sorghum and fermented and dried sorghum.

Bread Ingredient	Water requirement of dough (%)	pH of dough	Loaf volume (cm^3)	Loaf weight (g)	Specific volume (cm^3/g)
Wheat flour (100%)[1]	63.0a[2]	5.9a	4008a	835b	4.8 a
Sorghum grain flour (30%)[1]	63.0a	5.8a	2998c	855a	3.5b
Fermented and dried sorghum flour (30%)[1]	63.0a	4.9b	3117 b	860a	3.6b

TABLE III-2b. Volume, weight, specific volume, and crumb firmness of composite breads containing sorghum, fermented and dried sorghum and fermented sorghum flour (sourdough process).

Bread Ingredient	Loaf volume[3] (cm^3)	Loaf weight[3] (g)	Specific volume[3] (cm^3/g)	Crumb firmness[4] (g)
Wheat flour (100%)[1]	2133a[2]	429b	5.0a	11.0c
Fermented and dried sorghum flour (30%)[1]	1816c	424b	4.3b	20.6a
Fermented sorghum flour (30%) (sourdough process)[1]	1875b	433a	4.3b	16.6b

[1] Dry matter basis
[2] Values followed by the same letters in the same column are not significantly different (*P* <0.05).
[3] 500 g loaves
[4] 1-day crumb firmness

Figure III-2. Effect of different treatments on the volume, crumb structure and color of sorghum and wheat composite breads: (left to right) bread made with wheat flour (100%), sorghum grain flour (30%), boiled sorghum malt flour (30%) (see Chapter 4-II), and fermented and dried sorghum flour (30%).

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).

The crumb firmness of the breads over 3 days of storage is presented in Figure III-3. The bread made with fermented and dried sorghum flour (30%) was slightly softer and somewhat more resistant to firming compared to bread made with unfermented sorghum grain flour. The bread made with wheat flour was still the softest and had the lowest crumb-firming rate. The decreased crumb firmness of breads made with fermented and dried sorghum flour can be attributed to the increased volume and improved crumb structure of this bread. The low pH of rye and wheat sourdough has also been reported to contribute to a more cohesive and staling resistant crumb by inactivating the amylases (Seibel and Brümmer 1991). Because the low pH represses the activity of intrinsic amylases in sourdough (Siljeström, Björck, Eliasson, Lönner, Nyman and Asp 1988; Seibel and Brümmer 1991), the dextrinization of starch cannot account entirely for the decreased crumb firmness of breads made with fermented and dried sorghum flour, as reported by Martin and Hoseney (1991). According to these authors low-molecular weight dextrins prevent the staling of bread by interfering with crystallisation of starch.

Heating and drying the fermented sorghum flour obviously costs energy and takes time. As an alternative to drying, sorghum and wheat composite bread was prepared by mixing the fermented sorghum flour (1:1.2 water to liquid ratio), directly with the wheat flour, as in rye and wheat sourdough process. As shown in Table III-2b, the fermented sorghum flour (sourdough process) significantly increased both, the weight and the volume of bread and

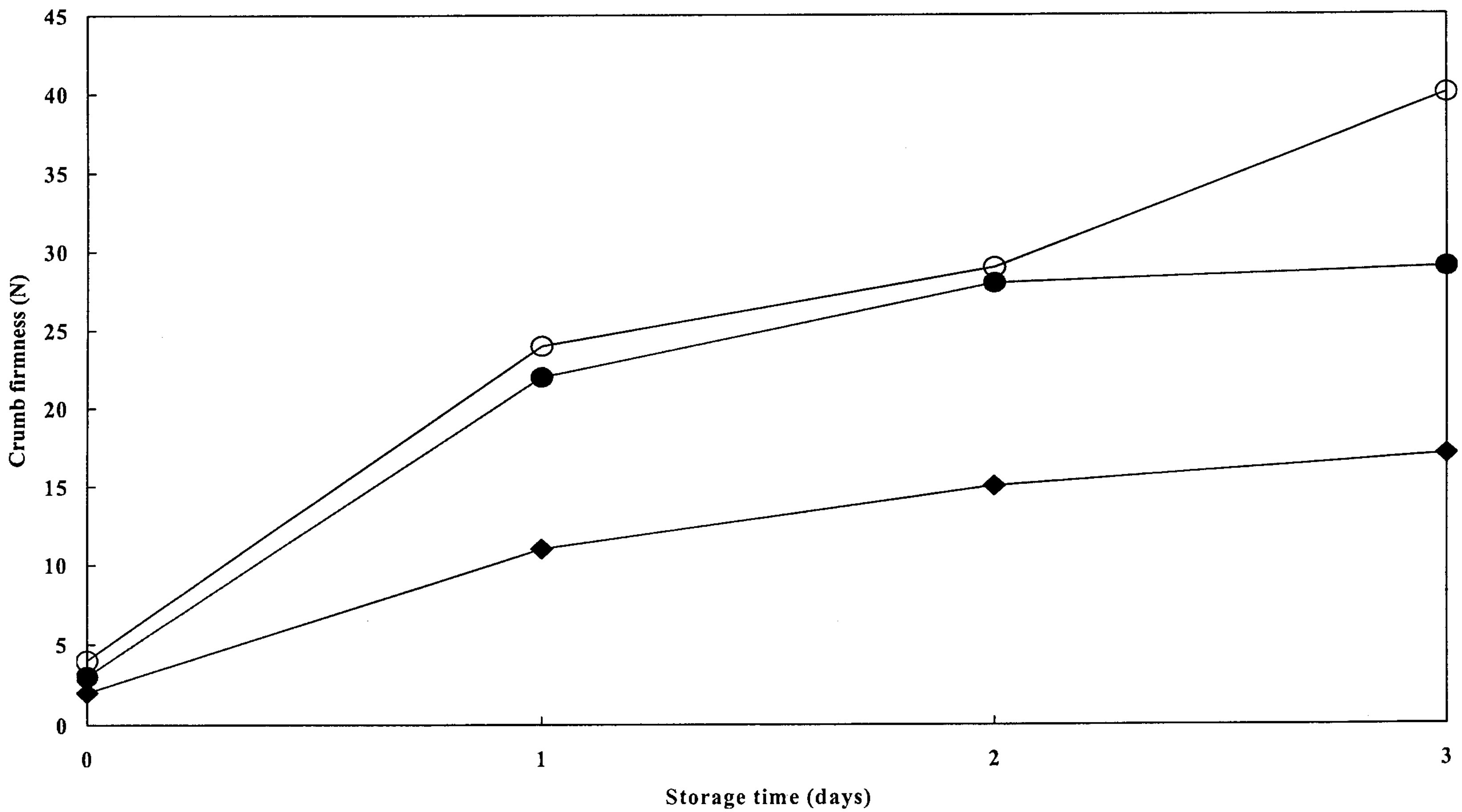

Figure III-3. Crumb firmness of sorghum and wheat composite breads as a function of storage time. (◆) Wheat flour (100%), (●) fermented and dried sorghum grain flour (30%), and (O) sorghum grain flour (30%).

decreased the 1-day crumb firmness, compared to fermented and dried sorghum flour. The slightly higher loaf weight of bread made with fermented sorghum flour (sourdough process) indicates a decrease on the water-holding capacity of fermented sorghum flour with heating and drying. This adverse effect of heating and drying on the bread-making quality of fermented sorghum flour could be because during drying, the condensation reactions brought about structural changes in flour polymers which interfered with their swelling power and solubility (Damodaran 1996). Thus the water-holding capacity of sorghum flour decreased, hence decreasing the weight of bread. The composite bread made by the sourdough process, as well has having a higher volume than the bread made with fermented and dried sorghum, had a lighter crumb color and a more open structure (Figure III- 4).

Protein quality of sorghum and wheat composite breads

As shown in Table III-3, bread-making 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 bread made with fermented and dried sorghum flour (30%) had a higher volume and a softer crumb compared to bread made with unfermented sorghum grain flour

Figure III-4. Effect of fermented sorghum flour (sourdough process) on the volume, crumb structure and color of sorghum and wheat composite breads: (left to right) WW, bread made with wheat flour (100%); DFS, bread made with fermented and dried sorghum flour (30%); and SFS, bread made with fermented sorghum flour (sourdough process) (30%).

TABLE III-3. Protein quality of breads made with wheat flour and fermented and dried and non-fermented sorghum and wheat composite flours

Bread ingredient	Total protein (%)	*In vitro* protein digestibility (%)
Sorghum grain flour (30%) [1]	12.5c[2]	64.0c
Fermented and dried sorghum grain flour (30%) [1]	12.9b	68.0b
Wheat flour (100%) [1]	13.2a	74.8a

[1] Dry matter basis

[2] Values followed by the same letter in the same column are not significantly different (P <0.05).

(30%), panel members liked it less and preferred it less (Table III-4). Panel members liked and preferred more the bread made with boiled sorghum malt flour (Hugo et al 2000). Apparently, they disliked the very sour taste of the bread made with fermented and dried sorghum flour. This suggests that a shorter fermentation, which would decrease the level of flour sourness, may be necessary to improve bread acceptability.

CONCLUSIONS

Fermenting and drying sorghum flour improves the volume and crumb structure, and decreases the crumb firmness of sorghum and wheat composite bread. Apparently the low pH of the fermented sorghum flour inactivates amylases, thus increasing the viscosity of sorghum flour and hence increasing the gas-holding capacity of dough and the bread volume. The fermentation process also improves the IVPD of sorghum and wheat composite bread. Adding the fermented sorghum flour directly in a sourdough process improves further the volume and the weight of bread, decreases the crumb firmness of sorghum and wheat composite breads and simplifies the bread-making process. Shorter fermentation time could produce a less pronounced sour taste, which could probably be more preferred.

TABLE III-4. Sensory evaluation of fermented and dried and non-fermented sorghum and wheat composite breads

Bread ingredients	Panellists liked bread	Rank sum of the sample[1]
Sorghum grain flour (30%)[2]	47	111a[3]
Fermented and dried sorghum grain flour (30%)[2]	38	136b

[1] Rank sum of the sample = Σ(number of panellists x the respective rank position). Lower rank sum indicates the better liked sample.

[2] Dry matter basis

[3] Values followed by the same letters in the same column are not significantly different (*P* <0.05).

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4. CHAPTER IV

FUNCTIONALITY OF SORGHUM NON-STARCH POLYSACCHARIDES IN COMPOSITE BREAD-MAKING

ABSTRACT

Whole boiled sorghum malt and whole sorghum grain flour were fractionated and reconstituted to determine whether some of the bread improving effect of whole boiled sorghum malt flour (Chapter II) was due to modifications of the non-starch polysaccharides of sorghum grain. Malting and boiling increased the NSPs of sorghum and modified them by slightly decreasing the total pentosans and increasing the water-soluble pentosans and crude fiber. These modifications increased the water-holding capacity of sorghum flour, decreased the crumb firmness and improved the crumb structure of sorghum and wheat composite bread. Treatment of sorghum grain flour with endo-(1-4)-β-xylanase increased the water-soluble pentosans only slightly and gelatinized the starch greatly due to subsequent heating to inactivate the enzyme. Bread made with endoxylanase treated sorghum flour had a slightly improved water-holding, but the volume was considerably lower, compared to bread made with untreated grain flour. Consumer panel members liked most the breads made with reconstituted flour containing boiled malt bran, apparently because these breads had a softer, more moist crumb, and malt flavor. The improved bread making quality of sorghum malt appears to be due mainly to its higher content of total and water-soluble pentosans, and crude fiber.

INTRODUCTION

Most research on the functionality of non-starch polysaccharides (NSPs) in bread-making indicates that water-soluble pentosans play an important role in the bread-making quality of wheat and rye flours; increasing dough viscosity (Jelaka and Hylinka 1972; Izydorczyk, Biliaderis and Bushuk 1991), enhancing bread volume (D'Appolonia, Gilles and Medcalf 1970; Delcour, Vanhamel and Hoseney 1991), and by decreasing the rate of starch retrogradation (Kim and D'Appolonia 1977a,b; Gudmusson, Eliasson, Bengtsson and Åman 1991). In contrast, the water-insoluble pentosans have an adverse effect on bread quality (Rouau, El-Hayek and Moreau 1994; Courtin, Roelants and Delcour 1999). For this reason, to improve the bread-making quality of wheat and rye flours, endoxylanases are commonly added to bread formula to partly solubilize and/or decrease the molecular weight of water-insoluble pentosans (Rouau 1993; Gruppen, Hormelink and Voragen 1993; Courtin et al 1999).

Most pentosans of sorghum are highly substituted and water-insoluble (Verbruggen, Beldman, Voragen and Hollemans 1993), unlike wheat and rye pentosans (reviewed by Fincher and Stone 1986). The mechanism by which the pentosans of sorghum affect the bread-making qualities of sorghum flour is not understood. However, the water-soluble pentosans of sorghum (replacing 1% wheat flour) have been found to improve the rheological properties of dough and the bread volume (Hahn and Rasper 1974), whereas the water-insoluble pentosans of sorghum, as those of wheat and rye grains, have adverse effects on dough and bread quality

Whole boiled sorghum malt (Chapter II) improved the crumb structure and decreased the crumb firmness of sorghum and wheat composite bread. It is possible that the NSPs of sorghum, particularly its arabinoxylans, which are known to become partly solubilized (EtokAkpan and Palmer 1994) and partly depolymerized (Verbruggen, Beldman and Voragen 1995) with malting, contributed to improving the bread-making properties of sorghum malt flour.

The positive effect of endosperm modification, particularly dextrinization and gelatinization of starch in bread-making has been discussed (Chapter II). The work reported in this chapter was carried out to determine whether the bread improving effect of whole boiled sorghum malt was due to modifications of the endosperm or the bran of sorghum grain. The experimental procedure fractionated whole sorghum grain and whole boiled sorghum malt into flour and bran components. Then, the fractions (bran and endosperm) of whole sorghum grain were recombined with equivalent fractions from whole boiled sorghum malt. Sorghum flour treated with endoxylanases was also evaluated.

MATERIALS AND METHODS

Sorghum and wheat

The sorghum grain used for this study was Larsvyt 4685, a white, tannin-free sorghum variety, supplied by Foods Botswana Ltd, Serowe, Botswana. The wheat flour used was 'Favorita', a white bread flour produced by Companhia Industrial da Matola (CIM), Maputo, Mozambique. This was a relatively weak flour with a protein content of 12.9% (N x 5.7) and ash 1.9%, dry basis, a water absorption of 63% and its mixogram mixing times were peak time 3.0 min and stability to mixing 2.8 min.

Endoxylanase

An endoxylanase preparation for the baking industry, Pentopan™ Mono BG, was kindly provided by Enzymes SA, Sandton, South Africa. According to Enzymes SA (1996) Pentopan™ Mono BG is a purified endo-(1-4)-β-xylanase which is produced by a genetically modified strain of *Aspergillus oryzae*. Its mode of action involves interaction between wheat arabinoxylans and gluten proteins, thus improving the strength and elasticity of gluten. The activity of Pentopan™ Mono BG is 2500 fungal xylanase units (FXU) per gram. The optimum dosage is in the range of 50-400 FXU per kg flour, i.e., 2-16 g per 100 kg flour, corresponding to 20-160 ppm.

Preparation of malts

Whole boiled sorghum malt was produced as described in Chapter II. Grains were steeped for 24 h and germinated for 5 days in a humidified incubator set at 28°C and 100% relative humidity (Morrall, Boyd, Taylor and Van der Walt 1986). The germinated grains were boiled in excess water for 20 min. At the end of 20 min, the excess water was drained and the germinated grains were dried in a forced-draught oven set at 80°C. Earlier results (Chapter II) indicated that this treatment was sufficient to inactivate amylases. Whole boiled sorghum grain was also prepared using the same heat-treatment as for boiled sorghum malt. Flours of whole sorghum grain, whole boiled grain and whole boiled malt were produced by milling the samples with a hammer mill fitted with a 1 mm screen and then with a pin mill.

Fractionation of grain and malt

Whole sorghum grain and whole boiled sorghum malt were fractionated as shown in Figure IV-1. Roller milling consisted essentially of 2 break and 2 reduction and several

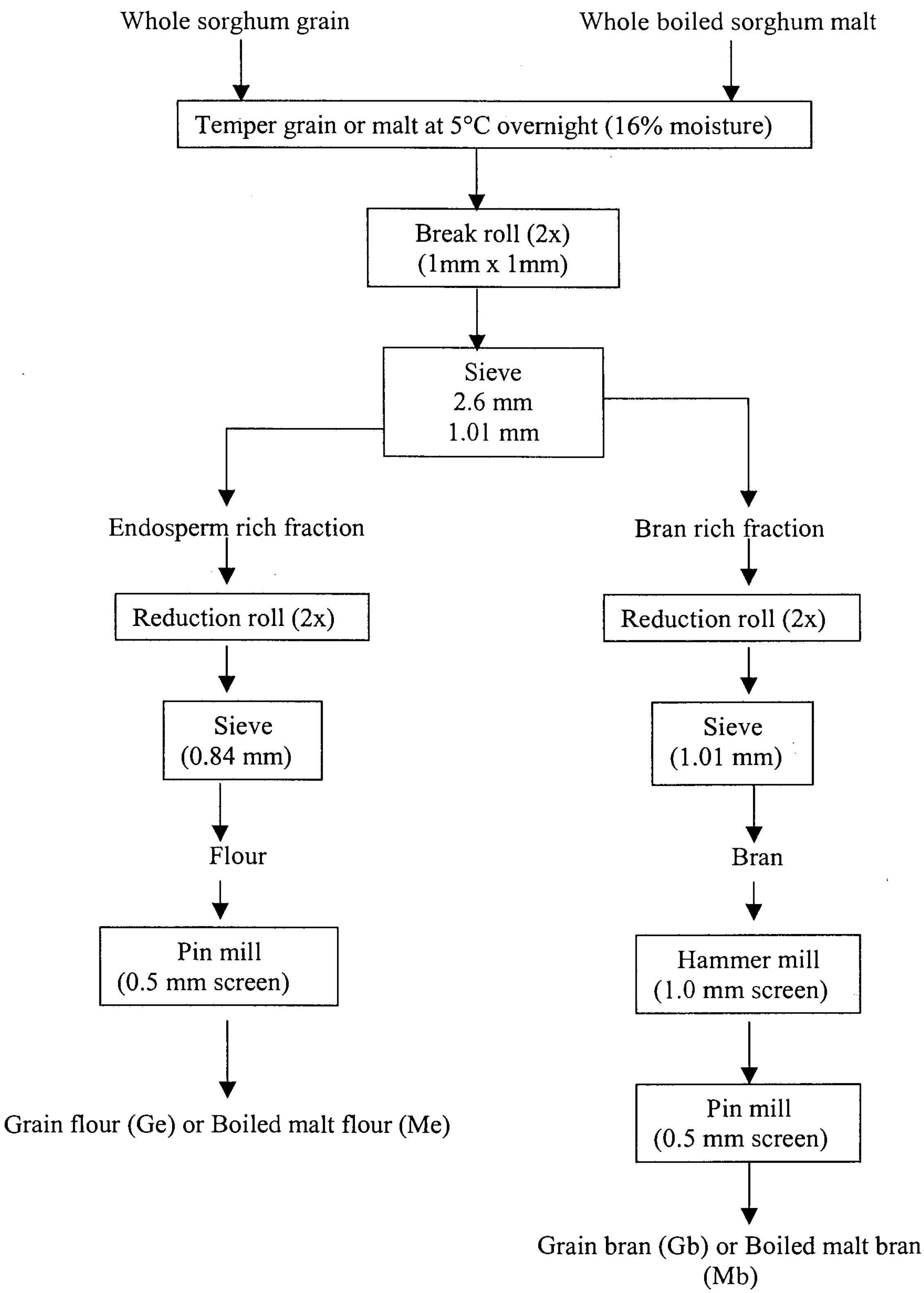

Figure IV-1. Procedure for fractionation of whole sorghum grain andwhole boiled sorghum malt hand sifting steps. Whole grains and malts were milled to extraction rates in the range of 75 to 80%. Four components were produced: Grain flour (Ge), Malt flour (Me), Grain bran (Gb) and Malt bran (Mb). Reconstituted grain and malt flours, respectively GeGb and MeMb flours and their cross-recombined flours, GeMb and MeGb flours, were also produced (Figure IV-2). For reconstitution of flours, the ratio of flour to bran fraction was 80% to 20%.

Endoxylanase treatment of flour

Endoxylanase treated whole sorghum grain flour was produced by weighing 1.0 g Pentopan^{TM} Mono BG into a 2 l volumetric flask and making up to volume with distilled water. Enzyme solution and whole grain sorghum flour, corresponding to a dosage of 2500 FXU per kg flour, were mixed and incubated for 2 h at 37°C, with shaking at intervals. After incubation, the mixture was heated to and maintained at 75-80°C for 30 min to stop enzyme activity, then dried at 50°C in a forced draught oven. The material was then milled with a hammer mill and a pin mill as described.

Bread-making

Bread was produced using wheat flour (70%), whole sorghum flour (30%), active dried yeast (1%), salt (2%), sugar (1%), ascorbic acid (20 ppm), fat (1%) and water, 65% for whole grain and GeGb flour, 70% for GeMb flour, and 75% for whole boiled malt flour and MeMb flour. Different amounts of water were added due to the higher water requirements of the flours containing boiled malt fractions. 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 of (275 by 100 by 105 mm). The dough

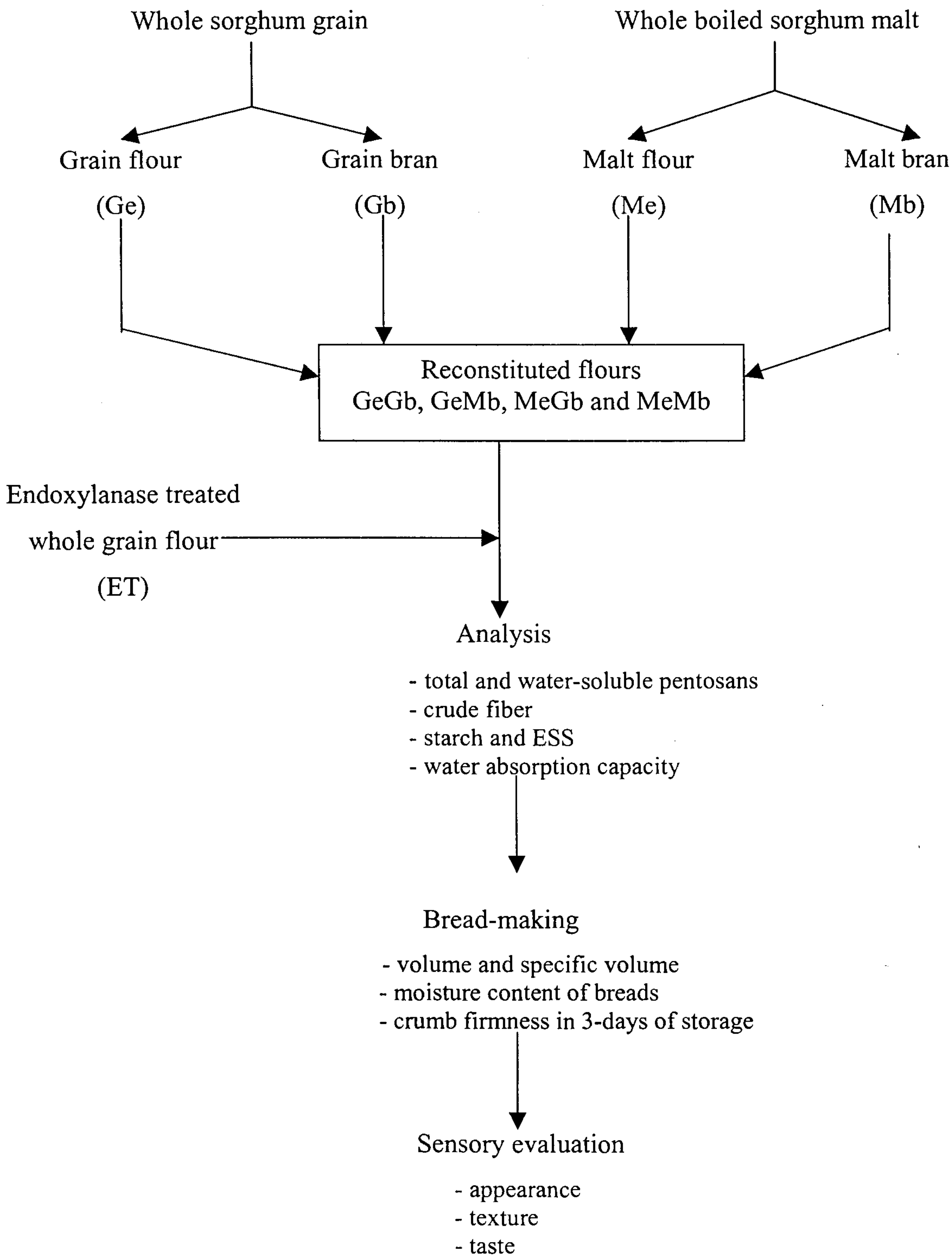

Figure IV-2. The experimental design for reconstitution and evaluation of bread-making properties of sorghum flours composited with wheat flour was proofed for 45-50 min, at 40°C and 95% RH and baked at 230°C for approximately 30 min.

Analyses

Moisture content of flours, moisture content of breads, crude fiber, crude fat and water absorption capacity (WAC), were determined using approved methods 44-15A, 44-18, 32-10, 33-25 and 88-04, respectively, of the American Association of Cereal Chemists (AACC) (1983). Total starch and enzyme susceptible starch (ESS) were determined using an α-amylase and amyloglucosidase hydrolysis method (Taylor 1992).

Total and water-soluble pentosans were determined using the Orcinol-hydrochloric acid method as described by Hashimoto, Shogren and Pomeranz (1987). For determination of total pentosans, samples were hydrolyzed in an autoclave at 100 kPa for 10 min, instead of 100°C for 2.5 h. Also, the flours were extracted at 37°C and not at 30°C.

Bread volume was determined by rapeseed displacement and the specific volume was calculated from the volume and weight of bread.

Crumb firmness, the amount of force required to compress bread slices, was determined with a TA-XT2 Texture Analyzer (Stable Micro Systems, Godalming, UK), using approved method 74-09 (AACC 1983), except that the instrument was fitted with a 28 mm diameter cylinder probe. Samples were prepared and cooled to ambient temperature for 2 to 3 h. After cooling, samples were wrapped in polyethylene bags (35 μm thickness). The loaves were then stored in baskets, in ambient conditions (about 20°C) until required for testing. Measurements of crumb softness began 4 h after baking for day zero (0), and thereafter at one-day intervals until the third day.

Sensory evaluation of the bread was performed using a consumer acceptability test (Stone and Sidel 1993). Panel members (50) were asked to evaluate the samples for appearance, texture and taste, and give explanations to why they preferred eating the bread. Samples were coded and presented to panelists in a random order. A 9-point hedonic scale was used.

All analyses were made at least in triplicate. All statistical comparisons were made on 5% level of significance, using one way analysis of variance (StatSoft 1995) computer program.

RESULTS AND DISCUSSION

Chemical composition of flours

Chemical composition of wheat flour, and boiled and unboiled whole sorghum grain and whole sorghum malt and their fractionated and reconstituted flours, and the enzyme treated whole sorghum grain flour are presented in Table IV-1. The major changes to the NSPs of sorghum grain resulting from malting were a slight decrease in total pentosans, from 5.5 to 5.1%, an increase in water-soluble pentosans, from 0.7 to 1.4%, and an increase in crude fiber, from 2.2 to 3.0%. The water-soluble pentosans, as a percentage of the total pentosans in the grain, increased significantly, from 12.7 to 27.5%. The total pentosans and the crude fiber of whole sorghum grain (WG) and whole boiled sorghum malt flours (WM) were higher than in wheat flour (WW). In contrast, notwithstanding the increase in the water-soluble pentosans with malting, water-soluble pentosans of WG and WM were much lower

Table IV-1. Composition of wheat flour and sorghum grain and sorghum malt flours boiled, fractionated and reconstituted (dry basis).

Flour	Starch (%)	ESS[1] (% of total starch)	Crude fiber (%)	Crude fat (%)	Total pentosans (%)	Soluble pentosans (%)	Soluble pentosans (% of total pentosans)
Wheat flour (WW)	73.4c[2]	21.3m	0.5k	1.7ig	4.3g	1.4b	32.6b
Whole sorghum grain flour (WG)	71.6e	23.6m	2.2i	3.7c	5.5e	0.7f	12.7g
Whole boiled sorghum grain flour (WBG)	71.6e	54.2f	2.7g	3.7c	4.4gf	0.3g	6.8h
Whole sorghum malt flour	65.0g	26.2j	3.0e	3.2d	5.1e	1.4c	27.5c
Whole boiled sorghum malt flour (WM)	68.6f	84.0a	3.6d	3.0d	4.8f	1.0d	20.8d
Sorghum grain flour (Ge)	78.4a	20.3n	1.6j	3.0d	4.6e	0.4g	8.7e
Boiled sorghum grain flour	76.1b	47.6g	1.5j	3.1d	5.1e	0.4g	7.8m
Sorghum malt flour	76.7b	25.4l	1.7j	2.3h	4.8f	0.6f	12.5g
Boiled sorghum malt flour (Me)	76.3b	72.9d	2.3h	2.4h	5.6d	0.7f	12.5g
Sorghum grain bran (Gb)	61.9h	18.6o	4.3c	4.8a	7.5c	0.8e	10.7h
Boiled sorghum grain bran	57.3i	54.6f	5.8a	3.9c	9.4a	0.5g	6.7n
Sorghum malt bran	53.3j	36.4h	4.9b	4.4b	9.2a.	2.7a	39.3a
Boiled sorghum malt bran (Mb)	61.2h	74.8b	5.0b	3.9c	9.0b	1.0d	10.8h
Sorghum grain flour and grain bran (GeGb)	73.5c[3]	20.4n[3]	2.1i[3]	3.4e[3]	5.5e[3]	0.5g[3]	9.5j[3]
Sorghum grain flour and boiled malt bran (GeMb)	73.2c[3]	29.9i[3]	2.3h[3]	3.2e[3]	5.9d[3]	0.5g[3]	9.8i[3]
Boiled sorghum malt flour and grain bran (MeGb)	72.2d[3]	64.8e[3]	2.7g[3]	3.0f[3]	5.6e[3]	0.7f[3]	13.0f[3]
Boiled sorghum malt flour and boiled sorghum malt bran (MeMb)	71.8e[3]	74.1b[3]	2.8f[3]	2.7g[3]	6.0d[3]	0.9e[3]	13.2f[3]
Endoxylanase treated whole sorghum flour[4]	71.6e	73.2c	2.2i	3.6d	5.4e	1.0d	18.5e

[1] ESS= Enzyme susceptible starch

[2] Values followed by the same letter in the same column are not significantly different (P <0.05).

[3] Estimated by calculation

[4] Whole grain sorghum flour treated with endo (1-4)-β-xylanase, with 2500 fungal xylanase units per kg flour.

than in WW. Malting and boiling decreased the starch content and increased the ESS content of sorghum grain. The starch content of WM was lower than WW and the ESS content much higher.

The increase in water-soluble pentosans of sorghum grain with malting has been attributed to hydrolytic degradation of the NSPs (EtokAkpan 1993) and the increase in ESS to hydrolytic degradation of starch (Bhise, Chavan and Kadam 1988), respectively. The increase in crude fiber with malting can be attributed to growth of the roots and shoots of germinated grains (Novellie 1962). The decrease in starch content of sorghum malts has been attributed to hydrolytic degradation of starch into simple sugars, and their oxidation, through respiration of the simple sugars into CO_2 and water, during germination (Pathirana, Sivayogasunderam and Jayatissa 1983).

Boiling decreased the total and the water-soluble pentosans, and increased the crude fiber of WBG and WM (Table IV-1). Boiling significantly increased the ESS content of grain and malt through starch gelatinization. The decrease in total and water-soluble pentosans and the increase in crude fiber of WBG and WM due to boiling can be attributed to leaching and loss of some of the water-soluble materials, including pentosans, into the boiling water. About 3.0% of the dry weight of malts were lost into the boiling water.

The endosperm-rich fractions, grain flour (Ge) and boiled malt flour (Me), contained too much fiber (i.e. bran) and the bran fractions, grain bran (Gb) and boiled malt bran (Mb) contained too much starch (i.e. flour) (Table IV-1). Notwithstanding this, fractionation was achieved to a certain extent, with the flours containing more starch and the brans containing more fiber than whole grain or whole boiled malt. As expected, the flour fractions contained less total and water-soluble pentosans compared to the respective bran fractions.

The contents of total pentosans and crude fiber of endoxylanase treated whole sorghum grain flour (ET flour) remained the same, compared to untreated whole sorghum grain flour, but the water-soluble pentosans increased from 0.7 to 1.0% (Table IV-1). This is in accordance with EtokAkpan (1993) who found that endoxylanase solubilized, however slightly, the pentosans of sorghum. The ESS content of endoxylanase treated whole sorghum grain flour also increased, from 23.6 to 73.2%, as a result of the heat treatment applied to inactivate the enzyme.

Bread-making characteristics of reconstituted and enzyme treated sorghum flours

Whole sorghum grain flour (WG) gave bread with highest loaf volume (1950 cm^3) and lowest water-holding, i.e., lowest weight and moisture content. These were 528 g and 36.8%, respectively (Table IV-2). The bread made with whole boiled sorghum malt flour (WM) had lower loaf volume (1825 cm^3) but highest water-holding. These changes corresponded to a decrease of 6.4% in the bread volume, and to an increase of 1.5 and 10.9% in the weight and moisture content of breads, respectively. As discussed (Chapter II), the ESS content of WM flour, accounted for the decreased volume and some of the increased weight and moisture content of breads made with WM flour. Whole boiled sorghum grain flour (WBG) gave bread with the lowest loaf volume and a slightly increased weight and moisture content. Presumably, the high ESS content of WBG flour caused much of the decrease on the bread volume and some of the increase on the weight and moisture content of bread. In comparison, the higher loaf volume and water-holding

Table IV-2. Volume, weight, specific volume and moisture content of wheat flour bread and breads containing wheat flour and reconstituted sorghum grain, sorghum malt flours, and endoxylanase treated whole sorghum grain flour.

Bread ingredient[1]	WAC[2] (cm^3/g)	Loaf volume (cm^3)	Loaf weight (g)	Loaf specific volume (cm^3/g)	Moisture content (%)
Wheat flour (WW)	0.8h[3]	2150a	537b	4.0a	39.7b
Whole sorghum grain flour (WG)	1.1g	1950b	528c	3.6b	36.8f
Whole boiled sorghum grain flour (WBG)	1.4f	1594h	529c	2.7f	37.9d
Whole boiled sorghum malt flour (WM)	1.6c	1825d	536b	3.1c	41.3a
Sorghum grain flour and grain bran (GeGb)	1.5d	1869c	531c	3.2c	36.6f
Sorghum grain flour and boiled malt bran (GeMb)	1.3e	1794e	539a	3.0d	37.0e
Boiled sorghum malt flour and grain bran (MeGb)	1.5d	1663g	536b	2.8e	38.3d
Boiled sorghum malt flour and boiled malt bran (MeMb)	1.7b	1600h	541a	2.6f	38.6c
Endoxylanase treated whole sorghum grain flour (ET)[4]	2.6a	1706f	537b	2.9e	37.3e

[1] Except for wheat flour (100%), recipes contained sorghum flour (30%) and wheat flour (70%).

[2] WAC, water absorption capacity of flours.

[3] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

[4] Whole sorghum grain flour treated with endo (1-4)-β-xylanase, 2500 fungal xylanase units per kg flour.

of bread made with WM, would appear to be mainly due to the high contents of total and water-soluble pentosans in the WM flour, since it also had a high ESS content.

Among the reconstituted sorghum flours, the GeGb flour, which had the lowest contents of total and water-soluble pentosans and crude fiber (Table IV-1), gave bread with the highest volume but lowest water-holding (Table IV-2). GeMb flour decreased the bread volume by 4.0% and increased the weight and the moisture content of bread by 1.5 and 1.1%, respectively, compared to GeGb. This is probably because GeMb flour had higher total pentosans, lower water-soluble pentosans and crude fiber, and higher ESS (Table IV-1). The MeGb flour decreased the bread volume by 11.0% and increased the weight and moisture content of bread by 1.5 and 1.9%, respectively. The MeMb flour also decreased the bread volume, by 14.4% and increased the weight and moisture content of breads by 1.9% and 5.5%, respectively.

The MeGb flour and the MeMb flours by decreasing the bread volume much more, compared to GeGb and GeMb flours, respectively, indicated that Me fraction had a particularly depressing effect on the bread volume. The Mb fraction caused most of the increase of the water-holding property of breads. Mb containing flours, i.e., GeMb and MeMb flours, by giving breads with finer crumb structure (Figure IV-3), compared to GeGb and MeGb flours, indicated that Mb improved also the bread crumb structure.

The improving effect of Mb, can be due to the higher content of total and water-soluble pentosans, compared to Gb. Pentosans stabilize and prevent coalescence of bread air cells by a combination of bulk viscosity and surface effects (Sarker, Wilde and Clark 1998), and

Figure IV-3. The volume and crumb sructure of sorghum and wheat composite breads. From left to right: WG, whole grain flour; GeGb, grain flour and grain bran; GeMb, grain flour and boiled malt bran; MeGb, boiled malt flour and grain bran; MeMb, boiled malt flour and boiled malt bran; and WM, whole boiled malt flour.

increase bulk viscosity of bread dough basically by the formation of polysaccharides-protein complexes through oxidative gelation (Hoseney and Faubion 1981; Vinkx, Van Nieuwenhove and Delcour 1991) and arabinoxylan-mediated cross-linking (Dickinson 1993).

The high content of crude fiber and the lower ESS content of Mb, compared to Gb (Table IV-1), may have also played an important role on the moisture-holding property of breads. Crude fiber, i.e., bran, has been reported to increase the water absorption of dough and to decrease the bread volume (Shogren, Pomeranz and Hashimoto 1981). A particular amount of ESS, perhaps about 30% ESS, as in GeMb flour, may have a beneficial effect on the crumb structure. This is particularly important taking into consideration that starch gelatinization is the main factor for structuring and setting the bread crumb (Rotsch 1954). However, too much ESS, about 80.0%, as in WM, decreased the strength and the gas-holding property of sorghum and wheat composite dough (Chapter II).

The endoxylanase treatment did not improve bread quality much (Figure IV-4). The volume of bread made with endoxylanase treated whole sorghum grain flour (ET flour) decreased by 12.5% and its weight and moisture content increased only by 1.1% and 1.3%, respectively, compared to bread made with untreated whole sorghum grain flour (WG) (See Table IV-2). The water-soluble pentosans (1.0%) improved only and then only slightly the moisture holding and the crumb structure of sorghum and wheat composite breads (Figure IV-4). The high ESS content of ET, 73.2% compared to 23.6% of WG, can account for the poor bread volume and dense crumb of bread made with ET flour.

Figure IV-4. Effect of endoxylanase treatment on the volume and crumb structure of sorghum and wheat composite bread: WG, bread made with whole sorghum grain flour and 1.0%, bread made with whole sorghum grain flour treated with endo-(1-4)-β-xylanase, 2500 fungal xylanase units per kg of flour.

Crumb firmness

The crumb firmness of wheat bread (WW) was the lowest, and the crumb firmness of composite bread made with whole boiled sorghum malt flour (WM) was lower compared to bread made with whole sorghum grain flour (WG) (Figure IV-5). The decreased crumb firmness of bread made with WM flour was due to the dextrinization of starch induced by malting, as discussed earlier (Chapter II). The highest crumb firmness of bread made with whole boiled sorghum grain flour (WBG), indicates that high content of gelatinized starch, does not improve crumb softness. Gelatinized starch retrogrades easily thus producing a faster staled bread (Kulp 1981).

The initial crumb firmness of breads made from reconstituted flours decreased from 416 g for GeGb flour to 377 g when bread was made with MeGb flour, but the 3-days crumb firmness increased from 664 g to 734 g. This indicates that Me decreased the initial crumb firmness but increased the crumb-firming rate. These changes can be attributed to very high ESS content of Me, compared to Ge. On the other hand, the lower initial and three-day crumb firmness of breads made with GeMb and MeMb flours, 383 and 393 g and 626 and 646 g, respectively, appears to indicate that boiled malt bran (Mb) decreased both the initial crumb firmness and crumb firming rate. This can be explained by the fact that Mb was richer in crude fiber and total and water-soluble pentosans, whereas Me was much higher in starch and ESS content.

The initial and the three-day crumb firmness of bread made with endoxylanase treated whole sorghum grain flour (ET flour), were much higher than bread made with WG flour (Figure IV-5). The lower bread volume and the high ESS content of the flour may have contributed for these results. However, the initial and three-day crumb firmness, of bread

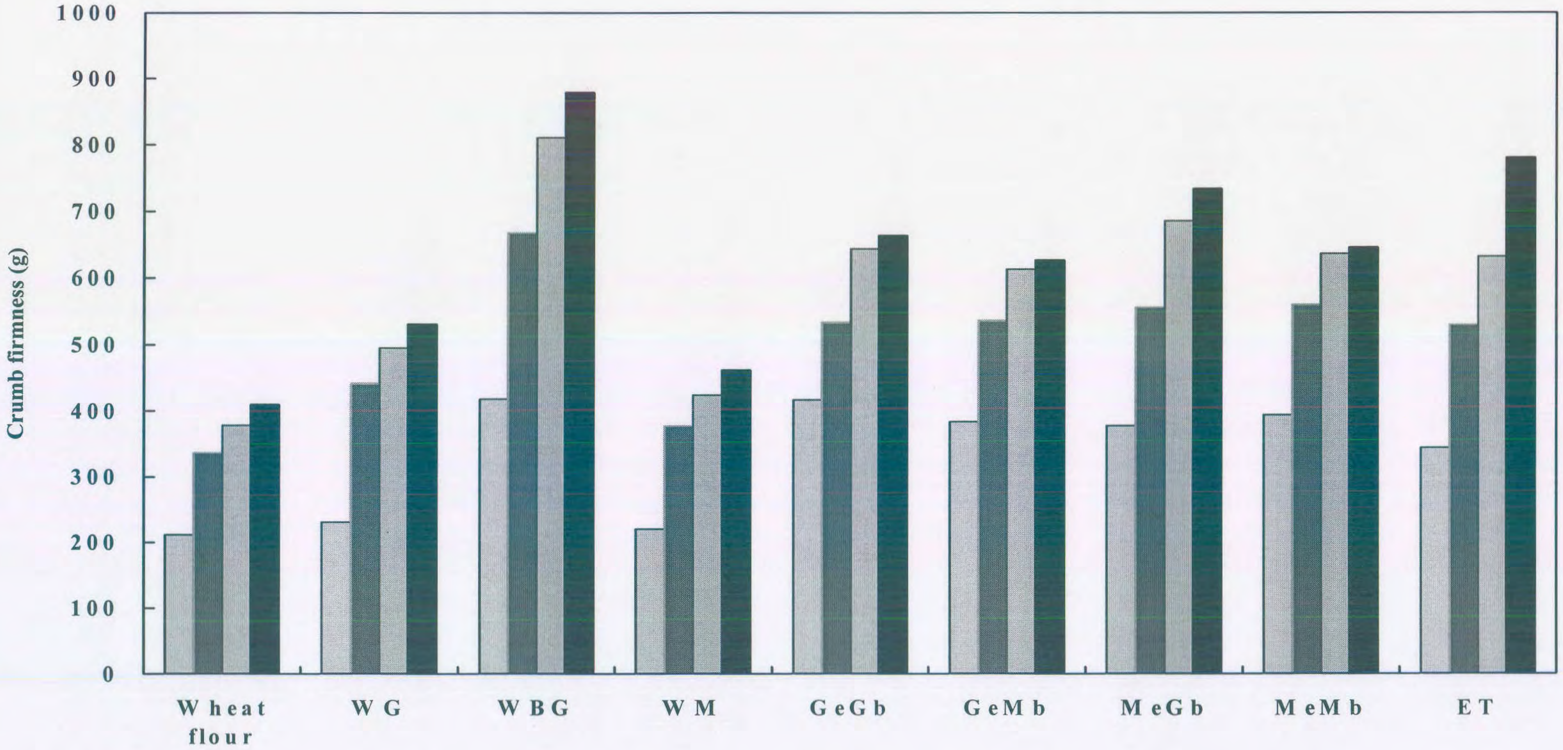

Figure IV-5. Crumb firmness of breads made with wheat flour and wheat flour composited with whole sorghum grain flour, WG, whole boiled sorghum grain flour, WBG, whole boiled sorghum malt flour, WM, grain flour and grain bran, GeGb, grain flour and boiled malt bran, GeMb, boiled malt flour and grain bran, MeGb, boiled malt flour and boiled malt bran, MeMb, and endoxylanase treated whole sorghum grain flour, ET, where: ▪ day 0, ▪day 1, ▪ day 2, ▪ day 3.

made with ET flour were lower, compared to bread made WBG flour, probably due to the somewhat higher content of water-soluble pentosans of ET flour, as ET had higher ESS than WBG.

GeMb gave the highest bread quality overall considering all physical factors (loaf volume, water holding and crumb firming) among the reconstituted sorghum flours (Table IV-2). GeMb flour had the highest content of total pentosans among the reconstituted flours and the highest ratio of total to water-soluble pentosans. Taking into account that most of the pentosans of sorghum grain are water-insoluble, it is possible that the increase in total pentosans, not particularly the increase in water-soluble pentosans, was the most important factor in increasing the water-holding property of breads. However, it could be because the amount of water-soluble pentosans induced by malting and boiling (1.0%) (Table IV-1), was still too low to produce improvements in the bread quality.

Sensory evaluation

The appearances of bread made with WG, GeGb and GeMb flours were most liked (Figure IV-6), because of finer crumb structure and the lighter crumb color. The breads made WM, MeGb and MeMb flours, were less acceptable. The denser crumb and darker color of these breads, were undesirable. The bread made with ET flour was the least liked, because of its dense crumb.

The breads made with WM flour, GeGb flour and GeMb flour had best texture, followed by the breads made with WG flour, MeGb flour, MeMb flour and ET flour (Figure IV-6). As reported in Chapter II, the bread made with WM flour was more moist, compared to bread made with WG flour. GeGb and GeMb breads were liked as much as the breads

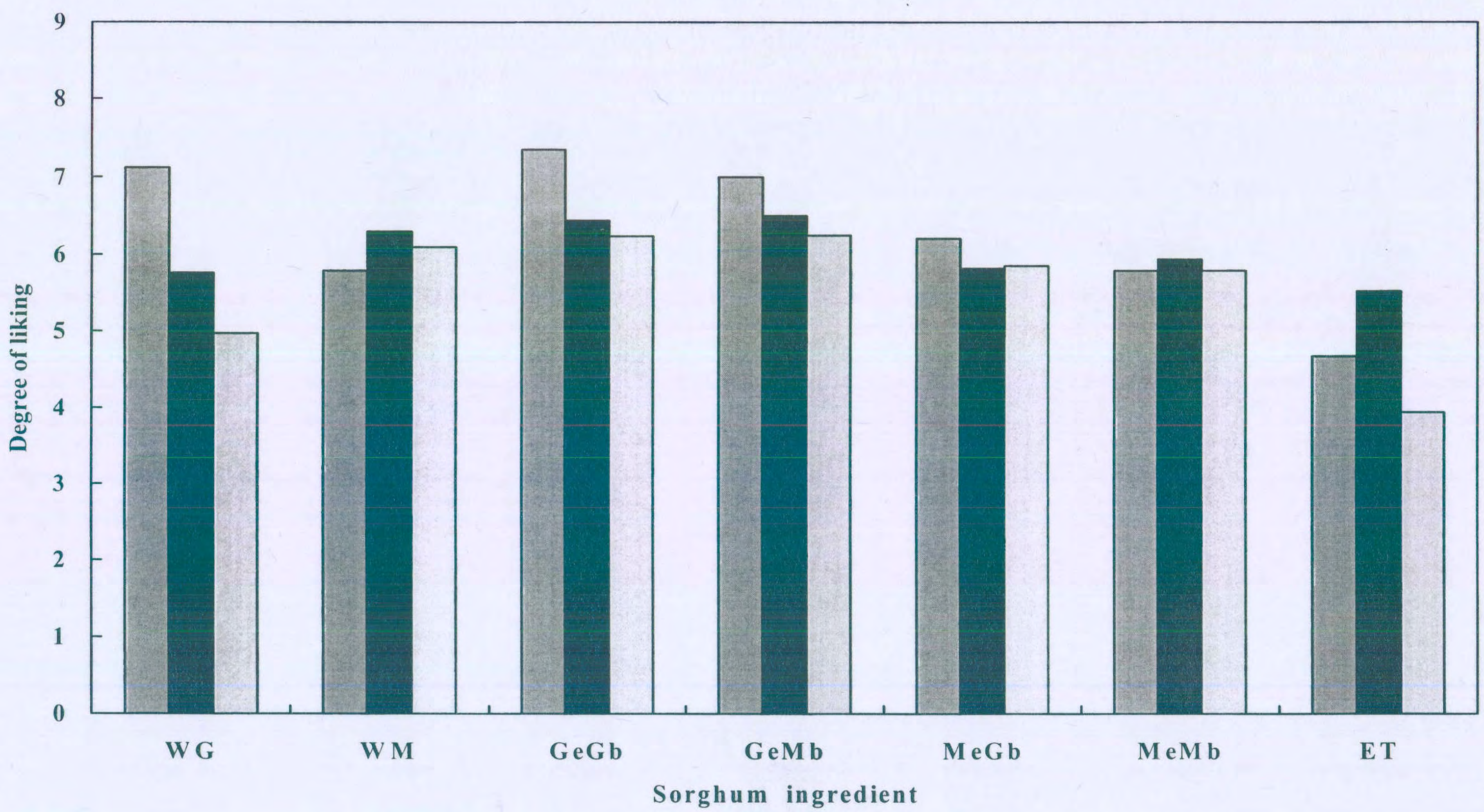

Figure IV-6. Sensory evaluation of composite breads made with whole sorghum grain flour, WG, whole boiled sorghum malt flour, WM, and the reconstituted grain flour and grain bran, GeGb, grain flour and boiled malt bran, GeMb, boiled malt flour and grain bran, MeGb, and boiled malt flour and boiled malt bran, MeMb, and endoxylanase treated whole sorghum grain flour, ET, where 1=dislike extremely, and 9= like extremely and ■ appearance, ■ texture, ■ taste of bread.

made WM flour. Apparently, as a result of their high loaf volume, these breads were soft. Most panel members commented on the dryness of breads made with WG and GeGb flours, but no mention was made of the grittiness of breads. Presumably, as a result of the improvements made in the baking procedure (see Chapter II).

The breads made with WM flour, GeGb and GeMb flours, had a highly desirable taste, followed by breads made with MeGb and MeMb flours (Figure IV-6). The taste of bread made with WG flour was intermediate. The taste of bread made with ET flour was disliked. Malt flavor increased composite bread acceptability.

CONCLUSIONS

Malting increases the NSPs of sorghum flour by greatly increasing the crude fiber. Malting and boiling modifies the NSPs of sorghum by decreasing the total pentosans and increasing the crude fiber and the water-soluble pentosans. These modifications occurring on the bran fraction of the sorghum grain increase greatly the water-holding property of sorghum and wheat composite dough and bread and decrease significantly the crumb firmness and crumb firming rate, as well as improve the crumb structure. Crude fiber appears to improve the moisture-trapping property of bread and decrease the crumb firmness, whereas water-soluble pentosans improve the bread crumb structure and decrease the crumb firming rate. Malting and boiling also modifies the flour fraction of the sorghum grain by dextrinizing and increasing the amount of gelatinized starch. The dextrinization and the increase of gelatinized starch increasing slightly the water-holding property, decreased the initial crumb firmess and increased although slightly the crumb-firming rate. Treatment of whole sorghum grain flour with endo-(1-4)-β-xylanase, increased the water-soluble pentosans slightly but the quantity (1.0%), was too low to improve bread quality. In addition, the heat-treatment used to inactivate the enzyme caused excessive gelatinization of starch which reduced loaf volume, compared to untreated whole sorghum grain flour.

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5. GENERAL DISCUSSION

The present work suggests a novel approach which uses the simple technologies of malting and fermentation to modify, endogenously, the starch and the non-starch polysaccharides (NSPs) of sorghum, thus decreasing the gelatinization temperature of sorghum starch and increasing the water absorption capacity of sorghum flour. The real challenges with this approach were to try to use the type of relatively weak wheat flours, that are available in poor developing countries (Randall et al 1995), together with sorghum flours milled by simple and commonly available technologies, such as hammer and pin milling, to produce bread of acceptable quality.

As summarized in Table 5-1, malting and boiling prevented the grittiness and the dryness, and decreased the crumb firmness and crumb firming rate of sorghum and wheat composite bread. These beneficial effects were attributed to modifications of the starch and pentosans of the sorghum grain. The dextrinization of starch and its gelatinization, were the major modifications occurring to the endosperm of sorghum grain, with malting and boiling. Dextrinization decreased the gelatinization temperature of starch and the rate of starch retrogradation, and decreased the crumb firmness and the firming rate of breads. Starch gelatinization increased the moisture content of sorghum and wheat composite bread.

Modifications on the bran fraction of sorghum grain, with malting, resulted in decrease of total pentosans and increase of crude fiber and water-soluble pentosans. The growth of the roots and shoots of germinated grains contributed greatly to the increase of crude fiber (Novellie 1962), whereas the increase of the water-soluble pentosans with malting, has

Table 5-1: Merits, drawbacks and recommendations concerning malting and boiling, and endoxylanase-treatments on the bread-making properties of sorghum flour

Technological approach	Merits	Drawbacks	Recommendations
Malting and boiling	Decreased pasting temperature Dextrinized and gelatinized starch Increased water holding capacity Increased crude fiber and water-soluble pentosans Prevented the grittiness and the dryness of breads Decreased the crumb firmness and crumb firming rate Improved crumb structure Improved the moisture content of bread Improved the flavor of bread	Boiling decreased water-soluble proteins and pentosans. Boiling produced too much gelatinized starch Did not improve the IVPD[1] of composite breads Decreased the bread volume Bread had a dark color High cost of boiling and drying the malt	Steaming the malt[2] instead of boiling to decrease ESS of flour and the loss of water-soluble proteins and pentosans Sun drying the malt to produce malt flour with a lighter color, and also decrease the processing costs
Endoxylanase treatment	Increased water-soluble pentosans of sorghum flour Decreased firmness of bread Endoxylanases can also hydrolyse pentosans of wheat flour	Heating to stop the enzyme produced too much gelatinized starch High cost of heating and drying Enzymes have to be imported	Add endoxylanase to moistened sorghum flour, and allow some time for the enzyme activity before mixing into dough.

[1] IVPD, *in vitro* protein digestibility

[2] (See Chapter II)

been attributed to the development of endo-(1-3)-β-glucanase and pentosanases in germinated sorghum (Aisien et al 1983; EtokAkpan and Palmer 1990). Boiling, however, decreased significantly the total and the water-soluble pentosans of sorghum malt, due to leaching of water-soluble malt components into the boiling water. However, boiled sorghum malt flour was still considerably higher in crude fiber and slightly higher in water-soluble pentosans, compared to sorghum grain flour.

The increased water-holding capacity as well as the decreased crumb firmness and crumb-firming rate of sorghum and wheat composite bread, with malting and boiling, can be attributed to the higher content of crude fiber and water-soluble pentosans of boiled sorghum malt flour. Increased amounts of crude fiber and pentosans increase the water-holding capacity of wheat and rye flours (Bechtel and Meisner 1954; Maleki et al 1980; Hoseney and Mattern 1980) and an increased content of water-soluble pentosans decreases the staling of bread (Kim and D'Appolonia 1977a,b; Gudmundsson et al 1991). An increase in the moisture content of bread gives softer bread crumb (Kulp and Ponte 1981).

The major drawbacks of malting and boiling on the bread-making quality of sorghum flour (Table 5-1) were the decreased volume and the dark color of bread made with boiled sorghum malt flour, and the decreased protein digestibility of sorghum flour. Most of these adverse effects of malting and boiling on the bread-making quality of sorghum flour were attributed to the boiling part of the process. Boiling gelatinized the starch and decreased the products of malt hydrolysis, such as the water-soluble proteins and water-soluble pentosans. A high amount of gelatinized starch decreased the bread volume. According to Hoseney (1994) high content of gelatinized starch in bread flour decreases the strength of the dough, and hence the bread volume. On the other hand, the decreased content of water-soluble components in dough, decreases the viscosity of dough, and decreases its gas-holding capacity and the loaf volume (Sarker, Wilde and Clark 1998). Boiling eliminated the beneficial effect of malting on the solubility and digestibility of sorghum protein, thus decreasing the protein digestibility of sorghum and wheat composite breads. The storage proteins of sorghum become less digestible after cooking, apparently due to an increase of the levels of cross-linking (Axtell et al 1981; Hamaker et al 1987).

Notwithstanding these drawbacks, malting has a considerable potential to improve the composite bread-making quality of sorghum flour. The adverse effects of boiling which was used to inactivate malt enzymes, so as to increase the pasting viscosity of sorghum malt flour, could be decreased with steaming. Steaming the malt should inactivate malt enzymes, decrease the amount of gelatinized starch and reduce the loss of the water-soluble components. Drying the boiled sorghum malt was also a necessary process for dry milling the malt and to produce a shelf-stable product. Alternatively, sun drying the boiled malt, instead of drying in a forced draught oven at 50°C would give malts with a lighter color and decrease the processing costs, but it would probably reduce the flavor of malts. The preferred roasted malt flavor was produced during drying the malt at high temperatures, as 50°C.

The poor protein digestibility of sorghum malt flour and sorghum and wheat composite bread could also be improved with steaming the malt. Decreasing the leaching losses of water-soluble protein should improve the protein digestibility of sorghum flour and composite bread. It is also recommended to use sorghum grain with high protein content, such as the Local White (Chapter II), as this characteristic of the sorghum grain contributed significantly to the high protein improvement of sorghum malts.

Treatment of sorghum flour with endo-(1-4)-β-xylanase (summarized in Table 5-1), slightly increased the water-soluble pentosans of sorghum flour. In sorghum grain, where about 87.0% of the total pentosans are water-insoluble (Verbruggen et al 1993), and also hardly solubilized with endoxylanases (EtokAkpan 1993; Verbruggen et al 1993), this result indicates that endoxylanases have some potential to improve the bread-making quality of sorghum flour. In wheat flour, about 30% of the total pentosans occur as water-soluble pentosans (Shogren et al 1987), and enhance dough viscosity and the bread volume (Jelaka and Hylinka 1972).

The poor bread-making quality of the endoxylanase treated sorghum flour was related to excessive gelatinized starch, caused by heat-treating the flour to inactivate the enzyme. Heat-treating the flour to inactivate the enzyme was necessary to determine the effect of endoxylanases on the pentosans of sorghum by preventing the added endoxylanases from solubilizing the pentosans of wheat flour. However, because the ESS content of endoxylanase treated sorghum flour was too high it decreased the bread volume.

In a real bread-making situation endoxylanases can be added directly into the flour or dough, and hence probably improve the bread-making quality of the composite flour by solubilizing the pentosans of both the sorghum flour and the wheat flour. The actual effects of such approach will have to be investigated. However, the major problem with this flour treatment for poor developing countries will be that the endoxylanases would have to be imported.

As summarized in Table 5-2, fermentation also prevented the grittiness and the dryness of sorghum and wheat composite bread and improved its crumb structure. Fermentation and

Table 5-2: Merits, drawbacks and recommendations concerning the fermentation and drying treatment on the bread-making properties of sorghum flour

Technological approach	Merits	Drawbacks	Recommendations
Fermentation	Decreased the pH of dough Gelatinized some of the starch Improved the gas-holding capacity of dough. Prevented the grittiness and dryness of bread Increased the volume of bread Decreased slightly the crumb firmness Increased the IVPD1[1] of sorghum flour and composite bread Did not change the color of bread Greatly decreased crumb firmness Simpler technology compared to malting and boiling	Did not decrease gelatinization temperature of sorghum starch Did not increase the water-holding capacity of sorghum flour much. Produced to much sourness of flour and bread Decreased slightly the crumb firming rate High cost and high time-consumption of heating and drying	Fermenting the sorghum flour and adding it directly into dough, as in sourdough process Decreasing the fermentation time and hence the sourness of flour Reduce the loss of water-soluble components and the drying costs

[1] IVPD, *in vitro* protein digestibility

drying significantly increased the volume and decreased the crumb firmness but did not significantly decrease the crumb-firming rate of composite bread. The decreased crumb firmness with a slight decrease of the crumb-firming rate of composite bread made with fermented and dried sorghum flour was attributed simply to the higher bread volume and improved crumb structure, compared to bread made with sorghum grain flour. As reported by Axford, Cowell, Cornford and Elton (1968) and Zobel and Kulp (1996) bread with higher loaf volume gives softer crumb.

The positive modifications brought about by fermentation and drying on the bread-making quality of sorghum flour were due to the decrease of the pH of sorghum flour. The slight increase in gelatinised starch in the fermented and dried sorghum flour may have contributed only slightly to the slight increase in the weight of bread. Apparently the low pH of the fermented sorghum flour suppressed the amylase activity of flour (Wanink et al (1994) and increased the pasting viscosity of sorghum flour. It is possible that the low pH of fermented sorghum and wheat flour dough increased the swelling power of pentosans, and thus contributed to the increased dough viscosity and cohesiveness. Increased dough cohesiveness in rye and wheat sourdough, increases the volume and the resistance of bread to staling (Seibel and Brümmer 1991).

Fermentation also improved the protein digestibility of whole sorghum flour and sorghum and wheat composite bread. According to Taylor and Taylor (2002) the increase in the protein digestibility of sorghum during fermentation appears to be due to structural modifications in the insoluble proteins (prolamins and glutelins) of sorghum. These modifications, being induced by rapid lowering of the pH. According to the same authors, the mechanism by which fermentation improves the protein digestibility differs from that of malting. Whereas malting results in the increase of water-soluble proteins, as a result of proteolysis (Taylor 1983; Bhise et al 1988), there is a decrease in the water-soluble proteins during fermentation.

The main drawbacks of fermentation (Table 5-2) were that it did not significantly decrease the gelatinization temperature of sorghum flour and it did not significantly improve the water-holding capacity of sorghum flour. The excessive sourness of flour and bread, although it was a disadvantage, can be controlled by the extent of fermentation. Heating and drying the fermented sorghum flour had adverse effects on the water-holding capacity of sorghum flour, on the weight and volume of bread, and in the crumb firmness. It is possible that due to condensation reactions during drying the solubility and the water-holding capacity of the grain components, particularly of the water-soluble proteins and pentosans, decreased.

Fermentation appears to have a greater potential to improve the bread-making quality of sorghum flour, compared to malting and boiling, in that fermentation improved also the bread volume and increased the protein digestibility of bread. Additionally, fermentation is a much simpler technology, compared to malting, and it does not require the wet-heat treatment, the drying and re-milling, as it can be easily coordinated with the bread-making process. Wet fermented flour can be added directly in to the wheat flour, as in sourdough bread process, which would simplify the bread-making process. It would also prevent the loss of water-soluble components due to heating and drying. Further the fermentation time could easily be controlled, reducing the excessive sourness of the flour and bread.

6. GENERAL CONCLUSIONS AND RECOMMENDATIONS

By malting or fermentation whole sorghum grain flour (30%) can be successfully blended with the wheat flour available in Mozambique (70%), i.e., weak flour with a relatively low protein content, to produce bread of acceptable quality.

The simple technologies of malting and fermentation prevents the grittiness, the dryness and the crumb firmness of sorghum and wheat composite breads. Malting and boiling decrease the crumb firmness and crumb-firming rate and greatly increase the water-holding capacity of bread, and gives bread with fine malt flavor. However, it slightly decreases the bread volume. Fermentation greatly increases the bread volume, decreases less the crumb firmness and crumb firming rate, does not increase the water-holding capacity and gives bread with a pronounced sour flavor.

A complete inactivation of amylases, dextrinization and gelatinization of starch, and increased content of gelatinized starch, crude fiber and water-soluble pentosans of sorghum flour are the major factors for the bread improving effect of boiled sorghum malt flour. Dextrinization of starch is the most important factor to decrease the gelatinization temperature of sorghum starch and to decraese the crumb firming rate of composite bread. The increased content of gelatinized starch and the increased crude fiber of boiled sorghum malt flour are most important in increasing the water-holding capacity of flour, and the increase of water-soluble pentosans are most significant in improving the crumb structure and also in decreasing the crumb firming rate of sorghum and wheat composite bread.

Unlike malting and boiling, the bread improving effect of fermenting and dryng of sorghum flour, with respect to gelatinization of starch, was due to a slightly increase in the amount of gelatinized starch and pasting viscosity of sorghum flour. Apparently, the gelatinized starch improved the water-holding capacity of flour, enough to prevent grittiness and dryness of bread, and improved the gas-holding capacity of dough which increased the bread volume.

Sorghum grain with the highest protein content is the most suitable grain for malting for bread-making. The optimal malting time is 6 days. Whereas malting and boiling do not change the protein quality (digestibility) of sorghum and wheat composite bread, fermenting sorghum flour slightly increased it.

Endo-(1-4)-β-xylanases have some potential to improve the bread-making quality of sorghum flour, as they increase the water-soluble pentosans of sorghum. Endoxylanases could be added to moistened sorghum flour and allowed some time for the enzyme activity, before mixing into dough. However, the major problem with using endoxylanases is that they would have to be imported.

The bread improving potential of malted and fermented sorghum flour can be improved, provided that the adverse effects of boiling and heating to dry, respectively, are reduced. Steaming the malt instead of boiling is recommended to decrease the amount of gelatinized starch and the loss of water-soluble components of the flour. Sun drying the malt, instead of drying in forced draught ovens, can also be considered to decrease malting costs. Fermenting and adding the sorghum flour directly into the dough, as in sourdough bread process, can further improve the bread-making quality of fermented sorghum flour. This would simplify the bread-making process, prevent the loss of water-soluble components and more easily control the level of bread sourness.

Fermentation of sorghum flour, as in a sourdough process, appears to be the most promising approach for poor developing countries, to improve the bread-making property of sorghum flour. Fermentation can improve the volume, the crumb softness and the protein digestibility of sorghum and wheat composite bread. Fermentation is also a slimpler technology to apply, compared to malting and boiling.

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8. PUBLICATIONS FROM THIS WORK

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