Trends and opportunities in the production, processing and consumption of staple food crops in Kenya

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3. Strategies for the production of gluten-free bread from sorghum-cassava flour blend

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INTRODUCTION

Wheat bread is one of the oldest and most popular staple foods in the world. Bread is an unstable, elastic, solid foam, the solid part of which contains a continuous phase composed in part of an elastic network of cross-linked gluten molecules and in part of leached starch polymer molecules, primarily amylose, both uncomplexed and complexed with polar lipid molecules, and a discontinuous phase of entrapped, gelatinized, swollen, deformed starch granules (Gray and Bemiller, 2003).

Wheat is the most important crop for breadmaking because of its supreme baking performance in comparison with other cereals. The unique dough-forming and breadmaking properties of wheat are attributed to gliadin and glutenin proteins which on mixing with water develop into gluten. Gluten is an artifact of processing flour and does not exist as such in the wheat kernel (Khan and Nygard, 2006). It is only formed when the two major classes of wheat protein, the gliadins and glutenins, interact to form a viscoelastic mass when they are hydrated. The glutenin fraction gives a rough rubbery mass when fully hydrated whereas the gliadin fraction forms a viscous fluid mass on hydration. Thus, dough strength and elasticity is due to the glutenin fraction, whereas dough viscosity and extensibility is due to the gliadin fraction (Wieser, 2007). The resultant gluten complex that they form is responsible for the elastic and extensible properties of dough and the protein-starch interaction that is related to gas cell formation, including stabilization and retention of gas cells within the dough structure. Gluten is also the main contributor to primary characteristics of bread such as the volume, chewy texture and flavour of the crust.
Gluten-free bread is made from non-wheat or non-gluten containing flours and starches, including cereals (such as rice, maize, sorghum and millet), pseudocereals (such as amaranth, buckwheat and quinoa), root or tuber crops (such as potatoes and sweet potatoes), plantains (cooking bananas) and legumes (such as beans and chick peas). The absence of gluten in these materials results in hydrated mixture with rheological character ranging from liquid batter to firm inelastic dough. Unlike wheat dough, gluten-free dough is unable to develop a continuous protein network with characteristics similar to gluten that can embed starch due to their different protein properties (Hättner and Arendt, 2010). The air retained in the dough during mixing and carbon dioxide developed by yeast does not find in such an unstable system enough coherent structures to be entrapped to make the dough rise (UNECA, 1998). Part of the gases escape too early and part are retained to form irregular, unstable cells. Consequently, the baked product has deficient quality characteristics such as crumbling dry texture, low specific volume, firm crumb and short shelf-life.

To overcome the technological difficulties of making gluten-free bread, it is necessary to incorporate gluten substitute(s) in the recipe. These compounds help to create a three-dimensional gas retaining network while permitting the dough to expand in volume. A single gluten substitute does not exist and the common approach is to incorporate modified starches, modified gluten-free flours (such as that obtained by sourdough fermentation or malting), emulsifiers, enzymes, hydrocolloids, non-gluten proteins, prebiotics and combinations thereof, to gluten-free recipes. Generally, gluten substitutes improve the ability of gluten-free dough to retain carbon dioxide, strengthen dough cohesiveness and improve crumb texture, appearance and the keeping quality of gluten-free bread.

Since gluten-free bread recipes are highly variable, we will limit this review mainly to the latest research work of our research group that has focused on the development of gluten-free bread from a composite flour mixture of sorghum and cassava.

**JUSTIFICATION FOR THE PRODUCTION OF GLUTEN-FREE BREAD**

Wheat is the single largest food import in Kenya. Between 1990 and 2010, wheat imports have fluctuate between 130,000 and 840,000 tons/year at a cost of US$ 23-220 million/year (Chapter 1). The average wheat imports in the country between 1990 and 2010 represented about 60% of total wheat consumption. Over the last two decades, Kenya has spent cumulatively over US$ 2 billion on wheat imports. This is staggering amount of money that could be used to improve health service provision, literacy, infrastructure and communication. It could also be used to increase access to safe drinking water, improve sanitation, a decrease social inequities and poverty in the country. Unless there is a paradigm shift in consumer des for wheat as a status attainment staple food crop, it is reasonable to assume that future demand for whe will continue to increase.
Sorghum and cassava are well adapted to a wider range of agro-ecological zones of Kenya than wheat. These crops can be grown with little management, have high production potential per unit of land and form part of mixed cropping systems. They are valuable assets for household food security for many farmers in times of drought. Despite these positive attributes, local consumption of sorghum and cassava is low, as compared to wheat-based products, because of the lack of variety of convenient ready-to-eat sorghum-, or cassava-based foods. The crops are mainly processed into flour which is used to make thick or thin porridge. Nonetheless, because of the rapidly increasing population and the high cost of imported wheat, it is essential to develop novel food products from these crops that can appeal to a wide cross-section of consumers.

Although wheat bread is one of the most widely consumed staple foods in the world, certain individuals have to totally avoid bread in their diet because they suffer from a medical condition referred to as coeliac disease. Coeliac disease is a life-long auto-immune mediated enteropathy which is triggered when genetically susceptible individuals ingest wheat proteins (gliadins and glutenins) and related proteins in rye, barley, durum wheat, spelt wheat, kamut, einkorn and triticale. When these proteins enter the digestive tract, they are broken down into peptides which trigger the immune response. The disease is manifested as damage to the mucous membrane of the small intestine (duodenum and jejunum) leading to malabsorption of basic nutrients like proteins, carbohydrate and fat; micronutrients such as vitamins and minerals; and in some cases water and bile salts. The individual also develops associated disorders that can affect almost any organ or body system. The classic intestinal symptoms of the disease include dental enamel defects, abdominal distension, constipation, diarrhoea and vomiting. Extra-intestinal manifestations of the disease include iron-deficiency anaemia, weight loss, infertility, arthritis, osteoporosis and dermatitis herpetiformis. The individual may also develop neurological and psychological disturbances (Catassi and Fasano, 2009; Green, 2009).

Another adverse immune reaction associated with ingestion of wheat-containing food by certain individuals is wheat allergy. Wheat allergy is an immunological reaction that is mediated by immunoglobulin E. Among the wide spectrum of gluten antigens that elicit the allergic reaction are the α-, β-, γ- and ω-gliadins and low molecular weight glutenins. The allergic reactions are characterized by skin reactions (such as urticaria and angioedema), gastrointestinal reactions (such as vomiting and diarrhoea), nausea, rhinitis and asthma (Catassi and Fasano, 2009).

The only effective treatment for coeliac disease and wheat allergy is based on life-long exclusion of gluten-containing cereals, whether as ingredients or additives, from the diet (Box 1). Strict adherence to a gluten-free diet prevents morbidity and reduces the incidence of the associated gastrointestinal malignancy for coeliac patients. This means that, with the exception of wheat, rye and barley, all cereals in the Poaceae (formerly Gramineae) family are suitable for the production of gluten-free bread. Pseudocereals (amaranth,
buckwheat, quinoa), root and tuber crops (such as sweet potatoes, potatoes, yams, arrow roots) and plantains are also carbohydrate-rich gluten-free foods that can be tolerated by people suffering from coeliac disease and wheat allergy.

**BOX 1: GLUTEN-FREE FOODS**

Gluten-free foods are dietary foods consisting of or made only from one or more ingredients which do not contain wheat (i.e. all *Triticum* species, such as durum wheat, spelt and kamut), rye, barley, oats\(^1\) or their crossbred varieties, and the gluten level does not exceed 20 mg/kg in total (i.e. 20 ppm), based on the food as sold or distributed to the consumer, and/or consisting of one or more ingredients from wheat (i.e. all *Triticum* species, such as durum wheat, spelt, and kamut), rye, barley, oats\(^1\) or their crossbred varieties which have been specially processed to remove gluten, and the gluten level does not exceed 20 mg/kg in total (i.e. 20 ppm), based on the food as sold or distributed to the consumer.

\(^1\)Oats can be tolerated by most but not all people who are intolerant to gluten. Therefore, the allowance of oats that are not contaminated with wheat, rye or barley in foods covered by this standard may be determined at the national level.


**SORGHUM**

Sorghum is a monocotyledonous plant that belongs to the Poaceae (formerly Gramineae) family, Panicoideae subfamily and Andropogoneae tribe. Two of the best known species are *Sorghum vulgare* and *Sorghum bicolor* (L.) Moench. Due to genetic diversity, the grains vary widely in shape, size and colour. The kernels are typically round, varying in weight from 20-30 g per 1000 kernels (Delcours and Hoseney, 2010). The kernel is a naked caryopsis, typically 2-5 mm in length and 2-3 mm thick at the widest point (Taylor and Belton, 2002). The colour of the kernel varies from white or yellow to red, whereas the endosperm colour can be yellow or white (Schober and Bean, 2008).

Sorghum grain is made up of a pericarp, endosperm (storage tissue) and germ (embryo). The pericarp region comprises a pericarp, testa (seed coat) and aleurone layer. Sorghum is unique in that it is the only cereal grain that has starch granules in the pericarp. The testa separates the pericarp from the aleurone layer. The testa is thin in low tannin sorghum varieties but thicker and highly pigmented in high tannin sorghums (Taylor and Belton, 2002). The outer edge of the endosperm is composed of the aleurone layer containing lipids, enzymes and protein bodies. Under the aleurone layer is the outer corneous (i.e. hard or vitreous) endosperm fraction surrounding an inner floury (i.e. soft) core (Schober and Bean, 2008).
The main nutrient component of sorghum is carbohydrate, which exists predominantly as starch (50-75%) and is located in the endosperm and pericarp of the grain. Starch granules in sorghum range from 2-30 μm in diameter and contain 20-30% amylose (Taylor and Belton, 2002). Proteins make up 9-14% of the grain (Waniska et al., 2004) and are principally located in the endosperm. The protein quality of sorghum is poor because of the low content of essential amino acids such as lysine, tryptophan and threonine (Badi et al., 1990). Minor components of sorghum grain are lipids, vitamins and minerals. Although these compounds occur in small amounts, they have great influence on the processing parameters and nutrient quality of the grain. The lipid content of sorghum varies from 2.1-6.6%. The lipids are mainly located in the germ, although there are smaller amounts in the endosperm (Taylor and Belton, 2002). The whole grains are a good source of the B vitamins: thiamine (vitamin B₁), riboflavin (vitamin B₂), niacin (vitamin B₃), pyridoxine (vitamin B₆) and biotin (vitamin B₇). The main minerals in sorghum are potassium and phosphorous. Minerals and vitamins are naturally present in higher amounts in whole milled flour than in refined flour but they can be added back to refined flour through the process of enrichment.

Sorghums are rich in phytocomplexes (i.e. polyphenols, anthocyanins, phytosterols and policosanols) with potential significant impact on human health. The ability of sorghum tannins to complex with proteins has the potential to slow digestion and reduce caloric intake of foods. Tannin-containing sorghum varieties show high antioxidant activities against different free radicals in vitro that compare favourably with high antioxidant fruits and vegetables. Sorghum bran is rich in phytosterols and policosanols that promote cardiovascular health. There is epidemiological evidence to suggest that sorghum consumption reduces the risk of certain types of cancers (Rooney and Awika, 2005; Awika and Rooney, 2004).

**CASSAVA**

Cassava is a dicotyledonous perennial plant that belongs to the Euphorbiaceae family. The root is rich in starch and is a valuable source of energy in human nutrition. Root size, shape and colour depend on the variety and environmental conditions. Cassava roots are about 15-100 cm long and 3-15 cm wide. They are cylindrical, conical or oval, with a coffee, pink, or cream-coloured peel that is covered by a thin brown bark (the periderm). The parenchyma (the edible portion of the root) is white, cream or yellow. Cassava plants produce 5-10 roots weighing 0.5-2.5 kg each (Wheatley et al., 2003).

The major nutrient component of cassava is carbohydrate which makes up over 90% of parenchyma dry-weight. Plant carbohydrates include celluloses, gums and starches, but starches are the main source of nutritive energy because celluloses are not digested (FAO, 1990). The starch content in cassava is 64-72% on dry-weight-basis. The other carbohydrate fractions are sugar and non-starch polysaccharides such as celluloses and hemicelluloses. The protein, fat and ash contents of cassava are generally below 1%. The fibre content is more variable and increases with plant age. Cassava roots contain cyanogenic glycoside which is converted to toxic hydrocyanic acid when it comes into contact with linamarase, an enzyme that is
released when the cells of cassava roots are ruptured. The cyanogenic glycoside content of cassava roots varies widely and is related to environment factors, size of roots and moisture content. The values range from 30-100 mg/kg in low-cyanogenic cultivars for direct consumption to 1350 mg/kg in industrial varieties used for processing (Wheatley et al., 2003).

GLUTEN-FREE BREAD FROM SORGHUM AND CASSAVA
Sorghum and cassava flours are unable to form cohesive, gas-holding viscoelastic dough when added to water because they do not contain gluten. The rheological character of the mixture ranges from inelastic dough to free-flowing batter, depending on the nature and amount of ingredients and additives. Onyango et al. (2011a) reported that the consistency of sorghum-starch gluten-free dough changes from a stiff inelastic mass to a thin pourable batter with increasing starch content. At a starch to sorghum ratio of 10:90 the mixture has the rheological character of inelastic dough that can be shaped but cannot stretch. On the other hand, the mixture has the rheological character of thin pourable batter when the sorghum content is decreased relative to starch content. By contrast, when pregelatinised starch is used, dough strength increases with increasing content of pregelatinised starch (Onyango et al., 2011b). The rheological character of gluten-free mixture is also affected by the amount of mechanically damaged starch in the flour (Schober and Bean, 2008). Flour with a higher amount of damaged starch will produce thicker batter than flour with a lower amount of damaged starch.

Starch is the most important structure-forming ingredient in gluten-free bread due to the absence of gluten that performs this role in wheat bread. The overall bread quality is influenced by the interaction of starch with the other dough components and its behaviour on hydration, heating and cooling. Increasing starch content in gluten-free recipes induces early onset gelatinization, resulting to an early increase in crumb consistency during baking. This facilitates the development of a cohesive crumb network that traps gas bubbles and prevents loss of carbon dioxide and crust collapse. Increasing starch content also improves the volume of gluten-free bread by diluting the endosperm and bran particles which interfere with the stability of the sorghum gel and liquid films around the gas cells (Taylor et al., 2006). Increasing starch content in gluten-free recipes also improves crumb texture properties. Onyango et al. (2011a) investigated the effect of different starch concentrations on the crumb properties of sorghum-based gluten-free bread and found that crumb firmness and chewiness decreases with increasing starch content, whereas springiness, cohesiveness and resilience increases. However, starch breads have certain disadvantages that include rapid staling, high glycemic index and bland flavour. Furthermore, starch breads are poor in micronutrients, proteins and dietary fibre (Schober, 2009). Figure 1 shows an outline for the production of gluten-free bread from sorghum flour and cassava starch at a ratio of 1:1. Figure 2 shows the baking pan with the lid and the appearance of the gluten-free breads.
Dehulled and finely milled sorghum flour → Prepare composite flour in a ratio of 1:1 → Cassava starch

Mix the composite flour with the major ingredients and desired gluten substitute

Proof at 32°C, 85% relative humidity

Proofing time is dependent on quantity of batter/dough added to the pan

Because of differences in flour batches, it is recommended to proof to a desired height rather than for a specific time

Bake for about 30 minutes at 210°C without steam injection

Preferably bake in a pan with a lid in order to control loaf shape

Cool for 2 hours and pack in a moisture-permeable bag

Gluten-free bread

**Major ingredients measured on flour-weight-basis**
- Water (75-100%)
- Salt (2%)
- Active dry yeast (3.5-4%)
- Sugar (6%)
- Fat (3%)

**Possible gluten substitutes:**
- Hydrocolloids
- Enzymes
- Emulsifiers
- Sourdough
- Malt flour
- Modified starch

Figure 1. Outline of steps required to make gluten-free bread from sorghum flour and cassava starch.
Starches from different botanical origins have variable sizes and shapes and possess diverse ranges of pasting, gelling, thermal and textural characteristics, depending on their composition and structural properties (Abdel-Aal, 2009). Onyango et al. (2011a) studied the rheological character and crumb quality of gluten-free batter and bread, respectively, prepared from blends of sorghum flour and either cassava, maize, rice or potato starches. They reported that batter prepared from sorghum flour and rice starch was less firm than batter from sorghum flour and cassava, maize or potato starches. On baking, they found that the crumb texture of sorghum-cassava bread was softer, springier and more resilient and cohesive than the crumb texture of bread prepared from sorghum with either maize, potato or rice starch.

It has previously been argued (Taylor and Belton, 2002; Hugo et al., 1997; Olatunji et al., 1992b) that when pregelatinised cassava starch is blended with or substituted for native starch, the crumb quality of gluten-free bread is improved. The rheological character of batter prepared from sorghum flour and pregelatinised cassava starch is distinctly different from that prepared from sorghum flour and native cassava starch (Onyango et al., 2011b). Batter prepared from sorghum flour and pregelatinised cassava starch has firm, inelastic character and can be shaped because pregelatinised starch, which is rich in damaged starch, has several exposed hydroxyl groups that form multiple bonds with water. However, formation of a firm inelastic mass from sorghum and pregelatinised starch does not translate in gluten-free bread with better crumb properties. Bread prepared from sorghum flour and pregelatinised starch is firm and has a wet and sticky (i.e.adhesive) crumb (Onyango et al., 2011b), which is due to the high water-binding capacity of pregelatinised starch. On the other hand, gluten-free bread made from sorghum flour and native cassava starch has a soft non-adhesive crumb (Figure 3).
The kernels of sorghum varieties show tremendous diversity in terms of colour, weight and composition (Table 1). These differences, in turn, affect the processing properties and taste, texture and nutritional value of sorghum-based products. Schober et al. (2005) compared the effect of nine sorghum cultivars and commercial sorghum flour on the quality of gluten-free bread (70 parts sorghum and 30 parts corn starch). They found that crumb grain (pore size and number of pores) and firmness were affected by sorghum hybrid and concluded that the amount of mechanically damaged starch in the flour, which was influenced by kernel hardness, was responsible for the differences. Varieties with higher amounts of damaged starch had coarser crumbs (because of damaged starch’s greater susceptibility to the action of amylases) than those with lower amounts of damaged starch. Sorghum variety, however, did not affect bread volume, height, bake loss and water activity.

Table 1. Composition of five sorghum varieties in the Kenyan market.

<table>
<thead>
<tr>
<th>Sorghum variety</th>
<th>Pericarp colour</th>
<th>1000-kernel weight</th>
<th>Carbohydrate</th>
<th>Starch</th>
<th>Protein</th>
<th>Fat</th>
<th>Fibre</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gadam</td>
<td>White</td>
<td>17.87</td>
<td>79.63</td>
<td>64.41</td>
<td>13.19</td>
<td>3.62</td>
<td>2.00</td>
<td>1.56</td>
</tr>
<tr>
<td>Kaguru</td>
<td>Pink</td>
<td>14.58</td>
<td>83.05</td>
<td>60.69</td>
<td>10.51</td>
<td>2.77</td>
<td>2.22</td>
<td>1.46</td>
</tr>
<tr>
<td>KARI Mtama II</td>
<td>Reddish-brown</td>
<td>21.29</td>
<td>83.12</td>
<td>61.81</td>
<td>9.48</td>
<td>2.67</td>
<td>2.61</td>
<td>2.02</td>
</tr>
<tr>
<td>Seredo</td>
<td>Reddish-brown</td>
<td>24.96</td>
<td>80.97</td>
<td>58.77</td>
<td>11.46</td>
<td>3.37</td>
<td>2.49</td>
<td>1.71</td>
</tr>
<tr>
<td>Serena</td>
<td>Brown</td>
<td>22.15</td>
<td>84.76</td>
<td>63.49</td>
<td>8.16</td>
<td>3.23</td>
<td>2.24</td>
<td>1.61</td>
</tr>
</tbody>
</table>

All numeric values are given as g/100 g dry-weight basis.

The choice of non-gluten protein in a gluten-free recipe is determined by its availability, cost, ease of production, types and levels of inhibitors, allergic potential, and nutritional and functional influence on product characteristics. For instance, whereas milk sugar (lactose) causes bloating and diarrhoea in lactose-intolerant people, it also supplements the limiting amino acids (lysine, methionine and tryptophan) and
improves the flavour and crust colour of gluten-free bread. In another example, Ribotta et al. (2004) reported that non-heat treated soybean flour gives gluten-free bread with better quality (i.e. well-aerated bread structure and a good loaf volume) than heat-treated soybean flour. They argued that heat treatment inactivates soybean enzymes and causes protein aggregation and subsequent loss of protein solubility, which have negative effects on the application of soybean flour in gluten-free bread. Onyango et al. (2009a) compared the effect of egg white, skim milk powder, soy protein isolate and soy protein concentrate on the crumb quality of gluten-free bread prepared from sorghum and pregelatinised cassava starch. They reported crumb firmness of 1,000, 1,573, 2,249 and 2,168 g (force) for gluten-free bread containing egg white, skim milk powder, soy protein isolate and soy protein concentrate, respectively. The corresponding values for specific volume were 3.26, 2.91, 2.69 and 2.77 cm³/g, whereas the staling rates were 58, 260, 168 and 229 g/day. Figure 4 shows the effect of different amounts of egg white on the volume and appearance of gluten-free bread prepared from sorghum and pregelatinised cassava starch. The volume and shape of the bread improved with increasing content of egg white in the formulation. The superior functional property of egg white powder is associated with its capacity to create continuous web-like structures in gluten-free dough and bread, which resembles the network structure in wheat dough and bread (Ahlborn et al., 2005; Moore et al., 2004).

![Figure 4. Effect of different amounts of egg white on volume of gluten-free bread prepared from sorghum and pregelatinised cassava starch.](image)

Hydrocolloids (also commonly called gums) are substances consisting of hydrophilic long-chain, high molecular weight molecules, usually with colloidal properties, that in water-based systems produce gels or thickened liquids (Hoefler, 2004). They include a wide range of polysaccharide and protein biopolymers that are derived from natural sources such as plants, animals, sea weeds and microorganisms, but can also be of synthetic origin. Hydrocolloids are naturally present or added to a wide range of foodstuffs to modify texture, appearance as well as improve product stability (Abdel-Aal, 2009). The functional effects of hydrocolloids in baked products stem from their ability to modify dough handling properties, increase quality of fresh bread and extend the shelf-life of stored bread (Rosell et al., 2001; Guarda et al., 2004).
Pentosans are naturally occurring hydrocolloids in sorghum. They are found in small amounts in the pericarp (ca. 1.5%) but because most are lost during refining, they have minimal effect on crumb properties of sorghum bread. Nonetheless, water-extractable pentosans can be used as additives to improve volume and retard staling of gluten-free sorghum bread (Schober and Bean, 2008). They contribute to the water-holding capacity and viscosity of dough and produce a film inside the vacuoles of the fermenting dough that contributes to gas retention and loaf volume (Abdel-Aal, 2009).

Hydrocolloids have been used in gluten-free bakery formulations to mimic the viscoelastic properties of gluten and improve bread quality (Crockett et al., 2011; Hüttner and Arendt, 2010; Lazaridou et al., 2007). They help to stabilize and retain gas cells in the dough, promote water absorption, improve bread volume, height and crumb porosity and retard crumb staling (Gallagher et al., 2004; Bemiller, 2008). The specific effect of hydrocolloids is dependent on its origin, chemical structure, concentration, technique of application and properties of the flour. Onyango et al. (2009) studied the effect of five cellulose-derivatives on the crumb texture of gluten-free bread prepared from sorghum and pregelatinised cassava starch and found that firmness decreased in the following order: hydroxypropylcellulose > microcrystalline cellulose > hydroxypropylmethylcellulose (HPMC) > methylcellulose > carboxymethylcellulose. Anton and Artfield (2007) reviewed the application of hydrocolloids in gluten-free recipes and concluded that HPMC and xanthan gum were the most effective in mimicking gluten properties in the dough and final product. HPMC is especially effective in gluten-free recipes because of its ability to thicken dough (thereby preventing phase separation) and stabilize foams (thereby improving gas retention, crumb structure and loaf volume) (Schober, 2009; Crockett et al., 2011, Sivaramakrishnan et al., 2004). Xanthan gum, on the other hand, thickens dough but does not stabilize foams. Consequently, gluten-free bread containing HPMC has a more regular crumb, larger volume and slower staling rate than that containing xanthan gum or without any additive (Schober and Bean, 2008; Schober, 2009).

Enzymes are widely applied as food processing aids because they are natural, non-toxic food additives that are preferred by consumers over their chemical counterparts (James and Simpson, 1996). The effect of a number of enzymes on the quality of sorghum-based gluten-free bread has been investigated. Renzetti and Arendt (2009) found that the bread making performance of sorghum flour is not improved when its proteins are degraded by proteases but is enhanced when glucose oxidase is added. Olatunji et al. (1992a) reported that fungal amylase improves the sensory characteristics of sorghum-based gluten-free bread, whereas Schober et al. (2007) attributed limited α-amylase activity in sourdough fermented sorghum bread to the acidic environment which inactivated the enzyme. Onyango et al. (2010a) reported that α-amylase increased crumb adhesiveness but decreased firmness, cohesiveness, springiness, resilience and chewiness of sorghum-bread supplemented with native or pregelatinised cassava starch. They also noted that the amount of α-amylase in the gluten-free formulation and the nature of starch (native or pregelatinised) influenced the crumb texture. The recipe that had pregelatinised cassava starch was more susceptible to
enzymatic degradation which contributed to improved crumb cohesiveness and resilience. However, this bread also had an undesirably wet and sticky crumb (i.e. high adhesiveness), which could be attributed to enzyme-mediated generation of high levels of low molecular weight branched dextrins (degree of polymerization 10-100) in the bread crumb (Carroll et al., 1987).

Transglutaminase (protein-glutamine γ-glutamyltransferase, EC 2.3.2.13) is an enzyme that promotes covalent crosslinking between proteins through the reaction between ε-amino group on protein-bound lysine residues and a γ-carboxamide group on protein-bound glutamine residues. It can also catalyse the introduction of free amine groups into proteins through the amide moiety of a glutamine residue and, in the absence of available amines, hydrolyse glutamine residues to glutamate residues (i.e. deamidate glutamine) (Gerrard and Sutton, 2005). Transglutamases are present in plant, animal and microbial cells but only microbial transglutaminase (mTG) is used in the food industry to modify protein functionality (Dekking et al., 2008). Onyango et al. (2010b) reported that mTG increased the elastic properties of gluten-free dough and crumb firmness and chewiness of gluten-free bread prepared from sorghum and pregelatinised cassava starch. They attributed these changes to increased molecular weight of protein fractions in the gluten-free recipe due to the cross-linking action induced by mTG. Similar effects have been observed in bread made from rice (Gujral and Rosell, 2004), buckwheat, brown rice or maize flour (Renzetti et al., 2008). Despite the positive functional role of mTG in gluten-free recipes, it should be noted that this enzyme is not recommended for processing cereals that are meant for consumption by coeliacs because it deamidates proteins in dough to generate the epitope that activates T cells in the coeliac response (Dekking et al., 2008).

Emulsifiers (surface-active agents or surfactants) are substances that lower the interfacial energy between two immiscible phases thus facilitating the dispersion of one phase into the other. Emulsifiers are commonly used in bakery products to strengthen the dough and soften the crumb. The level of natural emulsifiers in sorghum is low and so they have to be added to gluten-free dough to modify its rheological properties and the subsequent bread crumb texture. Onyango et al. (2009) studied the effect of four emulsifiers on the crumb texture of gluten-free bread prepared from sorghum and pregelatinised cassava starch. They reported that crumb firmness decreased in the following order: DATEM > calcium stearoyl-2-lactylate > glycerol monostearate > sodium stearoyl-2-lactylate. They also noted that although emulsifiers soften the crumb texture, they also create the undesirable crumb property of increased crumbliness (i.e. they decrease crumb cohesiveness).

Sourdough is a mixture of flour and water and other ingredients that is fermented by naturally occurring lactic acid bacteria and yeasts (Gobbetti et al., 2008). Other than being natural and additive-free, other positive attributes associated with sourdough in baking are improved texture, flavour, nutritional value and shelf-life (Gobbetti et al., 2008). These characteristic features derive from the complex metabolic activities
(such as acidification, production of exopolysaccharides, proteolytic- amylolytic- and phytase activity, and production of antimicrobial substances) of the sourdough microflora (Moroni et al., 2009). Schober et al. (2007) prepared gluten-free sorghum bread (70 parts sorghum and 30 parts potato starch) from sorghum flour that had been subjected to sourdough fermentation. They found that the bread developed a continuous cohesive crumb when sorghum proteins were degraded into peptides during sourdough fermentation. They attributed the improved crumb structure to the inability of the newly formed peptides to interfere with the starch gel. They also found that sourdough fermentation improved the shape of the bread and decreased the staling rate. Although sourdough gluten-free bread may be objectionable to consumers not accustomed to sour tasting bread, the sour taste can be neutralized with calcium carbonate (Schober et al., 2007).

CONCLUSION

Although good quality bread can be made from wheat, economic and health reasons have necessitated the development of gluten-free bread. Gluten-free bread is made from non-wheat or non-gluten containing flours and starches such as sorghum flour and cassava starch. Gluten-free dough has poor viscoelastic and gas retaining properties, which result in gluten-free bread with low specific volume, and poor crumb texture and keeping quality. The quality of gluten-free bread can be improved significantly by adding gluten-substitutes such as hydrocolloids, emulsifiers, enzymes, and modified flours and starches. These substances mimic the viscoelastic behaviour of gluten, and thus serve to improve the quality of gluten-free bread.

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