Opportunities and challenges for wholegrain staple foods in sub-Saharan Africa

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1. Introduction

Undernutrition, especially micronutrient malnutrition, remains a chronic problem in the sub-Saharan Africa. For example, anaemia, still affects some 29% of women and children (Christian and Dake, 2021). There is also concurrently a rapid increase in obesity, type-2 diabetes and cardiovascular disease, caused in part by overconsumption of high-energy-density foods due to people adopting a Western-type diet. Today, around 21% of women in the region are overweight and obese (Christian and Dake, 2021), with the incidence being far higher in some countries, particular South Africa.

Wholegrain cereals have much higher contents of several critical nutrients than refined grains, notably the indispensable amino acid lysine, essential fatty acids, minerals such as iron and zinc, B vitamins, tocopherols, dietary fibre and phytochemicals (McKevith, 2004). Additionally, high consumption of whole grain foods has been found to consistently be associated with lower risk of cardiovascular disease, type-2 diabetes and some cancers (Seal and Brownless, 2015). Hence, consumption of wholegrain foods as a major dietary staple could be highly beneficial to the nutrition and health of people in sub-Saharan Africa.

However, the wholegrain staple food needs of sub-Saharan Africa differ in several important respects from those of Western countries, which to date have been the focus of wholegrain food research (Grafenauer et al., 2020). The major staple foods of sub-Saharan Africa are porridge-type products, including steamed and boiled doughs, stiff porridges and thin gruels, which are generally made from maize, sorghum and millets (here referred to African cereals). Moreover, consumers have far less income. Additionally, many people in the region depend on food provided by State and non-governmental organizations, for example through school nutrition schemes. Therefore, factors affecting food product cost are a critical consideration.

This perspective paper focusses on research into improving African cereal wholegrain flour storage life and porridge product palatability. It draws on experience gained in a pilot project in Rwanda, which is aimed at introducing micronutrient-fortified wholegrain maize into school meal schemes in East Africa. The project is sponsored by the Rockefeller Foundation (https://www.rockefellerfoundation.org/initiative/africa-food/) and is in conjunction with the World Food Programme (WFP).

2. Cereal-specific sensory challenges of African wholegrain foods

Table 1 identifies the major sensory-related grain structure and composition differences between the African cereals and wheat. In the pilot project, the coarse texture and darker colour of wholegrain maize porridge, caused by the bran, was disliked by consumers and school cooks. Very fine milling of the maize grain particles to less than 0.5 mm improved porridge texture and colour. However, fine milling had some negative consequences. The milling production rate was halved with a consequent increase in energy consumption and cost. Additionally, the cooks perceived that the porridge volume from a given weight of maize meal was reduced.

The dark colour and bitter-type flavours imparted by the flavonoid-type polyphenols in the bran of sorghum and pearl millet is a problem common to wholegrain foods made from most cereals (Heiniö et al., 2016). Masking of these flavours with other food flavours appears to be best technological strategy (Heiniö et al., 2016). Sugar and salt are commonly used but high levels are required, which could have adverse consumer health consequences.

2.1 Fat rancidity

Fat rancidity is probably the most important negative sensory characteristic of wholegrain foods. Wholegrain food rancidity is a consequence of breaking of cells and cellular structure during milling, resulting in the release of oil from the oil bodies in the germ and aleurone layers and of lipid-degrading enzymes from the bran and germ. There are two processes of fat rancidity development: 1. hydrolytic rancidity, involving the release of unsaturated free fatty acids, which in grains is catalyzed by lipases, and 2. lipid oxidation, which is catalyzed by lipoxygenases and peroxidases but also takes place by autoxidation (Doblado-Maldonado et al., 2016). The ultimate products are volatiles like aldehydes and ketones, which are responsible for most of the rancid flavours. The high fat content of African cereal grains (Table 1) makes their flours particularly susceptible. For example, Mestres et al. (2003) found that when wholegrain flours from six maize varieties were stored at 35^{o}C, all exceeded a fat acidity (measure of hydrolytic rancidity) of 80 mg KOH/100 g (the WFP maximum specification) within 30 days, whereas with degermed maize flour, all remained below this level after 90 days storage.

Thermal treatment of the intact grains is probably the most effective way to retard rancidity development in wholegrain products. It inactivates the rancidity-inducing enzymes and drives off volatile free radical rancidity-inducing precursors. Industrially, both hot air roasting and steaming treatments are widely applied to oat grains because of their very high fat content. Both types of treatments have been found to be effective in extending oat flour shelf-life, reducing the rate of free fatty acid development, with steaming being more effective (Ruge et al., 2012). However, steaming requires that the grains must be dried afterwards in order to produce a flour, with a consequent additional cost. Thus, for sub-Saharan African wholegrain food applications, dry thermal treatment would seem to be preferable.

Table 2 summarizes published research findings on African cereals concerning prevention of rancidity development of their wholegrain flour and food products by grain thermal treatments. All the treatments: hot air drying and toasting, microwave heating and micronization (infrared) heating were effective in reducing hydrolytic rancidity development in the flours and most at reducing oxidative rancidity development. However, studies into the effects of the thermal treatments on porridge quality indicated that they reduced porridge viscosity. This viscosity reduction has been tentatively attributed to thermal damage of the starch granule structure (Adebowale et al., 2020).

Figure 1 shows a principal component analysis plot of the effects of microwave treatment of sorghum grain on the sensory attributes of porridges made from flours stored for up to 6 weeks at 50^{o}C (accelerated shelf-life test) (Adebowale et al., 2020). Without microwave treatment, the porridges made from the stored flours were associated with rancid fat flavours, both bitter taste and oily and painty aromas (Fig. 1B right side). Microwave heating the grains to 55^{o}C and 125^{o}C had similar effects on the sensory attributes of porridges made from the stored flours, with the porridges being associated with sweet taste and brown colour (Fig. 1B left side).

As microwave heating to just 55^{o}C substantially improved wholegrain flour shelf life (data not shown) and porridge product quality (Fig. 1), this suggested that elevated temperature grain drying, which is widely employed prior to grain storage and milling, could improve wholegrain flour shelf-life. In the pilot project in Rwanda, maize grain delivered at 13.3% moisture, was dried at elevated temperature in a commercial grain dryer to 11.6% and 9.6% moisture. Batches of grain of the three moisture contents were then hammer milled into fine meals, which were subjected to accelerated shelf-life storage testing. Samples were removed at intervals and analyzed for fat acidity (hydrolytic rancidity) and peroxide value (fat primary oxidation). Drying the maize considerably reduced meal fat acidity. However, the fat acidity increased rapidly in all meals during storage. The peroxide values increased more slowly and the meals from the dried maize remained considerably below the WHO specification at the end of the storage test (47 days at 40°C), whereas the meal from the non-dried maize exceeded the specification. A semi-trained sensory panel could not detect any statistically significant differences in the sensory characteristics of the stored meals or ugali (stiff porridge) made from them when compared to fresh meal from the non-dried maize and its ugali. However, comments made by panelists suggested that the meal from the non-dried maize after 47 days storage and its ugali tasted somewhat rancid. Taken together, the findings indicate that the shelf life of wholegrain maize meal can be extended considerably by drying the maize prior to milling, with a consequent improvement in the sensory quality of wholegrain porridge.

3. African wholegrain cereal food consumer attitude challenges

Probably, the major barrier to uptake of wholegrain foods in sub-Saharan Africa is the generally negative attitude to them by consumers. For example, a study of the preferences of women consumers in a traditional community in a rural area of South Africa for porridges made from different types of maize meals revealed that they preferred those made from commercially milled highly refined and even lightly refined meals to those from hammer milled maize meal (Khumalo et al., 2011). Much of the negative consumer attitude to wholegrain foods stems from the fact that harvested grain heads were traditionally threshed manually or by animal power on the bare ground. As a consequence, the threshed grain was contaminated with dirt and sand. Removal of the outer grain layers during milling also serves to remove these contaminants. Research with sorghum in Botswana, for example, revealed that milling using a traditional pestle and mortar removed some 25% of the grain, with concomitant reductions in oil and ash content, indicative of germ and bran removal (Kebakile et al., 2007).

In the Rwanda project, considerable effort is being made to educate institutional feeding organisations and consumers as to the benefits of wholegrain food consumption. This is being achieved through a comprehensive social and behavioural change communication strategy. Figure 2 shows examples of the creative materials. A key message is that wholegrain flours belong to the white", i.e. starchy food group, despite their darkish colour (Fig. 2A). Also, communication of the nutritional benefits of wholegrain consumption is done in a way that is easily comprehensible (Fig. 2B).

4. Conclusions

For wholegrain foods to become a major component in the diet of people in sub-Saharan Africa and hence deliver their nutritional and health benefits will require:

- Comprehensive consumer and food community stakeholder education,
- Development and implementation of innovative, simple and inexpensive processing technologies to improve food product stability and palatability.

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Declaration of competing interest

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CAPTIONS TO FIGURES

Fig. 1. Effect of microwave heating of sorghum grain on the sensory characteristics of wholegrain flour porridge made from stored wholegrain flour (slightly modified from Adebowale et al., 2020).

Raw-Control, MicH-Microwaved to 125^{o}C, MicL -Microwaved to 55^{o}C, w -weeks flour storage, Dotted lines are the best fitting trend lines.

Fig. 2. Creative materials of the type used in the Rwanda wholegrain communication strategy (reproduced with the kind permission of Vanguard Economics and Gardens for Health)

Table 1

African wholegrain cereal-specific sensory challenges, comparison with wheat

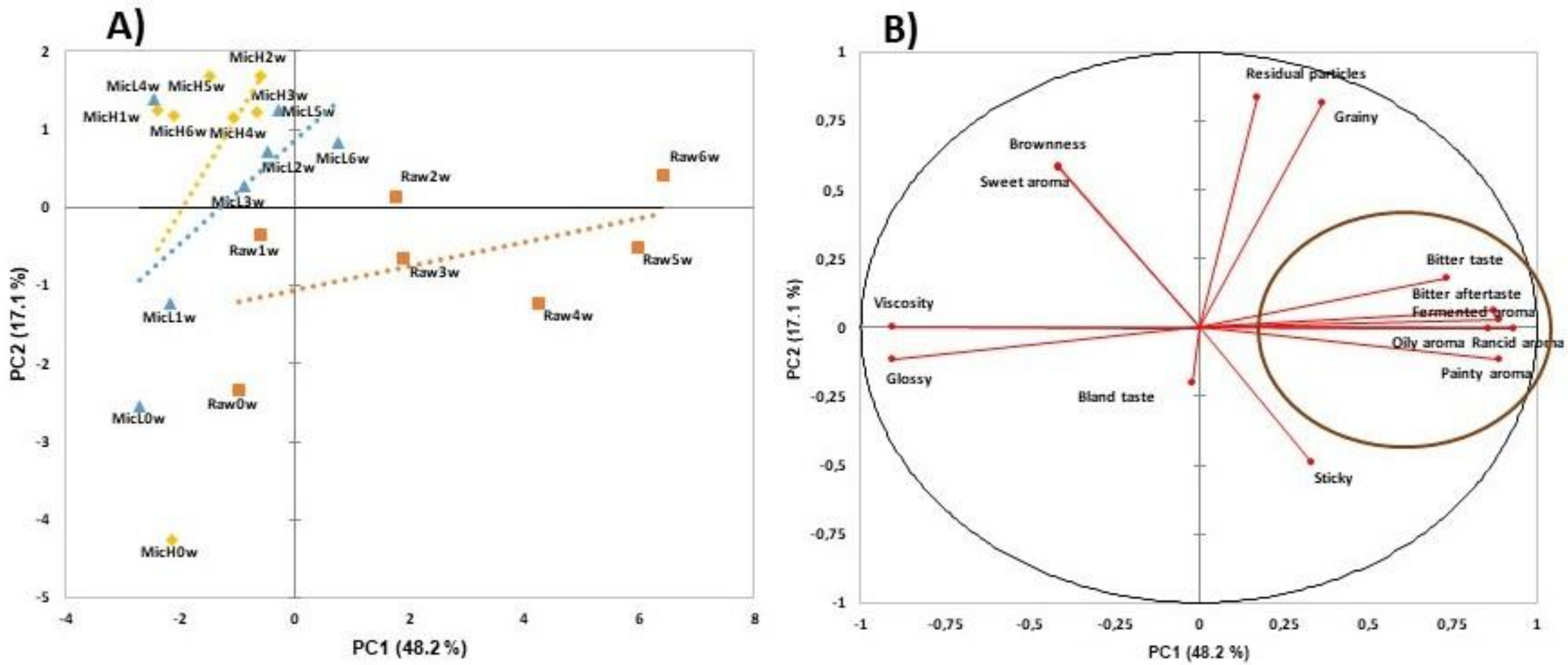
Cereal grain	Bran	Total phenolics (mg gallic acid equiv./g) (Dykes and Rooney, 2007)	Fat content (%) (data mainly from USDA FoodData Central, https://fdc.nal.usda.gov/)
Maize	Pericarp and testa fused into tough, unpalatable "hull"	2.0 (white maize)	4.7
Sorghum (red, non-tannin)	Bran fairly palatable, highly coloured and flavoured by flavonoids	4.2	3.5
Pearl millet	Bran fairly palatable, highly coloured and flavoured by flavonoids	2.7	5.6
Wheat (red)	Bran fairly palatable, moderately coloured and flavoured by flavonoids	1.4	1.9

Table 2

Research into the effects of dry-type thermal treatments of African cereal grains on flour rancidity development and product quality

Treatment	Cereal	Treatment conditions	Flour effects	Food product effects	Reference
Hot air drying and toasting	Pearl millet	Grains heated at air temperature of 100ºC for 2 hours -laboratory-scale.	Fat acidity development reduced. Lipase activity almost eliminated. Flour consumer acceptability slightly improved.	Chapatti consumer acceptability slightly improved.	Arora et al. (2002)
	Pearl millet	Grains toasted at air temperature of 120ºC for 16 hours -laboratory-scale.	Fat acidity greatly reduced in fresh and stored flours. Chemical indicators of oxidative rancidity not affected.	Some porridge rancidity sensory attributes less than the control. Consumer liking of porridge improved.	Nantanga et al. (2008)
Microwave heating	Pearl millet	Grains tempered and heated to 110ºC - laboratory-scale.	Lipase activity almost eliminated. No increase in fat acidity during storage. Consumer sensory acceptability of flour improved.	Porridge pasting viscosity reduced.	Yadav et al. (2012)
	Sorghum	Grains heated to 55ºC and 125ºC –pilot-scale.	Fat acidity greatly reduced in fresh and stored flours. Chemical indicator of	Porridge rancidity sensory attributes far lower in stored flour	Adebowale et al. (2020)

			oxidative rancidity greatly reduced in fresh and stored flour.	than control. Pasting viscosity reduced and brown colour increased.	
Micronization (infrared) heating	Maize	Grains tempered to 25% moisture, air temperature of 200ºC for 4 minutes - industrial-scale.	Lipase activity greatly reduced. Peroxidase activity eliminated. No increase in flour free fatty acids during accelerated shelf-life study. Very slight darkening of flour.	No data	Deepa and Hebbar (2017)



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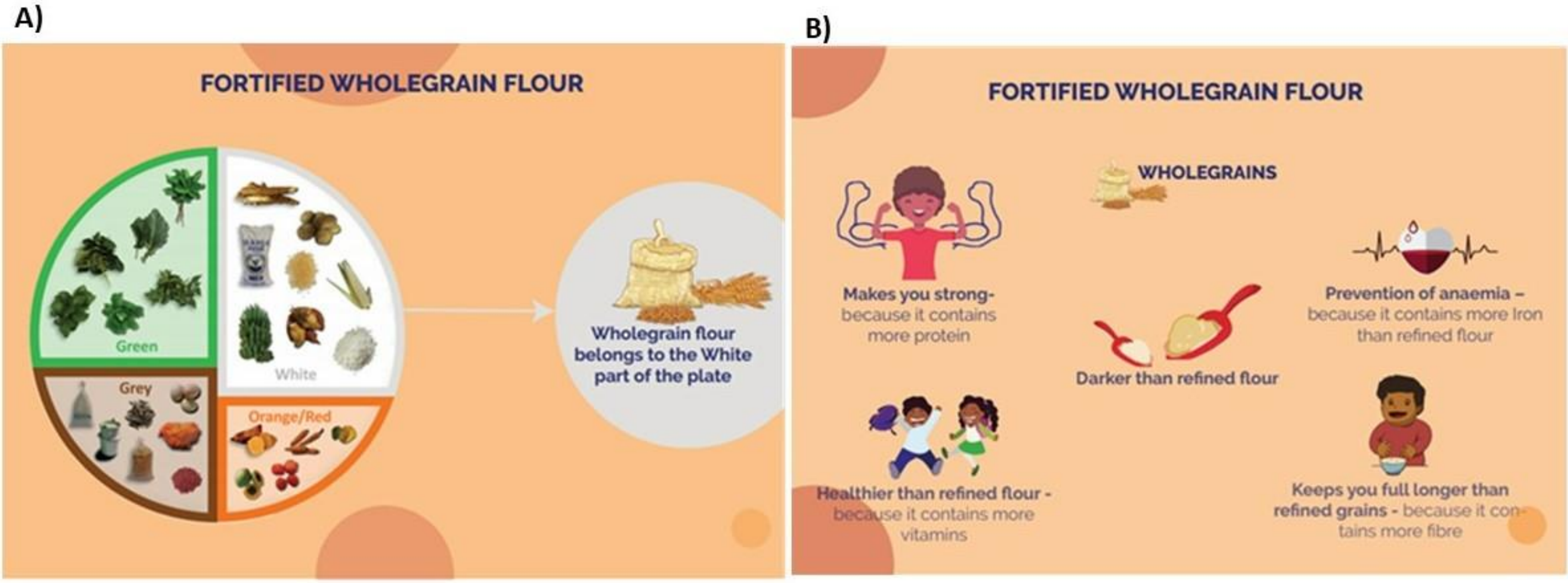

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