Evaluation of the functional quality of cowpea-fortified traditional African sorghum foods using instrumental and descriptive sensory analysis

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ABSTRACT

Despite nutritional advantages, the functional quality of cereal foods tends to decline when fortified with legumes. Traditional African cowpea-fortified sorghum foods were evaluated using instrumental and descriptive sensory analyses. Two sorghum cultivars, NS 5511 (tannin-type) and Orbit (non-tannin-type) were fortified with cowpea (70:30 ratio). Fortification reduced uji (fermented thin porridge) pasting peak viscosity and cool paste viscosity by up to 23% and 12%, respectively, probably as a result of starch content being reduced. NS 5511 injera (fermented thin flatbread) stiffness increased by up to 25%, probably due to a reduction in tannin content. Orbit injera stiffness reduced by up to 22% probably because increased protein content reduced starch retrogradation. Fortification increased the firmness of Orbit ugali (unfermented stiff porridge) by 45% and 17% as assessed by TA-XT2 Texture Analyser and the descriptive sensory panel, respectively. There was a 20% decrease in instrumental firmness of NS 5511 ugali as a result of fortification, which was not detected by the sensory panel. Fortification had generally no effect on the stickiness of ugali. Fortified ugali had a characteristic cowpea flavour. Principal component analysis (PCA) of ugali sensory attributes indicated a 30% variation due to the presence of cowpea. Most of the variation (47%) was attributed to sorghum cultivar. Sensory panel analysis concerning ugali firmness and stickiness correlated positively with the instrumental texture analysis. Fortification with cowpea affects texture and taste of traditional African sorghum foods, the extent to which largely depends on the sorghum cultivar concerned. Instrumental texture analysis relates well with human perception of sorghum food texture and can rapidly predict the effects of fortification with legumes on such foods.

1. Introduction

Many poor people in Africa, who live in areas with scarce rainfall, rely on sorghum (*Sorghum bicolor* L. Moench) as the main food crop as it is very hardy (ICRISAT, 2009). However, sorghum protein is nutritionally inferior because its major storage protein, kafirin, is very poor in essential amino acid, lysine (Taylor & Schüssler, 1986). This problem is aggravated by the poor digestibility of kafirins in cooked foods (reviewed by Duodu, Taylor, Belton, & Hamaker, 2003). Fortification with legumes is recommended as a practical way to improve the protein quality of sorghum foods (reviewed by Klopfenstein & Hoseney, 1995) as well as other cereals (FAO/WHO, 1994; Young & Pellett, 1994). This is because a combination of a legume, which is rich in lysine, with a cereal that contains a relatively good concentration of sulphur-containing amino acids results in protein nutritional compensation (Young & Pellett, 1994).

However, functional quality tends to decline when cereal foods are fortified with legumes (Fu, Nelson, Irvine, & Kanach, 1996). This is because consumer acceptance of a food hinges on their familiarity with the flavour, colour, and texture of the food as well as personal prejudices. Cowpea (*Vigna unguiculata* L. Walp) can be a useful legume for fortification in Africa as it is an indigenous tropical grain legume widely grown and is rich in quality protein (Chavan, Kadam, & Salunkhe, 1989). Studies have examined various aspects of cowpea incorporation into sorghum foods including protein nutritional improvement (Anyango, De Kock, & Taylor, 2011; Pelembe, Erasmus, & Taylor, 2002) and consumer acceptability (Akinyele & Fasaye, 1988).

Most sorghum for human use is consumed as porridges and flatbreads (FAO, 1995). The major sorghum foods in Africa are porridges. These are prepared by cooking sorghum flour in variable amounts of boiling water. Porridges can be thin or stiff, depending primarily on their solids content. People from different regions prefer sorghum porridges with different tastes. Sorghum porridge may be cooked at neutral pH, acidified to pH <4.0 by lactic acid

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fermentation or acidification with fruit juice, or alkaline (pH 8.0) due to cooking with wood ash (Taylor & Anyango, 2011). A type of porridge with the same texture and flavour may be known by different names depending on the region. For example, ugali is the name of stiff unfermented sorghum porridge (20−30% solids) in East Africa. The same porridge is known as pap in Southern Africa and as tô or tuwo in West Africa. Likewise, uji is the name of a fermented thin porridge (approx. 10% solids content) in East Africa, similar to ting in Southern Africa. Flatbreads are the most common sorghum foods in Northern Africa. The major African flatbreads are injera in Ethiopia and Eritrea, and kisra in Sudan. To prepare injera or kisra, a slurry of flour is subjected to lactic acid fermentation (Yetneberk, De Kock, Rooney, & Taylor, 2004).

The texture of these traditional sorghum foods is critical to their acceptability. This is because, for example, ugali is normally eaten by hand using fingers, which involves taking a small lump of ugali using fingers then rolling and moulding to an appropriate shape before eating. This makes finger feel an important quality parameter for ugali. A semi-solid consistency is preferred for thin porridges such as uji, especially when intended for children (Lorri & Svanberg, 1993). A flatbread such as injera is preferred when it is soft, rollable and fluffy (Yetneberk et al., 2004). In addition, flavour and colour may play significant roles in acceptability of sorghum foods (Zegeye, 1997).

To help solve the problem of decline in functional quality of cereal foods fortified with legumes, instrumental and descriptive sensory analyses were used in conjunction, to evaluate the sensory attributes of ugali, uji and injera made from tannin and non-tannin sorghum fortified with cowpea. These three types of traditional African sorghum foods were selected for this study based on their importance in the diets of most regions in Africa and the differences in their preparation methods.

2. Materials and methods

2.1. Preparation of flour samples

Two sorghum cultivars NS 5511, a red, tannin-type, 5.6 g/100 g catechin equivalents (CE) and Orbit (a white, tan-plant non-tannin-type, <1 g/100 g CE) and one cowpea variety, Bechuana white, (2.3 g/100 g CE) − were used in this study. NS 5511 was a year 2007 harvest grown in the Free State Province, South Africa; Orbit was a year 2005 harvest from Agricultural Research Council, Potchefstroom, South Africa, and cowpea was a 2007 harvest, grown in Delareyville, North West Province, South Africa. The NS 5511 sorghum, Orbit sorghum and cowpea grains had 11.0, 8.4 and 23.5 g protein/100 g, respectively. The grains were prepared according to the procedure by Anyango et al. (2011). Whole grain samples were separately milled using a laboratory hammer mill (Falling Number 3100, Huddinge, Sweden) fitted with a 500 μm screen to give whole grain meal which was then stored at 10 °C prior to food preparation and other treatments. Fortified flours were prepared by mixing whole sorghum and whole cowpea flours at 70:30 (w/w) ratio. The flours were used to prepare three traditional African sorghum foods, uji (fermented thin porridge), injera (fermented flatbread) and ugali (unfermented stiff porridge).

2.2. Preparation and measurement of uji texture

A natural inoculum was prepared according to the procedure of Taylor and Taylor (2002). Flour (30 g) and 60 mL tap water was inoculated with 10 mL inoculum in a closed plastic tub and incubated at 25 °C for 24 h. Tap water (160 mL) was added to the fermented slurry to make a uniform diluted suspension (30 g solids/250 g).

The fermented suspensions were used to prepare uji (pH 3.7) and study their pasting properties using a Rapid Visco Analyser (RVA) (Model 3 D) (Newport Scientific, Warriewood, Australia). The RVA was programmed to rapidly stir each freshly prepared suspension at 960 rpm for 10 s, then decrease and hold shear rate constant at 160 rpm for the remainder of the test period. The temperature profile involved holding initially at 50 °C for 2 min, then increasing to 91 °C over 4 min and holding at 91 °C for 8 min before finally cooling to 50 °C over 4 min and holding constant for 3 min. The peak viscosity (PV) and the cool paste viscosity (CPV) were determined for each suspension from the RVA plots. Each uji treatment was analysed three times in duplicate.

2.3. Preparation and measurement of injera texture

Injera was prepared according to Yetneberk et al. (2004) with modification. To initiate the second fermentation, 0.5 g commercial instant dried baker's yeast and 1.5 g sugar was added to the rest of the fermented batter and stirred thoroughly. The yeast fermented batter (20 g) was weighed into a 90 mm plastic Petri dish and baked in a 900 Watt microwave oven (for 45 s) until it formed a honey-combed structured surface.

The texture of injera was evaluated using a protocol similar to that of Yetneberk et al. (2004). Each injera was put into a separate ziplock-type polythene bag and stored at 25 °C in an incubator for 1 h, 24 h and 48 h. For texture analysis, each injera was cut using a 65 mm diameter cookie cutter while still fresh, to obtain a uniform sample size. The texture of each type of injera were analysed three times using a TA-XT2 Texture Analyser (Stable Micro Systems, Godalming, UK). The stiffness was measured as maximum bending force determined using a three-point bend rig with an aluminium bar (5 mm thick and 90 mm long) attachment, and the two adjustable supports of rig base plate were set 30 mm apart. The testing profile was set as follows: Pre-Test Speed was 1.0 mm/s; Test Speed was 3.0 mm/s; Post-Test Speed was 10.0 mm/s; Distance was 5 mm; Trigger type was 0.049 N. Three pieces of injera per treatment were analysed.

2.4. Preparation and instrumental measurement of ugali texture

Tap water (60 mL) was brought to boil in a beaker. Flour (30 g) was made into slurry with 30 mL water. The slurry was then added to the boiling water and cooked with constant heating and vigorous mixing until a uniform and well-cooked product was formed in 1 min.

The cooked ugali were filled immediately into 50 mL glass sample tubes, diameter 30 mm. Each of the tubes containing ugali was then covered with aluminium foil, and maintained in an oven at 50 °C for 90 min. To analyse the ugali, the aluminium foil was removed and the surface of the sample scraped off. The ugali were analysed immediately for maximum penetration force (firmness) and stickiness using a TA-XT2 Texture Analyser as described by Kebakile (2008). A cylindrical Perspex probe, diameter 20 mm, was used. The test settings were: Pre-Test Speed was 2.0 mm/s; Test Speed was 2.0 mm/s; Post-Test Speed was 10 mm/s; Penetration Distance was 10 mm; Trigger Force was 0.049 N.

2.5. Descriptive sensory evaluation of ugali

To be able to relate instrumental textural properties of the sorghum foods to the human perception of sensory qualities, ugali was subjected to descriptive sensory evaluation using a trained panel of eight females aged between 24 and 48 years. The cooking process involved first bringing to boil 400 mL tap water in a 1.9 L stainless steel cooking pan. Flour (200 g) was then added to the boiling water

and vigorously mixed to form a uniform product while heating on a hot plate maintained at medium heat for 10 min. This product was then allowed to stiffen by covering it in the cooking pan with a lid and heating on a hot plate set at medium heat for an additional 3 min. Ugali (40 g) was served in glass ramekins using a 40 mL ice-cream scoop. The ramekin of ugali was immediately covered with aluminium foil and maintained at 50 °C. For each tasting session, four ugali samples representing each of the four types of flour were freshly cooked. A reference maize ugali was prepared using 150 g commercial maize flour (Table 1) while maintaining the other cooking conditions the same as for sorghum ugali.

Descriptive sensory profiling of the ugali was performed based on the generic descriptive method of Einstein (1991). The panellists developed and used 17 sensory descriptors to describe the ugali (Table 1). After 14 h of panel training, the sensory evaluation was done in two sessions. The four types of ugali served in transparent glass ramekins were presented using a protocol similar to that of Kobue-Lekalake, Taylor, and De Kock (2007). The panellists handled the ugali with their fingers, the way ugali is normally eaten. Responses were entered directly into a computer system using Compusense software (Compusense® Five release 4.6, Compusense, Guelph, Ontario, Canada). Each type of ugali was

Table 1
Descriptive sensory lexicon developed by descriptive sensory panel to evaluate ugali.

Attribute	Definition	References	Rating scale
Appearance			
Colour intensity	Ugali colour ranging from cream white to dark amber/brown	0 = thick white maize meal porridge (25% solids) (Super Sun[a]) 9 = thick red sorghum porridge (25% solids) (Fine Mabele[b])	0 = Light 10 = Dark
White specks	Quantity of white specks visible on porridge		0 = None 10 = Many
Dark specks	Quantity of dark specks visible on porridge		0 = None 10 = Many
Roughness	The degree to which roughness could be visually perceived on the surface of ugali	0 = smooth peanut butter (Black Cat[b]) 10 = porridge (coarse red sorghum porridge) (33% solids) (Coarse Mabele[c])	0 = Not rough 10 = Very rough
Aroma			
Overall aroma intensity	Intensity of the aroma of the ugali		0 = Not intense 10 = Very intense
Sorghum porridge aroma	Intensity of the aroma of cooked sorghum	10 = thick red sorghum porridge (25% solids) (Fine Mabele[b])	0 = Not intense 10 = Very intense
Cooked-cowpea aroma	Intensity of the aroma of cooked cowpea	10 = boiled whole Bechuana white cowpea variety (boiled for 80 min in excess water)	0 = Not intense 10 = Very intense
Texture:			
Firmness	Force required to compress a lump of porridge with fingers	0 = thin white maize meal porridge (10% solids) (Super Sun[a]) 10 = stiff red sorghum porridge (33% solids) (Fine Mabele[b])	0 = Not firm 10 = Very firm
Springiness	Degree to which ugali sample returned to its original shape after compression with fingers	2 = thick white maize meal porridge (25% solids) (Super Sun[a]) 10 = white bread wheat flour (Snowflake[a]) dough	0 = Not springy 10 = Very springy
Stickiness	The extent to which material adhered to fingers during normal handling	1 = thick maize meal porridge (25% solids) (Super Sun[a]) 10 = Cooked starch (25% solids) (evaluated at 40 °C) (Maizena[d])	0 = Not sticky 10 = Very sticky
Rough texture	The degree to which roughness could be perceived in the mouth while eating ugali	0 = smooth peanut butter (Black Cat[b]) 10 = coarse red sorghum porridge (33% solids) (Coarse Mabele[c])	0 = Not rough 10 = Very rough
Flavour:			
Overall flavour intensity	Overall flavour intensity of ugali		0 = Not intense 10 = Very intense
Cooked-cowpea flavour	Intensity of the flavour of cooked cowpea	10 = boiled whole Bechuana white cowpea variety (boiled for 80 min in excess water)	0 = Not intense 10 = Very intense
Sorghum porridge flavour	Intensity of flavour of cooked sorghum	10 = thick red sorghum porridge (25% solids) (Fine Mabele[b])	0 = Not intense 10 = Very intense
Sensations after swallowing the sample			
Sorghum aftertaste	The intensity of cooked sorghum porridge flavour perceived in the mouth after swallowing.	10 = thick red sorghum porridge) (25% solids) (Fine Mabele[b])	0 = Not intense 10 = Very intense
Cowpea aftertaste	The intensity of a cooked cowpea flavour perceived in the mouth after swallowing	10 = boiled whole Bechuana white cowpea variety (boiled for 80 min in excess water)	0 = Not intense 10 = Very intense
Powdery residue	The extent to which particles of the pericarp felt dry in the mouth after swallowing	10 = uncooked sorghum flour (Fine Mabele[b])	0 = None 10 = Very much

[a] Premier Foods, Sandton, South Africa.
[b] Tiger Consumer Brands, Bryanston, South Africa.
[c] Pride Milling, Nigel, South Africa.
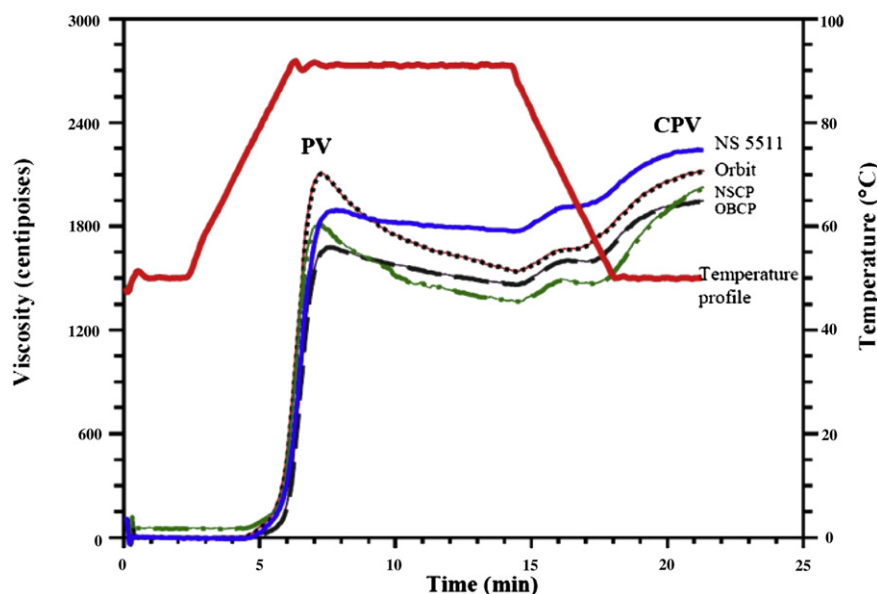[d] Bokomo Foods, Cape Town, South Africa.

Fig. 1. Effects of compositing with cowpea on the pasting properties of fermented uji slurries as measured using a Rapid Visco Analyser. Curves are representative of each type of uji. NS 5511 (red, tannin sorghum); NSCP (NS 5511 + Cowpea); , Orbit (white, tan-plant sorghum); OBCP (Orbit + Cowpea); PV (peak viscosity); CPV (cool paste viscosity). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

evaluated twice by each panellist giving 16 data points for each attribute per ugali type.

2.6. Statistical analyses

Instrumental textural measurements were subjected to a sample-related one-way analysis of variance (ANOVA). Panel mean scores of ugali attributes were subjected to a two-way ANOVA. Fisher's least significant difference test (LSD) ($p < 0.05$) was used to test for mean differences. Principal component analysis (PCA) was used to test for the correlation between the ugali types and the averaged scores for the attributes across panellists.

3. Results and discussion

3.1. Textural properties of uji

Fortification with cowpea reduced the pasting PV of NS 5511 uji and Orbit uji by 6% and 23%, respectively (Fig. 1). Likewise, fortification decreased the CPV of NS 5511 and Orbit uji, by 12% and 6%, respectively. These reductions in viscosities were probably due to the increase in protein content, with a concomitant decrease in starch content in flour as a result of addition of cowpea. As the increase in viscosity during heating is attributed to pasting of starch (Batey & Curtin, 2000), cowpea-fortified uji was expected to have a lower PV than unfortified uji due to a decrease in starch content. In addition, increasing protein content has been shown to reduce the PV of other cereals such as rice (Teo, Karim, Cheah, Norziah, & Seow, 2000).

As indicated, there was more reduction in PV of Orbit uji than NS 5511 uji through fortification with cowpea, even though the same proportion of cowpea was used in the preparation of the fortified flours. This suggests that starch content alone may not explain the differences in uji viscosity. The variations in the compositions of the different fermented flour suspensions may have played a role in the differences in observed PV. This is because as already mentioned, the sorghum cultivars possessed different chemical qualities, particularly tannin and protein contents. Protein content has been shown to affect CPV (Zhang & Hamaker, 2003). Proteins may interact with the C-2 and C-3 hydroxyl groups of glucose units through H-bonding and prevent intermeshing of amylose and amylopectin helices (reviewed by Preston, 1998). These protein—-glucose interactions may be an impediment to starch retrogradation, which is normally implicated in the development of CPV. However, the fact that sorghum with higher protein content (NS 5511 − 11.0% protein) had higher CPV than the one with lower protein content (Orbit − 8.4% protein) may be due to NS 5511 sorghum containing tannins. Proteins have a high affinity to bind to sorghum tannins (Hagerman & Butler, 1980), which in the case of NS 5511 sorghum uji, probably facilitated the starch molecules to interact between themselves, resulting in greater retrogradation compared to Orbit sorghum uji starch.

3.2. Textural properties of injera

As expected there was an increase in stiffness of injera over time (Table 2). Similar obsrevations were made by Yetneberk et al.

Table 2
Effects of compositing with cowpea on the maximum force (N) required for bending injera stored at 25 °C over a period of two days measured using a TA-XT2 Texture Analyser.

Sorghum cultivar	Flour	Storage time		
		1 h	24 h	48 h
NS 5511 (red, tannin sorghum)	Sorghum	$0.83^{ab} \pm 0.01$	$1.08^d \pm 0.02$	$1.22^e \pm 0.09$
	Sorghum + Cowpea	$0.87^b \pm 0.05$	$1.33^f \pm 0.03$	$1.53^g \pm 0.05$
Orbit (white, tan-plant, non-tannin sorghum)	Sorghum	$0.99^c \pm 0.07$	$1.58^g \pm 0.03$	$1.77^i \pm 0.03$
	Sorghum + Cowpea	$0.77^a \pm 0.02$	$1.37^f \pm 0.07$	$1.66^h \pm 0.03$

Values are Means ± Standard deviations ($n = 3$). Values within the table followed by different superscript letters are significantly different ($p < 0.05$).

Table 3
Effects of compositing with cowpea on the firmness and stickiness of ugali as determined by a TA-XT2 Texture Analyser and descriptive sensory panel (DSP).

Sorghum cultivar	Flour	Firmness		Stickiness	
		TA-XT2 (N)	DSP	TA-XT2 (N)	DSP
NS 5511 (red, tannin sorghum)	Sorghum	14.43[d] ± 0.84	6.25[c] ± 1.28	2.17[b] ± 0.76	4.17[a] ± 1.98
	Sorghum + Cowpea	11.56[c] ± 0.74	6.46[c] ± 1.10	0.96[a] ± 0.16	3.92[a] ± 1.77
Orbit (white, tan-plant, non-tannin sorghum)	Sorghum	6.22[a] ± 0.30	4.88[a] ± 1.52	3.62[c] ± 0.01	5.88[b] ± 1.69
	Sorghum + Cowpea	9.04[b] ± 0.14	5.70[b] ± 1.31	3.57[c] ± 0.30	5.28[b] ± 1.61

The values are Means ± Standard deviations ($n = 3$ for TA-XT2 data; $n = 8$ for DSP data). Values in a column followed by different superscript letters are significantly different ($p < 0.05$).
DSP score: Firmness 0 = Not firm; 10 = Very firm; Stickiness 0 = Not sticky; 10 = Very sticky.

(2004). The beginning of staling is normally associated with retrogradation of gelatinized starch (Kulp & Ponte, 1981). In addition, Martin, Zeleznak, and Hoseney (1991), working on a model for bread firming incorporating roles of gluten and starch as influencing factors, suggested that cross-linking (H-bonding) between protein matrix and the discontinuous remnants of starch granules during storage could contribute to bread firming especially in the initial stages. Fortification with cowpea did not significantly change the stiffness of NS 5511 injera after 1 h. However, there was a 23% and 25% increase in stiffness after 24 h and 48 h, respectively. On the other hand, fortification reduced stiffness of Orbit injera by 22%, 13% and 6%, after 1 h, 24 h and 48 h storage, respectively. These differences in the effects of fortification with cowpea on injera stiffness may be explained by the fact that NS 5511 is a tannin sorghum while Orbit is a non-tannin sorghum cultivar. As explained, tannins have a high propensity to complex with proteins (Hagerman & Butler, 1980) and the affinity is enhanced in high-molecular-weight protein (Emmambux & Taylor, 2003). Protein-tannin interaction occurs through weaker H-bonds (Orliac, Rouilly, Silvestre, & Rigal, 2002) instead of stronger protein–protein disulphide covalent bonds between sorghum protein (kafirin) molecules. As fortification with cowpea, which had higher protein content and low tannin content, reduced the tannin content of the flour by 16% (Anyango et al., 2011), this probably minimized the protein network-weakening effect of tannins in NS 5511 injera. In the case of Orbit injera, an important change due to cowpea fortification was the difference in the protein contents. Cowpea addition increased the protein content of the injera, thereby reducing the

proportion of starch. Starch retrogradation is a primary cause of textural staling of predominantly starch-containing systems (Bao & Bergman, 2004). Hence, a reduction in the proportion of starch as a consequence of cowpea addition may have resulted in softer injera. Furthermore, by adding cowpea, which has a relatively low concentration in sulphur-amino acids (USDA, 2009), this may have inhibited the formation of stronger disulphide linkages otherwise prevalent in cooked sorghum kafirin proteins, resulting in to weaker protein networks.

3.3. Textural properties of ugali

The ugali assessed using instrumental texture analysis had to be of lower solids content (25% solids) compared to that analysed by a trained sensory panel (33% solids), in order to obtain reasonably repeatable readings from the texture analyser. Despite the differences in absolute values for texture, the instrumental technique may be used to compare with the results from the sensory panel based on similarities in trends. Fortification increased the firmness of Orbit ugali by 45% and 17% as assessed by TA-XT2 Texture Analyser and the descriptive sensory panel, respectively (Table 3). There was a 20% reduction in instrumental firmness of NS 5511 ugali, which was not detected by the sensory panel. In the case of Orbit sorghum, it is likely that the increase in protein content from cowpea enhanced protein–protein and or protein–starch interactions, thus forming stronger extensive networks, as explained previously. On the other hand, preferential binding of proteins to tannins may have resulted in formation of weak H-bonds, thereby

Table 4
Effects of compositing with cowpea on the mean scores of sensory attributes of ugali as evaluated by descriptive sensory panel.

Attribute	Sorghum cultivar				F-Value	
	NS 5511 (red, tannin)		Orbit (white, tan-plant)		Sample effect	Panellist effect
	Sorghum	Sorghum + Cowpea	Sorghum flour	Sorghum + Cowpea		
Colour intensity	7.2[b] ± 1.2	7.3[b] ± 1.0	3.9[a] ± 0.9	4.0[a] ± 0.9	165.5*	8.4*
White specks	4.6[b] ± 1.5	4.4[b] ± 1.6	2.2[a] ± 1.6	2.4[a] ± 1.4	10.6*	0.7
Dark specks	1.9[a] ± 1.2	2.3[a] ± 1.9	4.9[c] ± 1.7	3.9[b] ± 2.0	19.0*	4.8*
Roughness	4.5[ab] ± 1.0	5.0[b] ± 0.9	4.1[a] ± 1.0	4.1[a] ± 1.0	3.6*	1.3
Aroma intensity	6.4[bc] ± 0.9	6.6[c] ± 0.7	5.2[a] ± 1.5	5.9[b] ± 1.4	8.6*	3.8*
Sorghum porridge Aroma	6.0[b] ± 0.9	5.0[a] ± 1.1	5.7[b] ± 1.0	4. 8[a] ± 1.1	6.0*	1.7
Cooked cowpea aroma	2.1[a] ± 1.5	5.0[b] ± 2.0	2.0[a] ± 1.4	5.1[b] ± 1.8	19.3*	1.5
Firmness	6.2[c] ± 1.3	6.4[c] ± 1.1	4.9[a] ± 1.5	5.7[b] ± 1.3	14.7*	9.8*
Springiness	4.9[b] ± 1.8	5.9[c] ± 1.2	4.0[a] ± 1.7	5.1[bc] ± 1.5	7.7*	5.2*
Stickiness	4.2[a] ± 2.0	3.9[a] ± 1.8	5.9[b] ± 1.7	5.3[b] ± 1.6	8.4*	4.6*
Rough texture	4.9[c] ± 1.0	4.6[c] ± 1.2	3.1[a] ± 0.7	4.0[b] ± 1.2	14.2*	2.9*
Overall flavour intensity	5.7[b] ± 1.2	6.8[c] ± 0.6	4.5[a] ± 1.7	6.3[bc] ± 1.2	18.9*	4.5*
Sorghum porridge Flavour	6.4[c] ± 0.8	4.9[ab] ± 1.3	5.5[b] ± 1.3	4.8[a] ± 1.2	9.4*	2.8*
Cooked cowpea flavour	2.0[a] ± 1.3	5.5[b] ± 2.0	1.6[a] ± 1.1	5.8[b] ± 1.4	46.9*	2.0*
Sorghum aftertaste	6.1[b] ± 1.2	4.3[a] ± 1.7	4.6[a] ± 1.4	4.1[a] ± 1.5	12.1*	4.7*
Cowpea aftertaste	1.7[a] ± 1.2	4.8[b] ± 2.1	1.2[a] ± 0.8	4.7[b] ± 1.6	34.1*	2.8*
Powdery residue	5.0[b] ± 1.6	4.4[b] ± 1.7	2.0[a] ± 1.0	2.4[a] ± 1.1	18.3*	0.9

Values are Means ± Standard deviations ($n = 8$). Values in a row followed by different superscript letter notations are significantly different ($p < 0.05$), *$p < 0.05$.
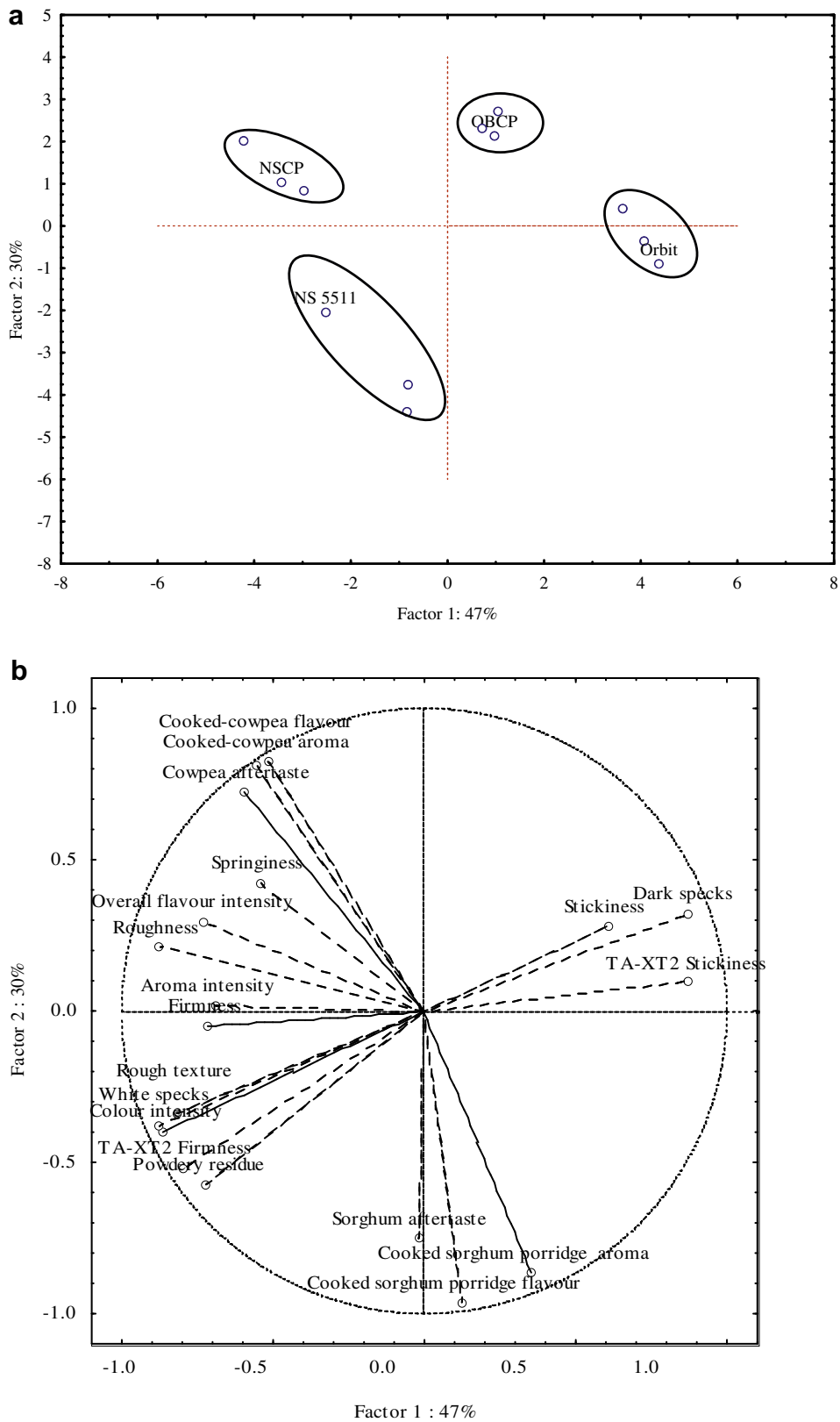
Fig. 2. Principal component analysis (PCA) of ugali sensory attributes including firmness and stickiness measured by TA-XT2 Texture Analyser. (a) Plot of the first two factors scores for ugali. (b) Plot of the loading vectors for sensory attributes of ugali from instrumental and descriptive sensory analyses. NS 5511 (red, tannin sorghum); NSCP (NS 5511 + Cowpea); Orbit (white, tan-plant sorghum); OBCP (Orbit + Cowpea).

inhibiting the formation of stronger covalent bonds in ugali containing NS 5511 sorghum.

Increase in firmness of ugali after fortification did not appear to be related to uji CPV reduction. This result is different from the findings for uji (Section 3.1). The apparent inconsistency may be explained by the differences in solids content hence, protein concentration, as well as the pH differences of these two types of porridges. Uji had 10% solids while ugali had 33% solids. A minimum protein concentration is required to form an extensive protein network (Acton, Hanna, & Satterlee, 1981; Damodaran, 1996). The relatively higher solids content of ugali and hence higher protein concentration may have resulted in firmer ugali, with increasing protein content from cowpea. On the other hand, uji CPV was probably dependent mainly on amount of retrograded starch, which was lower in fortified uji. A pH level which permits an optimum balance of protein–protein and protein–solvent interactions is required to form uniform strong extensive networks (Damodaran, 1996). The sorghum storage protein, kafirin, has an isoelectric point (pI) of 6, while cowpea's major storage protein, globulin, has a pI of 5 (Csonka, Murphy, & Jones, 1926). As uji was acidic (pH 3.7), its proteins would assume a net positive charge creating electrostatic repulsion thereby probably inhibiting formation of extensive protein network.

Fortification with cowpea had no effect on the stickiness of Orbit ugali, while NS 5511 showed no particular trend i.e. the panellists did not detect the difference noted by the instrumental analysis, suggesting that the effect was insubstantial for human perception threshold. The fact that fortification resulted in decrease in stickiness of NS 5511 sorghum ugali which was not detected by the sensory panel was possibly because the tannins present cause puckering of the skin and a feeling of dryness (Prinz & Lucas, 2000), which probably masked the stickiness.

3.4. Other sensory properties of ugali

Analysis of variance (ANOVA) F-values were significant ($p < 0.05$) for all the 17 sensory attributes of ugali (Table 4), indicating that the panellists were able to differentiate ugali prepared from the different types of flour using the descriptive terms selected.

Principal component analysis (PCA) was used to understand the relationships between the sensory attributes of ugali and the type of flour used in their preparation, and to relate instrumental textural properties of the sorghum foods to the human perception of sensory qualities of ugali. With respect to the first objective, Factor 1 (accounting for 47% of the variation in the sensory attributes), separated ugali samples in terms of the sorghum cultivar used in their preparation, whereas Factor 2 (representing 30% of the variation) separated the samples based on presence or absence of cowpea in the ugali (Fig. 2a). Concerning the second objective, results from instrumental analysis of ugali texture (firmness and stickiness) and the scores for these textural attributes by the descriptive sensory panel were positively correlated as shown by the PCA plot (Fig. 2b) and Table 5.

Cowpea-fortified ugali porridges were associated with springiness, more intense cooked cowpea flavour and aroma, cowpea aftertaste, less intense cooked sorghum flavour and stronger overall flavour intensity. Beany flavour, described by the panellists as cowpea flavour, appeared to be the most important attribute characterizing cowpea-fortified ugali. Beany flavour is attributed to the action of lipoxygenase enzyme, which catalyses the formation of odorous carbonyl compounds (pentyl furans) from components containing cis-1,4-pentadiene system (reviewed by Okaka & Potter, 1979).

Concerning the effects sorghum cultivar, ugali porridges made with red, tannin sorghum (NS 5511) were darker in colour, stiffer, more cohesive, less sticky, springier, rough textured, more strongly flavoured, with more white specks and had more powdery residue. Ugali prepared from white, tan-plant sorghum (Orbit) were characterized by lighter colour, dark specks, and stickiness and were generally less firm. The dark colour intensity of tannin sorghum ugali may be attributed to staining of the porridges by phenolic pigments (anthocyanins) present in the pericarp of red sorghum grain (Beta, Rooney, Marovatsanga, & Taylor, 1999; Hahn, Rooney, & Earp, 1984). Sorghum grain colour is associated with pigmented testa (if present) and the pericarp of the sorghum kernel, which varies in thickness and pigmentation colour depending on the sorghum type (Awika, McDonough, & Rooney, 2005; Rooney & Miller, 1982). The perception of powdery residue in NS 5511 ugali suggests mouth-puckering, the dry sensation effect of tannins (Prinz & Lucas, 2000). As explained by these authors, tannins reduce the lubricating qualities of human saliva by both decreasing its viscosity and increasing friction.

4. Conclusions

While the taste of traditional sorghum foods is affected by fortification with cowpea at 70:30 ratio, the textural quality of cowpea-fortified sorghum foods is mainly dependent on the sorghum grain cultivar's chemical characteristics, especially the presence of tannins. This implies that cowpea can be added to produce protein-rich traditional African sorghum foods but the functional quality of the fortified sorghum food will largely depend on the sorghum cultivar concerned. Instrumental texture analysis relates well with human perception of texture of traditional African cowpea-fortified sorghum foods. Therefore, instrumental texture analysis can be applied as a rapid way to predict the consumer perception of textural quality of legume-fortified sorghum foods.

References

Acton, J. C., Hanna, M. A., & Satterlee, L. D. (1981). Heat induced gelation and protein-protein interaction of actomyosin. *Journal of Food Biochemistry, 5*, 101–113.

Akinyele, I. O., & Fasaye, O. A. (1988). Nutrient quality of corn and sorghum supplemented with cowpeas (*Vigna unguiculata*) in the traditional manufacture of ogi. *International Journal of Food Science & Technology, 53*, 1750–1752.

Anyango, J. O., De Kock, H. L., & Taylor, J. R. N. (2011). Impact of cowpea addition on the Protein Digestibility Corrected Amino Acid Score and other protein quality parameters of traditional African foods made from non-tannin and tannin sorghum. *Food Chemistry, 124*, 775–780.

Awika, J. M., McDonough, C. M., & Rooney, L. W. (2005). Decorticating sorghum to concentrate healthy phytochemicals. *Journal Agricultural & Food Chemistry, 53*, 6230–6234.

Bao, J., & Bergman, C. J. (2004). The functionality of rice starch. In A. C. Eliasson (Ed.), *Starch in food: Structure, function and applications* (pp. 258–294). Cambridge, UK: Woodhead Publishing.

Table 5
Correlation coefficients between instrumental (TA-XT2 Texture Analyser) and descriptive sensory firmness and stickiness of ugali.

	TA-XT2 Firmness	TA-XT2 Stickiness	Sensory Firmness
TA-XT2 Stickiness	−0.62* (0.03)		
Sensory Firmness	0.63* (0.03)	−0.64* (0.03)	
Sensory Stickiness	−0.66* (0.02)	0.53 (0.08)	−0.08 (0.80)

*indicates significant correlation ($p < 0.05$). Corresponding p-values are given in the brackets.

Batey, I. L., & Curtin, B. M. (2000). Effects on pasting viscosity of starch and flour from different operating conditions for the Rapid Visco Analyser. *Cereal Chemistry, 77*, 754–760.

Beta, T., Rooney, L. W., Marovatsanga, L. T., & Taylor, J. R. N. (1999). Phenolic compounds and kernel characteristics of Zimbabwean sorghums. *Journal of the Science of Food & Agriculture, 79*, 1003–1010.

Chavan, J. K., Kadam, S. S., & Salunkhe, D. K. (1989). Cowpea. In D. K. Salunkhe, & S. S. Kadam (Eds.), *Handbook of world food legumes: Nutritional, chemistry, processing, technology, and utilization* (pp. 1–21). Boca-Raton, FL: CRC Press.

Csonka, F. A., Murphy, J. C., & Jones, D. R. (1926). The iso-electric points of various proteins. *Journal of Biological Chemistry, 48*, 763–768.

Damodaran, S. (1996). Functional properties. In S. Nakai, & H. W. Modler (Eds.), *Food proteins properties and characterization* (pp. 167–234). , New York: Wiley-VCH.

Duodu, K. G., Taylor, J. R. N., Belton, P. S., & Hamaker, B. R. (2003). Factors affecting sorghum protein digestibility. *Journal of Cereal Science, 38*, 117–131.

Einstein, M. A. (1991). Descriptive techniques and their hybridization. In H. T. Lawless, & B. P. Klein (Eds.), *Sensory science theory and applications in foods* (pp. 317–338). , New York: Marcel Dekker.

Emmambux, N. M., & Taylor, J. R. N. (2003). Sorghum kafirin interaction with various phenolic compounds. *Journal of the Science of Food & Agriculture, 83*, 402–407.

FAO/WHO. (1994). *Codex alimentarius: Foods for special dietary uses (including foods for infants and children)* (2nd edition). Rome, Italy: FAO.

FAO. (1995). *Sorghum and millets in human nutrition*. FAO Food and Nutrition Series No 27. Rome, Italy: FAO.

Fu, B., Nelson, P. E., Irvine, R., & Kanach, L. L. (1996). Processing of nutritious, safe and acceptable foods from CELSS candidate crops. *Advances in Space Research, 18*, 241–250.

Hagerman, A. E., & Butler, L. G. (1980). Determination of protein in tannin-protein precipitates. *Journal of Agricultural & Food Chemistry, 28*, 944–947.

Hahn, D. H., Rooney, L. W., & Earp, C. F. (1984). Tannins and phenols of sorghum. *Cereal Foods World, 29*, 776–779.

ICRISAT. (2009). *ICRISAT press releases 2009*. http://www.icrisat.org/icrisat-pr-2009. htm [accessed April 2010].

Kebakile, M.M. (2008). *Sorghum dry-milling processes and their influence on meal and porridge quality*. PhD thesis, Pretoria, South Africa: University of Pretoria.

Klopfenstein, C. F., & Hoseney, R. C. (1995). Nutritional properties of sorghum and millets. In D. A. V. Dendy (Ed.), *Sorghum and millets: Chemistry and technology* (pp. 125–168). St. Paul, MN: AACC.

Kobue-Lekalake, R. I., Taylor, J. R. N., & De Kock, H. L. (2007). Effects of phenolics in sorghum grain on its bitterness, astringency and other sensory properties. *Journal of the Science of Food & Agriculture, 87*, 1940–1948.

Kulp, K., & Ponte, J. G., Jr. (1981). Staling of white pan bread: fundamental causes. *Critical Reviews in Food Science & Nutrition, 15*, 1–48.

Lorri, W., & Svanberg, U. (1993). Lactic acid-fermented cereal gruels: viscosity and flour concentration. *International Journal of Food Science & Nutrition, 44*, 207–213.

Martin, M. L., Zeleznak, K. J., & Hoseney, R. C. (1991). A mechanism of bread firming. I. Role of starch swelling. *Cereal Chemistry, 68*, 498–503.

Okaka, J. C., & Potter, N. N. (1979). Physico-chemical and functional properties of cowpea powders processed to reduce beany flavour. *Journal of Food Science, 44*, 1235–1240.

Orliac, O., Rouilly, A., Silvestre, F., & Rigal, L. (2002). Effects of additives on the mechanical properties, hydrophobicity and water uptake of thermomoulded films produced from sunflower protein isolate. *Polymer, 43*, 5417–5425.

Pelembe, L. A. M., Erasmus, C., & Taylor, J. R. N. (2002). Development of a protein-rich composite sorghum-cowpea instant porridge by extrusion cooking process. *Lebensmittel Wissenschaft und Technologie, 35*, 120–127.

Preston, K. R. (1998). Protein-carbohydrate interactions. In R. J. Hamer, & R. C. Hoseney (Eds.), *Interactions: The keys to cereal quality* (pp. 81–93). St Paul, MN: AACC.

Prinz, J. F., & Lucas, P. W. (2000). Saliva tannin interactions. *Journal of Oral Rehabilitation, 27*, 991–994.

Rooney, L. W., & Miller, F. R. (1982). Variations in the structure and kernel characteristics of sorghum. In L. W. Rooney, & D. S. Murty (Eds.), *Proceedings of the international symposium on sorghum grain quality* (pp. 143–162). Patancheru, India: ICRISAT.

Taylor, J. R. N., & Anyango, J. O. (2011). Sorghum flour and flour products: production, nutritional quality, and fortification. In V. R. Preedy, R. R. Watson, & V. B. Patel (Eds.), *Flour and breads and their fortification in health and disease prevention* (pp. 127–139). London, Burlington, San Diego: Academic Press, Elsevier.

Taylor, J. R. N., & Schüssler, L. (1986). The protein compositions of the different anatomical parts of sorghum grain. *Journal of Cereal Science, 4*, 361–369.

Taylor, J., & Taylor, J. R. N. (2002). Alleviation of the adverse effect of cooking on sorghum protein digestibility through fermentation in traditional African porridges. *International Journal of Food Science & Technology, 37*, 129–137.

Teo, C. H., Karim, A. A., Cheah, P. B., Norziah, M. H., & Seow, C. C. (2000). On the roles of protein and starch in the ageing of non-waxy rice flour. *Food Chemistry, 69*, 229–236.

USDA. (2009). *National nutrient database for standard reference*. Release 22. www. nal.usda.gov/fnic/foodcomp/search [accessed January 2010].

Yetneberk, S., De Kock, H. L., Rooney, L. W., & Taylor, J. R. N. (2004). Effects of sorghum cultivar on injera quality. *Cereal Chemistry, 81*, 314–321.

Young, V. R., & Pellett, P. L. (1994). Plant protein in relation to human protein and amino acid nutrition. *The American Journal of Clinical Nutrition, 59*(Suppl.), 1203S–1212S.

Zegeye, A. (1997). Acceptability of injera with stewed chicken. *Food Quality & Preference, 8*, 293–295.

Zhang, G., & Hamaker, B. R. (2003). A three-component interaction among starch, protein, and free fatty acids revealed by pasting profiles. *Journal of Agricultural & Food Chemistry, 51*, 2797–2800.