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Full Length Research Paper

Quality of porridge from sub-Saharan Africa evaluated using instrumental techniques and descriptive sensory lexicon - Part 1: Thick (stiff) porridge

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The sensory attributes of thick porridges made from different composite flours in neutral, citric acid or sodium bicarbonate media was identified using instrumental methods and modified quantitative descriptive analysis. The results showed that composite flours with high cassava concentrations had lower pasting temperatures but higher peak, breakdown, final and setback viscosities than the cereal-rich flours. The onset pasting temperatures of alkali-treated slurries were higher ($p < 0.05$) than for the neutral- or acid-treated slurries. Acid-treated slurries had higher ($p < 0.05$) peak viscosities than neutral- or alkali-treated slurries. Acid-treated slurries had higher ($p < 0.05$) breakdown viscosities as compared to the neutral slurries. The toughness and work of shear of thick porridge ranged between 0.21 - 0.58 kg and 0.83 - 5.95 kg·mm, respectively. Thick porridge cooked in alkaline media was significantly darker ($p < 0.05$) than that made in neutral or acid media. Principal component analysis identified four major principal components (PCs) that accounted for 87.6% of the total variance in the sensory attribute data. The principal component scores indicated that the location of each porridge along each of the four scales corresponded with attributes associated with sodium bicarbonate aroma and taste (PC1); cassava aroma and hardness (PC2); colour of thick porridge (PC3); and finger millet/sorghum aroma (PC4). Thick porridges targeting specific consumer groups in sub-Saharan Africa can be developed by appropriate choice of flours and pH thereby forming the basis for commercial production of thick porridges for different population categories in sub-Saharan Africa with diverse sensory expectations of the product.

Key words: Colour, texture, thick porridge, quantitative descriptive analysis.

INTRODUCTION

Thick porridge (also known as stiff porridge) is an important source of calories for millions of people in sub-Saharan Africa. It is also recommended as a functional food for the management of certain non-communicable

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diseases such as type II diabetes (Eli-Cophie et al., 2016; Mlotha et al., 2016). Thick porridge is prepared from straight (that is, unblended) or composite flours of tropical cereals such as finger millet (*Eleusine coracana*), pearl millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and maize (*Zea mays*); and roots crops such as cassava (*Manihot esculenta*) (Wanjala et al., 2016; Murty and Kumar, 1995). The porridge is prepared by adding flour to boiling water (20-30% w/v) in increments while vigorously stirring, until it forms a thick, homogenous and well-gelatinized mass devoid of lumps (Murty and Kumar, 1995; Taylor and Emmambux, 2008).

Thick porridge is cooked in neutral, acidic or alkaline media. Neutral thick porridge, which is cooked in water, is known as *ugali* in Kenya, Uganda and Tanzania; *nsima* in Zambia and Malawi; *mafo* in Somalia; *sadza* in Zimbabwe; *mosokwane* (*bogobe*) in Botswana; *tuwo* in Nigeria; *tuo* in Ghana; *boule* in Mauritania and Chad; *bita* in Niger; and *pap* in South Africa (Murty and Kumar, 1995; Anyango et al., 2011). Acidic thick porridge is made by cooking flour in water containing lemon or tamarind pulp, and is known as *tô* in Burkina Faso and Mali and *kunun tsamiya* in Nigeria (Murty and Kumar, 1995; Taylor and Emmambux, 2008). Acidic thick porridge can also be made from spontaneously fermented slurry, and includes *umqo* and *umpokoqo* (or *phuthu*) in South Africa, *motogo wa ting* (*ting* or *bogobe*) in Botswana, *aceda* in Sudan, *dalaki* in Nigeria and *nsima* in Malawi (Mlotha et al., 2016; Murty and Kumar, 1995). Alkaline thick porridge, such as *tô* in Mali, is made by cooking the flour with wood or peanut hull ash extract or potash (Murty and Kumar, 1995; Da et al., 1982; Scheuring et al., 1982).

The sensory character of thick porridge is dependent on the botanical origin of the raw materials and the processing conditions (Anyango et al., 2011; Kebakile, 2008). The most important sensory qualities of thick porridge are a thick and firm texture, non-stickiness and good keeping quality (Murty and Kumar, 1995; Mukuru et al., 1982; Obilana, 1982). Starch, which is the main constituent of thick porridge, has the most influence on its texture. Starch gelatinization gives thick porridge a firm, cohesive and non-sticky texture, which is evaluated by the tactile and kinesthetic senses during moulding in the hand and mastication in the mouth (Onyango, 2014; Bolade et al., 2009; Aboubacar et al., 2006). The pH of thick porridge may also affect its texture. Da et al. (1982) found that thick porridge made in alkali medium was stickier than that made in acid media.

The taste of thick porridge is influenced by its pH. Thick porridge prepared from native unmodified flour has a starchy taste and slightly burnt aroma, whereas acidic thick porridge has a sour taste (Wanjala et al., 2016). Although there is limited published information that describes the characteristic taste or aroma of alkaline-treated porridge, Hou and Kruk (1998) described alkaline-treated noodles as having an 'alkaline flavour.'

Nonetheless, in most cases, the taste of thick porridge is masked by the side-dishes consumed with it and consequently is not as important as other sensory properties (Murty and Kumar, 1995). Scheuring et al. (1982) noted that taste was the least significant sensory property of alkaline thick sorghum porridge, and consumers tended to judge the porridge quality on the basis of its colour and texture rather than taste.

The colour of thick porridge ranges from white through yellow to dark brown because it is prepared from various combinations of white-coloured cassava, maize and sorghum; and coloured maize, sorghum and millets (Wanjala et al., 2016). The pH of the slurry used to prepare thick porridge may also affect its colour. Thick porridge made in acid medium is lighter in colour than that made in alkaline media (Da et al., 1982, Scheuring et al., 1982). A variation in the expected colour of the product can cause consumers to reject the product even if it is nutritionally superior. Studies conducted in Kenya and South Africa show that consumers prefer thick porridge prepared from white maize rather than yellow maize or the nutritionally superior biofortified yellow maize (De Groote and Kimenju, 2012; Khumalo et al., 2011).

The sensory quality factors of foods that influence consumers' choices and preferences are measured using instrumental or sensory techniques. Instrumental methods are appropriate where product evaluations are repetitive, fatiguing and dangerous (Kilcast, 2013). However, consumer enjoyment of foods is determined by a wide range of responses from the senses that cannot be fully mimicked by instruments (Kilcast, 2013). In view of some of the limitations of instrumental techniques of evaluating sensory properties of foods, analytical sensory methods such as Quantitative Descriptive Analysis (QDA) that uses trained panellists instead of instruments have been developed. The QDA method gives objective assessment of the sensory properties of foods because panellists are trained to measure specific attributes of a product in a reproducible manner in order to obtain a quantitative product profile that is amenable to statistical analyses (Chapman et al., 2001). The results of QDA are commonly analysed using principal component analysis (PCA), which reduces the set of dependent variables (that is, attributes) to a smaller set of underlying variables (that is, factors) based on patterns of correlation among the original variables (Lawless and Heymann, 2010). The objective of the current study is to use instrumental techniques and modified QDA to evaluate the impact of pH and type of composite flour on the sensory quality of thick porridge. The choice of composite flours used in the current study was derived from the results of a field study done in western Kenya in 2016 (Wanjala et al., 2016).

MATERIALS AND METHODS

Preparation of composite flours and slurries

Maize (*Z. mays*) was purchased from a local market in Kisumu

County, Kenya. Finger millet (*E. coracana* (L) Geartn.) “P224” and sorghum (*S. bicolor* (L.) Moench “IESV 24029-SH” were donated by ICRISAT (Alupe Research Station, Busia, Kenya). The grains were cleaned to remove dirt and foreign matter and milled in a hammer mill fitted with 800 µm sieve to obtain whole-milled flours. Mould-fermented cassava flour (*M. esculenta* Crantz) was purchased in Busia County, Kenya.

Five types of composite flours (cassava-sorghum, 20:80; cassava-sorghum, 85:15; cassava-finger millet, 20:80; cassava-finger millet, 85:15; and cassava-maize, 20:80) were prepared, packed in moisture-proof zip-lock polythene bags and stored at 10°C prior to use. Neutral slurries (pH range: 6.08 - 6.35) were prepared by mixing the composite flours with distilled water. Food-grade anhydrous citric acid (2 g/1,000 ml) was used to prepare acidic slurries (pH range: 3.83 - 4.22). Food-grade bicarbonate of soda (sodium bicarbonate; 8 g/1,000 ml) was used to prepare alkaline slurries (pH range: 7.31 - 7.74).

Pasting properties of composite flours

The pasting properties of the composite flours were measured using a Brabender Viscograph-E (Brabender GmbH and Co. KG, Duisburg, Germany) at 85 rpm and 700 cmg torque. Neutral, acidic or alkaline slurries made up of 40 g flour (adjusted to 14% moisture content) and 420 ml distilled water was added into the Viscograph-E canister. The canister was put in the Viscograph-E heating chamber and the mixing spindles attached. The slurry was heated from 30°C and the temperature increased at 1.5°C/min up to 93°C. The temperature of the slurry was held at 93°C for 15 min before it was decreased at 1.5°C/min up to 30°C and subsequently held at this temperature for 15 min. The resistance to stirring was recorded as viscosity in Brabender Units (BU). The pasting temperature (°C), peak viscosity, time to peak viscosity (min), breakdown viscosity (peak viscosity minus trough viscosity) and setback viscosity (cold paste viscosity minus trough viscosity) were determined from the viscograph.

Objective evaluation of the texture of thick porridge

Thick porridge was made from the composite flours (240 g) and 600 ml water, citric acid or sodium bicarbonate solutions. The water or chemical solution was brought to boil in a stainless steel cooking pan before adding 70% of the flour and heating continued without any intervention until boiling resumed. The rest of the flour was added and the paste gently mixed with the aid of a flat wooden cooking stick (ladle) for 5 min until a homogenous fully hydrated paste devoid of lumps was obtained. The cooking pan was covered and further heated for 5 min while intermittently kneading. The porridge was transferred to a clean wooden surface and shaped into a cylinder. A piece measuring 6 cm diameter and 3.5 cm high was punched out from the porridge using a biscuit cutter. Edible vegetable oil was applied on the inner surface of the biscuit cutter to facilitate easy removal of the thick porridge. The oil was also applied on the surface of the test sample to prevent dehydration. The test sample was incubated in a laboratory incubator (Memmert GmbH + Co. KG, Schwabach, Germany) at 25°C for 2 h to allow for temperature equilibration. The texture of the test sample was evaluated using a TA-XT*plus* Texture Analyzer (Stable Micro Systems, Surrey, UK) equipped with a 50 kg load cell and an extended craft knife probe (A/ECB). Measurement was made at the following conditions: height of the blades from the base of the plate: 40 mm; test speed: 5 mm/s; post-test speed: 5 mm/s; target mode: distance; distance travelled: 19 mm; trigger type: button. The force (N) versus time (s) required by the probe to compress the test porridge was recorded. The toughness (kg) and work of shear (kg·mm) of the thick porridge were calculated using EXPONENT Texture Analysis software version 6.1.5.0 (Stable Micro Systems, Surrey, UK).

Objective evaluation of the colour of thick porridge

Thick porridges were prepared as described above and subsequently dried in a laboratory incubator (Memmert GmbH + Co. KG, Schwabach, Germany) at 70°C to about 10% moisture content. The dried thick porridge was milled using a MRK hummer mill (Mitamura Riken Kogyo Inc., Tokyo, Japan). A Konica Minolta Chroma Meter CR-200 (Minolta Co. Ltd., Osaka, Japan) was used to evaluate the colour of the dehydrated thick porridge flour. Each flour sample (20 g) was put in a clean Petri dish and covered. The equipment was calibrated using the standard white tile provided with the equipment. CIE-LAB-System colour values of light (L^* = 100) to dark (L^* = 0); red (+a^*) to green (-a^*); and yellow (+b^*) to blue (-b^*) were recorded for each sample.

Descriptive sensory evaluation of thick porridge

Thick porridges were prepared as described above using 320 g flour and 400 ml water or chemical solution. After cooking, the thick porridge was cooled to 30ºC and served in white plastic plates. Eight students from local universities were recruited to undertake descriptive sensory evaluation of the thick porridges. They were given a consent form to sign, listing ingredients in the products and possible allergens. The study was done in a well-ventilated laboratory at 25±1ºC. Since sensory booths were not available, the panellists were spaced 2 m apart to avoid interaction. The panellists were trained for 10 sessions. The first five sessions consisted of attribute generation, whereby the panellists listed all sensory attributes present in the porridges. The panel generated 18 descriptive terms (Table 1). The next five sessions involved identifying references (Table 1) that fit the sensory attributes of thick porridge and rating them on 100 mm unstructured line scales for intensity. The panellists rinsed their mouth with mineral water before testing each sample and in between the tests. Samples were given randomized three-digit codes and served monadically in random order with a 5 min break between each sample evaluation. All attributes of a specific sample were evaluated before the next sample was served. Panel sessions were repeated until all samples were scored in triplicate.

Experimental design and statistical analysis

The instrumental experiments were set-up as a 5×3 factorial combination in a randomized complete block design. The treatment combinations consisted of five types of composite flours at three pH levels (neutral, acidic and alkaline). Each treatment was conducted in triplicate and the results reported as mean ± standard deviation. The data were analysed using a two-way factorial analysis and further analysis done using a one-way factorial analysis. The sensory evaluation data was analysed using PCA in a covariance matrix with the product in rows and the mean panellists and replication scores for the 18 sensory attributes in columns. All data were analysed with Minitab Release 14 (Minitab Inc., Pennsylvania, USA).

RESULTS AND DISCUSSION

Pasting properties of composite flours

The pasting properties of the composite flours in neutral, acidic or alkaline media are presented in Table 2.

Table 1. Descriptive sensory lexicon developed by the sensory panel to evaluate the quality of thick porridge.

Attribute	Description	Reference and rating scale
Appearance		
Colour	Perception of colour ranging from white to dark brown	Cassava starch (10% w/v) stirred in hot water = 0 (white) [a]Baker's dark compound chocolate = 10 (dark brown)
White specks	Quantity of white specks on the surface of porridge	0 = No white specks 10 = Many white specks
Brown and dark specks	Quantity of brown and dark specks on the surface of porridge	Cassava starch (30% w/v) stirred in hot water = 0 (no dark specks) [b]Indian hemp hair and scalp treatment oil = 7 (many dark specks)
Gloss	Perception of a shiny appearance on the surface of porridge	[c]Brookside farm fresh milk (fat content 3%) = 0 (not glossy) Pure glycerin for cosmetic application = 10 (very glossy)
Aroma		
Cassava aroma	Aroma characteristic of cassava flour in hot water	Cassava flour (30% w/v) stirred in hot water = 10 (very intense)
Finger millet aroma	Aroma characteristic of finger millet flour in hot water	Whole-milled finger millet flour (30% w/v) stirred in hot water = 10 (very intense)
Maize aroma	Aroma characteristic of maize flour in hot water	Whole-milled maize flour (30% w/v) stirred in hot water = 10 (very intense)
Sorghum aroma	Aroma characteristic of sorghum flour in hot water	Whole-milled sorghum flour (30% w/v) stirred in hot water = 10 (very intense)
Sodium carbonate aroma	Aroma characteristic of sodium carbonate cooked in starch slurry	0 = No characteristic smell 10 = intense characteristic smell
Taste		
Sour taste	Intensity of sour taste associated with fermented milk	[c]Brookside farm fresh milk (fat content 3%) = 0 (not sour) [d]Bio yoghurt natural (fat content 3%) = 5 Whole-milled maize porridge (10% w/v) cooked in citric acid solution 1% w/v = 10
Soapy taste	Intensity of taste associated with soap in water	No soapy taste = 0 Soapy taste = 10
Texture		
Hardness	Force required to compress porridge between the thumb and index finger	Cassava porridge (28% w/v) = 0 (soft) Maize porridge (28% w/v) = 10 (hard)
Adhesiveness	Degree to which porridge particles remain sticking on the hand after rolling a piece of it between the fingers and palm of the hand into a ball	0 = Not adhesive 10 = Very adhesive
Gumminess	Degree of mastication required before the food disintegrates and is ready for swallowing	Maize porridge (28% w/v) = 0 (mealy, 5 chews before swallowing) Cassava porridge (28% w/v) = 10 (gummy, 10 chews before swallowing)
Coarseness	Degree to which particles are perceived in the mouth during mastication	Honey = 0 (not perceived) Fresh pressed, unsieved carrot juice = 10

Table 1. Contd.

After swallow		
Sour aftertaste	Perception of lingering sourness in the mouth after mastication and swallowing	0 = No sour aftertaste 10= Strong sour aftertaste
Soapy aftertaste	Perception of lingering saltiness in the mouth after mastication and swallowing	0 = No soapy aftertaste 10= Strong soapy aftertaste
Residual particles	Amount of material left between teeth after mastication and swallowing	Water melon = 0 (no residual particles) Fresh pressed, unsieved carrot juice = 10 (many residual particles)

[a]PT Gandum Mas Kencana, Tangerang, Indonesia; [b]Dynamix Trading Ltd., London , Britain; [c]Brookside Dairy Ltd., Ruiru, Kenya; [d]Bio Food Products Ltd., Nairobi, Kenya.

Cassava-rich slurries tended to have lower pasting temperatures but higher peak, breakdown, final and setback viscosities than cereal-rich slurries. The different pasting behaviours of the composite flours reflected the influence of the predominant flour in the mixtures. Swelling of starch granules and the attainment of peak viscosity is largely associated with the amylopectin fraction of starch, whereas amylose-lipid complexes inhibit granule swelling and decrease the peak, breakdown and final viscosities of flours (Morrison et al., 1993; Tester and Morrison, 1990; Blazek and Copeland, 2008). Thus, the high content of branched-chain amylopectin polymers and low lipid content in cassava flour as compared to cereal flours (Breuninger et al., 2009) enable it to swell more readily and acquire higher peak, breakdown, final and setback viscosities.

Two-factor analysis of variance showed that the interaction effect between the type of composite flour and pH was significant ($p < 0.05$) for pasting temperature (°C), peak viscosity (BU), time to peak viscosity (min), breakdown viscosity (BU), final viscosity (BU) and setback viscosity (BU). The simple main effects of pH on the pasting properties of the composite flours showed that the onset pasting temperatures of alkali-treated slurries were higher ($p < 0.05$) than for the neutral- or acid-treated slurries. These results are in agreement with those of Karim et al. (2008) and Cai et al. (2014). Karim et al. (2008) postulated that sodium hydroxide increases the pasting temperature of starch through diffusion of sodium ions into the starch granules and subsequent stabilisation of the granule through electrostatic interactions between sodium ions and the hydroxyl groups of starch. Alkali-treated cassava-sorghum (20:80) and cassava-maize (20:80) slurries had significantly lower ($p < 0.05$) peak viscosity as compared to the neutral slurries. Alkali treatment significantly decreased ($p < 0.05$) the setback viscosity of cassava-sorghum (20:80) and cassava-maize (20:80) slurries as compared to the neutral slurries. Alkali attacks the amorphous regions of starch thereby increasing leaching of amylose polymers and facilitating depolymerization of starch, which results in decreased peak, breakdown, setback and final viscosities (Karim et al., 2008; Nadiha et al., 2010; Wang and Copeland, 2012; Israkarn et al., 2014).

The pasting temperature of cassava-sorghum (20:80) and cassava-sorghum (85:15) slurries treated with citric acid were significantly lower ($p < 0.05$) than those of neutral slurries. Acid-treated slurries had significantly higher ($p < 0.05$) peak viscosities than neutral- or alkali-treated slurries.

In addition, the acid-treated slurries had significantly higher ($p < 0.05$) breakdown viscosities than the neutral slurries. The effect of organic acids on the rheological properties of starch is dependent on the degree of pH adjustment. Hirashima et al. (2005) reported that when the pH of corn starch is lowered to 3.6 using citric acid, leaching of amylose and amylopectin polymers increases resulting in higher paste viscosity. By contrast, pH values lower than 3.5 promotes hydrolysis of amylose and amylopectin polymers resulting to decreased paste viscosity (Hirashima et al., 2005). The final viscosities of cassava-finger millet (85:15) and cassava-maize (20:80) slurries significantly increased ($p < 0.05$) after treatment with citric acid. These results partially agree with those of Hirashima et al. (2004, 2012) who noted that organic acids accelerate retrogradation of starch gels by promoting faster re-association of shorter chains.

Objective evaluation of the texture of thick porridge

The toughness and work of shear of thick porridge made from the composite flours in neutral, acidic or alkaline media ranged between 0.21 - 0.58 kg and 0.83 - 5.95 kg·mm, respectively (Table 3). Two-factor analysis of variance showed that the

Table 2. Pasting properties of composite flours segregated by pH.

Treatment (pH)	PT (°C)	PV (BU)	Time PV (min)	BV (BU)	FV (BU)	SV (BU)
Cassava-sorghum (20:80)						
Neutral[1] (6.35)	84.1±0.6^{b}	282±8	43.6±0.4^{a}	7±6^{a}	450±18^{b}	221±25^{b}
Citric acid[2] (3.83)	80.2±0.1^{a}	313±1	42.7±0.0^{a}	97±4^{b}	423±2^{b}	232±1^{b}
Sodium bicarbonate[3] (7.74)	91.2±0.1^{c}	294±13	56.6±0.4^{b}	0±0^{a}	218±21^{a}	-64±9^{a}
Cassava-sorghum (85:15)						
Neutral (6.17)	68.9±0.4^{b}	607±16^{a}	43.9±0.1^{ab}	93±5^{a}	830±51^{ab}	347±40
Citric acid (4.01)	67.0±0.1^{a}	761±5^{c}	43.1±0.4^{a}	307±1^{b}	728±9^{a}	314±4
Sodium bicarbonate (7.66)	81.4±0.3^{c}	663±1^{b}	44.5±0.2^{b}	110±11^{a}	867±14^{b}	368±0
Cassava-finger millet (20:80)						
Neutral (6.23)	77.4±1.7	365±3^{a}	43.7±0.0	44±9	496±18^{ab}	183±24
Citric acid (4.22)	79.2±0.1	381±1^{b}	43.3±0.1	78±1	532±1^{a}	233±1
Sodium bicarbonate (7.55)	79.3±0.9	361±3^{a}	44.2±0.7	49±17	480±5^{b}	174±11
Cassava-finger millet (85:15)						
Neutral (6.22)	68.2±0.3^{a}	552±4^{a}	43.2±0.0	121±6^{a}	728±13^{a}	314±17
Citric acid (3.85)	67.3±0.1^{a}	744±0^{b}	43.6±0.1	247±0^{b}	815±1^{b}	352±0
Sodium bicarbonate (7.38)	72.3±0.1^{b}	722±11^{b}	40.8±1.5	263±1^{c}	695±14^{a}	335±7
Cassava-maize (20:80)						
Neutral (6.08)	88.5±0.2^{a}	82±4^{b}	54.8±0.8^{c}	0±0^{a}	149±0^{b}	81±5^{b}
Citric acid (4.07)	88.5±0.1^{a}	135±0^{c}	49.4±0.3^{b}	9±0^{b}	205±1^{c}	117±1^{c}
Sodium bicarbonate (7.31)	93.2±0.1^{b}	26±0^{a}	42.7±0.1^{a}	16±2^{c}	13±2^{a}	2±0^{a}

[1]Neutral slurry (10% w/v) prepared using distilled water; [2]Acidic slurry (10% w/v) prepared using anhydrous citric acid in distilled water (2 g/1000 ml); [3]Alkaline slurry (10% w/v) prepared using sodium bicarbonate in distilled water (8 g/1000 ml). PT – pasting temperature; PV – peak viscosity; Time PV – time to peak viscosity; BV – breakdown viscosity; FV – final viscosity, SV – setback viscosity, BU – Brabender Units. Values having superscripts of the same letter in the same column for each type of composite flour are not significantly different at $p < 0.05$. Data sets without superscript letters for each type of composite flour are not significantly different at $p < 0.05$.

interaction effect between the type of composite flour and pH was significant ($p < 0.05$) for toughness (kg) and work of shear (kg·mm) of the thick porridges. The simple main effect of pH had a significant effect ($p < 0.05$) on the toughness of all thick porridges, whereas work of shear was significant ($p < 0.05$) for thick cassava-finger millet (85:15) and cassava-maize (20:80) porridges only (Table 3). The relative proportion of cassava versus cereal flours in the composite flours has a major influence on the texture of thick porridge.

Unblended cassava flour is unsuitable for making thick porridge because it gives a gummy product that is difficult to knead in the hand and masticate. Cereals on the other hand, give very firm and cohesive thick porridges. However, when cassava is mixed with cereal flours in appropriate ratios, cassava flour decreases the firmness and cohesiveness of thick porridge, whereas cereal flours decrease its gumminess (Wanjala et al., 2016). It is difficult to compare our data with previous published studies on the texture of thick porridge because of different sample preparation and measurement techniques (Onyango, 2014; Anyango et al., 2011). Therefore, it is necessary to develop standard methods for evaluating the texture of thick porridge.

Objective evaluation of the colour of thick porridge

The degree of lightness, redness and yellowness of thick porridges cooked in neutral, acidic or alkaline media are shown in Table 3. Irrespective of the pH, cassava-maize (20:80) porridges were the least dark (that is, had the highest L* values), least red (that is, had the lowest a* values) and most yellow (i.e. had the highest b* values). The intense yellow colour of cassava-maize porridge treated with sodium bicarbonate can be attributed to the reaction of the alkali with colourless flavonoids in white maize kernels (Morris et al., 2000). A similar reaction is responsible for the characteristic yellow colour of noodles made from wheat flour treated with sodium hydroxide (Hou and Kruk, 1998). Yao et al. (2006) suggested that the yellow colour that develops when wheat dough is treated with sodium hydroxide and when making pretzels is not due to flavonoids in the flour, but is rather caused

Table 3. Texture and colour of thick porridges segregated by pH.

Treatment (pH)	Toughness (kg)	Work of shear (kg·mm)	Colour		
			L*	a*	b*
Cassava-sorghum (20:80)					
Neutral[1] (6.35)	0.41±0.02[ab]	3.15±0.12	57.4±0.5[b]	7.7±0.1[b]	9.8±0.3[b]
Citric acid[2] (3.83)	0.49±0.10[b]	3.06±1.44	57.9±0.5[b]	7.7±0.1[b]	10.7±0.5[b]
Sodium bicarbonate[3] (7.74)	0.34±0.02[a]	1.94±0.25	50.2±0.5[a]	6.3±0.1[a]	6.2±0.2[a]
Cassava-sorghum (85:15)					
Neutral (6.17)	0.33±0.04[a]	2.79±0.61	68.0±0.9[b]	5.2±0.2[a]	11.5±0.2[a]
Citric acid (4.01)	0.38±0.03[ab]	2.33±0.37	66.5±0.6[b]	6.7±0.1[b]	13.5±0.4[b]
Sodium bicarbonate (7.66)	0.40±0.04[b]	3.02±0.99	60.0±0.4[a]	7.8±0.2[c]	11.2±0.2[a]
Cassava-finger millet (20:80)					
Neutral (6.23)	0.28±0.04[a]	2.50±0.72	55.6±0.7[b]	5.8±0.1[b]	8.6±0.2[a]
Citric acid (4.22)	0.43±0.05[b]	3.27±0.89	61.0±0.1[c]	7.0±0.2[c]	10.7±0.1[b]
Sodium bicarbonate (7.55)	0.41±0.02[b]	2.88±0.46	52.1±0.6[a]	5.1±0.2[a]	7.9±0.7[a]
Cassava-finger millet (85:15)					
Neutral (6.22)	0.34±0.07[b]	2.92±0.75[b]	67.8±1.5[b]	4.4±0.1[a]	14.1±0.3
Citric acid (3.85)	0.21±0.04[a]	1.09±0.38[a]	68.8±1.0[b]	4.3±0.3[a]	13.6±0.2
Sodium bicarbonate (7.38)	0.58±0.05[c]	5.95±0.86[c]	63.2±0.7[a]	5.9±0.2[b]	13.7±0.4
Cassava-maize (20:80)					
Neutral (6.08)	0.20±0.02[a]	1.84±0.19[b]	78.6±0.6[b]	2.3±0.3[a]	19.9±0.8[b]
Citric acid (4.07)	0.22±0.01[a]	0.83±0.24[a]	80.5±0.0[c]	2.3±0.1[a]	17.7±0.6[a]
Sodium bicarbonate (7.31)	0.32±0.04[b]	2.12±0.92[b]	67.7±0.2[a]	3.4±0.2[b]	21.9±0.5[c]

L*: lightness; a*: redness; b*: yellowness; [1]Neutral slurry (10% w/v) prepared using distilled water; [2]Acidic slurry (10% w/v) prepared using anhydrous citric acid in distilled water (2 g/1000 ml); [3]Alkaline slurry (10% w/v) prepared using sodium bicarbonate in distilled water (8 g/1000 ml). Values having superscripts of the same letter in the same column for each type of composite flour are not significantly different at $p < 0.05$. Data sets without superscript letters for each type of composite flours are not significantly different at $p < 0.05$.

by the reaction within or between the starch and protein hydrolysis derivatives.

Two-factor analysis of variance showed that the interaction effect between the type of composite flour and pH was significant ($p < 0.05$) for lightness, redness and yellowness of the thick porridges. The simple main effect of pH was significant ($p < 0.05$) for lightness, redness and yellowness of all thick porridges except yellowness of cassava-finger millet (85:15) porridge. Thick porridge cooked in sodium bicarbonate media was significantly darker ($p < 0.05$) than that made in neutral or acid media for all samples. The colour of pigmented grains is associated with the presence of phenolic acids in the pericarp (Kobue-Lekalake, 2008; Liu et al., 2010). The phenolic pigments in coloured grains stain thick porridge with a dark colour during cooking (Kebakile, 2008;

Anyango et al., 2011). In addition, non-enzymatic browning from Maillard-type reaction products that develop during heating also contributes to the dark colour of thick porridge (Martins et al., 2001; Pathare et al., 2013). The dark colour of thick porridges cooked in sodium bicarbonate solution could also be attributed to the radical-mediated reaction of the phenolic compounds in these cereals with sodium bicarbonate to form highly rearranged and oxidatively-coupled products (Beta et al., 2000).

Descriptive sensory evaluation of thick porridge

Modified QDA was used to describe the sensory attributes of thick porridges made from composite flours in neutral, acidic or alkaline media. The panellists identified 18 sensory attributes in the thick porridges. The data was analysed using PCA in order to identify the number of fundamentally different sensory properties of the thick porridges. Principal component analysis identified three major principal components (PCs) that accounted for 87.6% of the variance in the sensory attribute data (Table 4). These PCs were used to explain the relationships between the variables. Loadings with absolute values greater than 0.449 (marked with an

Table 4. Principal component factor loadings for sensory attributes of thick porridge.

Attribute	PC1	PC2	PC3	PC4
Colour	-0.237	-0.095	-0.621*	0.168
White specks	0.107	-0.059	0.199	0.041
Dark specks	0.018	-0.214	-0.140	-0.379
Gloss	0.006	-0.348	0.118	-0.095
Cassava aroma	0.229	-0.454*	0.193	0.121
Finger millet aroma	0.074	-0.004	-0.399	-0.595*
Maize aroma	0.186	0.383	0.376	-0.106
Sorghum aroma	0.085	0.083	-0.302	0.626*
Sodium bicarbonate aroma	-0.656*	0.035	0.181	-0.050
Sour taste	0.227	0.038	0.038	-0.033
Soapy taste	-0.527*	0.024	0.147	-0.040
Hardness	-0.013	0.449*	0.029	0.086
Adhesiveness	0.079	-0.002	-0.120	-0.047
Gumminess	-0.072	-0.338	0.156	0.101
Coarseness	0.039	0.329	-0.088	-0.131
Sour aftertaste	0.102	0.004	0.025	-0.019
Soapy aftertaste	-0.215	0.001	0.058	-0.010
Residual particles	0.062	0.182	-0.067	-0.063
Variance (%)	35.5	25.6	17.3	9.2
Cumulative variance (%)	35.5	61.0	78.4	87.6

*Loadings with absolute values greater than 0.449.

asterisk) represented a strong influence on the thick porridges and implied that the PC was related to those variables. The first PC accounted for 35.5% of the variance and distinguished alkali-treated thick porridges from acid-treated or neutral thick porridges (Figure 1a). Alkali-treated thick porridges were located on the left side of the PC plot, whereas acid-treated and neutral thick porridges were on the right side (Figure 1a). The loading plot shows the mutual relations among the variables (Figure 1b). The alkali-treated thick porridges were notable for their sodium bicarbonate aroma (loading value -0.656) and soapy taste (loading value -0.527) (Figure 1b).

The second PC accounted for 25.6% of the variance in the sensory attribute data (Table 4). It distinguished the thick porridges on the basis of cassava aroma (loading value -0.454) and hardness (loading value 0.449). Thick porridges located on the upper part of the PC plot had low cassava and high cereal concentrations, whereas those in the lower part of the PC plot had low cereal and high cassava concentrations (Figure 1a). The thick cassava-rich porridges had a stronger cassava aroma and were less firm than their cereal-rich counterparts. In addition, thick cassava-rich porridges had a glossy appearance and gummy texture while their cereal-rich counterparts had a coarse mouth-feel (Figure 1b). Cassava is normally mixed with cereal flours when making thick porridge in order to decrease the perception of coarse particles in the mouth caused by cereals (Wanjala et al., 2016). The coarse mouthfeel of thick cereal porridges is due to the lignocellulosic layers, large particles and insoluble fibre (Heiniö, 2009). Kebakile (2008) found that firmness of sorghum porridge is affected by the amount of coarse endosperm particles. Coarse particles absorb water slowly and thereby restrict swelling of starch granules, resulting in a high proportion of non-ruptured gelatinised starch granules that reinforce the porridge matrix (Kebakile, 2008). Kebakile (2008) also reported that corneous sorghum varieties with high protein content give firmer porridges due to the presence of a hard and less water-permeable protein-starch matrix in the endosperm meal particles.

The third PC accounted for 17.3% of the variance in the sensory attribute data (Table 4). This PC was associated with the colour (loading value -0.621) of the raw materials (white maize and cassava versus dark coloured finger millet or sorghum) and the colour developed when the composite flours were cooked in neutral, acidic or alkaline media. These findings were in agreement with the instrumental colour results reported in the instrumental analysis of colour (Table 3).

The fourth PC accounted for 9.2% of the variance in the sensory attribute data (Table 4). This PC was associated with a large negative loading value for finger millet aroma (-0.595) and a large positive loading value for sorghum aroma (0.626). Variables located close to

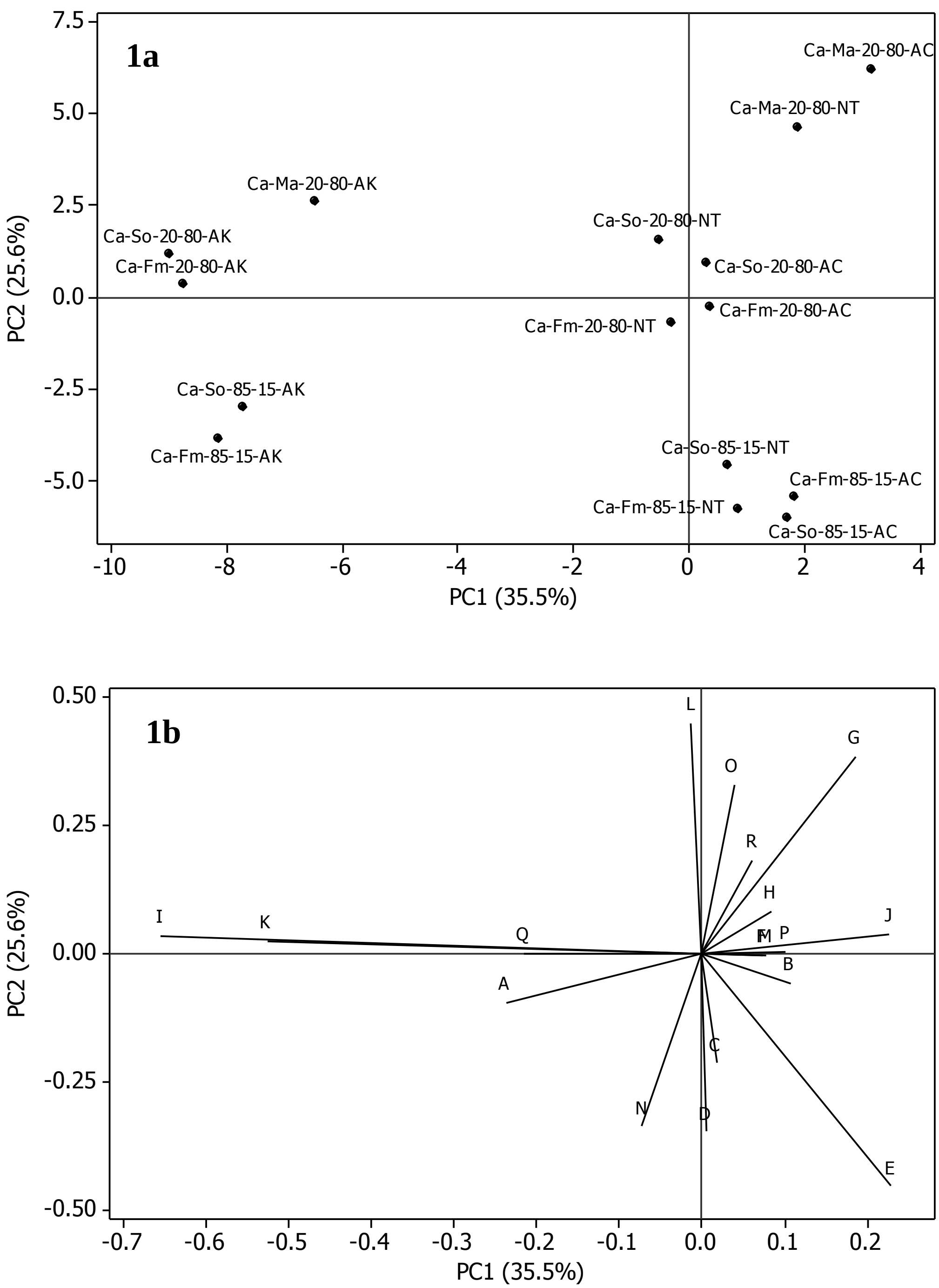

Figure 1. Principal component analysis of thick porridge. (a) Plot of the first two principal component scores of composite flours used to prepare thick porridge (b) Plot of the first two principal component loading vectors of sensory attributes of thick porridge. Ca: cassava; So: sorghum; Fm: finger millet; Ma: maize; AC: acid; AK: alkali; NT: neutral. The numbers refer to the ratios of the flours used to prepare the composite flours. A: colour; B: white specks; C: dark specks; D: Gloss; E: cassava aroma; F: finger millet aroma; G: maize aroma; H: sorghum aroma; I: sodium bicarbonate aroma; J: sour taste; K: soapy taste: L: hardness; M: adhesiveness; N: gumminess; O: coarseness; P: sour aftertaste; Q: soapy aftertaste; R: residual particles.

each other on the loading plot are positively correlated, whereas variables located opposite each other are negatively correlated (Destefanis et al., 2000). Thus, the locations of the loading values for sorghum and finger millet aroma imply that the aroma of the grains are located far apart in the PC space and are caused by different chemical constituents.

Small loadings (that is, values close to zero) are also a source of valuable information in the interpretation of PCA data because they indicate that the PC is not related to those variables (Lawless and Heymann, 2010). Thus, the low loading value across all PCs for adhesiveness, sour aftertaste and perception of residual particles in the mouth after swallowing (Table 4) indicate that these were insignificant sensory attributes of thick porridge. Well-prepared thick porridge should have a firm texture and not exhibit adhesiveness when it is kneaded in the hand (Onyango, 2014; Murty and Kumar, 1995). The sour aftertaste of thick porridge treated with citric acid may have been an insignificant sensory property because of the low content of citric acid in the porridge. Nonetheless, in normal circumstances thick porridge is consumed with side-dishes and hence flavour is a minor sensory attribute because it is masked by the flavour of the accompanying food (Murty and Kumar, 1995). The perception of residual particles in the mouth after swallowing thick porridge was an insignificant sensory attribute possibly because of the dense mealy texture of thick porridge and its high moisture content.

Conclusion

The diversity of thick porridges consumed in sub-Saharan Africa can be differentiated using instrumental and sensory techniques in order to identify important sensory attributes. Pasting properties of the slurries, and the texture and colour of the porridges were affected by the pH. Aroma, hardness and colour were identified as the major sensory attributes of thick porridges. Thus, thick porridges targeting specific consumer groups in sub-Saharan Africa can be developed by appropriate choice of flours and pH. These findings can form the basis for commercial production of thick porridges for different population categories in sub-Saharan Africa with diverse sensory expectations of the product.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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