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Quality of porridge from sub-Saharan Africa evaluated using instrumental techniques and descriptive sensory lexicon. Part 2: Thin porridge

Calvin Onyango* and George W. Wanjala

Food Technology Division, Kenya Industrial Research and Development Institute, P. O. Box 30650-00100, Nairobi, Kenya.

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Thin porridge is a popular nourishment drink for adults and complementary food for children in sub-Saharan Africa. It is made from straight (unblended) or composite flours of maize, sorghum, finger millet and cassava in neutral or chemically-acidified media, or after spontaneous fermentation of the flours. The objective of this study was to determine the impact of type of composite flour and pH on the sensory quality of thin porridges. Instrumental methods and modified quantitative descriptive analysis were used to identify the main sensory attributes of thin porridges made from different composite flours in neutral or acidic media or after spontaneous fermentation. The results of the study indicated that irrespective of the pH, cereal-based composite flours had higher onset pasting temperatures; and lower peak, breakdown, final and setback viscosities than cassava-cereal flours. Thin porridges formulated from cereal-based composite flours tended to have lower firmness, consistencies, cohesiveness and indices of viscosity than those made from cassava-cereal flours. The colour of thin porridges depends on the botanical origin of the composite flours, their ratios and whether the pH was adjusted using citric acid or by spontaneous fermentation. Principal component analysis identified three major principal components (PCs) that accounted for 83.7% of the total variance in the sensory attribute data. The principal component scores indicated that the location of the thin porridges on each of the three scales corresponded with cassava aroma (PC1), finger millet/maize aroma (PC2), and colour and fermented aroma (PC3). This study has shown that thin porridges with different sensory profiles can be produced in sub-Saharan Africa for different population groups.

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

INTRODUCTION

Thin porridge is an important breakfast and refreshment drink for adults (Oi and Kitabatake, 2003), complementary food for children (Kikafunda et al., 2006; Oi and Kitabatake, 2003; Onyango, 2003) and a source of nourishment for the sick and invalid in sub-Saharan Africa (Wanjala et al., 2016). Thin porridge is prepared from tropical cereal and root crops, such as maize (*Zea mays*), finger millet (*Eleusine coracana*), pearl millet

(*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and cassava (*Manihot esculenta*) (Wanjala et al., 2016; Taylor and Emmambux, 2008). Thin porridge is prepared by stirring flour (10 to 20% w/v) in boiling water for a few minutes to obtain viscous slurry (Taylor & Emmambux, 2008). The transformation of flour into thin porridge is associated with irreversible physical modification of starch in excess water. This process involves loss of starch lamellar structure as it gelatinizes followed by formation of complex fractal structures during pasting and retrogradation (Doutch et al., 2012).

Thin porridge is made from unfermented, fermented or chemically-acidified slurries. Unfermented thin porridge, which is prepared by cooking the flour in tap water, includes *uji* in East Africa, *edi* in Uganda, *isidudu* in South Africa and *kunu* in Nigeria (Murty and Kumar, 1995). Fermented thin porridge, which is prepared from spontaneously fermented slurry, includes *uji* in East Africa, *Obushera* in Uganda, *nasha* in Sudan, *ogi* (*kamu* or *akamu*) in Nigeria, *koko* in Ghana, and *imbila* in South Africa (Mukisa et al., 2010; Murty and Kumar, 1995; Obilana, 1982). The slurry used to make thin porridge may be fermented before (Mukisa et al., 2010; Onyango et al. 2004) or after cooking it (Mugula et al., 2003; Kitabatake et al., 2003). Chemically-soured thin porridge is prepared by adding plant extracts, such as lemon (*Citrus limon*) juice extract, tamarind pulp (*Tamarindus indica*) or the shoot of the camel foot plant (*Piliostigma thonningii*) to the slurry during cooking (Wanjala et al., 2016). Chemical-souring can also be achieved by adding pure citric (Wanjala et al., 2016) or lactic acid to the flour (Novellie, 1982).

The texture, flavour and colour of thin porridges are important sensory attributes that affect consumer preferences and acceptance of the products. The texture of thin porridge is described by attributes such as stiffness, stickiness, cohesiveness and coarseness (Kebakile, 2008). Aboubacar et al. (1999) reported that stickiness in the mouth and cohesiveness are the most important textural attributes of thin porridge. Thin porridge with acceptable sensory texture has homogenous distribution of gelatinized starch granules, a free-flowing creamy consistency and smooth texture (Obilana, 1982). When the porridge is drank or eaten with a spoon, it disperses readily in the mouth before it is swallowed. Consumer perception of the texture of thin porridge is influenced by the botanical origin of the flour (Kebakile, 2008), processing technique (Onyango, 2014) and solids concentration (Carvalho et al., 2014; Ojijo and Shimoni, 2004).

Taste and aroma are also important sensory attributes of thin porridge. Thin porridge made from plain flours has a starchy taste and aroma (Wanjala et al., 2016). Sugar and milk are frequently added to thin porridge in order to improve its taste (Murty & Kumar, 1995). Fermented thin porridges are more popular than their unfermented counterparts because the process of fermentation gives the product a complex sour taste, which is due to lactic acid and other flavour and aroma compounds produced by lactic acid bacteria (Mukisa et al., 2016; Mugula et al., 2003; Muyanja et al., 2003). By contrast, thin porridge soured with pure organic acids has a sharp, 'clean' sourness devoid of any taste overtones (Novellie, 1982).

Colour is the first contact point of a food for the consumer even before it enters the mouth (Wu and Sun, 2013). Colour has a close association with quality factors such as desirability, however, when the colour of a food product changes consumers' reactions to the product are likely to be affected (Wu and Sun, 2013). The colour of thin porridge is dependent on the colour of the flour used to prepare it (Aboubacar et al., 1999; Obilana, 1982). Sorghum and millet-based porridges or their composites with maize or cassava are generally light- to dark-brown in colour, with a tinge of redness (Wanjala et al., 2016; Mukisa et al., 2010).

The choice of composite flours used in the current study to prepare thin porridges was derived from the results of a field study done in western Kenya in 2016 (Wanjala et al., 2016). The objective of the current study was to utilize modified quantitative descriptive analysis and instrumental techniques to evaluate the impact of type of composite flour and pH on the sensory quality of thin porridges. The pH of the flours was adjusted with the aid of normal tap water, spontaneous fermentation or citric acid.

MATERIALS AND METHODS

Preparation of composite flours and slurries

Maize (*Zea mays*) and cassava (*Manihot esculenta* Crantz) flour were purchased in Busia County, Kenya. Finger millet (*Eleusine coracana* (L) Geartn) variety P224 and sorghum (*Sorghum bicolor* (L.) Moench variety IESV 24029-SH were donated by ICRISAT (Alupe Research Station, Busia, Kenya). The grains were cleaned to remove foreign substances and milled in a hammer mill fitted with 800 µm sieve to obtain whole-milled flours. Four types of composite flours (cassava: finger millet, 90:10; cassava: finger millet, 30:70; finger millet: maize, 90:10; and maize: sorghum, 75:25) were prepared, packed in moisture-proof zip-lock polythene bags and

*Corresponding author. E-mail: calonyango@yahoo.com.

stored at 10°C prior to use. Neutral slurries (pH range: 6.34-6.52) 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 3.88 to 4.22). Fermented slurries were prepared by adding 200 g composite flour to 200 ml distilled water and incubating the mixture at 25°C for 24 h. After 24 h, the fermented slurry was added to fresh slurry (400 g flour and 400 ml water) and incubated at 25 °C for 24 h. The pH of the fermented slurries ranged between 3.92 and 4.48. The fermented slurries were dried in the oven at 50 °C to about 11% moisture content.

Pasting properties of composite flours

Pasting properties of the composite flours were measured using a Brabender Viscograph-E (Brabender GmbH & Co. KG, Duisburg, Germany) at 85 rpm and 700 cmg torque. Neutral, acidic or spontaneously fermented 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 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 thin porridge

Thin porridge was made by mixing 40 g composite flour with 150 ml tap water to make a slurry. Separately, 200 ml water was brought to boil in a stainless steel pot on an electric cooker set at 150°C. The cold slurry was added to the boiling water and stirred continuously for 5 min, using a flat wooden ladle, to avoid formation of lumps. The porridge was boiled for a further 2 min without intervention. After cooking it was cooled to 26±1°C before pouring 80 g into a 50 mm diameter A/BE back extrusion container (Stable Micro Systems, Surrey, UK). Back extrusion force was measured using TA-XT*plus* Texture Analyzer (Stable Micro Systems, Surrey, UK) at the following settings: 50 kg load cell; height calibration: 50 mm; disc diameter: 45 mm; pre-test speed: 1 mm/s; test speed: 1 mm/s; trigger force: 0.05 N; post-test speed: 10 mm/s; data acquisition rate: 200 pps. When a surface trigger force (that is, point at which the disc's lower surface was in full contact with the product) of 10 g was attained the disc proceeded to penetrate the porridge to a depth of 30 mm after which it returned to its original position. Firmness (maximum positive force), consistency (area of the positive region of the curve), cohesiveness (maximum negative force) and work of cohesion or index of viscosity (area of the negative region of the curve) were calculated using EXPONENT Texture Analysis software version 6.1.5.0 (Stable Micro Systems, Surrey, UK).

Objective evaluation of the colour of thin porridge

Thin porridges were prepared as described earlier and subsequently dried in a laboratory incubator (Memmert GmbH + Co. KG, Schwabach, Germany) at 70°C to about 10% moisture content. The dehydrated thin 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) operating at D65 standard illuminant and observer 2º was used to evaluate the colour of dehydrated thin porridges. The 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 thin porridge

Thin porridges were prepared as described earlier using:

(1) 80 g composite flour and 900 ml water
(2) 80 g fermented composite flour and 900 ml water; and
(3) 80 g composite flour and 900 ml citric acid solution.

After cooking, the thin porridge was cooled to 30°C and served in white plastic cups. Sugar was not added to the thin porridge because in preliminary studies it was found to mask the aroma of the porridge. Eight students from local universities were recruited to undertake descriptive sensory evaluation of the thin 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±1°C. Since sensory booths were not available, the panellists were spaced 2 m apart to avoid interaction. The panellists were trained for 10 sessions with each session lasting 2 h. The first five sessions consisted of attribute generation, whereby the panellists were asked to list all the sensory attributes present in the thin porridges, which were served in random order. The panel generated 15 descriptive terms (Table 1). The next five sessions involved identifying references (Table 1) that fit the sensory attributes of thin porridges and rating them on 100 mm unstructured line scales for intensity. During product evaluation, panellists were served with 50 g of thin porridge in 120 ml white plastic cups labeled with three-digit codes. The samples were served monadically in random order with a 5 min break between each sample. Panellists rinsed their mouth with mineral water before testing each sample and in between the tests. 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 4x3 factorial combination in a randomized complete block design. The treatment combinations consisted of four types of composite flours and three treatment methods (neutral, chemically-acidified and spontaneously fermented). 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 15 sensory attributes in columns. All data were analysed with Minitab Release 14 (Minitab Inc., Pennsylvania, USA).

Table 1. Descriptive sensory lexicon developed by the sensory panel to evaluate the quality of thin 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 observed on the surface of porridge in a white plastic cup	0 = No white specks 10 = Many white specks
Brown and dark specks	Quantity of brown and dark specks in porridge when it is lifted with the back of a white teaspoon	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 when light is directed on it	[c]Brookside farm fresh milk (fat content 3%) = 3 (slightly 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)
Fermented aroma	Intensity of aroma associated with fermented and cooked cereal porridge	Unfermented and cooked finger millet porridge = 0 (no aroma) Fermented and cooked finger millet porridge = 10 (intense fermented aroma)
Taste		
Sour taste	Intensity of sour taste associated with fermented milk	[b]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
Texture		
Viscosity	Resistance to flow when the porridge is stirred with a teaspoon once in a clockwise direction	[b]Brookside farm fresh milk (fat content 3%) = 1 (thin) Honey = 10 (thick)
Coarseness	Degree to which particles are perceived in the mouth during mastication	Honey = 0 (not perceived) Fresh pressed, unsieved carrot juice = 10 (intensely perceived)
Adhesiveness	Degree to which porridge adheres to the palate when it is manipulated by the tongue	Water melon = 0 (not adhesive) [e]American Garden U. S. creamy peanut butter = 10 (very adhesive)
After swallow		
Sour aftertaste	Perception of lingering sourness in the mouth after mastication and swallowing	0 = No after taste 10= Strong after taste
Residual particles	Perception of particles in the mouth after swallowing porridge	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; [e]American Garden Co. New York, USA.

RESULTS AND DISCUSSION

Pasting proprieties of composite flours

The pasting properties of the composite flours in neutral or acidic media or after spontaneous fermentation are shown in Table 2. Cereal-based slurries (finger millet-maize, 90:10; and maize-sorghum, 75:25) tended to have higher onset pasting temperatures but lower peak, breakdown, final and setback viscosities than cassava-cereal slurries (cassava-finger millet, 90:10; and cassava-finger millet, 30:70). The cassava-cereal slurry with a high cassava content (that is, cassava-finger millet, 90:10) had higher onset pasting temperature but lower peak, breakdown, final and setback viscosities than that with a lower cassava content (that is, cassava-finger millet, 30:70). Among the cereal-based slurries, maize-sorghum slurry (75:25) had higher onset pasting temperature but lower peak, breakdown, final and setback viscosities than the finger millet-maize slurry (90:10).

Starch is the main structure- and texture-forming constituent of cereal- and cassava-based foods (Delcour et al., 2010; Moorthy, 2002). The starch content and relative proportions of amylose and amylopectin polymers in starch granules influence their pasting behaviour (Biliaderis, 2009; Colonna and Buleon, 2010). The viscous nature of gelatinized starch is due to suspended swollen starch granules dispersed in a macromolecular solution created by amylose polymers (Alloncle and Doublier, 1991). Cereal flours have lower starch contents but higher amylose contents than cassava flour (Eckoff and Watson, 2009; Breuninger et al., 2009). In addition, the high lipid content of cereal flours enables them to form more amylose-lipid complexes than cassava flour, which has a low lipid content (Colonna and Buleon, 2010). As a result of the preceding factors, cassava starch has a lower gelatinization temperature but higher peak, breakdown, final and setback viscosities than cereal starches. Consequently, when cassava flour is blended with cereal flours, the pasting behaviour of the composite flour is a reflection of the relative amounts of the cereal and cassava flours in the blends.

The time to peak viscosity of the composite flours ranged between 42 to 44°C except for spontaneously fermented cassava-finger millet (30:70) and maize-sorghum (75:25) slurries where it was about 50°C. The time taken by starch to reach peak viscosity in a viscograph is a reliable indicator of the amount of energy required to produce rapidly digestible starch. Slurries that require more time to reach peak viscosity consume more energy than those that require less time (Bolade et al., 2009). Also, the time taken by starch to reach peak viscosity affects the texture of thin porridge. Slurries that require more time to reach peak viscosity have lower rates of water absorption and swelling of starch granules and consequently have lower hot paste viscosities than those with higher rates of water absorption and swelling of starch granules (Ragaee and Abdel-Aal, 2006).

The viscosity of starch slurry begins to decline in the viscograph after reaching peak viscosity because the solubilised starch polymers reorient themselves in the direction of the shearing force. In addition, temperature- and shear-induced destruction of swollen starch granules also contribute to the decrease in viscosity after the peak viscosity has been attained (Delcour and Hoseney, 2010; Ragaee and Abdel-Aal, 2006). Slurries with low breakdown viscosities are better able to withstand temperature and shear-induced destruction of starch granules than slurries with high breakdown viscosities (Bressiani et al., 2017; Ragaee and Abdel-Aal, 2006). During the cooling phase, starch molecules begin to re-associate leading to formation of a gel structure with higher viscosity than the hot-paste slurry. The paste viscosity increases due to decreased energy in the system, which allows re-association of leached amylose molecules with each other and with gelatinized starch granules (Delcour and Hoseney, 2010; Ragaee and Abdel-Aal, 2006).

Two-factor analysis of variance showed that the interaction effect between the type of composite flour and pH was significant ($p < 0.05$) for onset pasting temperature; and the peak, breakdown, final and setback viscosities. The simple main effect of pH was significant ($p < 0.05$) for all pasting properties except for the setback viscosity of the maize-sorghum slurry (75:25) (Table 2). In comparison with the neutral slurries, spontaneous fermentation increased ($p < 0.05$) the pasting temperature and decreased ($p < 0.05$) the breakdown and setback viscosities of all slurries. On the other hand, citric acid increased the pasting temperature of all slurries, except cassava-finger millet (90:10) slurry. It also increased the peak, breakdown and final viscosities of all slurries, except the final viscosity of the cassava-finger millet (90:10) slurry. Pure organic acids (Bertolini et al., 2000; Haros et al., 2004) and organic acids produced during lactic acid fermentation (Yang and Tao, 2008) hydrolyse starch granules internally causing them to lose the ability to absorb water and swell resulting in products with low (thin) viscosity. This effect was not clearly evident in our results probably due to the minimal impact of the weak acids on the starch granules in the composite flours.

Objective evaluation of the texture of thin porridge

The texture of thin porridge was measured using the back-extrusion method in a Texture Analyzer (Stable Micro Systems, Surrey, UK). The back-extrusion method is recommended for evaluating the texture of viscous

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

pH	PT (°C)	PV (BU)	Time PV (min)	BV (BU)	FV (BU)	SV (BU)
Cassava-finger millet (90:10)						
Neutral[1] (6.52)	**66.9±0.3[b]**	751±24[b]	44.3±0.2[b]	135±11[b]	1016±14[c]	433±4[c]
Citric acid[2] (4.08)	65.9±0.0[a]	825±8[c]	43.9±0.2[b]	250±6[c]	937±9[b]	387±6[b]
Spontaneously fermented[3] (4.48)	78.8±0.1[c]	552±1[a]	42.8±0.1[a]	109±3[a]	582±1[a]	155±2[a]
Cassava-finger millet (30:70)						
Neutral (6.34)	76.8±0.1[a]	361±6[ab]	43.4±0.0[a]	71±4[b]	483±6[a]	202±5[b]
Citric acid (4.18)	78.9±0.7[b]	402±11[b]	43.3±0.1[a]	82±8[b]	553±2[b]	241±0[c]
Spontaneously fermented (4.42)	87.5±0.1[c]	350±16[a]	48.6±0.2[b]	12±1[a]	442±14[a]	112±1[a]
Finger millet-maize (90:10)						
Neutral (6.36)	78.9±0.2[a]	133±1[a]	42.1±0.1[a]	39±1[b]	217±0[a]	127±1[b]
Citric acid (4.22)	84.4±0.1[b]	221±0[c]	42.9±0.0[b]	58±0[c]	335±1[c]	175±1[c]
Spontaneously fermented (4.24)	86.7±0.1[c]	192±1[b]	43.3±0.2[b]	18±1[a]	289±1[b]	117±1[a]
Maize-sorghum (75:25)						
Neutral (6.51)	82.8±0.1[a]	65±9[a]	41.6±0.5[a]	5±0[b]	137±14[a]	91±8
Citric acid (3.88)	85.6±0.1[b]	82±0[a]	42.5±0.0[a]	8±2[b]	172±2[ab]	104±1
Spontaneously fermented (3.92)	86.9±0.1[c]	114±6[b]	50.0±0.8[b]	0±0[a]	224±18[b]	114±7

PT - pasting temperature; PV - peak viscosity; Time PV - time to peak viscosity; BV - breakdown viscosity; FV - final viscosity; SV - setback viscosity; BU – Brabender Units.
[1]Neutral slurry (10% w/v) was prepared using distilled water; [2]Chemically-acidified slurry (10% w/v) was prepared using anhydrous citric acid solution (2 g/1000 ml); [3]Spontaneously fermented and dried slurry (10% w/v) was reconstituted in distilled water.
Values with the same superscript letters 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 $p < 0.05$.

foods with a paste-like consistency and suspended particles (Carvalho et al., 2014; Gujral and Sodhi, 2002). The firmness, consistency, cohesiveness and index of viscosity of the thin porridges ranged from 0.73 to 3.54 N, -19.89 to -95.64 N·s, -1.09 to -7.13 N and -2.34 to -8.98 N·s, respectively (Table 3). Thin porridges made from cereal-based composite flours (that is, finger millet-maize and maize-sorghum) tended to have lower firmness, consistencies, cohesiveness and indices of viscosity than similar products made from cassava-cereal flours. Cassava-based thin porridge with high cassava content (that is, cassava-finger millet, 90:10) had higher firmness, consistency, cohesiveness and index of viscosity than that with lower cassava content (that is, cassava-finger millet, 30:70).

Generally, the consistency of cooked starch slurries increases sharply with increasing amount of flour from about 10% w/v (Carvalho et al., 2014). This is due to the high volume occupied by the swollen starch granules and the leached amylose polymers (Carvalho et al., 2014; Carvalho et al., 2013). Nonetheless, cassava-based thin porridges still tend to be thicker than cereal-based thin porridges because of the higher starch content and lower amounts of extraneous substances, such as fats and proteins in cassava as compared to cereal flours (Juliano, 1999).

Two-factor analysis of variance showed that the interaction effect between the type of composite flour and pH was significant ($p < 0.05$) for firmness, consistency, cohesiveness and index of viscosity. The simple main effect of pH had no significant effect ($p > 0.05$) on the firmness, consistency, cohesiveness and index of viscosity of the maize-sorghum porridge (75:25, Table 3). The simple main effect of pH showed that firmness, consistency, cohesiveness and index of viscosity of thin cassava-finger millet (90:10), cassava-finger millet (30:70) and finger millet-maize (90:10) porridges treated with citric acid tended to be higher than for the neutral or spontaneously fermented porridges. The higher acidity of thin porridges treated with citric acid as compared to the neutral or spontaneously fermented thin porridges (Table 3) may be responsible for the observed differences in the textures of the porridges. The authors postulated that citric acid freed the starch granules from any interfering

Table 3. Texture of thin porridge segregated by pH.

pH	Firmness (N)	Consistency (N·s)	Cohesiveness (N)	Index of viscosity (N·s)
Cassava: finger millet (90:10)				
Neutral[1] (6.52)	2.33±0.11[a]	64.24±2.66[a]	-4.28±0.19[a]	-5.11±1.28[b]
Citric acid[2] (4.08)	3.54±0.76[b]	95.64±20.94[b]	-7.13±1.10[b]	-8.98±4.02[b]
Spontaneously fermented[3] (4.48)	2.50±0.49[a]	66.78±11.23[a]	-5.24±1.10[a]	-4.35±1.97[a]
Cassava: finger millet (30:70)				
Neutral (6.34)	0.73±0.11[b]	19.89±3.34[a]	-1.28±0.28[a]	-2.87±0.62
Citric acid (4.18)	1.65±0.07[a]	44.74±1.30[b]	-3.44±0.17[b]	-4.38±1.27
Spontaneously fermented (4.42)	1.61±0.24[a]	44.65±6.51[b]	-3.09±0.58[b]	-3.69±1.10
Finger millet: maize (90:10)				
Neutral (6.36)	0.90±0.18	24.86±5.14	-1.43±0.29[a]	-3.07±0.51[a]
Citric acid (4.22)	1.25±0.08	34.00±2.05	-2.18±0.15[b]	-4.45±0.30[b]
Spontaneously fermented (4.24)	1.20±0.33	33.01±9.57	-2.12±0.61[b]	-4.05±0.73[b]
Maize: sorghum (75:25)				
Neutral (6.51)	0.94±0.22	24.74±5.96	-1.26±0.30	-2.65±0.57
Citric acid (3.88)	0.89±0.31	23.21±8.00	-1.09±0.40	-2.34±0.84
Spontaneously fermented (3.92)	1.02±0.12	27.24±3.47	-1.54±0.16	-3.28±0.32

[1]Neutral slurry (10% w/v) was prepared using distilled water; [2]Chemically-acidified slurry (10% w/v) was prepared using anhydrous citric acid solution (2 g/1000 ml); [3]Spontaneously fermented and dried slurry (10% w/v) was reconstituted in distilled water..
Values with the same superscript letters 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 $p < 0.05$.

matrices, thus enabling them to swell more readily and form thicker pastes.

Objective evaluation of the colour of thin porridge

The lightness, redness and yellowness of thin porridges prepared in neutral or acidic media or from spontaneously fermented composite flours ranged between 53.1-68.8, 4.4-9.3 and 8.4-15.7, respectively (Table 4). 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. Acid-treated thin cassava-finger millet (90:10) porridge was the least dark sample (that is, it had the highest L* and b* values), which implies that addition of citric acid to the cassava-rich sample actually made the porridge lighter in colour. By contrast, neutral finger millet-maize (90:10) porridge was the darkest sample (that is, it had the lowest L* and b* values). This could have been due to the high content of coloured finger millet and low content of white maize in this thin porridge. Pigmented grains are rich in phenolic acids which stain porridges with a dark colour during cooking (Anyango et al., 2011; Kebakile, 2008). Comparison of thin porridges made from cereal-based composite flours showed that irrespective of the method of pH adjustment, thin maize-sorghum (75:25) porridges were lighter, yellower and redder than the finger millet-maize (90:10) porridges. In conclusion, these results show that the colour of thin porridge was influenced by the botanical origin of theflours, their ratios and the method of acidification.

Descriptive sensory evaluation of thin porridge

Principal component analysis was used to evaluate the mean panellist and replication scores of the 15 sensory attributes identified in thin porridges (Table 1). The first three PCs accounted for 83.7% of the total variance (Table 5).

Loadings with absolute values greater than 0.354 (marked with an asterisk) represented a strong influence on the sensory character of the thin porridges. The first PC accounted for 32.9% of the variance in the sensory attribute data and separated the thin porridges on the basis of the botanical origin of the flour (Table 5). Thin porridges made from cereal-based composite flours were situated on the right side of the PCA plot whereas those containing cassava were on the left side, except for the

Table 4. Colour of thin porridge segregated by pH.

pH	Colour		
	L*	a*	b*
Cassava: finger millet (90:10)			
Neutral[1] (6.52)	64.6±0.1[b]	4.7±0.1[a]	13.1±0.1[b]
Citric acid[2] (4.08)	68.8±0.6[c]	6.1±0.1[b]	15.7±0.4[c]
Spontaneously fermented[3] (4.48)	57.4±0.3[a]	6.2±0.3[b]	8.7±0.2[a]
Cassava: finger millet (30:70)			
Neutral (6.34)	57.2±0.3[a]	6.3±0.1[b]	9.1±0.2[a]
Citric acid (4.18)	58.1±0.7[a]	7.4±0.3[c]	9.8±0.4[a]
Spontaneously fermented (4.42)	65.8±0.9[b]	4.4±0.1[a]	13.1±0.3[b]
Finger millet: maize (90:10)			
Neutral (6.36)	53.1±0.4[a]	6.4±0.2[a]	7.8±0.2[a]
Citric acid (4.22)	53.8±0.7[a]	7.8±0.1[b]	9.1±0.1[c]
Spontaneously fermented (4.24)	57.2±0.4[b]	6.4±0.1[a]	8.4±0.3[b]
Maize: sorghum (75:25)			
Neutral (6.51)	56.2±0.3[a]	6.9±0.1[a]	9.3±0.3[a]
Citric acid (3.88)	62.2±0.6[c]	9.3±0.1[c]	14.2±0.4[c]
Spontaneously fermented (3.92)	59.6±0.3[b]	7.7±0.2[b]	10.9±0.3[b]

L*: lightness; a*: redness; b*: yellowness.
[1]Neutral slurry (10% w/v) was prepared using distilled water; [2]Chemically-acidified slurry (10% w/v) was prepared using anhydrous citric acid solution (2 g/1000 ml); [3]Spontaneously fermented and dried slurry (10% w/v) was prepared using distilled water.
Values with the same superscript letters 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 $p < 0.05$.

Table 5. Principal component factor loadings for thin porridge attributes.

Attribute	PC1	PC2	PC3
Colour	0.196	-0.327	-0.354*
White specks	0.163	0.217	0.196
Dark specks	0.088	-0.261	-0.238
Gloss	-0.213	-0.168	0.100
Cassava aroma	-0.393*	-0.221	0.380
Finger millet aroma	0.347	-0.496*	-0.212
Maize aroma	0.297	0.406*	0.230
Sorghum aroma	0.021	0.070	0.011
Fermented aroma	-0.289	0.326	-0.672*
Sour taste	-0.315	0.252	-0.248
Viscosity	-0.264	-0.182	0.073
Coarseness	0.342	0.183	-0.050
Adhesiveness	-0.126	-0.073	0.003
Sour aftertaste	-0.165	0.125	-0.064
Residual particles	0.325	0.163	-0.039
Variance %	32.9	27.4	23.4
Cumulative variance %	32.9	60.3	83.7

*Loadings with absolute values greater than 0.354.

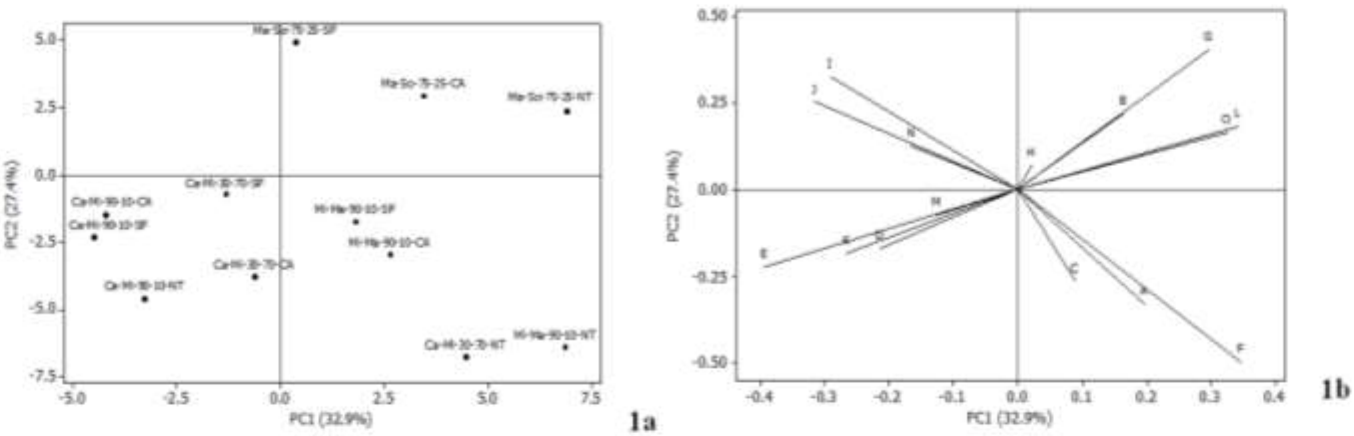

Figure 1. Principal component analysis of thin porridge. (1a) Plot of the first two principal component scores of composite flours used to prepare thin porridge. (1b) Plot of the first two principal component loading vectors of sensory attributes of thin porridge. Ca: cassava; So: sorghum; Mi: finger millet; Ma: maize; SF: spontaneously fermented; CA: chemically acidified; NT: neutral. The numbers refer to the ratios of the flours used. A: colour; B: white specks; C: dark specks; D: gloss; E: cassava aroma; F: finger millet aroma; G: maize aroma; H: sorghum aroma; I: fermented aroma; J: sour taste; K: viscosity; L: coarseness; M: adhesiveness; N: sour aftertaste; O: residual particles.

neutral cassava-finger millet (30:70) porridge (Figure 1a). Cassava-containing thin porridges were characterized by a strong cassava aroma (loading value -0.393) in addition to being more viscous and glossy than the cereal-based thin porridges (Figure 1b). Cereal-based thin porridges were characterized by finger millet or maize aroma, coarse mouthfeel, and residual particles in the mouth after swallowing.

Unblended flours are largely unsuitable for making thin porridges. Thin porridge made from cassava flour has a starchy taste and flavour, and jelly-like consistency, whereas cereal-based thin porridges have a bland taste and rough mouthfeel (Wanjala et al., 2016). These undesirable sensory attributes of thin porridges can be mitigated by blending cassava with cereal flours in appropriate ratios. Cassava imparts a smooth texture to thin porridges and decreases the grittiness caused by the cereal endosperm and bran particles. By contrast, cereal flours decrease the viscosity of thin porridges that contain cassava flour (Wanjala et al., 2016).

The second PC accounted for 27.4% of the variance in the sensory attribute data (Table 5). It separated the thin porridges on the basis of maize aroma (loading value 0.406) and finger millet aroma (loading value -0.496). Thin porridges located in the upper part of the plot were characterized by a strong maize aroma due to the high concentration of maize in the composite flours (Figure 1a). The thin maize-sorghum porridges were also characterized by presence of many white specks, coarse mouthfeel and residual particles in the mouth after swallowing (Figure 1b). By contrast, the thin maize-finger millet (90:10) porridges, which were located in the lower part of the plot, were dark in colour and had many dark specks (Figure 1b). Cereal grains each have their characteristic flavour profiles and precursors, which intensify further during processing due to process-induced changes in grain biopolymers and flavour-active compounds (Heiniö, 2003). The flavour of cereal grain products originate from the inherent volatile compounds, such as aldehydes, ketones and alcohols; and non-volatile compounds such as phenolic compounds, amino acids, small peptides, fatty acids and sugars (Heiniö et al., 2016).

The third PC accounted for 23.4% of the variance in the sensory attribute data (Table 5). It separated the thin porridges on the basis of the fermented aroma (loading value -0.672) and colour (loading value -0.354). The aroma of spontaneously fermented thin porridges is due to the production of lactic acid and minor products of bacterial metabolism during fermentation (Mugula et al., 2003; Muyanja et al., 2003; Mukisa et al., 2016). As shown in the section on instrumental analysis of colour, the colour of thin porridges was influenced by the botanical origin of the flour, their ratios and the method of acidification (Table 4).

Small loadings (that is, values close to zero) are 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 for sorghum aroma across all PCs (Table 5) is in agreement with the low content of sorghum in the thin maize-sorghum (75:25) porridge. Sorghum aroma was hardly detectable in the neutral, chemically-acidified or spontaneously fermented thin porridges made from maize-sorghum (75:25) flours.

Conclusion

Thin porridge is an important refreshment drink for millions of people in sub-Saharan Africa. In addition, it is an important complementary food and source of nourishment for the sick and the elderly. Instrumental and sensory methods are both useful in identifying the sensory attributes of thin porridge. Instrumental tests showed that the pH and type of composite flour affected the firmness, cohesiveness, consistency, index of viscosity and colour of thin porridges. The sensory attributes identified were influenced by the blending ratios of the flours and pH of their slurries. Aroma and colour were identified as the most important sensory attributes of thin porridge.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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