academicJournals

Vol. 8(8), pp. 435-443, August 2014
DOI: 10.5897/AJFS2014.1185
Article Number: D15B75246742
ISSN 1996-0794

http://www.academicjournals.org/AJFS

African Journal of Food Science

Full Length Research Paper

Physical properties of dry-milled maize meals and their relationship with the texture of stiff and thin porridge

Calvin Onyango

Food Technology Division, Kenya Industrial Research and Development Institute, Nairobi, Kenya.

Received 18 June, 2014; Accepted 25 July, 2014

Selected physical properties of white maize meal, obtained by different dry-milling techniques were evaluated and correlated to the texture of stiff and thin porridge. Sifted or par-cooked maize meals had finer particles than hammer-milled maize meals. Hammer-milled maize meals had lower water absorption indices (17-38%) and higher water solubility indices (WSI, 4-5%) than sifted (41-42 and 2-3%, respectively) or par-cooked (114 and 2%, respectively) maize meals. Sifted or par-cooked maize meals had lower breakdown viscosities (0-19 BU) and higher final viscosities (818-1925 BU) than hammer-milled maize meals (89-173 BU and 530-780 BU, respectively). Stiff porridge prepared from par-cooked maize meal (34% w/v), and thin porridge from dehulled and hammer-milled maize meal (10% w/v) had the firmest textures at 80.93 and 1.28 N, respectively. There was a negative correlation (P < 0.05, r = -1.00) between the WSI and total shearing force of stiff porridge prepared from par-cooked maize meal.

Key words: Maize, porridge, texture, Pearson correlation coefficient.

INTRODUCTION

White maize (*Zea mays*) is an important source of starch, protein, fiber and a wide range of micronutrients for millions of people in sub-Saharan Africa. Maize meal, the main product obtained from white maize kernels, is used to make stiff (thick) or thin porridge. The porridges are known by different local names in different countries in the region. Stiff porridge is known as *pap* in South Africa; *ugali* in Kenya, Uganda and Tanzania; *sadza* or *isitshwala* in Zimbabwe; *nsima* in Zambia and Malawi; *phaletshe* in Botswana; *banku* or *kenkey* in Ghana; *fufu or tuwo* in the western Africa sub-region; and Mawè in Benin and Togo. Thin porridge is known as *uji* in Kenya, Uganda and Tanzania; and also as *togwa* in Tanzania and *obushera* in Uganda; *nasha* or *hulu-mur* in Sudan; *lakh* or *fonde* in Senegal and Gambia; *mahewu* or *magou* in South Africa and Zimbabwe; *koko* or *akasa* in Ghana and Nigeria; *ogi* in Nigeria, and *poto poto* in Democratic Republic of Congo (FAO, 1995).

The main difference between stiff and thin porridge relates to the amount of maize meal that is used to prepare them, and consequently how they are eaten. Stiff maize porridge is made by adding ca. 30% w/v maize

E-mail: calonyango@yahoo.com.

meal to boiling water. The gruel is stirred with a flat wooden handle to make a stiff homogeneous and well-gelatinized mass that is free from lumps. The product is consumed at lunch or dinner as the main energy-giving food, preferably when it is still hot or warm. Stiff porridge has a bland taste because it is commonly prepared from unfermented maize meal without any other ingredients or additives. Thin maize porridge is prepared in a similar manner to stiff porridge but with less maize meal (ca. 10% w/v). It can also be prepared from lactic spontaneous fermented maize slurry (Afoakwa et al., 2010) or chemically-acidified maize slurry (Onyango et al., 2005). The energy density of thin maize porridge can be enhanced by adding amylase-rich cereal malt (Afoakwa et al., 2010). Thin maize porridge is commonly sweetened with sugar and is drank or eaten with a spoon as a refreshment any time of the day.

The physical quality of dry-milled maize meal used to prepare stiff and thin porridge in sub-Saharan Africa is variable. Sifted maize meal is obtained by roller milling and sifting shelled clean maize. Whole maize meal is obtained by grinding clean whole maize kernels using a hammer mill or other impact-grinding methods. Dehulled maize meal is obtained from kernels that have been dehulled, commonly using a PRL dehuller (Munck, 1995), and subsequently hammer-milled. Par-cooked maize meal is made from degerminated endosperm grits that are subsequently conditioned, steamed, flaked, dried and milled. This maize meal requires almost 10 times less time to make porridge from it than sifted or hammer-milled maize meal and can, therefore, save energy and time associated with porridge preparation. Par-cooked maize meal is a new product that has been introduced in the southern Africa market by Buehler AG (Uzwil, Switzerland) through its local subsidiary Buehler Pty Ltd. (Johannesburg, South Africa).

The transformation of maize meal into porridge is associated with gelatinization of starch in excess water. This process involves loss of starch lamellar structure with gelatinization followed by formation of complex fractal structures during starch pasting and retrogradation (Doutch et al., 2012). The behaviour of starch when heated in excess water is influenced by the quality of the flour (Bolade et al., 2009) as well as its botanical origin (Seetharaman et al., 2001; Singh et al., 2003). Bolade et al. (2009) showed that maize flour particle size influences starch functional characteristics, such as water absorption capacity, bulk density, damaged starch, and pasting behaviour; and stiff porridge texture, such as hand mouldability and mouth feel characteristics. Seetharaman et al. (2001) found that the thermal, pasting and textural properties of maize starch is affected by maize variety; and there is a strong correlation between the thermal properties and pasting and textural properties. The objective of this work was to evaluate the physical properties of maize meal and the texture of stiff and thin porridges made from them.

MATERIALS AND METHODS

Proximate composition of maize meal

White flint maize grain (*Zea mays* var. *indurate* Sturt), Hybrid 614, was purchased from Baraka Grain Millers, Nairobi, Kenya. It was cleaned to remove foreign matter and divided into three lots. Coarse (WM-TP) and fine (WM-SP) whole maize meal were obtained by milling the kernels in a hammer mill having 1,000 or 500 µm sieves, respectively. Coarse (DM-TP) or fine (DM-SP) dehulled maize meal were obtained by dehulling the kernels (75% extraction rate) using a PRL dehuller having 13 carborundum stones (Munck, 1995) before milling them in a hammer mill having 1,000 or 500 µm sieves, respectively. Three commercial sifted maize meals were purchased from a supermarket in Nairobi and labelled SF-T1, SF-T2 and SF-T3. Par-cooked maize meal (PC-MM) was donated by Buehler Pty Ltd. (Johannesburg, South Africa). Moisture, crude protein (N x 6.25), total ash and crude fiber contents of the maize meals were determined using AACC methods 44-40, 46-12, 08-01 and 32-10, respectively (AACC, 2005). Crude oil content was determined using AOAC method 945.16 (AOAC, 2005). Carbohydrate content (%) was calculated by subtracting protein, oil and ash contents from 100.

Physical properties of maize meal

Particle size distribution of the maize meals was determined by sieving 50 g maize meal for 20 min in a Minor M200 electric sieve shaker (Endecotts Limited, London, UK) with 125, 180, 300, 400 and 500 µm sieves to obtain the following fractions: 125-180, 180-300, 300-400, ≥400. The different maize meal fractions were weighed and expressed as a percentage of the total weight of the maize meal.

Water absorption and solubility indices were determined by weighing maize meal (2.0 g) in pre-weighed centrifuge tubes and 20 ml distilled water added. The caps were secured and the tubes hand-shaken 10 times to suspend the maize meals. The suspensions were allowed to solvate and swell for 30 min in a water-bath at 30°C with intermittent shaking after every 10 min. The samples were centrifuged using a CN-2060 centrifuge (MRS Laboratory Equipment, Holon, Israel) at 4,000 rpm for 30 min. The supernatants were decanted into tared aluminum pans and weight gain in the gel noted. Water absorption index (WAI) was calculated as [(weight of the gel - sample weight) / (sample weight) x 100] (Inglett et al., 2009). The supernatants were evaporated to dryness at 105°C to constant weight. Water solubility index (WSI) was determined as [(weight of dried supernatant) / (dry sample weight) x 100]. Damaged starch content was determined using a Megazyme starch kit (Megazyme International Ireland Limited, Co. Wicklow, Ireland).

The pasting behavior of the maize meals was investigated in a Brabender Viscograph-E (Brabender GmbH and Co. KG, Duisburg, Germany) at 85 rpm and 700 cmg torque. Slurry, made up of ca. 40 g maize meal (adjusted to 14% moisture content) and ca. 315 ml water was poured in the Viscograph-E canister. The canister was placed in the Viscograph-E heating chamber and the instrument head lowered into it. The suspension was heated from 30 to 95°C at the rate of 1.5°C/min; held at 95°C for 15 min; cooled from 95 to 30°C at the rate of -1.5°C/min; and finally held at 30°C for 15 min. Paste temperature (°C), peak viscosity (Brabender Units, BU), time to peak viscosity (min), breakdown viscosity (BU), final viscosity (BU) and setback viscosity (BU) were determined.

Table 1. Proximate composition (%) of white maize meal.

Maize meal	Moisture content	Carbohydrate	Crude protein	Crude oil	Crude fiber	Total ash
WM-TP	11.09±0.01[b]	84.81±0.24[a]	9.30±0.26[d]	4.73±0.03[c]	2.27±0.80[e]	1.17±0.07[d]
WM-SP	9.13±0.12[a]	86.07±0.13[b]	7.51±0.04[b]	5.08±0.04[c]	1.73±0.01[c]	1.33±0.07[e]
DM-TP	11.52±0.37[b]	87.83±0.04[c]	6.75±0.09[a]	4.53±0.11[c]	1.44±0.02[b]	0.89±0.07[bc]
DM-SP	9.48±0.14[a]	88.79±0.73[d]	6.91±0.03[a]	3.34±0.80[b]	1.65±0.02[c]	0.95±0.07[c]
SF-T1	12.55±0.15[c]	85.07±0.13[a]	11.61±0.07[e]	2.56±0.00[b]	1.34±0.01[ab]	0.76±0.07[b]
SF-T2	11.17±0.08[b]	86.80±0.21[b]	9.08±0.22[d]	3.25±0.01[b]	2.20±0.02[e]	0.87±0.02[bc]
SF-T3	12.29±0.15[c]	90.69±0.21[e]	7.90±0.22[bc]	0.95±0.03[a]	1.98±0.01[d]	0.46±0.05[a]
PC-MM	12.30±0.10[c]	91.08±0.24[e]	8.13±0.27[c]	0.49±0.03[a]	1.29±0.08[a]	0.30±0.00[a]

Values are means of three replicates ± standard deviation. Means followed by different superscript letters in the same column are significantly different at $P < 0.05$. Values are given on dry-matter basis except for moisture content. WM-TP: coarse whole hammer-milled maize meal; WM-SP: fine whole hammer-milled maize meal; DM-TP: dehulled and coarsely hammer-milled maize meal; DM-SP: dehulled and finely hammer-milled maize meal; SF-T1, SF-T2 and SF-T3 represent commercial sifted maize meal brands; PC-MM: par-cooked maize meal.

Texture of thick and thin porridge

Stiff porridge was made by adding 34% w/v maize meal in boiling tap water in a stainless steel cooking pan. The mixture was kneaded with a flat wooden handle for 7 min to obtain homogenous stiff paste that was devoid of lumps. The cooking pan was covered and heated further for 3 min with intermittent kneading. The stiff porridge was transferred to a clean surface and manually moulded in the shape of a dome. A block measuring 50 mm high x 40 mm wide x 72 mm long was punched out from the stiff porridge using a stainless steel die. The die was lightly oiled with edible vegetable oil on the inner surface to facilitate easy removal of the stiff porridge. The stiff porridge block was incubated in a Memmert oven (Memmert GmbH + Co. KG, Schwabach, Germany) at 55°C. A block was punched out from the residual stiff porridge and a Eutech pH510 temperature probe (Eutech Instruments Pte. Ltd., Ayer Rajah, Singapore) inserted in it before putting it in the cabinet. When the internal temperature of the residual stiff porridge block had reached 55°C, it was assumed that the analytical blocks were fully equilibrated at 55°C. This took about 10 min. A TA-XT*plus* Texture Analyzer (Stable Micro Systems, Surrey, UK) equipped with 50 kg load cell and Kramer shear cell probe attachment (HDP/KS5) was used to measure the firmness of stiff porridge at the following test conditions: height of the blades from the base of the plate was calibrated at 70 mm; pretest speed 1 mm/s; trigger force 0.05 N (the point at which the probe's lower surface was in full contact with the product); test speed 2 mm/s; distance travelled by the blades from the calibration height was 60 mm (40 mm penetration depth of blades in porridge or 80% of product height); post-test speed 5 mm/s. The force (N) versus time (s) required to cut through the porridge was recorded. The peak force (N) and total shearing force (N·s) were calculated using EXPONENT Texture Analysis software version 6.1.5.0 (Stable Micro Systems, Surrey, UK).

Thin porridge was prepared using 10% w/v maize meal in tap water. A portion of the water (ca. 40%) was initially mixed with all the maize meal to make cold slurry, which was then added to the remaining portion of boiling water in a stainless steel pan. The porridge was kept boiling for 10 min with intermittent stirring, to avoid formation of lumps, using a flat wooden handle for 10 min. The thin porridge was placed in a 50 mm diameter standard size A/BE back extrusion container (TA-XT*plus* Texture Analyzer, Stable Micro Systems, Surrey, UK) approximately 75% full (80 g) and incubated in a water bath at 60°C to allow for temperature equilibration. Porridge temperature was confirmed to have reached 60°C using a Eutech pH510 temperature probe (Eutech Instruments Pte. Ltd., Ayer Rajah, Singapore). Extrusion force was measured at the following settings: 50 kg load cell; height calibration 30 mm; disc diameter 45 mm; pretest 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 0.05 N surface trigger was attained (the point at which the disc's lower surface was in full contact with the product) 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).

Experimental design and statistical analysis

All experiments were set-up as single-factor completely randomized designs. All tests were made in triplicate and results reported as mean ± standard deviation. The data was analyzed using one-way analysis of variance and differences in treatment means evaluated using Tukey's test at 5% using Minitab Statistical Software version 13 (Minitab Inc., Pennsylvania, USA). Pearson correlation coefficients (r) between all maize meal physical properties and stiff or thin porridge texture were calculated using SPSS software version 13.0 (SPSS, Chicago, USA).

RESULTS AND DISCUSSION

Proximate composition of maize meal

Maize meals were obtained from adequately dried grains with moisture contents ranging from 9.13 to 12.55% (Table 1). The variable distribution of nutrients among the maize meals (Table 1) reflects the different dry-milling techniques that the grains were subjected to. Sifted maize meals and PC-MM maize meal had lower oil and ash contents as compared to whole hammer-milled maize meals (WM-TP and WM-SP). Dehulled and hammer-

Table 2. Water absorption and solubility indices, and damaged starch content of white maize meal.

Maize meal	WAI (%)	WSI (%)	DS (g/100 g)
WM-TP	21.73±1.32[a]	4.43±0.18[d]	5.98±0.88[a]
WM-SP	37.94±1.60[b]	5.35±0.36[e]	11.44±0.75[c]
DM-TP	17.06±2.66[a]	4.23±0.25[d]	5.95±0.04[a]
DM-SP	35.98±0.33[b]	4.02±0.18[d]	9.33±0.18[b]
SF-T1	41.75±5.26[b]	2.72±0.15[b]	7.25±0.26[a]
SF-T2	42.26±3.26[b]	3.32±0.15[c]	7.44±0.03[a]
SF-T3	40.64±2.49[b]	1.84±0.07[a]	11.12±0.61[c]
PC-MM	113.60±5.52[c]	1.58±0.23[a]	10.92±0.13[bc]

Values are means of three replicates ± standard deviation. Means followed by different superscript letters in the same row are significantly different at P < 0.05. WM-TP: coarse whole hammer-milled maize meal; WM-SP: fine whole hammer-milled maize meal; DM-TP: dehulled and coarsely hammer-milled maize meal; DM-SP: dehulled and finely hammer-milled maize meal; SF-T1, SF-T2 and SF-T3 represent commercial sifted maize meal brands; PC-MM: par-cooked maize meal.

milled maize meals (DM-TP and DM-SP) had higher carbohydrate and lower protein, fat, ash and fiber contents than whole hammer-milled maize meals (WM-TP and WM-SP).

The proximate composition of the maize meals was compared with Kenya Standard (KS 168:2007) for dry-milled maize products. The proximate composition of whole maize meal agreed with Kenya Standard which set maximum fiber, oil, moisture and ash contents at 3.0, 5.0, 14.0 and 2.0%, respectively (KS 168:2007). Bran and germ removal in sifted and PC-MM maize meals was responsible for their lower oil and ash content as compared to whole hammer-milled maize meals (WM-TP and WM-SP). Some proximate composition parameters of sifted maize meals (SF-T1, SF-T2 and SF-T3) did not comply with Kenya Standard (KS 168:2007), which requires this type of maize meal to have maximum fiber, oil, moisture and ash contents of 0.7, 3.0, 14.0 and 0.75%, respectively. All the proximate composition parameters of PC-MM maize meal complied with Kenya Standard (KS 168:2007) for sifted maize meal.

Physical properties of maize meal

More than 75% of the hammer-milled maize meal particles were retained on the 400 µm sieve as compared to 55-64% of sifted maize meal particles. The PC-MM maize meal had the lowest proportion of particles that were ≥400 µm (41%) and the highest proportion of particles with sizes between 125-400 µm (59%). The PC-MM maize meal had the highest WAI (113%) and lowest WSI (1.58%, Table 2). The WAI of sifted maize meals was about 40% while their WSI ranged between 1.84 and 3.32%. Sifted maize meals had significantly lower (P < 0.05) WSI (1.58-3.32%) than hammer-milled maize meals (4.02-5.35%). Coarsely hammer-milled maize meals had significantly lower (P < 0.05) WAI (WM-TP: 21.73%; DM-TP: 17.06%) than finely hammer-milled maize meals (WM-SP: 37.94%; DM-SP: 35.98%). Water solubility index was lower in PC-MM maze meal and sifted maize meals than in hammer-milled maize meals. Nonetheless, all these values were lower than the 9-15% reported by Sandhu and Singh (2007) for maize starch. These differences appear to be associated with naturally occurring substances, such as lipids, in the maize meal matrix, which inhibit starch granule swelling and leaching of soluble polysaccharides (Tester and Morrison, 1990). Due to the high degree of refinement, maize starch granules have less interfering substances than sifted, par-cooked or hammer-milled maize meals.

The damaged starch content of the maize meals was not explicitly related with the milling technique (Table 2). Whole hammer-milled maize meal (WM-SP), one brand of the commercial sifted maize meal (SF-T3) and PC-MM maize meal had higher damaged starch contents (ca. 11%) than the other maize meals (6-9%). Finely hammer-milled maize meals had higher damaged starch contents than coarsely hammer-milled maize meals (WM-SP > WM-TP and DM-SP > DM-TP).

A major technical consequence of milling is particle size reduction and associated changes in the physical properties of starch, such as generation of damaged starch, and modification of starch pasting profile (Hossen et al., 2011; Bolade et al., 2009). In this study, particle size reduction of maize yielded coarse maize meal since more than 90% of the particles were greater than 297 µm and smaller than 638 µm (Arendt and Zannini, 2013). The different WAIs of the maize meals implied differences in the degree of availability of water binding sites. Native starch can hold up to 30% of its dry weight as moisture (Delcour and Hoseney, 2010), and this amount can be enhanced by increasing the damaged starch content (Craig and Stark, 1984) or decreasing the flour particle size (Scanlon et al., 1988). Thus, the high WAI in PC-MM maize meal could be attributed to exposure of more starch granule sites to water as a result of the more complicated processing procedure (conditioning, steaming, flaking, drying and milling) as compared to sifted or hammer-milled maize meal production. On the other hand, the high WAI of sifted maize meals could be attributed to a combination of the high damaged starch contents and small particle sizes relative to their hammer-milled counterparts. The higher WAI of finely hammer-milled maize meals as compared to the coarsely hammer-milled fractions could be attributed to the higher damaged starch content in the former.

Statistical analyses of the pasting properties of maize meals are summarized in Table 3. The onset pasting temperature of the maize meals ranged between 71.7°C

Table 3. Pasting properties of white maize meal.

Maize meal	Pasting temperature (°C)	Time to peak viscosity (min)	Peak viscosity (BU)	Breakdown viscosity (BU)	Final viscosity (BU)	Setback viscosity (BU)
WM-TP	80.7±0.2[e]	43.04±0.1[ab]	334.7±10.1[cd]	88.7±9.0[c] (27)*	652.0±23.6[a]	489.3±13.9[b] (75)**
WM-SP	71.7±0.2[a]	40.23±0.1[a]	316.7±5.7[bc]	131.7±6.4[e] (42)	530.0±8.2[a]	385.0±9.2[a] (73)
DM-TP	77.5±0.4[c]	42.59±0.1[ab]	398.7±6.0[ef]	106.3±2.1[d] (27)	773.0±8.7[ab]	568.7±4.6[bc] (74)
DM-SP	73.1±0.3[b]	41.75±0.3[ab]	431.7±23.8[f]	173.0±7.8[f] (40)	779.3±44.2[b]	603.3±32.9[bc] (77)
SF-T1	81.3±0.3[e]	52.84±3.2[c]	237.7±2.3[a]	2.3±2.3[a] (0)	825.3±18.9[b]	572.3±14.7[bc] (69)
SF-T2	80.9±0.2[e]	45.70±1.5[b]	297.0±3.6[b]	19.0±1.7[b] (6)	818.7±23.3[b]	633.3±28.9[c] (77)
SF-T3	78.6±0.3[d]	50.57±0.2[c]	322.7±9.1[bc]	4.7±1.5[a] (1)	1605.3±65.2[c]	932.0±48.0[d] (58)
PC-MM	78.6±0.4[d]	56.97±1.4[d]	368.3±20.6[de]	0.0±0.0[a] (0)	1925.0±110.7[d]	974.0±70.4[d] (51)

Values are means of three replicates ± standard deviation. Means followed by different superscript letters in the same column are significantly different at P < 0.05. WM-TP: coarse whole hammer-milled maize meal; WM-SP: fine whole hammer-milled maize meal; DM-TP: dehulled and coarsely hammer-milled maize meal; DM-SP: dehulled and finely hammer-milled maize meal; SF-T1, SF-T2 and SF-T3 represent commercial sifted maize meal brands; PC-MM: par-cooked maize meal. Breakdown viscosity = Peak viscosity – trough viscosity. Setback viscosity = Final viscosity – trough viscosity; BU: Brabender units. *Values in parentheses indicate breakdown viscosity calculated as a percentage of peak viscosity. **Values in parentheses indicate setback viscosity calculated as a percentage of final viscosity.

for WM-SP and 81.3°C for SF-T1. These values agreed well with published reports. Ji et al. (2004) found that the onset pasting temperature of maize starch ranges between 62-87°C, while Sandhu and Singh (2007) reported a range of 76-84°C. Finely hammer-milled maize meals (WM-SP and DM-SP) had significantly lower (P < 0.05) onset pasting temperatures than coarsely hammer-milled maize meals (WM-TP and DM-TP), sifted maize meals and PC-MM maize meal.

The viscous character of starch paste is as a result of the suspension of swollen starch granules, mainly amylopectin, dispersed in a macromolecular solution created by amylose polymers (Alloncle and Doublier, 1991). This viscous environment is determined by several factors such as the volume fraction occupied by the swollen granules, rigidity of the swollen granules, visco-elasticity of the continuous phase, and adhesion between the starch granules and continuous phase (Eliasson and Bohlin, 1982). In this study, it appeared that maize meal quality also had an influence on the viscous character of the cooked paste. Dehulled and hammer-milled maize meals (DM-TP and DM-SP) had significantly higher peak viscosities (P < 0.05) than whole hammer-milled maize meals (WM-TP and WM-SP) whereas PC-MM maize meal had significantly higher peak viscosity (P < 0.05) than sifted maize meals.

Furthermore, we observed that hammer-milled maize meals required less time to reach peak viscosity (40.23-43.04 min) than sifted (45.70-52.84 min) or PC-MM maize meals (56.97 min). Although PC-MM maize meal is par-cooked, its peak viscosity was within the range for sifted and hammer-milled maize meals. Inglett et al. (2009) reported that pregelatinized starch shows almost instantaneous peak viscosity development when analysed in a viscograph. We did not observe this behaviour with PC-MM maize meal probably because of its low content of pregelatinized (damaged) starch (Table 2).

The time taken by starch slurry to reach peak viscosity is an important cooking property because it is associated with energy consumption. Starch slurry that requires more time to reach peak viscosity consumes more energy than slurry that requires less time (Bolade et al., 2009). Furthermore, Ragaee and Abdel-Aal (2006) reported that flours that require more time to reach peak viscosity have lower rate of water absorption and swelling of starch granules than those that require less time. These findings do not totally agree with our results. Although PC-MM maize meal took the longest time to reach peak viscosity (Table 3), this maize meal requires almost 10 times less time to make it into porridge than sifted or hammer-milled maize meal. Also, PC-MM maize meal exhibited higher water absorption (Table 3) than the other maize meals as a result of the par-cooking treatment it was exposed to.

The viscosity of starch slurry starts to decline after reaching peak viscosity when molecules of soluble starch begin to reorient themselves in the direction of the shearing force and due to temperature- and shear-induced destruction of the swollen granules (Delcour and Hoseney, 2010; Ragaee and Abdel-Aal, 2006). The decline in paste viscosity (breakdown viscosity) appeared to be further influenced by the milling technique and meal particle size. Sifted and PC-MM maize meals exhibited lower (P < 0.05) breakdown viscosities (0-19 BU) than hammer-milled maize meals (88-173 BU); finely hammer-milled maize meals had higher (P < 0.05) breakdown viscosities than coarsely hammer-milled maize meals (WM-SP > WM-TP and DM-SP > DM-TP); and, finally, whole hammer-milled maize meals had lower (P < 0.05)

Table 4. Texture of stiff and thin porridge prepared from white maize meal.

Maize meal	Stiff maize meal porridge*		Thin maize meal porridge**			
	Peak force (N)	Total shearing force (N·s)	Firmness (N)	Consistency (N·s)	Cohesiveness (N)	Index of viscosity (N·s)
WM-TP	42.25±3.81[a]	409.87±41.92[a]	0.82±0.06[c]	22.21±1.52[c]	-0.85±0.08[cd]	-1.78±0.13[cd]
WM-SP	50.49±4.51[b]	460.07±38.90[a]b	0.91±0.16[c]	24.38±4.07[c]	-1.02±0.19[d]	-2.11±0.41[d]
DM-TP	46.67±2.44[ab]	454.13±21.25[ab]	0.67±0.04[bc]	17.78±1.02[b]	-0.67±0.07[bc]	-1.41±0.12[bc]
DM-SP	58.86±4.53[b]	540.98±45.97[b]	1.28±0.18[d]	34.04±3.94[d]	-1.54±0.22[e]	-3.01±0.31[e]
SF-T1	53.57±7.32[b]	559.44±85.99[b]	0.58±0.05[b]	14.80±1.52[b]	-0.55±0.05[b]	-1.18±0.11[b]
SF-T2	55.01±4.99[b]	568.47±70.55[b]	0.91±0.11[c]	24.92±3.34[c]	-1.03±0.12[d]	-2.13±0.26[d]
SF-T3	48.87±6.74[ab]	527.52±89.27[ab]	0.50±0.07[b]	13.27±2.09[b]	-0.64±0.12[b]	-1.44±0.30[bc]
PC-MM	80.93±10.45[c]	838.99±100.61[c]	0.24±0.04[a]	5.58±1.19[a]	-0.23±0.06[a]	-0.34±0.28[a]

Values are means of three replicates ± standard deviation. Means followed by different superscript letters in the same column are significantly different at P < 0.05. WM-TP: coarse whole hammer-milled maize meal; WM-SP: fine whole hammer-milled maize meal; DM-TP: dehulled and coarsely hammer-milled maize meal; DM-SP: dehulled and finely hammer-milled maize meal; SF-T1, SF-T2 and SF-T3 represent commercial sifted maize meal brands; PC-MM: par-cooked maize meal. *Texture of stiff porridge was measured using a Kramer shear blade of TA-XT*plus* Texture Analyser. **Texture of thin porridge was measured using a back extrusion cell of TA-XT*plus* Texture Analyser.

breakdown viscosities than dehulled and hammer-milled maize meals (DM-TP > WM-TP, and DM-SP > WM-SP). When breakdown viscosity was calculated as a percentage of peak viscosity, we noted that sifted and PC-MM maize meals had the lowest percent breakdown viscosity (0-6%) followed by coarsely hammer-milled maize meals (27%) and finely hammer-milled maize meals (40-42%). These findings imply that maize meals with lower breakdown viscosities (sifted and PC-MM maize meals) had stronger associative forces and cross-links within starch granules, which were better able to withstand shear thinning or breakdown. By contrast, maize meals with higher breakdown viscosities (hammer-milled maize meals) had less ability to withstand heating and shear stress during cooking.

Starch molecules begin to re-associate in the cooling phase leading to formation of a gel structure with higher viscosity than the hot-paste slurry. The increase in viscosity is caused by a decrease of energy in the system, which allows re-association of leached amylose molecules with each other and with gelatinized starch granules (Zhang et al., 2011; Delcour and Hoseney, 2010). Par-cooked maize meal had the highest final viscosity (1,925 BU), indicating that it had a higher degree of amylose re-association than the other maize meals. Dehulling the grains prior to milling also affected the final viscosity. Whole hammer-milled maize meals had lower final viscosities than dehulled and hammer-milled maize meals (WM-TP < DM-TP and WM-SP < DM-SP). The final viscosities of sifted maize meals could not be distinctly differentiated from those of hammer-milled maize meals. Whereas the final viscosities of SF-T1 and SF-T2 were not different (P > 0.05) from those of DM-TP and DM-SP, we observed that the final viscosity of SF-T3 was significantly different (P < 0.05) from that of hammer-milled maize meals.

The setback viscosity (final viscosity - trough viscosity), which is also associated with reordering of soluble amylose molecules (Leelavathi et al., 1987), showed a similar pattern as the final viscosity. The par-cooked and SF-T3 maize meals had the highest setback and final viscosities whereas WM-TP and WM-SP had the lowest (Table 4). Whole hammer-milled maize meals had lower setback viscosities than dehulled and hammer-milled maize meals (WM-TP < DM-TP and WM-SP < DM-SP). The setback viscosity of SF-T1 and SF-T2 was not significantly different (P > 0.05) from that of DM-TP and DM-SP whereas the setback viscosity of SF-T3 was significantly different (P < 0.05) from that of hammer-milled maize meals. When the setback viscosity was calculated as a percentage of final viscosity it was noted that SF-T3 and PC-MM had lower values (51 and 58%, respectively) than the other maize meals whose values ranged between 69 and 77%.

Texture of stiff and thin porridge

The texture of maize meal porridge is determined by the relative proportions of maize meal and water used to prepare it, which in turn is determined by socio-cultural preferences of different consumer groups in sub-Saharan Africa. From the nutritional point of view, the maize meal to water ratio is also important because it determines the energy content of the porridge (Kikafunda et al., 1997). In this study, we used a maize meal to water ratio of 1:1.95 (w/w) and 1:12.5 (w/w) to make stiff and thin porridge, respectively, that would be acceptable to consumers in eastern Africa. By contrast, stiff maize porridge from western Africa is prepared using a maize meal to water

Table 5. Pearson correlation coefficients between the physical and textural properties of thin maize meal porridge.

		1	2	3	4	5	6	7	8	9	10	11	12
1.	WAI	1											
2.	WSI	-0.889	1										
3.	PT	-0.580	0.143	1									
4.	PV (BU)	-0.362	-0.106	0.969	1								
5.	TP (min)	0.690	-0.945	0.189	0.425	1							
6.	BV (BU)	-0.343	-0.126	0.964	1.000*	0.444	1						
7.	FV (BU)	-0.389	-0.077	0.976	1.000*	0.399	0.999*	1					
8.	SV (BU)	-0.410	-0.053	0.981	0.999*	0.377	0.997*	1.000*	1				
9.	Firmness (N)	0.887	-0.577	-0.891	-0.752	0.277	-0.738	-0.770	-0.785	1			
10.	Consistency (N·s)	0.846	-0.508	-0.925	-0.803	0.199	-0.790	-0.820	-0.833	0.997	1		
11.	Cohesiveness (N)	-0.724	0.327	0.982	0.905	0.000	0.896	0.917	0.926	-0.961	-0.980	1	
12.	Index of viscosity(N·s)	-0.805	0.443	0.951	0.845	-0.125	0.834	0.860	0.872	-0.988	-0.997*	0.992	1

WAI: Water absorption index; WSI: water solubility index; PT: pasting temperature (°C); PV: peak viscosity, BU; TP: time to peak viscosity, min; BV: breakdown viscosity, BU; FV: final viscosity; SV: setback viscosity, BU. *Correlation is significant at the 0.05 level (2-tailed).

ratio of 1:3.5 (w/w) (Bolade et al., 2009) whereas in southern Africa a ratio of 1:4 (w/w) and 1:6 are recommended for stiff and thin porridge, respectively (Buhler Pty Ltd., Johannesburg, South Africa).

Stiff porridge prepared from PC-MM maize meal had significantly higher ($P < 0.05$) peak force (80.93 N) than that prepared from sifted or hammer-milled maize meals (Table 4) whose values ranged between 42.25 N for WM-TP and 58.86 N for DM-SP. The total shearing force (the product of force and time) was also significantly higher ($P < 0.05$) in stiff porridge prepared from PC-MM maize meal (838.99 N·s) than from sifted or hammer-milled maize meals where the values ranged between 409.87 N·s for WM-TP and 568.47 N·s for SF-T2 (Table 4). On the other hand, thin porridge (Table 4) prepared from DM-SP maize meal was more viscous ($P < 0.05$) than porridge prepared from the other maize meals. This porridge had the highest firmness (1.28 N), consistency (34.04 N·s), cohesiveness (-1.54 N) and work of cohesion (-3.01 N·s). Thin porridge prepared from PC-MM maize meal was the least viscous since it had the lowest firmness (0.24 N), consistency (5.58 N·s), cohesiveness (-0.23 N) and work of cohesion (-0.34 N·s).

Pearson correlation coefficient analysis

Pearson correlation coefficient (r) analysis was made for the relationships between all physical and textural properties of PC-MM (Table 5) and DM-SP (Table 6). Stiff and thin porridge prepared from these two maize meals were the only ones analyzed because they had the firmest textures. The most important kinesthetic quality of stiff porridge is a firm, cohesive and non-sticky texture. Moulding of stiff porridge with the aid of the finger and palm is part of the preliminary actions normally carried out before it is put in the mouth (Bolade et al., 2009). Par-cooked maize meal gave the firmest stiff porridge possibly due to a combination of factors associated with physical properties of the maize meal. It had the highest WAI, damaged starch content and final and setback viscosity; and lowest breakdown viscosity. However, when this data was analyzed by Pearson correlation coefficient analysis, the only significant correlation occurred between WSI and total shearing force ($P < 0.05$, $r = -1.00$). Nonetheless, some physical properties of PC-MM maize meal showed significant correlations with each other. The time to peak viscosity was positively correlated with WAI ($P < 0.05$, $r = 0.99$); setback viscosity was positively correlated with final viscosity ($P < 0.01$, $r = 1.00$); whereas starch damage was positively correlated with time to peak viscosity ($P < 0.05$, $r = -0.99$) but negatively

Table 6. Pearson correlation coefficients between the physical and textural properties of stiff maize meal porridge.

		1	2	3	4	5	6	7	8	9	10
1.	WAI	1									
2.	WSI	-0.760	1								
3.	PT	-0.932	0.943	1							
4.	PV (BU)	0.528	-0.953	-0.799	1						
5.	TP (min)	-0.793	0.999*	0.960	-0.936	1					
6.	BV (BU)	-**	-	-	-	-	-				
7.	FV (BU)	0.366	-0.883	-0.678	0.984	-0.875	-	1			
8.	SV (BU)	0.380	-0.890	-0.688	0.986	0.986	-	1.000*	1		
9.	Peak force (N)	0.686	-0.994	-0.902	0.980	0.980	-	0.928	0.934	1	
10.	Total shearing force (N·s)	0.703	-0.997	-0.913	0.975	0.975	-	0.919	0.925	1.000*	1

WAI: Water absorption index; WSI: water solubility index; PT: pasting temperature (ºC); PV: peak viscosity, BU; TP: time to peak viscosity, min; BV: breakdown viscosity, BU; FV: final viscosity; SV: setback viscosity, BU. *Correlation is significant at the 0.05 level (2-tailed). **Not computed because breakdown viscosity values were constant.

correlated with WSI ($P < 0.01$, $r = -1.00$). Among the textural properties, the peak force of PC-MM stiff porridge showed positive correlation with total shearing force ($P < 0.05$, $r = 1.00$).

Thin porridge is drank or eaten with a spoon and, thus, mouthfeel is one of its most important sensory properties. Thin porridge must have homogeneous consistency that is free from lumps and should disperse easily in the mouth, without being chewed, prior to swallowing. It should neither be too thin nor too viscous and the maize meal particles should leave a slight sensation of grittiness in the mouth. There was no significant correlation ($P > 0.05$) between the physical properties of DM-SP maize meal and thin porridge texture but some physical properties of DM-SP maize meal correlated well with each other. Breakdown viscosity and final viscosity were positively correlated with peak viscosity ($P < 0.01$, $r = 1.00$) whereas final viscosity was positively correlated with breakdown viscosity ($P < 0.05$, $r = 1.00$). Setback viscosity was positively correlated with peak viscosity ($P < 0.05$, $r = 1.00$), breakdown viscosity ($P < 0.05$, $r = 1.00$) and final viscosity ($P < 0.01$, $r = 1.00$). Among the textural properties, the viscosity of thin DM-SP maize meal porridge was negatively correlated with its consistency ($P < 0.05$, $r = -0.99$).

Conclusion

Maize meal is a major source of energy and protein for millions of people in sub-Saharan Africa, and is principally used to prepare stiff or thin porridge. Physical quality differences that exist among maize meals are partially influenced by the milling technique. Although we did not find statistically significant correlations between physical properties of maize meals and the textures of stiff or thin porridge texture (except for the negative correlation between WSI and total shearing force of PC-MM stiff porridge), it was apparent that the maize meal quality differences were reflected in the texture of porridges. We therefore, recommend that additional physical, and possibly chemical, properties of maize meals that can be used to predict the textural quality of stiff and thin maize meal porridge should be identified.

Conflict of Interests

The authors did not declare any conflict of interests.

ACKNOWLEDGEMENT

The authors would like to thank Buehler Pty Ltd. (Johannesburg, South Africa) for providing free samples of par-cooked maize meal for this study.

REFERENCES

AACC International (2005). American Association of Cereal Chemists. Approved methods of the AACC, 10th ed. The Association: St. Paul, MN.

Afoakwa EO Adjonu R, Asomaning J (2010). Viscoelastic properties and pasting characteristics of fermented maize: influence of the addition of malted cereals. Int. J. Food Sci. Technol. 45: 380-386.

Alloncle M, Doublier JL (1991). Viscoelastic properties of maize starch / hydrocolloid pastes and gels. Food Hydrocol. 5: 455-467.

AOAC (2005). AOAC Official Methods of Analysis. 18th ed. AOAC Int. Gaithersburg, MD.

Arendt EK, Zannini E (2013). Cereal Grains for the Food and Beverage Industries. Woodhead Publishing Limited, Cambridge, UK.

Bolade MK, Adeyemi IA, Ogunsua AO (2009). Influence of particle size fractions on the physicochemical properties of maize flour and textural characteristics of a maize-based non-fermented food gel. Int. J. Food Sci. Technol. 44:646-655.

Craig SAS, Stark JR (1984). The effect of physical damage on the molecular structure of wheat starch. Carbohydr. Res. 125: 117-125.

Delcour JA, Hoseney RC (2010). Principles of Cereal Science and Technology. 3rd Edition. AACC Int. Inc., St Paul, MN.
Doutch J, Bason ML, Franceschini F, James K, Clowes D, Gilbert EP (2012). Changes in starch molecular structure during pasting. Carbohydr. Polym. 88:1061-1071.
Eliasson AC, Bohlin L (1982). Rheological properties of concentrated wheat starch gels. Starch / Stärke 34:267-271
FAO (1995). Sorghum and millets in human nutrition. Food and Agriculture Organisation of the United Nations, Rome, Italy
Hossen S, Sotome I, Takenaka M, Isobe S, Nakajima M, Okadome H (2011). Effect of particle size of different crop starches and their flours on pasting properties. Jpn. J. Food Eng. 12:29-35.
Inglett GE, Xu J, Stevenson DG, Chen D (2009). Rheological and pasting properties of buckwheat (*Fagopyrum esculentum* Möench) flours with and without jet-cooking. Cereal Chem. 86:1-6.
Ji Y, Pollak LM, Duvick S, Seetharaman K, Dixon PM, White PJ (2004). Gelatinization properties of starches from three successive generations of six exotic corn lines grown in two locations. Cereal Chem. 81:59-64.
Kikafunda JK, Walker AF, Abeyasekera S (1997). Optimising viscosity and energy density of maize porridges for child weaning in developing countries. Int. J. Food Sci. Nutr. 48:401-409.
KS 168:2007 (2007). Kenya Standard. Dry milled maize products - Specifications. Kenya Bureau of Standards (KEBS), 10th ed. 4 pp.
Leelavathi K, Indrani D, Sidhu JS (1987). Amylograph pasting behavior of cereal and tuber starches. Starch / Staerke 39: 378-381.
Munck L (1995). New milling technologies and products: whole plant utilization by milling and separation of the botanical and chemical components. In: Sorghum and Millets. Chemistry and Technology. Ed: David A. V. Dendy. AACC, St. Paul, MN, USA.
Onyango C, Noetzold H, Ziems A, Hofmann T, Bley T, Henle T (2005). Digestibility and antinutrient properties of acidified and extruded maize-finger millet blend in the production of uji. LWT- Food Sci. Technol. 38:697-707.
Ragaee S, Abdel-Aal EM (2006). Pasting properties of starch and protein in selected cereals and quality of their food products. Food Chem. 95:9-18.
Sandhu KS, Singh N (2007). Some properties of corn starches II: Physicochemical, gelatinization, retrogradation, pasting and gel textural properties. Food Chem. 101:499-1507.
Scanlon MG, Dexter JE, Biliaderis CG (1988). Particle-size related physical properties of flour produced by smooth roll reduction of hard red spring wheat farina. Cereal Chem. 65:486-492.
Seetharaman K, Tziotis A, Borras F, White PJ, Ferrer M, Robutti J (2001). Thermal and functional characterization of starch from Argentinean corn. Cereal Chem. 78:379-386.
Singh N, Singh J, Kaur L, Sodhi NS, Gill BS (2003). Morphological, thermal and rheological properties of starches from different botanical sources. Food Chem. 81:219-231.
Tester RF, Morrison WR (1990). Swelling and gelatinization of cereal starches. I. Effects of amylopectin, amylose, and lipids. Cereal Chem. 67: 551-557.
Zhang Y, Gu Z, Hong Y, Li Z, Cheng L (2011). Pasting and rheologic properties of potato starch and maize starch mixtures. Starch / Staerke 63:11-16.