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Nutrient composition, sensory attributes and starch digestibility of cassava porridge modified with hydrothermally-treated finger millet

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ABSTRACT

Cassava (CAS) porridge has low energy density and is a poor source of several nutrients. Its energy density and nutrient composition is normally improved by blending it with other flours. The aim of this study was to determine the effect of hydrothermally-treated (HTT) finger millet on nutrient composition, sensory attributes and starch digestibility of cassava porridge. Composite flour had higher protein, fibre, lipid and mineral content than cassava flour. The high α-amylase activity of HTT finger millet permitted the quantity of CAS-HTT flour to be raised from 9.5% w/v to 19% w/v without altering the free-flowing drinkable consistency of porridge. Partial substitution of CAS with HTT finger millet had no effect on starch digestibility and tannin content but increased the phytate content of CAS-HTT porridge. Hydrothermally-treated finger millet masked the aroma and colour of cassava resulting in dark-coloured CAS-HTT porridge with a bitter taste.

1. Introduction

Cassava is an important source of dietary energy for millions of people in sub-Saharan Africa [1]. Cassava flour is used to prepare porridge, which is an important food for infant nutrition and a refreshment drink for other age groups. Despite its high starch content, cassava porridge is a poor source of dietary energy because the high water-binding capacity of cassava starch limits the amount of flour (10–14% w/v) required to prepare porridge with acceptable semi-liquid consistency [2–4].

The energy density of African porridges is normally improved by fermentation or with the aid of diastatic malt [2,4]. Lactic acid fermentation with a pure culture of *Lactobacillus plantarum* enables the amount of flour to be increased to 14–17% w/v. Fermentation with natural starter culture consisting of lactic acid bacteria and yeast enables the amount of flour to be increased to 15–26% w/v, whereas a combination of natural starter culture and diastatic malt allows the amount of flour to be raised to 30–35% w/v when preparing porridge [4]. The amount of flour required to prepare porridge can also be increased to 30% w/v by adding diastatic malt to gelatinized porridge [2]. The viscosity-reducing effect of starter cultures in porridge is attributed to the acidic environment and amylases produced by the microorganisms [4], whereas diastatic malt exerts its action through amylases that are synthesized and activated during grain germination [2,5].

Malted grain is widely used as an ingredient in food processing in Africa to make beverages and infant foods [6]. Finger millet malt is made by steeping clean grains with water after which they are spread on with wet jute bags and covered with the same. The covered material is sprinkled with water regularly and left to germinate at room temperature for 3–4 days [7,8] after which it is dried and milled. The high amylolytic activity of germinated grains limits the amount of malt (usually about 5–10% w/v) that can be used to prepare porridge [2,4,7]. This implies that nutritional benefits of malted grain, such as high starch and protein digestibility, and low phytate and tannin content [5,9–11] is limited by the quantity used to prepare porridge.

Another traditional method for modifying finger millet prior to using it to prepare porridge is also practiced in Kenya. The grains are tempered with limited water (10:1) before they are packed in woven polypropylene sack, which is then tightly wrapped with polythene sheet. The sack is incubated at 60–70 °C for 10 days after which the grains are removed, washed, dried and milled. A slightly different version of this process has been described by Wanjala et al. [12] and the modified finger millet is known as *emifuname*. Unlike malting, the grains become dark after incubation and do not germinate because of the high incubation temperature and limited moisture content. By contrast, the high moisture content and low incubation temperature activates endogenous enzymes during malting and causes grain germination [13]. We refer to finger

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millet incubated with limited moisture as hydrothermally-treated (HTT) rather than malted because the incubation conditions are different from malting, the grains do not germinate and they become darker after incubation. The aim of this study was to evaluate the physico-chemical properties of HTT finger millet and determine its effect on the nutrient quality, sensory properties and starch digestibility of cassava porridge.

2. Materials and methods

2.1. Materials

Native (NAT) and hydrothermally prepared (HTT) finger millet were purchased from a local market in Kisumu, Kenya. Hydrothermally-treated finger millet was prepared by the vendor by tempering the grains with water (10:1). The grains were put in 100 kg woven polypropylene sack and covered with a polythene sheet. The sacks were incubated outside (environment temperature 25–30 °C) for 5 days. The temperature in the centre of the sack ranged between 60 and 70 °C. After 5 days, the grains were removed, tempered with water (10:1) and incubated further for 5 days in the sack. The grains were then sun-dried to about 10% moisture content. The grains were milled using a laboratory pin mill fitted with 1 mm screen. Cassava flour (CAS) was purchased from Mhogo Foods Ltd (Nairobi, Kenya) and blended with NAT or HTT flours to obtain CAS-NAT (1:1) and CAS-HTT (1:1). The flours were stored at 4 °C prior to use.

2.2. Nutrient composition

Moisture content was determined according to ICC No. 109/1 [14]. Starch content was determined according to Ewers polarimetric method - ISO 10520:1997 [15]. Insoluble dietary fibre (IDF), soluble dietary fiber (SDF) and total dietary fibre (TDF) were measured using K-TDFR-100A kit (Megazyme Int. Ireland Ltd., Wicklow, Ireland). Protein (N x 6.25), lipid and mineral content were determined according to ICC No. 105/2, 136 and 104/1, respectively [14].

2.3. Pasting properties

Pasting properties were measured using a Brabender Viscograph-E (Brabender GmbH & Co. KG, Duisburg, Germany) at 85 rpm and 700 cmg torque. Slurries made up of 40 g flour (adjusted to 14% moisture content) and 420 ml distilled water added in the Viscograph-E canister. The canister was placed in the heating chamber and spindles attached. The slurry was heated from 30 °C to 93 °C at a rate of 1.5 °C/min; held at 93 °C for 15 min; cooled to 30 °C at a rate of 1.5 °C/min; and finally held at 30 °C for 15 min. Resistance to stirring was recorded as viscosity in Brabender Units (BU). The pasting temperature (°C), peak viscosity (BU), time to peak viscosity (min), breakdown viscosity (peak viscosity minus trough viscosity, BU), setback viscosity (final viscosity minus trough viscosity BU) and final viscosity (BU) were determined using the Viscograph-E correlation software.

2.4. Porridge texture

Slurries obtained from the Brabender Viscograph-E were cooled to 26 ± 0.5 °C then poured (80 g) into 50 mm diameter A/BE back extrusion containers (Stable Micro Systems, Surrey, UK). Back extrusion force was measured using TA.XT-*plus* Texture Analyser (Stable Micro Systems, Surrey, UK) at the following TA settings: - mode of measurement: force; load cell: 50 kg; height calibration: 60 mm; disc diameter: 45 mm; pre-test speed: 1 mm/s; test-speed: 1 mm/s; trigger force: 10 g; post-test speed: 10 mm/s; data acquisition rate: 200 pps; penetration distance: 30 mm. Firmness (maximum positive force, g), consistency (area of positive region of curve, g·s), cohesiveness (maximum negative force, g) and work of cohesion or index of viscosity (area of negative region of curve, g·s) were calculated using Texture Analysis software.

2.5. Porridge colour

Porridge colour was measured using a Konica Minolta Chroma Meter CR-5 (Konica Minolta, Sakai Osaka, Japan) with a spot diameter view of 8 mm. Colour measurements were taken using conditions of the standard illuminant D65 and 10° observer. The equipment was calibrated using a black Konica Minolta cell. 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. Browning Index was calculated using the following expression [16]:

$$BI = \frac{[100(x - 0.31)]}{0.17}$$

where

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)}$$

where a^* is redness, b^* is yellowness, and L^* is lightness

2.6. Starch digestibility

Porridge was prepared in Brabender viscograph as described above and then freeze-dried. Moisture content was determined according to ICC No. 109/1 [14]. Digestible and resistant starch was measured using Megazyme assay kit K-RAPRS 05/19.

2.7. Anti-nutrient and phosphorous content

Condensed tannin content was measured using the vanillin-HCl method as described by Price et al. [17]. Phytate and phosphorous content was determined using phytic acid (phytate)/total phosphorous assay kit (Megazyme Int. Ireland Ltd., Wicklow, Ireland).

2.8. Descriptive sensory evaluation

Porridge was prepared by mixing 40 g flour with 200 ml tap water. Separately, 640 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. The porridge was kept boiling for 4 min without intervention. It was cooled to 30 °C and served in white plastic cups. Eight panellists were recruited to perform descriptive sensory evaluation of the porridges. The panellists were trained for six sessions with each session lasting 2 h. The first three sessions consisted of attribute generation, during which the panellists were asked to list all the sensory attributes present in the porridges, which were served in random order. The panellists generated 11 descriptive terms (Table 1). The next three sessions involved identifying references (Table 1) that fit the sensory attributes of porridges and rating them on 100 mm unstructured line scales for intensity. During product evaluation, panellists were served with 50 g porridge in white plastic cups labelled with three-digit codes. The samples were served monadically in random order with 5 min break between each sample. Panellists rinsed their mouth with mineral water before testing each sample and 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.

2.9. Experimental design

A single-factor experimental design was used determine the effect of flour type on the physical and nutritional properties. The results were subjected to one-way analysis of variance and differences in treatment means identified by Tukey's Test at a family error rate of 5%. The descriptive sensory evaluation data was analysed using Principle

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

Attribute	Description	Reference and rating scale
Appearance		
Colour	Perception of colour ranging from white to black	Cassava starch (30% w/v) stirred in hot water = 0 (white) [a]Black shoe polish = 10 (black)
Particles	Quantity of particles in the porridge	No particles = 0 Many particles = 10
Dark specks	Quantity of dark specks observed 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)
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)
Red soil aroma	Aroma characteristic of wet red soil	Wet red soil (50% w/v) stirred in cold water = 10 (very intense)
Taste		
Bitterness	Intensity of bitter taste	Bland taste = 0 [c]Bite size particle of 100% pure instant freeze-dried MacCoffee = 10 (very bitter)
Texture		
Viscosity	Resistance to flow when porridge is tilted in a white cup	[d]Brookside low fat fresh milk (fat content 1.5%) = 1 (thin) Honey = 8 (thick)
Coarseness	Degree to which particles are perceived in the mouth during mastication	Honey = 0 (not perceived) [e]Minute Maid pulpy orange juice drink = 8
After swallow		
Bitter aftertaste	Perception of bitterness in the mouth after swallowing	No bitter aftertaste = 0 Bitter aftertaste = 10
Residual particles	Perception of particles in the mouth after swallowing porridge	Water melon = 0 (no residual particles) Roasted groundnuts = 10 (many residual particles)

[a] S. C. Johnson & Son Kenya Ltd., Nairobi, Kenya.
[b] Dynamix Trading Ltd., London, Britain.
[c] FES Industries Johor Baru, Malaysia.
[d] Brookside Dairy Ltd., Ruiru, Kenya.
[e] Nairobi Bottlers Ltd., Nairobi, Kenya.

Component Analysis in a covariance matrix with the product in rows, and mean panellists and replication scores for sensory attributes in columns. All data were analysed using Minitab Release 14 statistics software (Minitab Inc., Pennsylvania, USA).

3. Results and discussion

3.1. Nutrient composition

The nutrient composition of cassava, finger millet and composite flours is shown in Table 2. Cassava had higher starch and SDF content but lower IDF, TDF, protein, lipid and mineral content than finger millet. Cassava is a good source of dietary energy because of its high starch content but it is poor in other nutrients [1]. By contrast, finger millet has high starch content in addition to high content of lipids, dietary fibre, protein and minerals [18,19]. Starch and lipid content of finger millet did not change ($p > 0.05$) whereas protein, SDF, IDF, TDF and mineral content increased ($p < 0.05$) after HTT. Partial substitution of CAS with NAT or HTT finger millet yielded composite flours with higher ($p < 0.05$) protein, lipid, mineral and dietary fibre content than cassava flour.

3.2. Pasting properties

The pasting profiles of cassava, finger millet and composite flours are presented in Fig. 1. Cassava had a different pasting profile from NAT and HTT finger millet. Cassava had lower onset pasting temperature (63.7 °C), required less time to reach peak viscosity (33 min) and had higher peak viscosity (722 BU) than NAT or HTT finger millet. The onset pasting temperature, time to reach peak viscosity and peak viscosity was 75.2 °C, 43 min and 211 BU, respectively, for NAT finger millet; and 79.5 °C, 43 min and 275 BU, respectively, for HTT finger millet. Cassava had higher breakdown viscosity (481 BU) than NAT (61 BU) or HTT finger millet (39 BU). Cassava had higher final viscosity (479 BU) than NAT (301 BU) or HTT (342 BU) finger millet.

The pasting profiles of cassava and finger millet were strongly influenced by their nutrient compositions. The low onset pasting temperature, short time required to reach peak viscosity and high peak viscosity of cassava was attributed to its high starch content and low TDF, protein and lipid content (Table 2). Water-binding capacity of flour depends on its botanical origin, starch content and the gel-forming capacity of its macromolecules [20–22]. The high starch content of cassava flour implied that it had higher water-binding capacity, which resulted to higher peak viscosity than finger millet. By contrast, finger millet had lower onset pasting temperature and peak viscosity and required more time to reach peak viscosity than cassava because cereal starch granules have low water absorption and swelling capacities [23]. In addition, high protein and fibre content in cereals delay gelatinization because these macromolecules compete with starch for hydration [22], whereas lipids inhibit starch swelling by forming amylose-lipid complexes [24]. The high breakdown viscosity of cassava implied that swollen cassava starch granules were more susceptible to disintegration and solubilization at higher temperatures than swollen finger millet starch granules. Slurries with low breakdown viscosities are more resistant to temperature and shear-induced destruction of starch granules than slurries with high breakdown viscosities [23]. Finally, the high protein content of finger millet was responsible for the low final viscosity of finger millet slurry because proteins tend to interact with hydroxyl groups in starch through hydrogen bonding and impede starch retrogradation [20].

Composite flours had the same onset pasting temperatures (67 °C) but CAS-NAT flour had higher peak viscosity, time to peak viscosity, breakdown viscosity and final viscosity than CAS-HTT flour. The different pasting behaviours of composite flours were attributed to the different α-amylase activities of NAT and HTT finger millet (Table 3). The optimum temperature for finger millet α-amylase activity is 45–50 °C [25]. At this temperature range, α-amylase rapidly cleaved starch polymers in CAS-HTT flour and decreased the peak, breakdown and final viscosity. The peak and breakdown viscosity of flour is negatively correlated with

Table 2
Nutrient composition (g/100 g dm) of cassava and finger millet.

Flour	Starch	SDF	IDF	TDF	Protein	Lipid	TMC
CAS	85.7 ± 7.36^{a}	1.95 ± 0.13^{a}	3.45 ± 0.10^{d}	5.40 ± 0.06^{d}	0.96 ± 0.03^{d}	0.71 ± 0.02^{c}	1.20 ± 0.02^{e}
NAT	72.6 ± 1.62^{b}	0.37 ± 0.14^{c}	11.4 ± 0.23^{b}	11.7 ± 0.27^{b}	7.62 ± 0.04^{b}	1.90 ± 0.07^{a}	3.12 ± 0.03^{b}
HTT	70.2 ± 4.42^{b}	1.51 ± 0.05^{b}	12.2 ± 0.15^{a}	13.7 ± 0.11^{a}	8.52 ± 0.01^{a}	1.73 ± 0.02^{ab}	3.38 ± 0.01^{a}
CAS-NAT (1:1)	78.3 ± 1.86^{ab}	1.45 ± 0.09^{bc}	7.83 ± 0.29^{c}	9.28 ± 0.37^{c}	4.41 ± 0.02^{c}	1.31 ± 0.08^{b}	2.66 ± 0.02^{c}
CAS-HTT (1:1)	79.2 ± 0.71^{a}	1.38 ± 0.03^{c}	8.07 ± 0.15^{c}	9.45 ± 0.16^{c}	4.44 ± 0.00^{c}	0.84 ± 0.27^{bc}	2.32 ± 0.01^{d}

SDF – soluble dietary fibre; IDF – insoluble dietary fibre; TDF – total dietary fibre; TMC - total mineral content; CAS – cassava; NAT - native finger millet; HTT – hydrothermally-treated finger millet.
Values reported as mean ± standard deviation. Means in the same column with different superscript letters are significantly different ($p \leq 0.05$) from each other.

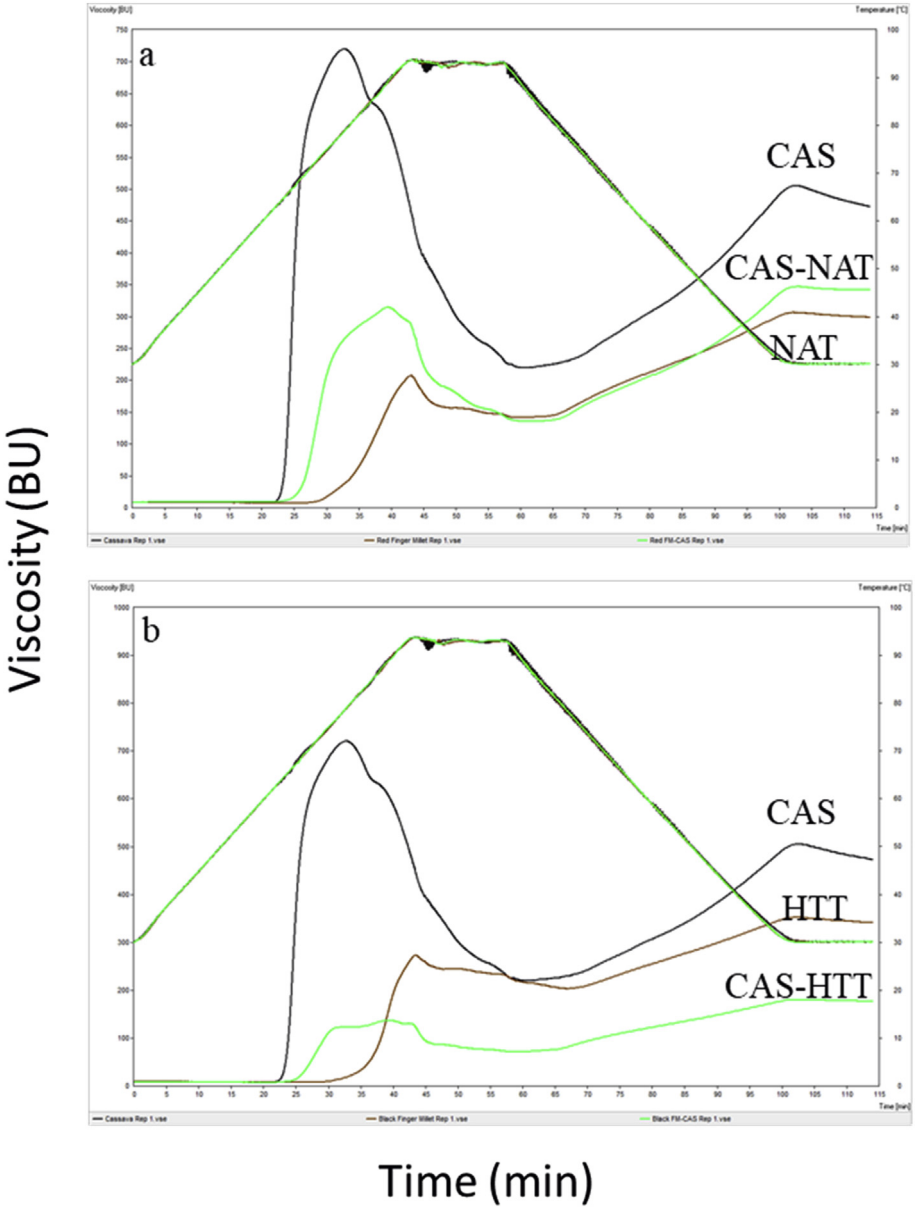

Fig. 1. Pasting profile of cassava and finger millet. CAS – cassava; NAT - native finger millet; HTT – hydrothermally-treated finger millet. Fig. 1a - each gridline on x-axis represents 5 min; each gridline on y-axis represents 50 BU. Fig. 1b - each gridline on x-axis represents 5 min; each gridline in y-axis represents 100 BU.

its α-amylase activity [26]. A similar behaviour has been observed in germinated grains, which also have lower peak, breakdown and final viscosities, than their non-germinated counterparts, due to enhanced α-amylase activity in the germinated grains [27,28].

Table 3
α-Amylase activity of cassava and finger millet.

Flour	α-amylase activity (CU/g)
CAS	0.02 ± 0.00^{d}
NAT	0.12 ± 0.02^{c}
HTT	11.69 ± 0.25^{a}
CAS-NAT (1:1)	0.08 ± 0.02^{c}
CAS-HTT (1:1)	3.06 ± 0.01^{b}

CAS - cassava; NAT - native finger millet; HTT - hydrothermally-treated finger millet.
Values reported as mean ± standard deviation. Means in the same column with different superscript letters are significantly different ($p \leq 0.05$) from each other.

3.3. Porridge texture

Cassava porridge had the same ($p > 0.05$) firmness and consistency

Table 4
Texture of porridge from cassava and finger millet.

Porridge (9.5% w/v)	Firmness (g)	Consistency (g·s)	Cohesiveness (g)	Index of viscosity (g·s)
CAS	82.7 ± 21.5^{ab}	2028 ± 456^{a}	-145 ± 18^{c}	-325 ± 49.2^{d}
NAT	59.2 ± 1.54^{bc}	1542 ± 35^{a}	-96.2 ± 1.54^{b}	-208 ± 1.46^{b}
HTT	64.0 ± 1.85^{bc}	1688 ± 53^{a}	-98.5 ± 5.89^{b}	-223 ± 13.3^{bc}
CAS-NAT (1:1)	108 ± 6.18^{a}	2130 ± 85^{a}	-133 ± 1.37^{c}	-296 ± 7.58^{cd}
CAS-HTT (1:1)	34.7 ± 0.63^{c}	841 ± 7.49^{b}	-46.0 ± 0.30^{a}	-100 ± 0.54^{a}

CAS - cassava; NAT - native finger millet; HTT - hydrothermally-treated finger millet.
Values reported as mean ± standard deviation. Means in the same column with different superscript letters are significantly different ($p \leq 0.05$) from each other.

but lower ($p < 0.05$) cohesiveness and index of viscosity than NAT or HTT finger millet porridge at 26 ± 0.5 °C (Table 4). These results show that as porridges cooled to the recommended temperature for drinking some rheological properties of cassava became similar to those of finger millet. The back-extrusion technique measures porridge firmness and consistency when the plunger is moving downwards and squeezing the product through the annulus (space between the plunger and inner walls of the cylinder). On the other hand, cohesiveness and index of viscosity of porridge are measured when the plunger is moving upwards and is bearing additional weight of the product. In dilute suspensions, viscosity is governed by the volume fraction of swollen starch granules whereas in closely packed systems rigidity of the particles is important [29]. As the temperature of finger millet porridge decreased, syneresis occurred leading to increased firmness and consistency as a result of closer packing of starch granules. Consequently, as the plunger moved downwards, finger millet starch granules packed more closely as additional liquid was squeezed out leading to increased firmness and consistency. However, when the plunger was moving upwards cassava became more cohesive than finger millet due to the weight of swollen cassava starch granules, which underwent less syneresis and consequently were more resistant to withdrawal of the plunger.

Cassava-NAT porridge had higher firmness and consistency but lower cohesiveness and index of viscosity than CAS-HTT porridge (Table 4). These results agree with the viscograph data which showed that CAS-NAT flour had higher water-binding capacity and hence higher peak and final viscosity than CAS-HTT flour. Despite the different textures of CAS-NAT and CAS-HTT porridges, they are low energy-dense foods because of their low solids content (9.5% w/v). Consumption of low energy-dense foods is a major cause of protein energy malnutrition amongst infants in sub-Saharan Africa [30]. This problem is overcome by decreasing the water-binding capacity of starch so that more flour can be used to prepare porridge [2,4,8]. The consistency of porridge is associated with the concentration of swollen and gelatinized starch granules suspended in an aqueous phase. The critical flour concentration required for gel formation by solubilized starch granules is 3.5% w/v [31]. Porridge consistency increases sharply when the amount of flour exceeds 10% w/v [3,32]. This implies that the amount of flour required to prepare porridge with sufficient energy density is limited by the water-binding capacity of swollen starch granules in aqueous suspension [2,30]. Hydrolysis of starch by α-amylase into low molecular weight dextrins and sugars decreased the water-binding capacity of starch in CAS-HTT flour and enabled the amount of CAS-HTT flour to be doubled from 9.5 to 19% w/v without altering the free-flowing drinkable consistency of porridge (Fig. 2). Firmness of CAS-HTT porridge increased from 34.7 to 98 g (force) when the amount of flour was doubled from 9.5 to 19% w/v, whereas firmness of 9.5% w/v CAS-NAT porridge was 108 g (force).

3.4. Porridge colour

Cassava porridge had the highest lightness index with no red or yellow colour indices (Table 5). The high lightness index of cassava flour was attributed to the starch-rich parenchyma tissue, which was separated from the outer coloured periderm and cortex tissues by peeling. Native finger millet was lighter, redder and yellower than HTT finger millet. These findings are consistent with those of Siwela et al. [33] and Ramashia et al. [34] who reported that native finger millet has wide diversity of seed coat colours that range from creamy-white to dark brown. Shobana and Malleshi [19] suggested that darkening of HTT finger millet

Table 5
Colour indices of cassava and finger millet porridge.

Porridge (9.5% w/v)	L*	a*	b*	Browning Index
CAS	36.2 ± 0.09^{a}	-2.44 ± 0.02^{e}	-5.57 ± 0.08^{e}	-18.5 ± 0.19^{e}
NAT	31.2 ± 0.84^{b}	8.60 ± 0.49^{a}	9.37 ± 0.50^{a}	55.3 ± 4.93^{a}
HTT	22.2 ± 0.33^{c}	3.99 ± 0.13^{c}	5.34 ± 0.28^{c}	40.3 ± 1.43^{c}
CAS-NAT (1:1)	31.8 ± 0.14^{b}	7.88 ± 0.07^{b}	8.81 ± 0.15^{b}	50.0 ± 0.85^{b}
CAS-HTT (1:1)	26.2 ± 0.42^{c}	3.06 ± 0.08^{d}	4.16 ± 0.17^{d}	25.4 ± 0.88^{d}

L* = 100 to dark = 0, red (+a*) to green (-a*), and yellow (+b*) to blue (-b*).
CAS - cassava; NAT - native finger millet; HTT - hydrothermally-treated finger millet.
Values reported as mean ± standard deviation. Means in the same column with different superscript letters are significantly different ($p \leq 0.05$) from each other.

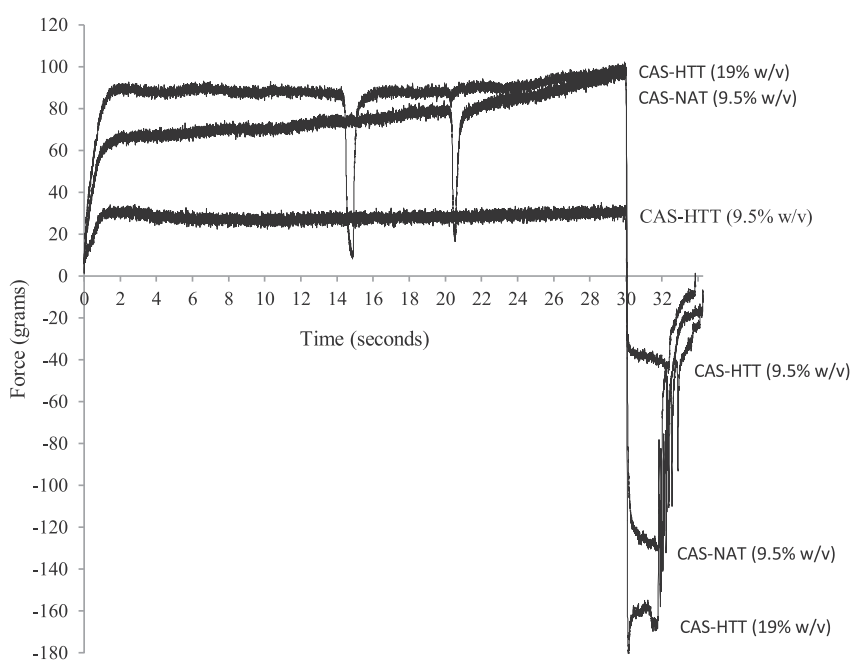

Fig. 2. Texture of porridge from cassava and native finger millet (CAS-NAT, 1:1) or cassava and hydrothermally-treated finger millet (CAS-HTT, 1:1).

after steaming could be due to browning or oxidative polymerization of polyphenols. We found that HTT finger millet had lower browning index than NAT finger millet (Table 5), which suggested that colour change had little association with Maillard browning reactions (which produces brown pigments), but was probably associated with oxidation of polyphenols (which produces dark pigments). Among composite porridges, CAS-NAT was lighter, redder and yellower than CAS-HTT due to the lighter, redder and yellower colour indices of NAT finger millet.

3.5. Starch digestibility

The digestible starch content of porridges is presented in Table 6. Cassava porridge had similar ($p > 0.05$) digestible starch content as the composite porridges but higher ($p < 0.05$) digestible starch content than NAT or HTT finger millet porridges. The low starch digestibility of finger millet is attributed to several factors such as starch granule morphology and starch complexation with lipids, proteins, fibre and polyphenols [35]. Thus, the high starch digestibility of composite porridge could have been due to dilution of these macromolecules by cassava flour. The ratio of digestible versus resistant starch in foods is a good indicator of its energy content and can be used in targeted nutrition programmes. Energy-dense foods with high digestible starch content are desired in foods for infants and persons suffering from protein energy malnutrition [30]. On the other hand, foods containing high levels of resistant starch yield fewer calories, reduce postprandial glycemia and insulinemia and increase the sensation of satiety [36] and are recommended for management of diabetes and obesity.

3.6. Anti-nutrient and phosphorous content

The phytate, tannin and phosphorous contents of cassava and finger millet porridges are shown in Table 7. Hydrothermal-treatment of finger millet had no effect ($p > 0.05$) on the phytate and phosphorous content but decreased ($p < 0.05$) the tannin content. Composite porridges had higher phytate and phosphorous contents than CAS porridge because of the inherently high content of these compounds in NAT or HTT finger millet. Cassava-NAT porridge had higher ($p < 0.05$) tannin content than CAS but CAS-HTT porridge had the same ($p > 0.05$) tannin content as CAS porridge. Phytates and tannins are considered to be antinutrients because they decrease mineral bioavailability, and lower starch and protein digestibility of foods [9,37]. Phytate reduction in cereals is an enzyme-mediated process with a temperature optimum for phytase activity at 30–55 °C [5,9,11,38]. Thus, phytate content of finger millet did not decrease during HTT because the high incubation temperature (60–70 °C) denatured phytase. The phosphorous content of finger millet also did not change because it is bound to phytate and is only released when phytate dissociates [38]. On the other hand, the tannin content of finger millet may have decreased due to leaching, and formation of hydrophobic associations with proteins, which decreased their extractability [11,39].

3.7. Descriptive sensory evaluation

The sensory attributes of porridges were evaluated using modified Quantitative Descriptive Analysis (Table 1). Principal component (PC) analysis was used to evaluate the mean panellist and replication scores of sensory attributes identified in porridge. All the identified sensory attributes were significant ($p < 0.05$) for the porridges. The first two PCs, identified by the Scree Test, accounted for 98% of the variance. The first PC accounted for 90% of total variance of the sensory data. It distinguished the CAS porridge from the NAT, HTT, CAS-NAT and CAS-HTT porridges. Cassava porridge was located on the left side of the PC plot whereas the other porridges were on the right side (Fig. 3). Cassava porridge was distinguished by its aroma and high viscosity, whereas the finger millet or composite porridges had several dark specks.

The second PC accounted for 8% of total variance of the sensory data (Fig. 3). It distinguished NAT and CAS-NAT porridges from the HTT and CAS-HTT porridges. The NAT and CAS-NAT porridges had strong finger millet aroma, whereas the HTT and CAS-HTT porridges were characterized by red soil aroma, bitter taste and aftertaste. The bitter taste of HTT and CAS-HTT porridges may be attributed to oxidation of phenolic compounds during HTT, which is consistent with the development of dark colour. The bitter taste of HTT and CAS-HTT porridge is in stark contrast to the sweet taste of porridges prepared from malted cereals [8]. The impact of CAS on the sensory profiles of the composite porridges appeared to be insignificant because the sensory properties of NAT porridge were close to CAS-NAT, and those of HTT were close to CAS-HTT. Porridge colour, coarseness and residual particles were close to zero on the y-axis and were common sensory characteristics of both NAT and HTT finger millet porridges.

Table 6
Starch digestibility of cassava and finger millet porridge.

Porridge	Digestible starch[§] (g/100 g dm)	Digestible starch (% total starch)
CAS	85.5 ± 7.35^{a}	99.8
NAT	72.1 ± 1.61^{b}	85.2
HTT	69.7 ± 4.37^{b}	81.5
CAS-NAT (1:1)	77.9 ± 1.85^{ab}	99.4
CAS-HTT (1:1)	78.2 ± 0.69^{ab}	98.8

CAS - cassava, NAT - native finger millet, HTT - hydrothermally treated finger millet.
Values reported as mean ± standard deviation. Means in the same column with different superscript letters are significantly different ($p \leq 0.05$) from each other.

Table 7
Antinutrient and phosphorous content of cassava and finger millet porridge.

Porridge	Phytate[§§]	Tannin[§§§]	Phosphorous[§§]
CAS	123 ± 8^{d}	78 ± 20^{c}	35 ± 2^{c}
NAT	849 ± 24^{a}	266 ± 24^{a}	239 ± 7^{a}
HTT	873 ± 4^{a}	63 ± 11^{c}	246 ± 1^{a}
CAS-NAT (1:1)	404 ± 5^{c}	182 ± 5^{b}	114 ± 1^{b}
CAS-HTT (1:1)	473 ± 13^{b}	75 ± 10^{c}	133 ± 4^{b}

[§§]mg/100 g dm.
[§§§]mg catechin equivalents/100 g, dm.
CAS - cassava, NAT - native finger millet, HTT - hydrothermally treated finger millet.
Values reported as mean ± standard deviation. Means in the same column with different superscript letters are significantly different ($p \leq 0.05$) from each other.

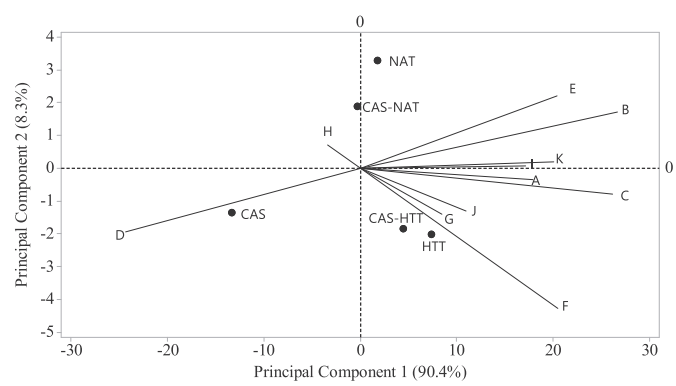

Fig. 3. Biplot of the first two principal component scores of porridge flours, and loading vectors of sensory attributes of porridge. A: colour; B: number of particles; C: number of dark specks; D: cassava aroma; E: finger millet aroma; F: red soil aroma; G: bitter taste; H: viscosity; I: coarseness; J: aftertaste; K: residual particles in mouth after swallowing; CAS: cassava; CAS-NAT: cassava-native finger millet; CAS-HTT: cassava-hydrothermally-treated finger millet.

4. Conclusions

The low energy density and poor nutrient quality of CAS porridge can be improved by blending it with HTT finger millet. Hydrothermally-treated finger millet had high α-amylase activity that hydrolysed cassava starch and reduced its water-binding capacity and allowed the amount of flour required to prepare porridge to be doubled. In addition, partial substitution of CAS with HTT finger millet flour gave composite porridge with better nutrient quality than cassava porridge. Digestible starch and tannin content were not impaired when CAS was blended with HTT finger millet but the increased phytate content suggested low mineral bioavailability in the composite porridge. Further work is required to optimise the traditional method for production of HTT finger millet with the aim of reducing its phytate content.

Declaration of competing interest

The authors declare that they have no conflict of interest to declare for this publication.

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