Effect of soy flour addition and heat-processing method on nutritional quality and consumer acceptability of cassava complementary porridges

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Abstract

BACKGROUND: The nutritional quality of cassava complementary porridge was improved through extrusion cooking and compositing with either defatted or full fat soy flour (65 : 35 w/w), and product acceptability by mothers with children of the target population was evaluated.

RESULTS: The protein digestibility-corrected amino acid score (PDCAAS) of extrusion- and conventionally cooked composite porridges was within the recommendations for complementary foods. The kinetics of starch digestibility showed that all porridges had a rapid rate of starch digestibility, but the rate was lower when defatted soy flour was added and lowest when full fat soy flour was added. The formation of amylase-lipid complexes as shown by X-ray diffraction and differential scanning calorimetry can be attributed to the lower digestibility of extrusion-cooked porridge with full fat soy flour. If fed thrice per day, extrusion-cooked porridge with defatted or full fat soy flour would meet the energy, protein and available lysine requirements of a child aged 6–8 months receiving low or average nutrients from breast milk. All porridges were well received by Mozambican mothers who use cassava as a staple food. The mean scores for sensory liking of all porridges were 3 and above on a five-point hedonic scale.

CONCLUSION: Extrusion-cooked cassava/soy flour porridges have good potential for use as high-energy/high-protein complementary foods and have acceptable sensory properties.

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Keywords: amylose-lipid complexes; available lysine; protein digestibility-corrected amino acid score (PDCAAS); starch digestion kinetics; X-ray diffraction

INTRODUCTION

Protein energy malnutrition (PEM) is a major health problem in Africa where complementary foods are based on starchy staple foods. Any nutrient-containing foods or liquids provided to young children along with breast milk are referred to as complementary foods. PEM mainly starts when complementary feeding is initiated. Nutritional improvement of staple foods is a suitable means to reduce PEM. In sub-Saharan Africa, cassava (Manihot esculenta Crantz) is a staple crop. It is adaptable in marginal soils and grows in erratic rainfall conditions. Except for histidine and leucine, cassava flour is deficient in essential amino acids compared with the recommended intakes for 1–2-year-old children.

Addition of soybean (Glycine max), whose cultivation and consumption are gaining popularity in sub-Saharan Africa, may enhance the protein quality of cassava complementary porridges. Soybean is high in protein (~400 g kg⁻¹) and has a good balance of amino acids that would complement the limiting amino acids in cassava.

Extrusion cooking is a well-known heat-processing technology used to produce ready-to-eat (instant), energy-dense cereal complementary porridge with a viscosity that is palatable by children. Extrusion cooking may either positively or negatively affect the protein and energy nutrition of foods. Extrusion cooking has been shown to reduce the amino acid content of foods, with lysine being most affected. The ε-amino group of lysine can react with reducing sugars during Maillard reaction, rendering lysine nutritionally unavailable. Extrusion cooking also enhances the protein digestibility of foods through protein denaturation, unfolding of polypeptide bonds and reduction in antinutritional factors.
The available literature on the effect of extrusion cooking on starch, the main caloric source in foods, is conflicting. The formation of resistant starch during extrusion of barley and corn has been reported, but no formation of resistant starch was observed during extrusion cooking of barley and maize/lima bean flour blends respectively. Resistant starch refers to starch and its degradation products not absorbed in the small intestine by normal individuals. This information is of nutritional significance because infants have an underdeveloped digestive system and are not able to ferment starch in the colon for additional metabolic energy.

Cassava porridge has a distinctive slimy texture, long cohesive consistency and bland taste that are lacking in commonly used cereal-based complementary porridges. Furthermore, extrusion cooking of cassava and soy flour is likely to cause Maillard reaction, leading to the development of colour and flavour. Although various studies have demonstrated the use of soy and extrusion to improve the protein quality and energy density of cereal complementary porridges, no studies have focused on cassava complementary porridges in terms of starch digestibility kinetics, available lysine, protein digestibility-corrected amino acid score (PDCAAS) and consumer sensory acceptability. Utilisation of cassava/soy flour complementary porridge will depend not only on its nutritional quality but also on its consumer acceptability. Therefore this study aimed to determine the effect of soy flour addition and heat-processing method (conventional or extrusion cooking) on the nutritional quality and consumer acceptability of cassava complementary porridges.

MATERIALS AND METHODS

Raw materials
The complementary porridges used in this study were prepared from cassava alone or composited with either full fat or defatted-toasted soy flour. To ensure that the raw materials had a similar configuration, soy oil was added to commercially available defatted-toasted soy flour instead of using full fat soy flour. Food-grade soy oil and defatted-toasted soy flour were purchased from Nedan Oil Mills Ltd (Pretoria, South Africa). Trypsin inhibitor was present at 1.5 ± 0.3 trypsin inhibitor units in the defatted soy flour as determined using AACC method 22–40. The common method of preparing cassava flour was followed. The total cyanide and acetone cyanohydrins contents determined according to the method described by Bradbury were 5.6 ± 0.2 and 2.7 ± 0.7 mg kg⁻¹ respectively, both below the safe level of 10 mg kg⁻¹.

Formulation of composites
Formulations were based on dry weight as follows: (1) 100% cassava flour (control); (2) 65% cassava flour and 35% defatted-toasted soy flour; (3) 65% cassava flour, 28% defatted-toasted soy flour and 7% soy oil. Commercial ready-to-eat complementary porridge used as a reference was purchased from a retail supermarket in Pretoria, South Africa.

Methods of heat processing
Conventional cooking
Complementary porridges (10% solids) were prepared following common practice in Africa with some modification. Water was boiled in a stainless steel cooking pot. Cold water was added to the flour to make a smooth slurry, which was added to the boiling water while stirring. Cooking continued for 20 min with stirring every 5 min. Hot water was added to compensate for moisture lost during cooking. Freshly cooked porridges were used for the analysis of in vitro starch digestibility. For the other analyses the porridges were first freeze-dried. Fresh porridges (10% solids) were used for consumer sensory testing. After preparation the porridges were kept warm (40–50 °C) during the testing session (30–60 min).

Extrusion cooking
Extrusion cooking was done using a Clextral BC 45 co-rotating twin-screw extruder (Clextral, Firminy, France). Freshly prepared composite formulations were conditioned overnight to a moisture content of 22%. Extruder conditions were a screw speed of 200 rpm, a barrel temperature of 120 °C and a retention time of 2 min. Extrudates were oven dried for 10 min at 100 °C and then milled to a particle size of about 500 μm. Milling was done using a roller mill (Maximill Roller Mill Cc, Kroonstad, South Africa) with the upper gap set at 2.1 mm and the lower gap at 0.5 mm. The milled extrudates were used for chemical analysis. To determine in vitro starch digestion, the milled extrudates and reference were reconstituted using boiling water to a solid content of 10% and analysed immediately. For the consumer acceptability study the porridges were reconstituted to 25% solid content. The porridges were kept at room temperature in covered cooking pots during the testing session (30–60 min). Immediately before serving, the porridges were reheated for 3 min in plastic bowls and then served warm (40–50 °C).

Proximate analysis
AACC methods were used to determine moisture content (method 44.15A), fat content (method 30–25), ash content (method 08–01) and protein (N × 6.25) content (Dumas combustion, method 46–30). Total starch was determined using an α-amylase/amyloglucosidase total starch assay kit (Megazyme International Ireland, Bray, Ireland) as described in AACC method 76–13. Gross energy was determined using a bomb calorimetric method.

Protein quality
The amino acid content of milled extrudates, freeze-dried conventionally cooked porridges and reference commercial complementary porridge (powder) was determined as described by Bidlingmeyer et al. The method of Hurrell et al. was followed to analyse available lysine. In vitro protein digestibility (IVPD) was determined as described by Hamaker et al. Residual protein was determined by the Dumas combustion method. The equation suggested by WHO/FAO/UNU Expert Consultation was used to calculate the PDCAAS.

In vitro kinetics of starch digestion
In vitro starch digestion of freshly prepared porridges (reference, extrusion-cooked and conventionally cooked) was determined according to the method proposed by Goni et al. with modifications. The rate of starch digestion was expressed as % of total starch digested at different times (0, 5, 30, 60, 90, 120 and 180 min). A nonlinear model Goni et al. was used to describe the kinetics of starch hydrolysis of the porridges in order to classify them nutritionally.
**X-ray diffraction**

Samples were prepared for X-ray diffraction (XRD) analysis using the back-loading method. They were analysed using an X’Pert PRO Powder diffractometer with an X’Celerator detector (PANalytical, Ostfildern, Germany). The diffractometer was equipped with variable divergence and receiving slits using Fe-filtered Co-Kα radiation (1.78901 Å) and operated at 35 kV and 50 mA. Samples were scanned at 25 °C with 2θ in the range 2–90°. Diffractograms were interpreted using X’Pert Highscore Plus (PANalytical).

To calculate total % crystallinity, X-ray diffractograms were normalised using OriginPro 7.5 (Originlab Corporation, Northampton, MA, USA). Total % crystallinity was the difference between the area under the sample diffractogram and the area under the amorphous starch diffractogram divided by the area under the sample diffractogram, multiplied by 100.28

**Thermal properties**

Thermal analyses were done by differential scanning calorimetry (DSC) (HP DSC 822e, Mettler Toledo, Schwerzenbach, Switzerland). Each sample (5 mg) was weighed into a 40 µL aluminium sample pan and 15 µL of water was added. Samples were equilibrated overnight at room temperature. The measurements were done using a heating rate of 10 °C min⁻¹ between 40 and 125 °C. The instrument was calibrated using indium, and an empty aluminium pan was used as reference.

**Colour determination**

The colour of freshly prepared porridges was assessed using a Chroma Meter CR 400 (Konica Minolta Sensing, Osaka, Japan). Colour values L°, a° and b° (CIE-LAB system) were recorded. The L° value gives a measure of lightness of the product, ranging from 100 for perfect white to 0 for black, the a° value describes redness (+)/greenness (−) and the b° value describes yellowness (+)/blueness (−). A white tile (L° = 96.76, a° = 0.12, b° = 1.80) was used to calibrate the colour meter. Hue angle (°) was calculated as

\[ \tan^{-1}(b°/a°) \]

**Consumer sensory evaluation**

Females (n = 122) aged above 20 years with children aged below 2 years participated in the study. They were recruited from six peri-urban health centres in Nampula and Zambieza provinces, Mozambique. Ethical approval was obtained from the University of Pretoria Ethics Committee and the provincial Directorate of Health, Nampula, Mozambique. The evaluation was done in meeting halls in Nampula and Zambieza. The porridges (~50 g) were served at 40–50 °C in 125 mL plastic cups. Plastic spoons were used to evaluate the porridges. Samples were blind-coded with three-digit random numbers. The order of serving was randomised per session, and consumers (n = 25) within a session evaluated all six porridges. Consumers expressed their liking of colour, consistency, smell, taste and overall acceptability using a five-point hedonic scale ranging from 1 = dislike very much to 5 = like very much. Water was provided at room temperature to clean the mouth between samples.

**Data analysis**

Analysis of variance (ANOVA) was applied to determine the effect of soy flour addition and heat-processing method on nutritional attributes, colour (L°, a°, b°) and kinetic parameters of in vitro starch digestion using Statistica Version 9.0 (StatSoft, Tulsa, OK, USA). Cooking method and type of composite were considered as independent variables, and measured or calculated parameters as dependent variables. Experiments were repeated three times. Means of consumer ratings were subjected to one-way ANOVA and separated using Fisher’s least significant difference (LSD) test.

**RESULTS**

**Nutrient composition and protein quality**

The nutrient composition of cassava/soy porridges is shown in Table 1. On a dry weight basis the energy content ranged between 14.0 MJ kg⁻¹ in conventionally cooked cassava porridge and 16.8 MJ kg⁻¹ in conventionally cooked porridge with full fat soy flour. Addition of full fat soy flour led to a 20- and 26-fold increase in lysine content.

<table>
<thead>
<tr>
<th>Type of porridge</th>
<th>Total starch (g kg⁻¹)</th>
<th>Fat (g kg⁻¹)</th>
<th>Energy (MJ kg⁻¹)</th>
<th>Protein (N × 6.25) (g kg⁻¹)</th>
<th>Lysine (g kg⁻¹ protein)</th>
<th>Available lysine (g kg⁻¹ protein)</th>
<th>IVPD (%)</th>
<th>Lysine scoreb PDCAASc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional cooking</td>
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<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>870.0 ± 10.7e</td>
<td>2.0 ± 0.5a</td>
<td>14.0 ± 0.14a</td>
<td>25.7 ± 0.7a</td>
<td>28 ± 0.1a</td>
<td>ND</td>
<td>59.9 ± 8.3a</td>
<td>0.53 ± 0.31</td>
</tr>
<tr>
<td>With defatted soy</td>
<td>591.9 ± 23.6c</td>
<td>2.2 ± 0.6a</td>
<td>15.4 ± 0.0c</td>
<td>164.0 ± 2.3d</td>
<td>54 ± 2.0c</td>
<td>48 ± 0.3b</td>
<td>83.8 ± 5.4b</td>
<td>0.99 ± 0.76</td>
</tr>
<tr>
<td>With full fat soy</td>
<td>551.3 ± 8.4b</td>
<td>52.3 ± 1.8d</td>
<td>16.8 ± 0.2d</td>
<td>137.3 ± 2.7b</td>
<td>53 ± 2.0c</td>
<td>48 ± 2.0b</td>
<td>78.5 ± 7.1b</td>
<td>1.00 ± 0.80</td>
</tr>
<tr>
<td>Extrusion cooking</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>877.6 ± 5.0e</td>
<td>1.9 ± 0.7a</td>
<td>14.5 ± 0.2b</td>
<td>22.3 ± 0.7a</td>
<td>33 ± 0.2b</td>
<td>ND</td>
<td>86.5 ± 1.4b</td>
<td>0.64 ± 0.56</td>
</tr>
<tr>
<td>With defatted soy</td>
<td>609.0 ± 14.2c</td>
<td>2.1 ± 0.2a</td>
<td>15.3 ± 0.9c</td>
<td>160.2 ± 5.9d</td>
<td>54 ± 5.0c</td>
<td>42 ± 5.0a</td>
<td>92.8 ± 4.3c</td>
<td>0.83 ± 0.83</td>
</tr>
<tr>
<td>With full fat soy</td>
<td>563.2 ± 13.7b</td>
<td>39.6 ± 0.5b</td>
<td>16.6 ± 0.2d</td>
<td>130.1 ± 7.3b</td>
<td>53 ± 4.0c</td>
<td>40 ± 2.0a</td>
<td>90.7 ± 2.5c</td>
<td>1.00 ± 0.94</td>
</tr>
<tr>
<td>Referenced</td>
<td>376.8 ± 30.4a</td>
<td>45.7 ± 1.8c</td>
<td>17.0 ± 1.1b</td>
<td>149.8 ± 5.0c</td>
<td>68 ± 3.0d</td>
<td>64 ± 0.2c</td>
<td>93.3 ± 2.2c</td>
<td>1.20 ± 1.00</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation of three independent experiments. Means within the same column followed by different letters are significantly different (P < 0.05). ND, not determined because amino acids histidine and arginine were not detected.

a Cassava: 100% cassava flour; with defatted soy: 65% cassava flour and 35% defatted soy flour; with full fat soy: 65% cassava flour, 28% defatted soy flour and 7% soy oil.

b Lysine score = mg lysine g⁻¹ protein of test sample/52 mg lysine requirement for a 1–2-year-old child.

c PDCAAS = lysine score × IVPD/10.

d Commercial ready-to-eat complementary porridge.
increase in extractable fat content in extrusion- and conventionally cooked porridges respectively compared with corresponding cassava porridges. Available lysine was lower than lysine content by 22 and 11% in extrusion- and conventionally cooked porridges with defatted soy flour respectively (Table 1). In porridges with full fat soy flour the decrease in available lysine compared with lysine content was 25 and 9% in extrusion- and conventionally cooked porridges respectively. The IVPD of extrusion-cooked porridges with defatted full fat soy flour was 9 and 12% higher than that of corresponding conventionally cooked porridges. The PDCAAS increased twofold in conventionally cooked composite porridges compared with cassava porridge. The PDCAAS in extrusion-cooked porridges increased by 35 and 67% for porridges with defatted and full fat soy flour respectively compared with cassava porridge.

Kinetics of starch digestion
Both cooking method and compositing significantly \((P < 0.05)\) influenced the starch digestion of porridges (Fig. 1). Preliminary analysis indicated a rapid digestion rate in all porridges. This prompted sampling after 5 min of digestion. The starch digestion after 5 min was 77.6, 67.7 and 50.2% in extrusion-cooked cassava porridge, porridge with defatted soy flour and porridge with full fat soy flour respectively. The corresponding values for conventionally cooked porridges were 66.0, 64.2 and 57.1% respectively. The hydrolysis time to reach maximum starch digestion was less than 60 min for all porridges.

The total starch digested (TSD) was significantly \((P < 0.05)\) reduced by addition of either defatted or full fat soy flour (Table 2). Extrusion-cooked porridge with full fat soy flour showed the lowest TSD (62.3%). Conventionally cooked porridge with full fat soy flour showed the lowest kinetic constant \(k\) value \((0.061\ \text{min}^{-1})\), indicating the highest resistance to digestion by \(\alpha\)-amylase. Extrusion-cooked cassava porridge showed the highest \(k\) value \((0.092\ \text{min}^{-1})\). The \(k\) value can be related to the glycaemic index (GI).\(^{16}\) The GI value ranged between 90.1 in extrusion-cooked porridge with full fat soy flour and 119.2 in extrusion-cooked cassava porridge.

X-ray diffractograms and thermal properties
The X-ray diffractograms of raw formulations showed peaks at \(2\theta = 20.4, 22.6, 23.9\) and \(29.9^\circ\) (Fig. 2). These peaks are a mixture of A and B polymorph starches.\(^{29}\) Conventionally cooked porridges seemed mainly amorphous; with no clear peaks. Extrusion-cooked cassava porridge and porridge with defatted soy flour had peaks at \(2\theta = 15.1\) and \(23.2^\circ\). Extrusion-cooked porridge with full fat soy flour had peaks at \(2\theta = 7.9, 13.0, 15.3, 20.4\) and \(23.3^\circ\). The peaks at \(2\theta = 7.9^\circ\) and \(13^\circ\) have been associated with the presence of amylose-lipid complexes.\(^{30,31}\) The total crystallinity of uncooked formulations was 30%. For extrusion-cooked cassava porridge, porridge with defatted soy flour and porridge with full fat soy flour the total crystallinity was 16, 17 and 19% respectively. The total crystallinity of conventionally cooked porridges was not determined because they were mainly amorphous.

Figure 3 shows the DSC thermograms of milled extrudates and freeze-dried conventionally cooked porridges heated from 40 to 125 °C. A transition endotherm occurred only in extrusion-cooked porridge with full fat soy flour. The onset and endset temperatures were 106.5 and 108.5 °C respectively. This endotherm peak has been associated with the melting of crystalline amylose-lipid complexes.\(^{32}\)

Colour
Extrusion-cooked porridges had higher \(L^*, +a^*\) and \(+b^*\) values compared with corresponding conventionally cooked porridges (Table 3). Extrusion-cooked porridge with full fat soy flour was
Quality and acceptability of extruded cassava/soy complementary porridges

Table 2. Effect of soy flour addition and heat-processing method on kinetic parameters of in vitro starch digestion of cassava complementary porridges

<table>
<thead>
<tr>
<th>Type of porridge</th>
<th>C∞ (%)b</th>
<th>k (min⁻¹)c</th>
<th>HI (%)c</th>
<th>GIc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional cooking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>92.5 ± 2.0d</td>
<td>0.091 ± 0.00ab</td>
<td>128.4 ± 2.3c</td>
<td>110.4 ± 0.5de</td>
</tr>
<tr>
<td>With defatted soy</td>
<td>78.8 ± 0.9bc</td>
<td>0.069 ± 0.00ab</td>
<td>114.0 ± 0.9b</td>
<td>102.7 ± 1.6bcd</td>
</tr>
<tr>
<td>With full fat soy</td>
<td>75.0 ± 0.9b</td>
<td>0.061 ± 0.00a</td>
<td>106.0 ± 1.1b</td>
<td>103.3 ± 2.1bc</td>
</tr>
<tr>
<td>Extrusion cooking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>89.3 ± 2.8d</td>
<td>0.092 ± 0.01b</td>
<td>144.9 ± 0.7d</td>
<td>119.2 ± 0.5e</td>
</tr>
<tr>
<td>With defatted soy</td>
<td>73.6 ± 1.4b</td>
<td>0.085 ± 0.01ab</td>
<td>115.6 ± 0.9b</td>
<td>104.1 ± 0.5cd</td>
</tr>
<tr>
<td>With full fat soy</td>
<td>62.3 ± 2.5a</td>
<td>0.072 ± 0.00ab</td>
<td>98.8 ± 1.1a</td>
<td>90.1 ± 0.5a</td>
</tr>
<tr>
<td>Reference⁶</td>
<td>93.1 ± 3.0d</td>
<td>0.065 ± 0.01ab</td>
<td>142.8 ± 1.0d</td>
<td>118.3 ± 0.5e</td>
</tr>
<tr>
<td>White bread*</td>
<td>62.9 ± 2.5a</td>
<td>0.069 ± 0.01ab</td>
<td>97.7 ± 0.3a</td>
<td>94.6 ± 1.9ab</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation of three independent experiments. Means within the same column followed by different letters are significantly different (P < 0.05).

Table 3. Effect of compositing on colour and consumer sensory ratings of cassava-soy flour porridges

<table>
<thead>
<tr>
<th>Type of porridge</th>
<th>Colour (L, a b values)</th>
<th>Visual Colour</th>
<th>Consumer ratings (n = 122)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L*</td>
<td>a*</td>
<td>b*</td>
</tr>
<tr>
<td>Conventional cooked</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>48.8a ± 1.2</td>
<td>−0.1a ± 0.3</td>
<td>0.2a ± 0.5</td>
</tr>
<tr>
<td>With defatted soy</td>
<td>48.9a ± 0.1</td>
<td>0.7b ± 0.0</td>
<td>2.0b ± 0.0</td>
</tr>
<tr>
<td>With full fat soy</td>
<td>53.1b ± 0.3</td>
<td>0.5b ± 0.1</td>
<td>3.7c ± 0.3</td>
</tr>
<tr>
<td>Extrusion cooked</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cassava</td>
<td>56.6b ± 0.4</td>
<td>−1.4a ± 0.0</td>
<td>2.6a ± 0.2</td>
</tr>
<tr>
<td>With defatted soy</td>
<td>52.1a ± 0.2</td>
<td>0.9b ± 0.3</td>
<td>5.0b ± 0.5</td>
</tr>
<tr>
<td>With full fat soy</td>
<td>58.3c ± 0.1</td>
<td>1.9c ± 0.1</td>
<td>8.8c ± 0.1</td>
</tr>
</tbody>
</table>

Values of instrumental colour measurements are means of three independent analyses ± standard deviation. Values in the same column and similar cooking method followed by the same letter are not significantly different (p > 0.05)

Cassava = 100% cassava flour
With defatted soy flour = 65% cassava flour and 35% defatted soy flour
With full fat soy flour = 65% cassava flour, 28% defatted soy flour and 7% soy oil

DISCUSSION

The decrease in available lysine compared with lysine content was higher (~10%) in extrusion-cooked composite porridges than in corresponding conventionally cooked porridges. A reduction in available lysine (0–32%) in sweet potato/soy flour extrudates

Porridge acceptability by mothers

The mean consumer sensory acceptability scores were 3 and above on a five-point hedonic scale for all sensory attributes (Table 3). Conventionally cooked composite porridges were liked significantly (P < 0.05) more than conventionally cooked cassava porridge. The average ratings for conventionally cooked porridges with defatted and full fat soy flour were not significantly different for all sensory attributes.

Consumers rated extrusion-cooked cassava porridge higher than extrusion-cooked composite porridges for all sensory attributes. Extrusion-cooked porridge with full fat soy flour was, on the contrary, rated significantly (P < 0.05) lower for all sensory attributes except overall acceptability. The overall liking of extrusion-cooked porridge with defatted soy flour had the highest variability, as indicated by the wide distribution of scores.

More red and yellow (higher +a* and +b* values respectively) than other extrusion-cooked porridges. Porridges with full fat soy flour (both extrusion- and conventionally cooked) were significantly (P < 0.05) lighter, as indicated by higher L* values, compared with corresponding cassava porridges and porridges with defatted soy flour. Extrusion-cooked cassava porridge had a significantly lower hue angle compared with extrusion-cooked porridges with defatted and full fat soy flour.
Figure 2. Effect of soy flour addition and heat-processing method on XRD pattern of cassava complementary porridges. Arrows indicate peaks related to amylase–lipid complexes.\textsuperscript{30,31}

Figure 3. Effect of soy flour addition and heat-processing method on DSC thermogram of cassava complementary porridges.

has also been reported.\textsuperscript{10} The decrease could be due to the occurrence of Maillard reaction between the ε-amino group of lysine and carbonyl groups of reducing sugars.\textsuperscript{33} A low moisture content during extrusion may favour the occurrence of greater Maillard reaction than in conventional cooking.\textsuperscript{9} The PDCAAS values of cassava composite porridges (extrusion- and conventionally cooked) were above 70\%, the recommended minimum level for complementary foods.\textsuperscript{34} The fat content of extrusion- and conventionally cooked porridges was lower than that of uncooked formulations. The formation of amylose-lipid complexes as indicated by Figs 2 and 3 could have contributed to the reduced fat recovery.

Starch digestion follows first-order kinetics\textsuperscript{16} whereby the catalytic rate increases with additional substrate until a maximum value is reached. The rate of starch digestion reached a plateau in all porridges within 60 min (Fig. 1). Addition of defatted soy flour reduced the TSD in extrusion- and conventionally cooked porridges compared with corresponding cassava porridges. A reduction in \textit{in vitro} starch digestibility has been reported in extrusion-cooked durum semolina and gluten blends.\textsuperscript{35} An increased physical barrier due to protein reducing the accessibility of starch to α-amylase has been suggested. All porridges had a high GI value.\textsuperscript{36} This can be attributed to the high rate of starch digestibility due to disruption of starch granules during extrusion and conventional cooking. Further, cassava has a low amylose/amylopectin ratio,\textsuperscript{20} which is associated with high digestibility and consequently high GI. The GI values found in this study are consistent with the literature on complementary foods.\textsuperscript{36}

The TSD was lowest in extrusion-cooked porridge with full fat soy flour. The formation of amylose-lipid complexes as seen to have occurred during extrusion cooking of porridge with full fat soy flour (Figs 2 and 3) may have contributed to the relatively low digestibility. A V-polymorph pattern of amylose-lipid complexes in extruded wheat/almond flour has been reported.\textsuperscript{37} Amylose–lipid complexes tend to reduce the accessibility of amylose to α-amylase for digestion.\textsuperscript{38} The limited accessibility could be due to the compact nature of the V-crystalline pattern of amylose-lipid complexes.\textsuperscript{39} Extrusion-cooked porridge with full fat soy flour had relatively higher total crystallinity (19\%), which may further explain...
the low TSD. A positive correlation between total crystallinity of starch and in vitro starch digestion has also been observed.\textsuperscript{30}

Extrusion-cooked porridge with full fat soy flour had less total digestible starch compared with conventionally cooked porridge with full fat soy flour. This can also be related to the absence of amylose-lipid complexes in conventionally cooked porridge as determined by DSC and XRD. It is possible that the high energy input during extrusion cooking compared with conventional cooking may be responsible for this difference. In extrusion cooking, the high temperature and high shear may allow more interaction between amylose and available lipids to produce amylose-lipid complexes, whereas the starch granules are not as extensively solubilised in conventional cooking (\textless 20 min). A second pasting peak associated with amylose-lipid complexes was only observed after 34 min of pasting of maize starch,\textsuperscript{41} suggesting that limited complexation occurred between amylose and lipids up to 30 min of pasting.

The mean TSD in extrusion-cooked porridges was lower than that in corresponding conventionally cooked porridges (Fig. 1). This could be due in part to the presence of a more crystalline structure in extrusion-cooked porridges compared with conventionally cooked porridges (Fig. 2). All extrusion-cooked porridges had peaks characteristic of the A-type polymorph.\textsuperscript{28} Similar findings were reported during extrusion of maize starch.\textsuperscript{31} Recrystallisation of starch at low water content and/or high temperature, as is the case during extrusion, forms the A-type polymorph.\textsuperscript{31,42} The A-type polymorph has a close-packed arrangement of double helices and is relatively resistant to digestive enzyme.\textsuperscript{28}

Table 4 shows a simulation of the amounts of energy, protein and lysine (calculated based on available lysine) that could be provided by cassava/soy porridges to a child aged 6–8 months receiving a low or average quantity of nutrients from breast milk. Low or average intake of nutrients from breast milk is common in Africa.\textsuperscript{2} To calculate the nutritional adequacy of cassava/soy flour porridges, extrusion- and conventionally cooked porridges were assumed to contain 25 and 10% solids by weight respectively. Preliminary analysis with a rotational viscometer also suggested that extrusion-cooked porridges at 25% solids had a viscous flow similar to that of conventionally cooked porridges at 10% solids and of the commercial reference (25% solids according to the manufacturer). More studies on the viscosity and viscoelastic properties are currently being carried out. These solid contents were therefore also used to prepare porridges for consumer sensory evaluation.

The energy content of extrusion-cooked porridges (25% solids) was between 0.9 kcal g\textsuperscript{−1} in cassava porridge and 1 kcal g\textsuperscript{−1} in porridge with full fat soy flour, which is within the recommendation of \(\geq 0.8 \text{ kcal g}^{-1}\) for complementary foods.\textsuperscript{2} If fed thrice per day, all extrusion-cooked porridges could meet the energy needs of children receiving average or low energy from breast milk. At this feeding frequency, conventionally cooked porridges would supply less than 50% of the energy required by a child receiving either low or average energy from breast milk. Furthermore, the low energy content (0.3–0.4 kcal g\textsuperscript{−1}) of conventionally cooked cassava/soy porridges would require large amounts of porridge to be consumed in order to meet energy needs. This is not possible owing to the low gastric capacity of children (30 g kg\textsuperscript{−1} body weight).\textsuperscript{2}

On an as-eaten basis, extrusion- and conventionally cooked composite porridges would exceed by 0.85–7 times the protein requirements of 6–8-month-old children receiving a low or average quantity of protein from breast milk. Furthermore, extrusion-cooked porridges with defatted and full fat soy flour would meet the lysine requirement (based on available lysine) of 6–8-month-old children receiving an average or low quantity of lysine from breast milk.

Colour lightness (\(L^*\) value) ranged from 48.8 to 58.3 in the six porridges. These values are within the range reported for sorghum porridge, which is one of the most commonly eaten porridges in Africa\textsuperscript{13} The presence of brown colour due to Maillard reaction during soy flour manufacture could have contributed to the higher \(+a^*\), \(+b^*\) and hue angle values in composite porridges.

Table 4: Simulation of contribution of cassava/soy flour complementary porridges to energy, protein and lysine requirements of a well-nourished 6–8-month-old child if fed thrice per day (249 g per feed)

<table>
<thead>
<tr>
<th>Recommended requirement</th>
<th>Amount (level) of nutrient intake from breast milk</th>
<th>Required nutrient from complementary food</th>
<th>Conventionally cooked porridges (10% solids)\textsuperscript{a}</th>
<th>Extrusion-cooked porridges (25% solids)\textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount from</td>
<td></td>
<td>Cassava</td>
<td>With defatted soy</td>
</tr>
<tr>
<td>Energy 769 (kcal day\textsuperscript{−1})\textsuperscript{c}</td>
<td>217 (low)</td>
<td>552</td>
<td>269.2</td>
<td>289.5</td>
</tr>
<tr>
<td>Protein 9.6 (g day\textsuperscript{−1})\textsuperscript{d}</td>
<td>413 (average)</td>
<td>356</td>
<td>269.2</td>
<td>289.5</td>
</tr>
<tr>
<td>Lysine 355 (mg day\textsuperscript{−1})\textsuperscript{d}</td>
<td>4.5 (average)</td>
<td>7.3</td>
<td>1.7</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td>176 (low)</td>
<td>179</td>
<td>1.7</td>
<td>12.2</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Cassava: 100% cassava flour; with defatted soy: 65% cassava flour and 35% defatted soy flour; with full fat soy: 65% cassava flour, 28% defatted soy flour and 7% soy oil. Calculations were based on conventionally cooked porridges containing 10% solids and extrusion-cooked porridges containing 25% solids to mimic traditional African complementary porridges and commercial ready-to-eat complementary porridge respectively.

\textsuperscript{b} Commercial ready-to-eat complementary porridge.

\textsuperscript{c} Calculations of energy and protein were based on requirements of a 6–8-month-old child receiving the maximum recommended feeding frequency (thrice per day).\textsuperscript{2}

\textsuperscript{d} Calculations were done using available lysine content of study porridges (Table 2) based on amino acid requirement of a child aged <2 years.\textsuperscript{5} The median weight of a 6-month-old male child (7.9 kg) was used to calculate lysine requirements (WHO child growth standards). ND, not determined because available lysine was not determined (Table 2).
during both conventional and extrusion cooking. The higher $+a^*$ and $+b^*$ values in extrusion-cooked porridges compared with corresponding conventionally cooked porridges could be due to additional Maillard browning during extrusion of the cassava/soy composite flours. Maillard browning is a chemical reaction involving free amino groups of proteins and carbonyl groups of reducing sugars.\textsuperscript{44} The reaction is dependent on the presence of amino acids and sugars and on processing conditions (time, temperature and moisture).\textsuperscript{13} Maillard reaction is favoured in conditions of high temperature and high shear (>100 rpm).\textsuperscript{45} Extrusion cooking was done under such conditions, as the temperature was 120 °C and the shear rate was 200 rpm.

In terms of consumer liking of the cassava/soy flour porridges, all sensory attributes of conventionally cooked composite porridges were more liked than those of conventionally cooked cassava porridge. Soy flour contains limited starch, so physical reduction of starch available in the continuous phase of porridge may have reduced the resulting viscosity. Limited reassociation of amylose, which accounts for retrogradation and increased viscosity in the short term during cooling of starch paste,\textsuperscript{19} may have also reduced viscosity. Tubur starches are devoid of lipids and therefore have a bland taste.\textsuperscript{19} Addition of soy flour could have introduced flavoured compounds associated with caramelisation and Maillard reaction, because the flour was toasted during manufacturing.\textsuperscript{10}

It was expected that extrusion-cooked composite porridges would be more liked than extrusion-cooked cassava porridge owing to increased flavour and aroma volatile compounds formed during extrusion cooking. Dimethyl disulfide and dimethyl trisulfide volatiles have been identified in extruded vegetable protein and wheat starch.\textsuperscript{46} Furthermore, extrusion of the starch in the presence of linoleic acid has been shown to form benzaldehyde and hexanal volatiles.\textsuperscript{46} The relatively lower liking of extrusion-cooked composite porridges found in the present study could be because the volatile compounds formed during extrusion were not familiar to the consumers. There were large variations in consumers’ opinions of the extrusion-cooked composite porridges, with some liking the porridges and others disliking them. Sensory profiling of these porridges is under way to further elucidate the drivers of consumer liking and disliking.

CONCLUSION
Extrusion-cooked cassava/soy flour complementary porridges are energy-dense and high in protein quality, with acceptable sensory properties. They therefore have good potential for use in reducing PEM in sub-Saharan Africa, where cassava is a staple food. Extrusion cooking and compositing of cassava and soy flour, either defatted or full fat, greatly improve the protein quality of cassava complementary porridges in terms of protein content, available lysine and PDCAAS. At 35% soy flour inclusion, extrusion-cooked porridges fed thrice per day would meet the protein, lysine (available) and energy requirements of a child aged 6–8 months receiving a low or average quantity of protein from breast milk. Cassava/soy flour porridges contain rapidly digestible starch, which is desirable in young children since their digestive system is underdeveloped.

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REFERENCES


