

Nutritional, rheological and sensory properties of extruded cassava-soy complementary porridges

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DECLARATION

I PENINA NGUSYE MUOKI declare that the thesis, which I hereby submit at the University of Pretoria for the award of PhD (Food Science) degree is my work and has not been submitted by me for a degree at any other university or institution of higher learning.

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Date:

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ABSTRACT

Nutritional, rheological and sensory properties of extruded cassava-soy complementary porridges

By

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Protein Energy Malnutrition (PEM) is a major health problem in Africa. PEM begins when complementary foods are introduced to infants because the foods often contain inadequate amount of energy and protein. The development of nutrient-dense, low cost foods from locally grown food ingredients using suitable small-to-medium scale technologies is a suitable approach to address the problem of PEM. The aim of this study was to evaluate the effect of adding soy flour and method of heat treatment (extrusion and conventional cooking) on nutritional, rheological and sensory properties of cassava complementary porridges. Three types of porridges were formulated and were either extruded or conventionally cooked. These porridges either contained either 100% cassava flour or 65% cassava flour and 35% defatted toasted soy flour or 65% cassava flour, 28% defatted soy flour and 7% soy oil. Commercial ready to eat complementary porridge was used as a reference.

To determine the nutritional quality of the porridges, proximate analysis, lysine content, available lysine, Protein Digestibility Corrected Amino Acid Score (PDCAAS) and *in vitro* starch digestion were determined. Flow properties, frequency sweep, temperature sweep and time sweep were done to establish the rheological properties of the porridges. Sensory properties of the porridges were determined using descriptive sensory panel and instrumental analysis. Consumer sensory acceptability was done by mothers of children under 2 years from northern Mozambique, where cassava is a staple food.

The PDCAAS of extruded and conventionally cooked composite porridges was within the World Health Organization's (WHO) recommendations for complementary foods. All porridges showed rapid rate of digestion. Time to reach the maximum starch digestion was within 60 min in all the porridges, but the rates were lower when defatted soy flour was added and lowest when full fat soy flour was added. Formation of amylose-lipid complexes as shown by X-ray diffraction and differential scanning calorimetry may be attributed for the lower digestibility of extruded porridge with full fat soy flour. If fed thrice per day, extruded porridge with defatted soy flour, and defatted soy flour with soy oil would meet the energy, protein and lysine (available) requirements of a child aged 6-8 months receiving low or average nutrients from breast milk.

In terms of rheology, all porridges showed shear thinning behaviour. Extrusion cooking markedly reduced the viscosity of cassava-soy flour porridges, possibly due to depolymerization of starch. The data of shear viscosity and shear rate showed a good fit ($r^2 \geq 0.98$ to 0.99) to power law model. Extrusion cooking allowed for an increase in solids content of porridge up to 2.5 times compared to conventional cooking. This is beneficial for infant feeding as the porridges contained higher energy density. At a shear rate of 100s^{-1} , the viscosity of extrusion cooked composite porridges with 25% solids content ranged between 2 and 3 Pa.s; similar to the reference porridge at 25% solids and within WHO recommendations for complementary porridges.

During handling at various small amplitude oscillatory shear rates, temperature conditions and storage/refrigeration, extrusion cooked porridges showed a slower rate of retrogradation and thus a slower increase in viscosity. These trends were showed by consistently lower storage modulus (G') values for extrusion cooked porridges as compared to the corresponding conventionally cooked porridges, suggesting slow rate of retrogradation. It seems that the viscoelastic properties of all extrusion cooked porridges have minimal change during cooling and refrigeration at $4\text{ }^\circ\text{C}$. This is beneficial in infant feeding as porridges of high nutrient density can be prepared and cooled to usual eating temperature while maintaining a consistency that is edible by infants. During cooling (90

to 15°C), all porridges showed a biphasic increase in G' values possibly due to commencement of retrogradation at below 60°C.

Sensory attributes of high viscosity, stickiness, translucency, jelly-like appearance and bland flavour were reduced by addition of soy flour and extrusion cooking. Extrusion cooked porridges were dense, slimy and had an oily mouth coating aftertaste. Flavour attributes of extrusion cooked porridges were overall intense flavour, caramel aroma and toasted nutty flavour. The lightness (L^* value) of all porridges was within ranges of commonly eaten sorghum porridge. Consumer sensory preference was more towards conventionally cooked porridges than towards extrusion cooked porridges. Perhaps this could be due to familiarity of the sensory attributes of conventionally cooked porridges to the consumers. However, overall both extrusion and conventionally cooked cassava-soy flour complementary porridges were well received by Mozambican mothers who use cassava as staple food. The scores of all sensory attributes were above 3 in a 5-point hedonic scale.

This study indicates that extruded porridges with either defatted or full fat soy flour have high energy density, protein quality and starch digestibility. Rheological properties of extrusion cooked cassava-soy flour porridges are favourable for complementary food, which have to maintain a consistency consumable by infants. The porridges have positive sensory attributes and are acceptable among consumers who use cassava as a staple food. Thus, extrusion cooked cassava-soy flour porridges have a great potential as complementary porridges to reduce PEM among children in sub-Saharan Africa where cassava is an important crop.

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1.0 INTRODUCTION

1.1 Statement of the problem

Protein energy malnutrition (PEM) continues to be a major health problem in Africa. This manifests itself in terms of wasting, stunting and underweight situations among children aged less than 5 years. Over 70 million undernourished children live in Africa (World Food Programme (WFP), 2008). Consequences of malnutrition include higher susceptibility to diseases, higher mortality rate (Müller and Krawinkel, 2005) and impaired physical and cognitive development (Grantham-McGregor, 1995). In addition, it is difficult to compensate for poor growth after the first two years of life (Dewey and Brown, 2003).

PEM begins when complementary foods are introduced to infants because such foods often contain inadequate amounts of nutrients (Mosha and Bennink, 2005). Among other causes of PEM is the poor nutritional quality of traditional African complementary foods that are mainly starchy porridges (Dewey and Brown, 2003; Walker, 1990). These starchy staples include maize (*Zae mays*), sorghum (*Sorghum bicolar L.*) finger millet (*Eleucine coracona*), rice (*Oryza sativa*), cassava (*Manihot esculenta Crantz L*) potato (*Solanum tuberosum*), sweet potato (*Ipomea batatas*) and banana (*Musa spp*) (Mosha *et al.* 2000; Mosha and Bennink, 2005).

During cooking of traditional complementary porridges, gelatinization/pasting causes an increase in viscosity (Copeland, 2009). Mosha and Svanberg (1983) proposed that the viscosity of complementary porridges for consumption by young children be between 1000-3000cP (about 1-3 Pa.s). To achieve this viscosity, traditional complementary porridges contain 5 to 10% solids content (Lorri and Svanberg, 1993). At this solid concentration, traditional complementary porridges do not meet the recommended energy density (> 3.35kJ/g or 0.8 kcal/g) (WHO/UNICEF, 1998). In addition, due to small gastric capacity of about 250g for children aged 6 months and 350g for children aged 23 months (WHO/UNICEF, 1998), children cannot eat enough of the low energy dense traditional complementary porridges to meet their energy needs.

Although cassava is an important staple food in Sub-Saharan Africa (FAOSTAT, 2010), literature regarding its application as complementary food is lacking. There are various plausible reasons for its low application. Cassava contains cyanogen, which can be toxic to humans if consumed in high amounts (McMahon *et al.* 1995). However, adequate household processing methods for example, fermentation, soaking, grinding, maceration, pounding, chipping or a combination of these methods followed by drying (Aloys and Ming, 2006; McMahon *et al.* 1995) reduce cyanogen to within safe levels of <10ppm (FAO/WHO, 1990). Compared to cereals, cassava has a bland taste (Radhika *et al.* 2008); neutral flavour (Sajeev *et al.* 2003), a long cohesive texture (Moorthy, 2004) and high viscosity (Peroni *et al.* 2006) that are apparently negative sensory attributes. Furthermore, cassava is grossly deficient in protein (Montagnac *et al.* 2009), which may worsen prevalence of PEM if it is used as a complementary porridge.

Strategies proposed to improve the energy density of complementary porridges include malting (Nout, 1997), compositing with legumes or oil seeds (Asma *et al.* 2006), irradiation (Rombo *et al.* 2001), addition of commercial α -amylase (Owino *et al.* 2007), and extrusion cooking (Peréz *et al.* 2008). Household strategies such as malting are time consuming and may cause food intoxication (Onyango *et al.* 2004a). The hot and humid conditions under which malting occurs favours proliferation of fungal and bacterial contamination (Taylor and Dewar, 2001). However, contamination can be reduced through proper housekeeping practices. On the other hand, compositing of starchy staples with legumes may limit overall nutritional quality of resulting porridges due to an increase in antinutritional factors such as trypsin inhibitors, that reduce protein digestibility (Mensah and Tomkins, 2003). Fermentation has limited effect on viscosity of porridge and energy density (Mouquet-Rivier *et al.* 2008).

Developing nutrient-dense ready-to-eat inexpensive foods from locally grown food ingredients using suitable small-to-medium scale production technologies has been recommended as a viable and suitable approach to address the problem of PEM (Mosha and Bennink, 2005; Owino *et al.* 2007). Extrusion cooking has been shown to cause

depolymerization of amylopectin (Liu, 2010), which can allow for increase of solids content of complementary porridges at a viscosity that can be consumed by children (6-24 months) (Onyango *et al.* 2004a). Considering that flours from starchy foods are generally not rich in protein, compositing with a protein rich source such as soy flour followed by extrusion cooking would significantly enhance their suitability as complementary foods. However, extrusion cooking of mixed food ingredients may affect the nutritional and sensory quality of the resultant complementary porridges (Björck and Asp, 1983; Friedman, 1996). Thus, the objective of this study was to determine the effect of compositing (cassava with soy flour) and heat processing methods on nutritional, rheological and sensory properties of cassava complementary porridges.

2.0 LITERATURE REVIEW

This review examines protein and energy requirements during complementary feeding. Nutritional aspects related to energy and protein quality of African traditional complementary foods are discussed. Home and industrial approaches for enhancing nutritional quality of complementary foods is also discussed. An overview of extrusion cooking technology and its effect on nutritional and sensory properties of porridges is also given.

2.1 Complementary feeding

After 6 months of age, it becomes increasingly difficult for infants to meet their nutritional needs from breast milk alone (WHO/UNICEF, 1998). This necessitates introduction of other foods. At 6 months, infants' gastro-intestinal tract is also developed to digest other foods in addition to breast milk (Naylor and Morrow, 2001). Any nutrient containing foods or liquids other than breast milk given to young children aged 6 to 23 months are defined as complementary foods (WHO/UNICEF, 1998). Estimates of nutrients required from complementary foods are on the basis of the difference between recommended total nutrient requirements and intakes supplied by breast milk (WHO/UNICEF, 1998). The nutrient density of the complementary food, age of child, quantity of nutrients received from breast feeding and frequency of feeding influence adequacy of complementary feeding (WHO/UNICEF, 1998). Table 2.1 illustrates energy and protein requirement of various age groups (6-23 months). As expected, when energy density of complementary foods reduces, a higher feeding frequency is required to meet the energy needs. In addition, during complementary feeding, nutrients supplied by breast milk progressively decrease while the energy required from complementary foods progressively increases. This trend further emphasizes the need for nutrient dense complementary foods.

2.1.1 Traditional African complementary foods

In Africa, traditional complementary foods are mainly porridges prepared from single or composite aqueous flour slurries of starchy cereals or root crops (Mosha *et al.* 2000). Starchy crops are used principally because these products are readily available. For example, cassava, also called tapioca or manioc (Stupak *et al.* 2006) is one of the widely grown staple crops in sub-Saharan Africa. Cassava is a dicotyledonous perennial plant belonging to the family Euphorbiaceae. *Manihot esculenta* Crantz and *Manihot utilissima* Phol are the two common botanical forms of cassava (Cock, 1985).

Cassava is a root crop that is well adapted to diverse African traditional farming systems. It is an efficient producer of calories providing twice as many calories, per hectare as maize and at a considerably lower cost (Dahniya, 1994). Cassava can grow in a wide range of soils and can yield satisfactorily, even on poor acid soils where most other crops fail (Hahn, 1984). It is also adaptable to relatively marginal soils, erratic rainfall conditions and yields highly per unit of land and labour (Mtunda *et al.* 2003). It is grown in 39 African countries, of which Nigeria, Democratic Republic of Congo, Ghana, Angola and Tanzania are among the top 10 producers in the world. Worldwide, Nigeria is the lead producer of cassava. The production in these countries ranges between 6 million and 43 million metric tonnes per year (FAO, 2010). In Africa, 88% of cassava is for human consumption; the remainder is for feed and starch-based products (FAO, 2004). However, similar to other staple starchy crops, cassava has limitations if used to prepare complementary porridges.

Table 2. 1: Requirements of energy and protein for children aged 6-23 months and desirable energy and protein content of complementary foods

		<i>6-8 Months*</i>			<i>9-11 Months*</i>			<i>12-23 Months*</i>		
		<i>Low</i>	<i>Average</i>	<i>High</i>	<i>Low</i>	<i>Average</i>	<i>High</i>	<i>Low</i>	<i>Average</i>	<i>High</i>
From breast milk	Energy (kcal/day)	217.0	413.0	609.0	157.0	379.0	601.0	90.0	346.0	602.0
	Protein (g/day)	3.9	7.1	9.1	2.9	6.5	9.6	1.8	5.9	9.7
From complementary food	Energy (kcal/day)	552.0	356.0	160.0	701.0	479.0	257.0	1,028.0	772.0	516.0
	Protein (g/day)	5.2	2.0	none	6.7	3.1	none	9.1	5.0	1.2
Desired energy and protein content of complementary food	Energy (kcal/g)									
	1 meal/day	2.22	1.43	0.64	2.46	1.68	0.90	2.98	2.24	1.50
	2 meals/day	1.11	0.71	0.32	1.23	0.84	0.45	1.49	1.12	0.75
	3 meals /day	0.74	0.48	0.21	0.82	0.56	0.30	0.99	0.75	0.50
	4 meals/day	0.56	0.36	0.16	0.61	0.42	0.23	0.74	0.56	0.37
	5 meals/day	0.44	0.29	0.13	0.49	0.34	0.18	0.60	0.45	0.30
	Protein (g/ 100kcal)	1.10	0.70	none	1.00	0.70	none	0.90	0.70	0.20

*Assumed gastric capacity (30g/kg reference body weight) is 249 g/meal at 6-8 months, 285g/meal at 9-11 months and 345 g/meal at 12-23 months (WHO/UNICEF, 1998). Categories low, average and high correspond to nutrient intake from breast milk: Low (mean -2 standard deviation), Average (mean), and High (mean + 2 standard deviation).

*1kcal= 4.2kJ

2.1.2 Limitations of traditional African complementary porridges

Key elements characterizing African traditional complementary porridges include high viscosity, low energy density (Mosha and Svanberg, 1983) and poor protein quality (Ejigui *et al.* 2007). These attributes have often been identified as causative factors of PEM (Walker, 1990). These factors are discussed in detail below.

a) High viscosity- low energy density

Using the Haake rotovisco, Mosha *et al.* (1983) found the viscosity of porridges that can be eaten by children (age not specified) to be 1-3 Pa.s (1000-3000 cP). Tréche and Mborne (2001), using the same equipment, found the viscosity of porridges fed to Congolese children aged 4-11 months to be 0.5-2.8 Pa.s (500-2800 cP). Using a rheometer at a shear range of 35-64 s⁻¹, cereal-cassava complementary porridges (target age not specified) contained 9g/100g total solids corresponding to 0.2-0.3 kcal/g and viscosity of about 3000cP (3 Pa.s) (Onyango *et al.* 2004b). Mouquet *et al.* (2008) reported the solids content of fermented millet complementary porridges consumed in Burkina Faso to contain 5-8g/100g solids content corresponding to energy density of 0.3 kcal/g. This energy density is markedly below the minimum recommendations for complementary foods (0.8 kcal/g) (WHO/UNICEF, 1998). At this low energy density, a child would need to be fed more than 5 times per day, which may not be feasible.

The low solids content/energy density of traditional complementary porridges has been attributed to characteristic swelling of starch during cooking, which causes starch gelatinization and pasting. Gelatinization can be defined as the loss of molecular order within a starch granule (Kent and Evers, 1994). Heating aqueous starch granules above gelatinization temperature (typically above 60°C) causes starch to paste. Gelatinization and pasting increase viscosity as a result of structural changes occurring in starch granules. These changes include absorption of water, irreversible swelling of the starch granules, melting of crystallites and leaching out of amylose (Jenkins and Donalds, 1998). Water first enters the amorphous region and at a certain degree of swelling disruptive stress is transmitted to the crystalline region (Jenkins and Donalds, 1998). This

corresponds to increase in viscosity that is followed by reduction in paste viscosity as the swollen starch granules rupture and starch molecules are dispersed in the aqueous phase (Copeland *et al.* 2009; Lagarrigue and Alvarez, 2001). Thus, heating starch in water results in a fluid, composed of porous, gelatinized and swollen granules with an amylopectin skeleton suspended in amylose solution (Morris, 1990). To achieve a viscosity that can be consumed by infants and young children (6-24 months), traditional complementary porridges is diluted to about 90% water which in turn reduces their energy density (Walker, 1990).

During cooling to a temperature at which the porridges can be eaten (about 40°C); molecular re-association referred to as retrogradation occurs (Atwell *et al.* 1988). Both amylose and amylopectin associate during this process with amylose retrogradation occurring at a faster rate than that of amylopectin. Thus, in dispersed starch system e.g. porridges, the proportion of amylose and amylopectin influence rate and degree of retrogradation (Goodfellow and Wilson, 1990). Retrogradation tends to increase viscosity of porridge due to molecular reassociation. Figure 2.1 is a schematic representation of phase transition of starch during gelatinization (a) and retrogradation (b).

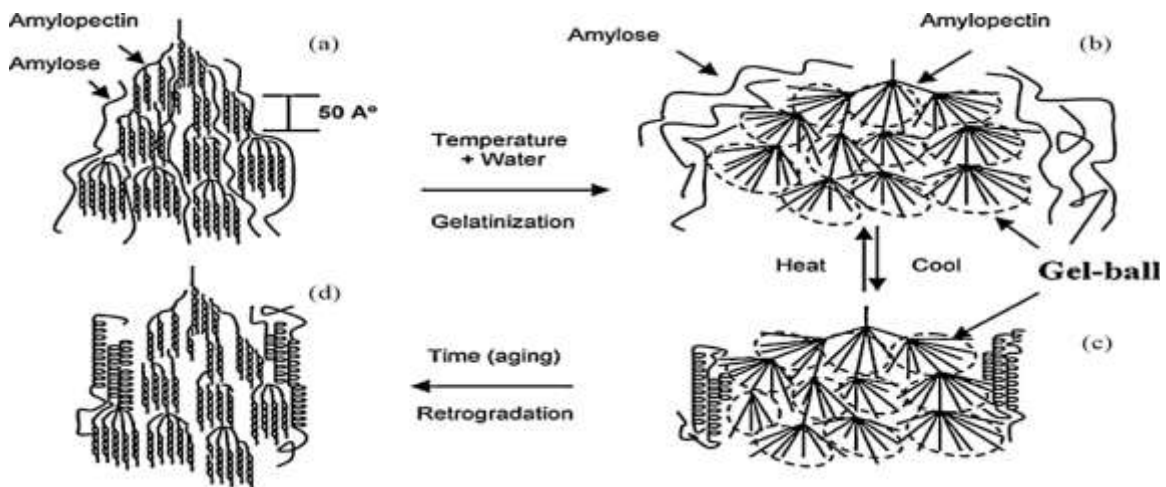


Figure 2. 1: Schematic representation of phase transition of starch during gelatinization and retrogradation (Long and Chistie, 2005)

Presence of other ingredients such as protein and lipids may affect pasting of starch. Kuar *et al.* (2000) found fatty acids to increase the viscosity of rice flour pastes. Formation of amylose-lipid complexes was proposed. Similarly, Obiro *et al.* (2012) found an increase in viscosity during long pasting of teff and maize starch in the presence of stearic acid. Bejosano *et al.* (1999) reported inclusion of 9% amaranthus and buckwheat proteins to increase the peak viscosity of maize starch paste. Proteins were suggested to have exerted a stabilizing effect on starch granule integrity.

Determination of viscosity in complementary porridges

Viscosity of complementary foods has received considerable attention as one of the important sensory attributes (Mouquet and Tréche, 2001). Viscosity of complementary porridges has been described in two ways: Using instrumental measurements such as a rotational rheometer (Onyango *et al.* 2004), Rapid Viscoanalyser (Rombo *et al.* 2001) Bostwick consistometer (Mouquet-Rivier *et al.* 2008); or using quantitative sensory descriptors by a trained sensory panel (Kayitesi *et al.* 2010). However, the available literature on instrumental findings differs due to variations in experimental conditions such as shear rate, shear time and temperature (Mouquet and Tréche, 2001). Table 2.2 illustrates some of the available literature on viscosity of complementary porridges.

b) Poor protein quality

Protein value of complementary porridges is dependent on protein content, protein digestibility and quantities of essential amino acids (FAO/WHO/UNU, 1985). Based on these criteria, the protein quality of complementary porridges prepared from cereals, roots and tubers is poor. For instance, cassava is grossly deficient in protein (1-2%) (Eke *et al.* 2008; Montagnac *et al.* 2009). In addition, cassava roots have phytate that bind protein preventing their complete enzymatic digestion (Montagnac *et al.* 2009). Cereals contain 7-13% protein (Morro *et al.* 1996). Protein digestibility is a measure of the proportion of nitrogen that would be absorbed after ingestion of a protein containing food (Damodaran, 1996). Duodu *et al.* (2002) found the *in vitro* protein digestibility (IVPD) of tannin free sorghum porridge to be 52-66% depending on variety.

Table 2.2: Compilation of qualitative sensory descriptions of porridge viscosity as related to instrumental determination available in literature

<i>Description</i>	<i>Qualitative definition</i>	<i>Viscosity range (Pa.s)</i>	<i>Measuring conditions</i>	<i>Reference</i>
Drinkable	With consistency of yoghurt	< 1	Haake VT500, measuring system SV-Din spindle , shear rate = $83s^{-1}$ porridge temperature= 45 °C	Tréche and Mborne, 1999
Spoonable		>1 <3		
Thick		>3		
Free flowing liquid		<1	Broofield syncholectic rheometer	Gopaldas <i>et al.</i> (1988)
Soup-like		>1<3	Temperature (35-40°C)	
Easily spoonable		>3<6	Shear rate not reported	
Thick, batter-like		>6<10		
Very thick		>10<40		
Non-spoonable dough-like		>40		
Watery		<1	UM Physical Rheometer, Shear rate - $35-64s^{-1}$, Temp = 40° C	Onyango <i>et al.</i> (2004)

Anyango *et al.* (2011) reported IVPD of fermented sorghum porridges prepared from tannin free and tannin sorghum varieties to range from 39-68%. Illustration of limitation of protein quality in traditional African complementary porridge using sorghum porridge was chosen because sorghum porridge is a common complementary food in sub-Saharan Africa, where malnutrition exists. Finger millet, which is another popular cereal used to prepare complementary porridges, contains antinutritional factors like tannins and trypsin inhibitors that have been shown to reduce protein digestibility (Usha and Chandra, 1998).

Protein Digestibility Corrected Amino Acid Score (PDCAAS) was adopted by FAO/WHO as the preferred method for the measurement of protein value in human nutrition. Determination of PDCAAS combines the quantity of the first limiting amino acid (in reference to the recommendations of a target consumer group) and the protein digestibility of food (WHO/FAO/UNU, Consultation Expert, 2007). The following equation is used in determining PDCAAS:

$$\text{PDCAAS (\%)} = \frac{\text{mg of limiting amino acid in 1 g of test protein} \times \% \text{ protein digestibility}}{\text{mg of same amino acid in 1g of reference protein}}$$

Due to the relatively low IVPD, Anyango *et al.* (2011) found the PDCAAS of fermented sorghum porridge ranged between 9% for the porridge prepared from tannin sorghum and 35% for the porridge prepared from tannin free sorghum. These ranges of PDCAAS fall far below the recommended value of >70% for children aged 1 to 2 years (FAO/WHO, 1994).

The protein quality of cereals, roots and tubers is further compromised because of low content of amino acids. For instance, the lysine content of cereals, roots and tubers, which is the most limiting amino acid is about 2-3% (Prasanna *et al.* 2001), which is less than half the concentration required during complementary feeding of 5.2% (WHO/FAO/UNU, Expert Consultation, 2007). Table 2.3 is a comparison of essential amino acids of common basic ingredients of traditional complementary porridges and the recommended pattern for children aged 1-2 years.

Table 2. 3: Approximate content of essential amino acids of common basic ingredients of traditional complementary porridges (g/100g protein) and recommended essential amino acid requirements for a 1 - 2 year old child (WHO/FAO/UNU, Consultation expert, 2007)

<i>Essential amino acids</i>	<i>Sorghum^a</i>	<i>Finger^b Millet</i>	<i>Maize^c</i>	<i>Cassava^d</i>	<i>WHO standard^e</i>
Histidine	2.2	2.6	2.7	2.7	1.8
Isoleucine	3.8	5.1	3.4	1.0	3.1
Leucine	13.2	13.5	12.2	11.7	6.3
Lysine	2.0	3.7	3.1	2.6	5.2
Methionine	1.5	2.6	6.7*	1	2.6*
Phenylalanine	4.8	6.2	9.1‡	1	4.6‡
Theonine	3.1	5.1	3.4	1	2.7
Tryptophan	1.1	1.3	0.9	0.5	0.7
Valine	5.0	7.9	4.9	1.5	4.2

^aUSDA, (2008)

^bMcDonough *et al.* (2000)

^cZarkadas *et al.* (2000)

^dMontagnac *et al.* (2009)

^eWHO/FAO/UNU, (2007)

*Methionine and cysteine.

‡Phenylalanine and tyrosine. (Cysteine and tyrosine are not essential amino acids but they can spare the requirements for methionine and phenylalanine, respectively).

The amino acid lysine (Figure 2.2) is not only important as an essential amino acid but it is also the first limiting amino acid in cereals and tubers. It is also the most susceptible to damage during cooking, processing and storage (Moughan and Rutherford, 2008). This is because the free ϵ -amino group of lysine can undergo reaction with many compounds including reducing sugars, fats, vitamins, polyphenols and food additives (Hurrell *et al.* 1979). The reaction with reducing sugars (Maillard reaction); one of the most important reactions is discussed in detail (section, 2.4.3).

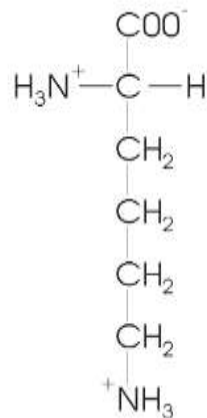


Figure 2.2: Chemical structure of lysine (Moughan and Rutherford, 2008)

Limited studies are available on available lysine of complementary porridges. Recently Anyango *et al.* (2011) reported 7-12% reduction in available lysine compared to lysine content of fermented sorghum porridges. During drum drying of infant food, Guerra-Hernandez *et al.* (1999) reported a 50 fold increase in furosine, an indicator of progress in Maillard reaction. Konstance *et al.* (1998) found up to 10% lysine reduction in corn-soy extruded blends as compared to unextruded blends. Iwe *et al.* (2004) found up to a 32% reduction in available lysine during extrusion cooking of sweet potato-soy flour extrudates. Thus, determination of the amino acid alone is likely to overestimate lysine in food.

2.2 Household approaches of improving the nutritional (protein and energy) and sensory quality of complementary porridges

Approaches that can be applied at home as well as at industrial level have been studied and applied in order to enhance the energy and protein quality of traditional African complementary porridges. Literature on improvement of cassava based complementary foods is scarce; thus improvement of mainly cereals will be reviewed.

2.2.1 Compositing cereals with legumes or oil seeds

Eliugui *et al.* (2007) evaluated 6 blends of maize: peanut or bean blends (70:30) after either germination or roasting or both. Compositing increased protein content in all the blends but the protein chemical score, also referred to as amino acid score remained below 1.0 indicating

that all amino acids were not met satisfactorily and therefore the blends were of low protein quality. Mosha and Vincent (2005) composited corn or sorghum with either beans, peanut or sardine and reported that the blends contained total essential amino acids in the ranges of 349-406 mg/g. These levels exceed the recommended content of total essential amino acids (339 mg/g) (FAO/WHO/UNU, 1985) by 2.9-19.8%. In addition, eight out of the nine composites exceeded the amino acid score recommendation of FAO/WHO/UNU (1985). These workers, however, noted that if protein digestibility was determined, the protein quality of the composite would be limited, although much better than without compositing.

Anyango *et al.* (2011) composited either tannin free or tannin sorghum with 30% cowpea and evaluated the *in vitro* protein digestibility (IVPD). These authors reported an increase in the range of 54-74% in IVPD of traditional sorghum foods containing tannin free sorghum while the ranges were 4-13% in tannin sorghum. These observations were attributed to replacement of poorly digestible sorghum kafirins (Hamaker *et al.* 1987) with highly digestible cowpea globulin proteins (Anyango *et al.* 2011). Bean (10-15%) and sardine (7%) were either blended with 50% cereals (maize, sorghum and rice) and subjected to conventional cooking, extrusion cooking or drum processing to produce a supplementary ready to eat food for children aged 2-5 years (Mosha and Bennink, 2005). In this study, lysine content was not significantly different between the processing technique, which was attributed to mild extrusion and drum processing conditions. However all the blends did not meet the recommended amounts of lysine (58 mg/g) for children aged 2 to 5 years. Available lysine was not determined in this study. All cooked blends had a PDCAAS > 60% which is the recommended level for children aged 2-5 years of age.

With regard to sensory attributes, addition of heat treated marama (a legume) flour increased overall aroma/flavour of sorghum porridges (Kayitesi *et al.* 2010). Roasted nutty aroma was more intense in porridges with heat treated marama flour as compared to the porridges with unheated marama flour (Kayitesi *et al.* 2010). However, Asma *et al.* (2006) reported that sorghum-cowpea porridges were less acceptable to the consumer (mothers) due to presence of beany flavour. Obatolu (2000) also reported low acceptability of soybean-maize porridges, which was attributed to presence of beany flavour.

Although compositing cereals and legumes enhances protein content of complementary porridges, composite porridges often exceed the recommended viscosity (1000-3000cP) and are therefore low in energy content. For example, using the RVA, Rombo *et al.* (2001) reported the viscosity of maize and bean composite porridge to be 10% higher than that of maize porridge at the same solids content (15%). At this solid concentration, the porridges also exceeded 3000cP (3616cP). Compositing cereals and legumes may also reduce IVPD due to introduction of anti-nutritional factors e.g. trypsin inhibitors from legumes (Mbiti-Mwikya *et al.* 2002).

2.2.2 Fermentation

Steinkraus (1997) defined fermented foods as “food substrates that contain edible microorganisms whose enzymes, particularly amylases, proteases and lipases, hydrolyze polysaccharides, proteins and lipids, respectively to form nontoxic products and produce flavours, aromas and textures that are pleasant and attractive to the consumer”. Fermentation causes degradation of the grain component especially starch by both intrinsic grain enzymes and enzymes emanating from microorganisms resulting in formation of simple sugars (Chavan *et al.* 1989). In this way, fermentation increases nutrient digestibility and causes reduction in viscosity and an increase in energy density. However, information on the effect of fermentation on viscosity is conflicting as some workers reported that fermentation did not reduce viscosity of porridges (Mouquet-Rivier *et al.* 2008; Onyango *et al.* 2004). Lorri and Svanberg (1993) reported a reduction in viscosity due to fermentation as indicated by an increase in solids content of porridge from 7% unfermented sorghum porridge to 15% in fermented porridge. The overall effect of fermentation on viscosity of porridge depends on the extend of breakdown of starch to simple sugars; which do not swell during cooking.

Taylor and Taylor (2002) evaluated the effect of fermentation on IVPD of five sorghum varieties. These workers found increases in IVPD after fermentation, which was attributed to modification of the protein structure that allowed more access by pepsin enzyme. Similarly, Onyango *et al.* (2004a) reported an increase in IVPD after fermenting maize-finger millet porridge. Osman *et al.* (2004) working on three sorghum varieties found a decrease in tannin and trypsin inhibitors while IVPD increased markedly after fermentation.

The most common household fermentation procedures are either spontaneous/natural or back slopping (Nout and Motarjemi, 1997). The main limitations of this method is marked differences in quality of porridges (Mouquet-Rivier *et al.* 2008) and possibility occurrence of food borne pathogens e.g. *Clostridium perfringens* and *Bacillus cereus* (Oguntoyinbo *et al.* 2011). In addition, fermentation may not allow for an increase in solids content within a viscosity that can be consumed by infants and young children (6-24 months) (Mouquet-Rivier *et al.* 2008; Onyango *et al.* 2004b).

2.2.3 Malting

Malting is a step-wise process that involves steeping, germination and drying (Taylor and Dewar, 2001). It results in hydrolysis of starch by α -amylase; β -amylase and limit dextrinases to simple sugars (Helland *et al.* 2002). The production of α -amylase, an enzyme that converts insoluble starch to soluble sugars, resulting in a thinning effect, is the most important nutritional effect of germination (Taylor and Dewar, 2001). Germination increases *in vitro* starch digestibility (IVSD) due to unfolding of protein structures and degradation of protein bodies during germination (Correia *et al.* 2008). These changes are accompanied by increases in total free sugars and free amino acids (Correia *et al.* 2008). Gahlawat and Sehgal (1994), working on malted complementary blend foods from wheat, barley and green gram reported 16-20% increase in starch digestibility and 17-32% increase in protein digestibility. Addition of a 5% malted mixture of sorghum and cowpea flour did not significantly ($p > 0.05$) influence sensory ratings (colour, aroma, taste, texture and overall acceptability) of porridges as rated by 20 mothers (Badau *et al.* 2005). Mtebe *et al.* (1993) observed an increase in consumer ratings for porridges prepared from cereals containing malted finger millet.

However, the malting technique at household level has some limitations. The high water activity of malted flour makes them susceptible to post-process contamination e.g. production of mycotoxins if fungi develop (Onyango *et al.* 2004b). The lengthy step-wise process may result in contamination of malt with pathogenic micro-organisms (Badau *et al.* 2005). Control measures must also be taken to avoid excessive loss of dry matter (Mbithi-Mwikya *et al.* 2001). Besides, the malt produced at household conditions is often variable (Tréche and Mouquet-Rivier, 2008).

2.3 Industrial approaches of improving the nutritional quality of complementary porridges

2.3.1 Irradiation

Farkas (2006) defined food irradiation as a process of exposing food to ionizing radiation such as gamma rays emitted from the radioisotopes cobalt-60 and cesium -137 or high energy electrons and X-rays produced by machine sources. The viscosity of irradiated maize-bean porridge (7.5kGy) was within the consumable range (1-3 Pa.s) at solids content of 20% if consumed at 40 °C. At the same temperature, unirradiated porridge (15% solids) had a viscosity of 3616 cP, which is higher than the consumable consistency. This reduction in viscosity was attributed to depolymerization of amylopectin to short, straight-chain molecules (Rombo *et al.* 2004). Lee *et al.* (2008) used γ -irradiation on porridges prepared from wheat, normal rice, waxy rice and maize and found irradiation of wet cooked porridge increased the possible solids content by 8% for wheat porridge and 80% for waxy rice porridge. At an irradiation dose of 20 kGy, these porridges maintained a viscosity of <3000 cP and contained a solids content of between 12g/100 g in maize porridge and 20g/100g in waxy rice porridge (Lee *et al.* 2007). The reduction in viscosity was suggested to be due to radiolysis of starch gel by radicals produced by gamma irradiation.

Gamma irradiation of sorghum flour at a dose of 10 kGy increased IVPD of wet cooked sorghum porridges by 12-18% (Fombang *et al.* 2005). It was suggested that irradiation modified the protein structure of sorghum that exposed more peptide bonds to pepsin hydrolysis (Fombang *et al.* 2005). However, at high irradiation dose (> 50kGy), IVPD was reduced probably due to crosslinking/aggregation of unfolded proteins (Fombang *et al.* 2005).

Using a trained panel of nine members, Pednekar *et al.* (2009) evaluated the acceptability of irradiated finger millet porridges. Porridges prepared from grains irradiated at a dose of 1 kGy were as acceptable as the control porridge (from unirradiated grains) in terms of appearance, colour, odour, taste, viscosity and overall acceptability. However, porridges prepared from grains irradiated at 5 kGy were less acceptable compared to the control in terms of aftertaste and viscosity (Pednekar *et al.* 2009). A panel of three trained panel members found semolina products irradiated at \leq 1kGy as acceptable in terms of appearance, colour, stickiness and overall acceptability as the control products (unirradiated). At 10 kGy,

the products were unacceptable due to excessive browning that was attributed to formation of melanoidins pigment due to occurrence of Maillard reaction (Azzeh and Amr, 2009).

Irradiation has a number of limitations; the initial costs and manning costs are prohibitively high (Farkas, 2006), especially to small and medium processors. At practical doses, irradiation does not inactivate enzymes (Diehl, 2001), which may be desirable while processing commodities such as soy-based products that require inactivation of enzyme e.g. lipoxygenase. Food irradiation may also result in undesirable changes in sensory properties of food (Thakur and Singh, 1995). Furthermore, the perception on wholesomeness of irradiated food has received mixed reactions especially from consumers (Farkas, 2006).

2.3.2 Use of commercial α -amylase

Commercial α -amylase could also be used to replace malting of cereals (Onyango *et al.* 2004b). The amount of commercial α -amylase required to achieve optimum viscosity in cereal-cassava composite porridges was 0.1-0.2% (Onyango *et al.* 2004b) as compared to 1-15% of malted flour that has been recommended to reduce viscosity of cereal and root crop porridges (Hansen *et al.* 1989). Addition of commercial α - amylase increased the possible solids content of porridges from 9% to 25% while maintaining an acceptable viscosity (Onyango *et al.* 2004b). Chakravarthi and Kapoor (2003) found bacterial and fungal amylase to effectively reduce viscosity at a concentration of 0.2% and 0.4% respectively. At these amylase concentrations, these authors reported 99% reduction in viscosity of cereal-legume porridges at 30% solids.

The taste and consistency of maize-bean porridges with α -amylase were more preferred by consumers (mothers) compared to porridge without α -amylase (Owino *et al.* 2007). This was attributed to breakdown of starch into maltose and dextrans that could have enhanced sweetness and reduced viscosity of the resultant porridges (Owino *et al.* 2007). However, compared to malting, use of commercial alpha-amylase may be costly.

2.3.3 Extrusion

Extrusion cooking is a high temperature short time process in which moistened, starchy and/or proteinacious food materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear, resulting in molecular transformation

and chemical reactions (Riaz, 2001). Extrusion cooking technology was used because it causes depolymerization of starch thus reducing viscosity of the resulting porridges. As indicated earlier, high viscosity in conventionally cooked complementary porridges is one of the causes of PEM. In addition, extrusion cooking results in instant or ready to eat complementary porridges that require minimal preparation time. Reduced preparation time of complementary foods is desirable in Africa as many mothers are now participating in the formal employment. Besides, extrusion cooking reduces antinutritional factors and enhances sensory properties. Extrusion cooking will be examined in detail in the following sections.

Application and mode of action

Extrusion cooking has some unique positive features compared with other heat processes because the material is subjected to intense mechanical shear. It is able to break the covalent bonds in biopolymers, and the intense structural disruption and mixing facilitate modification of functional properties of food ingredients and/or texturizing them (Riaz, 2001). During extrusion cooking, food materials are compressed within a cylinder by a piston and forced through a shaping orifice referred to as a die (Hauck and Huber, 1989). Materials are moved forward by rotation of screws from inlet to discharge as a result of the material slipping on the screw surface. Food extruders can either be single or twin screw in design; twin extruder can either be co-rotating or counter-rotating (Hauck and Huber, 1989).

Extruders have three processing zones namely: the feeding zone, transition zone and final cooking zone as shown in Figure 2.3. The feeding zone has screws designed to convey ingredients into the machine while in the transition zone materials are compressed to form plasticized dough or melt. The final cooking screw section allows high shearing and high compression; characterized by a visco-amorphous flowing mass (Hauck and Huber, 1989). Combination of screws in this section may be altered to achieve the desired functionalities (Harper, 1989). The die is the last restrictive element of the extruder, which causes the last pressure build-up to form the material before discharge (Ilo *et al.* 2000). Dies come in a wide variety and are selected as per required shape of the extrudates (Harper, 1989). Cutter knives are positioned at the end of the die to cut the extrudates into a specific length (Ilo and Berghofer 1999).

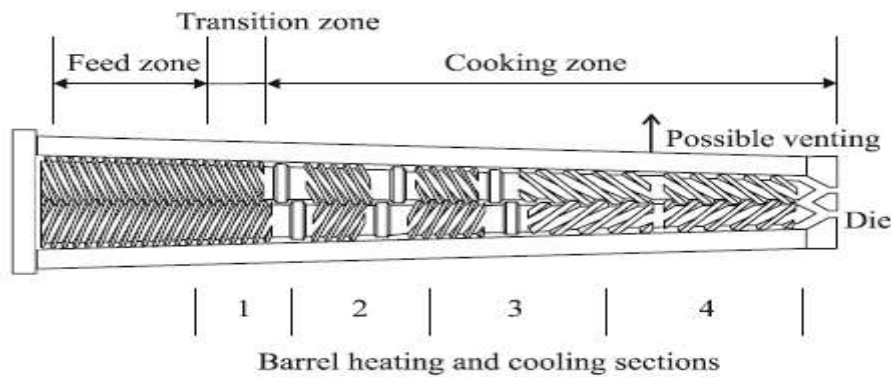


Figure 2. 3: Example of screw configuration in a co-rotating twin screw extruder (Ilo and Berghofer, 2000)

Extrusion cooking offers the food processor several advantages: it is a continuous process that combines various food processing steps like mixing, shearing, cooking and shaping, which eliminates the need for additional equipment. Extrusion cooking is versatile in the sense that parameters may be changed to suit the production of a wide range of products. Furthermore, extrusion cooking has minimal utility consumption such as electricity as cooking is a combination of mechanical shear and heat generated due to friction (Herpes, 1989).

2.4 Effect of extrusion cooking on nutritional quality (energy and protein) and sensory properties of complementary foods

2.4.1 Energy density/solids content

In part, contribution of complementary foods to energy depends on solids content of porridges. Onyango *et al.* (2004b) reported that extruded porridges could be prepared using 20% solids as compared to the conventionally cooked porridges that could be prepared using 9% solids. Bukusuba *et al.* (2008), working on extruded banana-soy composite complementary porridges found extruded flour to have 10% increase in energy density compared to conventionally cooked porridge. This increase in solids content and consequently energy density can be attributed to depolymerization of amylopectin during extrusion cooking (Bukusuba *et al.* 2008). Starch depolymerization is desirable in preparation of complementary foods because low molecular weight dextrans do not swell during reconstitution. In addition, extrusion cooking pre-cooks extrudates, which allows preparation of porridges of appropriate consistency at high solids content i.e. high energy density (Mouquet *et al.* 2003).

Starch depolymerization during extrusion cooking

Starch consists of two molecules that are closely packed in discrete granules. These are amylose, which is a linear polymer, and amylopectin, a highly branched polymer (Tester *et al.* 2004). Starch amylose has a helical structure made of glucose residues essentially linked by α - (1-4) glycosidic linkages (Figure 2.4 -a), whereas amylopectin consists of short linear chains branched by α (1-6) glycosidic linkages (Figure 2.4-b) (Tester *et al.* 2004). Selected parts of the macromolecules are shown below to illustrate fundamental differences in molecular structure.

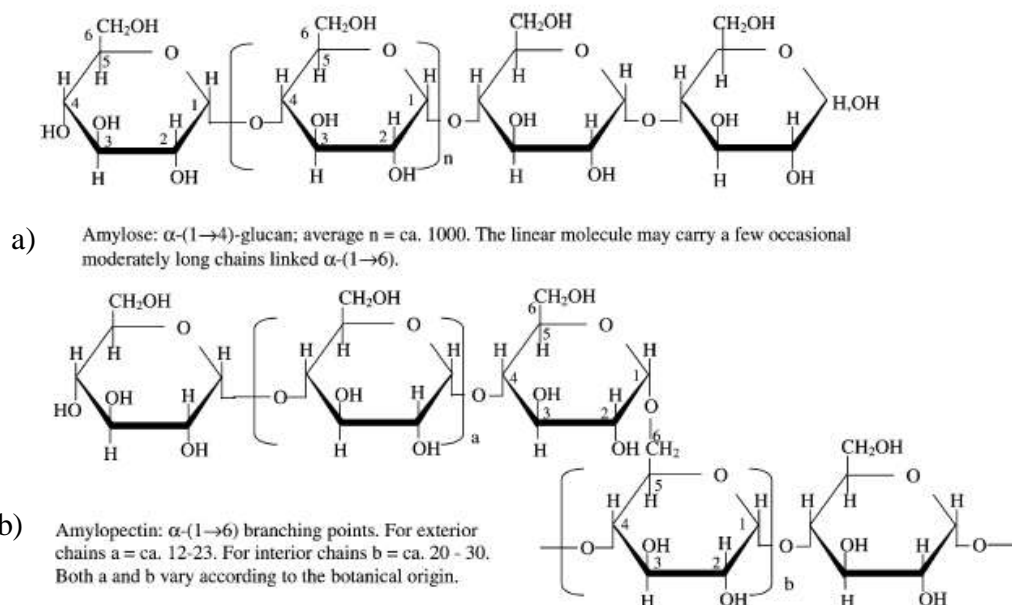


Figure 2. 4: Structure of amylose and amylopectin (Tester and Karkalas, 2002)

Liu *et al.* (2010) suggested that extrusion cooking leads to size dependent depolymerization of amylopectin as observed by highest depolymerization rate at the beginning of the extrusion process and gradual slowing down as the size of the polymer became smaller.

Extrusion cooking mainly depolymerized amylopectin while amylose did not seem to vary notably during extrusion of corn starch (Liu *et al.* 2010). This seem to be because amylopectin comprises of a large number of relatively short branches connected together to form a hyper branched structure (Figure 2.5). When one part of the molecule is subjected to shear force, the relatively low flexibility of a short branch means that the shear force cannot

be easily spread out to the entire molecule (Liu *et al.* 2010). A schematic diagram of amylopectin branching is shown below:

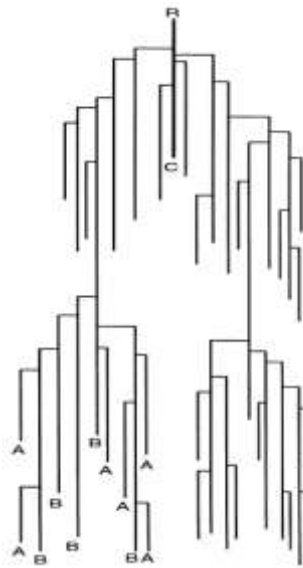


Figure 2. 5: A cluster model for the arrangement of amylopectin chains (A, B) indicates the position of A and B in one cluster and (C) indicates the position of the C chain in the molecule with its reducing end (R) (Source: Manners, 1989)

Evidence of macromolecular degradation during extrusion cooking is reduction in molecular weight distribution (Colonna and Mercier, 1983). Amylopectin depolymerization is directly correlated to specific mechanical energy (SME), while SME is inversely related to moisture (Mahasukhonthachat *et al.* 2010). When temperature exceeds 110-135°C extrusion cooking results in cooked products; whereby starch granule structure and starch crystallinity is destroyed (Mercier and Feillet, 1975).

2.4.2 Starch digestibility

Carbohydrates provide 45-65% of total energy intake, according to the United States Development Authority (Gao *et al.* 2005), indicating their role in human nutrition. However, the energy provided by a specific food cannot be accurately determined based only on its energy content alone due to variations in rate and extent of its digestion and absorption (Englyst *et al.* 2003; Jenkins *et al.* 1981). This is particularly applicable to infants. Infants are unable to synthesise adequate pancreatic α -amylase (Gillard *et al.* 1983) and their colon microflora is underdeveloped (Fuchs *et al.* 1996). Furthermore, infants are not able to ferment starch that escapes digestion for additional metabolic energy (Gillard *et al.* 1983). Despite this developmental inadequacy of the gastro-intestinal tract, energy needs increase during the

first two years of life (WHO/UNICEF, 1998). Thus, easily digestible starch would be preferred for complementary foods.

Extrusion cooking may positively or negatively affect starch digestibility and therefore contribution of extruded products to the overall energy provided by a portion of consumed food. This would depend on the extent of starch depolymerization, retrogradation and/or interaction of ingredients involved. Factors that have been shown to affect starch digestion in foods include degree of gelatinization, (Chung *et al.* 2006) amylose/amylopectin ratio (Vasanthan *et al.* 1998), starch-protein interaction (Jenkins *et al.* 1987), amylose-lipid complexes (Guraya *et al.* 1997; Jaisut *et al.* 2008) and amount of retrograded starch (Chung *et al.* 2006).

Nutritionally important starch has been divided into three groups: rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) (Englyst *et al.* 1992; Goni *et al.* 1997). The RDS and the SDS are digested in the small intestine while RS enter the large intestine undigested (Englyst *et al.* 1992). RS has been divided into four categories: physically inaccessible starch (RS₁), resistant starch granules (RS₂), retrograded amylose (RS₃) (Englyst *et al.* 1992) and thermally or chemically modified starch (RS₄) (Eerlingen and Delcour, 1995). Although the four types of resistant starch occur in foods at varying amounts, retrograded amylose appear to constitute the main source of resistant starch in processed foods (Englyst *et al.* 1992; Tovar and Melito 1996).

The available data on effect of extrusion cooking on formation of resistant starch is conflicting. Huth *et al.* (2000) and Unlu and Faller, (1998) reported formation of resistant starch during extrusion of barley and corn, respectively, while Ostergard *et al.* (1989) and Parchure and Kulkarni (1997) showed no formation of resistant starch during extrusion cooking of barley and rice, respectively. Formation of RS₃ has been observed during extrusion cooking of high amylose barley flour and not in low amylose barley flour (Vasanthan *et al.* 2002). Faraj *et al.* (2004) reported a decrease in RS₃ in waxy and barley flours when extruded at varying screw speed and moisture content. Interaction between extrusion conditions seems to determine whether resistant starch will be present in extruded products.

Food extrusion in the presence of high moisture may favour retrogradation of extrudates, resulting in reduction of starch digestibility (Mahasukhonthachat *et al.* 2010) due to formation of RS₃ (Englyst *et al.* 1992). Storage of extrudates at low temperature may favour recrystallization in extrudates, thus reducing starch digestibility (Hagenimana *et al.* 2006). Starch digestibility of extrudates may also be reduced due to formation of amylose-lipid complexes (De Pilli *et al.* 2006; Guraya *et al.* 1997) if starch is extruded in the presence of lipids. Hagenimana *et al.* (2006) found a decrease in enzyme hydrolysis of rice extrudates, which was attributed to presence of amylose-lipid complex as depicted by an endothermic peak at 103°C using a differential scanning calorimeter.

2.4.3 Effect of extrusion cooking on protein quality

The effect of extrusion cooking on protein quality can either be beneficial or detrimental to the physical and nutritional components of the extruded products. During extrusion, which involves intense shear forces and high specific mechanical energy; non-covalent interactions as well as covalent disulfide bonds between proteins are easily broken resulting in irreversible denaturation of protein (Arêas, 1992).

Heat treatment may increase lysine availability and protein digestibility due to unfolding of protein molecules that favours enzymatic attack and reaction with the test reagent (Kwok *et al.* 1998). Among the negative effects of extrusion cooking on protein include Maillard reaction (Björck and Asp, 1983).

Compared to increases in lysine availability, Maillard reaction (Figure 2.6) is of particular interest; it is a chemical reaction involving free amino groups of protein and carbonyl groups of reducing sugars (Singh *et al.* 2007) and leads to browning and flavour development (Millward, 1999). According to the reviews by Friedman (1996) and Moughan and Rutherford (2008), the initial step in Maillard reaction involves an irreversible condensation process, resulting in formation of a Schiff base. The Schiff base rearranges to a more stable ketoamine or Amadori products. Amadori products can then form cross-links between adjacent proteins or with other amino groups. The resulting polymeric aggregates are melanoidins (late Maillard products). This leads to a decrease in availability of amino acids

involved and a decrease in protein digestibility (Singh *et al.* 2007). Lysine appears to be the most reactive amino acid owing to the fact that it has two available amino groups (Singh *et al.* 2007). Lysine may thus serve as an indicator of protein damage during processing (Iwe *et al.* 2001). However, arginine, tryptophan, cysteine and histidine might also be affected by extrusion (Iwe *et al.* 2001). Reduction in lysine content during processing has nutritional implications because lysine is one of the essential amino acids that have carbon skeletons that cannot be synthesized to meet body needs from simpler molecules in humans, and therefore must be provided in the diet (National Academy of Science, 2005).

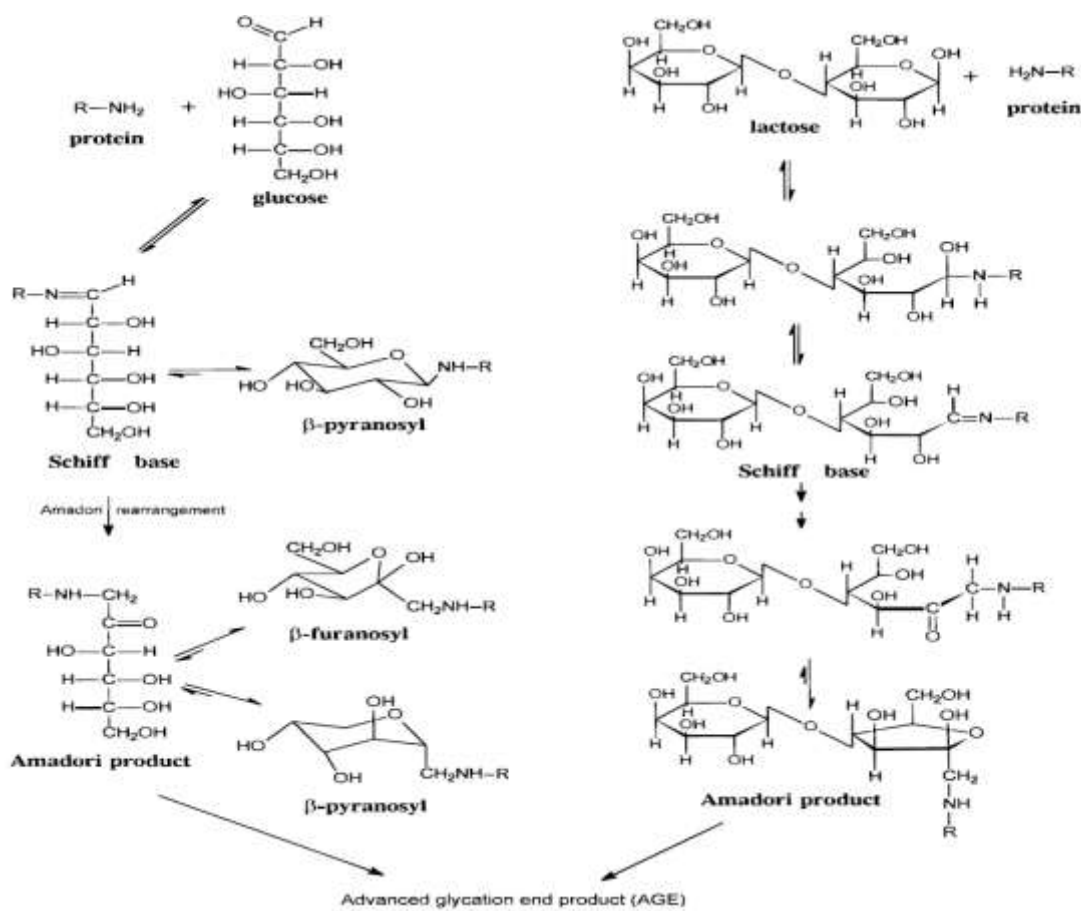


Figure 2. 6: The Maillard reaction: Glycation of protein NH₂ group by glucose or lactose (As reviewed by Friedman, 1996)

The overall effect of extrusion cooking on protein quality of extruded foods is affected by the extruder conditions and the composition of the feed stock. Table 2.4 shows some of the effects of extrusion conditions on lysine retention and protein digestibility.

Table 2.4: Effect of extrusion variables on damage of lysine and in vitro protein digestibility

<i>Extruder variable</i>		<i>Food source</i>	<i>Reference</i>
Lysine retention			
Screw speed	↑ with increasing screw speed	Defatted soy and sweet potato flour	Iwe <i>et al.</i> 2004
Die diameter	↓ with increasing die diameter	Defatted soy and sweet potato flour	Iwe <i>et al.</i> 2004
Temperature	↑ with decreasing temperature	Corn-soy flour blends	Konstance <i>et al.</i> 1998
Feed moisture	↓ with increasing feed moisture	Maize grits	Ilo and Berghofer, 2003
Protein digestibility			
Barrel temperature	↑ with increasing extrusion temperature	Corn-gluten-whey blend	Camire, 2001
Feed ratio	↑ increase with animal protein	Fish and wheat flour	Bhattacharya <i>et al.</i> 1988
Screw speed	↑ with increasing screw speed	Corn-gluten-whey blend	Camire, 2001

↑ increase, ↓ decrease

Onyango *et al.* (2004a) working on extruded maize-finger millet blends reported increases in IVPD after extrusion as indicated by reduction of the nitrogen solubility index from 10.97-5.26 in raw and extruded blends respectively. Hamaker *et al.* (1994) found extrusion cooking to increase IVPD of sorghum porridge from 46% in wet cooking to 79% in reconstituted porridges. Extruded corn-bean or sardine blend had the highest PDCAAS (86.4%), compared to conventional or drum processing which was attributed to improved access of digestive enzymes (Mosha and Bennink, 2005).

2.5 Sensory attributes of extruded porridges

Literature on extruded cassava porridge either singly or as a composite was not found. Literature on porridges from other ingredients is therefore reviewed. Extrusion of sorghum and cowpea at various ratios was reported to result in extrudates with colour values (L, a and b) similar to an extruded commercial baby porridge (Pelembé *et al.* 2002). Mosha and Bennink, (2005) found no significant difference between consumer overall sensory acceptability of extruded sorghum-bean-sardine and corn-bean-sardine porridges compared to conventionally cooked porridge containing either corn or sorghum.

Onyango *et al.* (2004) found extrusion cooking of sorghum flour resulted in porridges with acceptable consistency (< 3000cP) at a solids content of 25%. Wu *et al.* (2010) evaluated the flow behaviour of extruded flaxseed-maize blends and found a good fit to the power law model ($\sigma = K\dot{\gamma}^n$). Where σ the shear stress (Pa), K –value is the consistency index (Pa.s)ⁿ, and n is the power-law index (adimensional). The n - value indicates the extent of shear thinning behaviour (Bourne, 2002). High n -value at high solids content is desirable for infant feeding because it allows for an increase in nutrient density of porridges. The K value decreased with increase in moisture content of feed stock, which was attributed to plasticizer effect of moisture during extrusion that reduced mechanical shear and consequently degradation of starch granules. Undamaged starch granules have the capacity to absorb water and swell thus increasing viscosity and decreasing the n value (Wu *et al.* 2010). High K -value is thus undesirable for infant porridges as it indicates that low amount of flour would be required to prepare porridges within the viscosity that infants can consume.

2.6 Concluding remark

Studies focusing on improving traditional African complementary porridges have focused on cereals, with limited focus on starchy roots such as cassava, yet cassava is a staple in regions where PEM is prevalent. In addition, factors affecting protein quality of complementary porridges have often not been evaluated in combination within experiments. For example, most studies have focused on protein content, amino acids content and/or protein digestibility without focusing on available lysine and PDCAAS. Lysine is the most labile amino acid that

is vulnerable to Maillard reaction, thus determination of lysine content alone is likely to overestimate protein quality of complementary porridges.

In terms of starch, a focus has been given to increasing energy density and *in vitro* starch digestibility in cereal based complementary porridges. No studies on kinetics of starch digestion were found. Various workers have worked on extruded cereal-legume composites but not on cassava-legume composites. Work on rheological quality of extruded, reconstituted porridges meant for complementary feeding is lacking. Consequently, information on sensory quality and consumer acceptability of cassava or cassava-soy complementary porridges are not available. Cassava appears to be an important crop in Sub-Saharan Africa in terms of production and consumption but has poor properties as a complementary porridge. It is, therefore, worthwhile to improve its nutritional and sensory properties through approaches such as extrusion and compositing with legume.

2.7 Hypotheses and objectives

2.7.1 Hypotheses

1. Conventionally cooked porridge will have higher protein quality in terms of available lysine than extrusion cooked porridge because of severe Maillard reaction during extrusion cooking (Singh *et al.* 2007). Maillard reaction decreases available lysine (Friedman, 1996). However, extrusion cooking may increase protein digestibility due to unfolding of protein and mild denaturation (Raiz, 2001). Extrusion cooking of cassava and full fat soy flour composite will reduce *in vitro* starch digestibility of extruded porridge because of formation of amylose-lipid complexes (De Pilli *et al.* 2008) that inhibit access of α -amylase to starch during digestion (Cui and Oates, 1999).
2. Extrusion cooked porridges will have lower viscosity and gelling ability than conventionally cooked porridges due to depolymerization and reduced molecular re-association (Navarro *et al.* 1996). Extruded porridges containing defatted soy flour will have higher viscoelastic properties than the composite containing defatted soy flour with soy oil due to the filler effect of oil (Ndi *et al.* 1996).

3. Porridges prepared by extrusion cooking will have darker colour, more intense aroma and flavour compared to the conventionally cooked porridges. This will be due to occurrence of more Maillard reaction during extrusion cooking compared to during conventional cooking. This is because extrusion cooking will involve higher temperature and intense mechanical shear that will depolymerize starch to reducing sugars (Onyango *et al.* 2004; Camire, 2001; Cheftel, 1986). The reducing sugars will then react with amino groups in soy flour protein resulting in development of dark coloured Maillard reaction compounds, melanoidin (Millward, 1999) and volatile flavour and aroma compounds (Solina *et al.* 2007).
4. Nutritionally optimized porridges prepared by extrusion cooking will be more preferred by consumers (mothers of infants) than conventionally cooked porridges due to increased flavour (Solina *et al.* 2007). Flavour will be easily release during consumption since extrusion cooking will depolymerize amylopectin (Liu *et al.* 2010), which has been shown to hinder release of flavour and aroma compounds (Ruth and King, 2004). Depolymerization of starch will also allow for increase in solids content of porridge, which will further increase the intensity of flavour and aroma compounds.

2.7.2 Objectives

1. To determine the effect of adding soy flour and heat processing method (extrusion and conventional cooking) on nutritional quality (*in vitro* protein digestibility, amino acids profile, amino acids score, available lysine and *in vitro* starch digestibility) of cassava complementary porridge.
2. To determine the effect of adding soy flour and heat processing method (extrusion and conventional cooking) on the rheology (flow and viscoelastic properties) of cassava complementary porridge.
3. To determine the effect of adding soy flour and heat processing method (extrusion and conventional cooking) on descriptive sensory properties of cassava complementary porridge.
4. To determine the effect of adding soy flour and heat processing method (extrusion and conventional cooking) on acceptability of cassava porridge as a complementary food in target communities using mothers with children under 2 years.

3.0 RESEARCH

Thee research chapters are reported (sections 3.1, 3.2 and 3.3). The first section is an assessment of the effect of soy flour addition and heat processing method on nutritional and consumer acceptability of cassava complementary porridges. The second section has assessed the effect of adding soy flour and heat processing method on rheological properties of cassava complementary porridges. The final research chapter has evaluated the effect of adding soy flour and heat processing method on sensory properties of cassava complementary porridges.

3.1 Effect of soy flour addition (with and without soy oil) and heat processing methods on nutritional quality and consumer acceptability of cassava complementary porridges

Abstract

Nutritional quality of cassava complementary porridge improved though extrusion cooking and compositing with either defatted or full fat soy flour (65:35) and product acceptability by mothers with children of the target population was evaluated. Protein Digestibility Corrected Amino Acid Score (PDCAAS) of extruded and conventionally cooked composite porridges was within the recommendations for complementary foods. Kinetics of starch digestibility showed that all porridges had a rapid rate of starch digestibility, but the rates were lower than in 100% cassava porridge when defatted soy flour was added and lowest when soy oil was added. Formation of amylose-lipid complexes as shown by X-ray diffraction and differential scanning calorimetry can be attributed for the lower digestibility of extruded porridge with full fat soy flour. If fed thice per day, extruded porridge with defatted soy flour, and defatted soy flour with soy oil would meet the energy, protein and lysine (available) requirements of a child aged 6-8 months receiving low or average nutrients from breast milk. All the porridges were well received by Mozambican mothers who use cassava as staple food. The mean scores for sensory liking of all porridges were thee and above on a 5-point hedonic scale. Extruded cassava-soy flour porridges have a good potential for use as high energy and protein complementary foods; and have acceptable sensory properties.

This phase of the study has been published:

Muoki, P.N., DeKock, H.L., and Emmambux, N. M. (2012). Effect of soy flour addition and heat-processing method on nutritional quality and consumer acceptability of cassava complementary porridges. *Journal of the Science of Food and Agriculture* 92:1771-1779.

3.1.1 Introduction

Protein energy malnutrition (PEM) is a major health problem in Africa where complementary foods are based on starchy staple foods (Muller and Krawinkel, 2005). Any nutrient containing foods or liquids provided to young children along with breast milk are referred to as complementary foods (WHO/UNICEF, 1998). PEM mainly starts when complementary feeding is initiated (WHO/UNICEF, 1998). 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 (Maredia *et al.* 2000). Except for histidine and leucine, cassava flour is deficient in essential amino acids compared to the recommended intakes for 1-2 year –old children (Montagnac *et al.* 2009; WHO/FAO/UNU, 2007).

Addition of soybean (*Gycine max*), whose cultivation and consumption is gaining popularity in sub-Saharan Africa, may enhance protein quality of cassava complementary porridges. Soybean is high in protein (~ 40%) and has a good balance of amino acids that would complement the limiting amino acids in cassava (Zarkadas *et al.* 2007).

Extrusion cooking is a well-known heat processing technology used to produce ready to eat (instant), high energy dense cereal complementary porridge with a viscosity that is palatable by children (Onyango *et al.* 2004; Pérez *et al.* 2008). Extrusion cooking may either positively or negatively affect the protein and energy nutrition of extruded foods. Extrusion cooking has been shown to reduce amino acid content of food and lysine is the most affected (Hurrell *et al.* 1979; Iwe *et al.* 2004). The free ϵ -amino group of lysine can react with reducing sugars during Maillard reaction rendering lysine nutritionally unavailable (Huth *et al.* 2004) Extrusion cooking also enhances protein digestibility of food though protein denaturation, unfolding of polypeptide bonds and reduction in antinutritional factors (Björck *et al.* 1983).

The available literature on effect of extrusion cooking on starch, the main caloric source in food, is conflicting. Formation of resistant starch during extrusion of barley and corn has been reported; (Huth *et al.* 2000; Unlu and Faller, 1998), no formation of resistant starch was observed during extrusion cooking of barley and maize- lima bean flour blend, respectively (Parchure and Kulkarni, 1997; Pérez-Navarrete *et al.* 2008). Resistant starch escapes digestion in the small intestine and enters the large intestine (Goni *et al.* 1997). This information is of nutritional significance because infants have underdeveloped digestive system (Fuschs *et al.* 1996) and are not able to ferment starch in the colon for additional metabolic energy (Edward and Parret *et al.* 2002).

Cassava porridge has a distinctive slimy texture, long cohesive consistency and bland taste, (Radhika *et al.* 2008), which are lacking in commonly used cereal based complementary porridges. Further, extrusion cooking of cassava and soy flour is likely to cause Maillard reaction leading to development of colour and flavour (Björck *et al.* 1983). 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 focussed on cassava complementary porridges in terms of starch digestibility kinetics, available lysine, PDCAAS, and consumer sensory acceptability. Utilization of cassava-soy flour complementary porridges will not only depend on its nutritional quality but also consumer acceptability. Thus, this study aimed to determine the effect of soy flour addition and heat processing methods (conventional and extrusion cooking) on nutritional quality and consumer acceptability of cassava complementary porridges.

3.1.2 Materials and methods

Materials

3.1.2.1 Raw materials

The complementary porridges used in this study were prepared from cassava flour alone or composited with either full fat or defatted-toasted soy flour. To ensure that the raw material had 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, South Africa. Trypsin inhibitor was 1.5 ± 0.3

trypsin inhibitor units in the defatted soy flour as determined using method 22-40 (AACC, 2000).

Common method of preparing cassava flour was followed (Dziezoave *et al.* 2010). In brief, the steps indicated in the schetch below were followed.

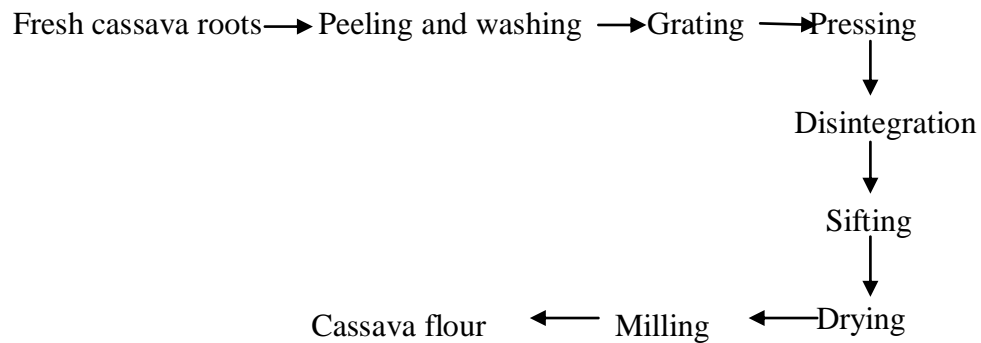


Figure 3.1. 1: Schematic diagram for preparation of cassava flour

The various steps were followed to reduce the amount of time spent in preparing the flour in order to reduce possibility of fermentation during drying. Pressing step ensured that cassava waste liquor is expelled out of the mash while sifting ensured that waste fiber was discarded. The total cyanide and acetone cyanohydrins content in the cassava flour was determined according to method described by Bradbury (Bradbury, 2009) were 5.6 ± 0.2 ppm and 2.7 ± 0.7 ppm respectively, which is below safe levels of 10 ppm (FAO/WHO, 1991).

3.1.2.2 Formulation of composites and reference samples

Ingredients used in preparation of the porridges were as follow based on dry weight: (1) 100% cassava flour (porridge used as the control sample) (2) 65% cassava flour and 35% defatted toasted soy flour (3) 65% cassava flour, 28% defatted toasted soy flour and 7% soy oil.

Cerelac, a commercial ready to eat complementary porridge for 6 month old infants was used as a reference was purchased from a retail supermarket in Pretoria, South Africa. The commercial porridge is a popular product among mothers. The main ingredients used prepare the reference were maize and milk.

The white wheat bread used as a reference in starch digestibility was purchased from a retail supermarket in Pretoria, South Africa. The ingredients used to bake the bread were wheat

flour, water, sugar and salt. The bread was purchased immediately after baking and transported to the laboratory within about 20 min. The bread was cut into small pieces using a kitchen knife.

Methods

3.1.2.3 Methods of heat processing

Conventional cooking

Complementary porridges (10% solids) were prepared following common practice in Africa (Kikafunda *et al.* 1998) with some modification. Water was boiled in a stainless steel cooking pot. Cold water was added to flour to make a smooth slurry and added to the boiling water while stirring. Cooking continued for 20 min, stirring every 5 min. Hot water was added to compensate for moisture lost during cooking. Freshly cooked porridges were used for analysis of *in vitro* starch digestibility to avoid occurrence of retrogradation that may lower starch digestibility. For the other analysis, 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 min to 1 h).

Extrusion cooking

Extrusion cooking was done using a Cleextral BC 45 co-rotating twin screw extruder (Cleextral Firminy, France). Freshly prepared composite formulations were conditioned overnight to a moisture content of 22%. Extruder conditions were: screw speed of 200 rpm, barrel temperature of 120 °C and 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, milled extrudates and reference were reconstituted using boiling water to a solids content of 10% and analysed immediately. For consumer acceptability study, porridges were reconstituted to 25% solids content. Porridges were kept at room temperature in covered cooking pots during testing session (30 min to 1 h). Immediately before serving, porridges were re-heated using a microwave at 360 Hz for 3 min in a plastic bowl and then served warm (40- 50°C).

Analysis

3.1.2.4. Proximate analysis

AACC (2000) methods were used to determine moisture (method 44.15A), fat (method 30-25), ash (method 08-01) and protein content ($N \times 6.25$) by Dumas combustion (method 46-30). Total starch was determined using Megazyme International Ireland, total starch assay kit, α -amylase/amyloglucosidase as described in AACC Method 76-13 (AACC, 2000) Gross energy was determined using a bomb calorimetric method (Smit *et al.* 2004)

3.1.2.5. Protein quality

Amino acids and available lysine content

Amino acids content of extruded porridges and freeze-dried conventionally cooked porridges was determined by the Pico-Tag method, which is a reverse phase HPLC method (Bidlemeier *et al.* 1984) after acid hydrolysis. The method described by (Hurrell *et al.* 1979) was followed to analyze available lysine using Crocein Orange G dye (70% dye content) (Fluka grade 27965: Sigma-Aldrich, Buchs, Switzerland).

In vitro protein digestibility (IVPD)

The pepsin method described by Hamaker *et al.* (1987) was followed to determine IVPD of extruded porridges and freeze-dried conventionally cooked porridges. Samples (200 mg) were digested with P7000-100G pepsin (activity 863 units/mg protein, Sigma-Aldrich, St Louis MO), for 2 h at 37 °C. The residual protein was determined by the Dumas combustion method.

Protein digestibility corrected amino acid score (PDCAAS)

The essential amino acid profile of the test porridges was compared with the essential amino acid requirement pattern for a 1–2-year-old child to compare the amino acid score. This was followed by calculation of PDCAAS according to the WHO/FAO/UNU consultative group (2007) equation as follows:

Amino acid score = mg of limiting amino acid in 1 g of test protein/ mg of the same amino acid in 1 g reference protein

PDCAAS= protein digestibility (%) \times Amino acid score.

3.1.2.6 *In vitro* starch digestibility

Starch digestion of porridges was determined according to the method proposed by Goni et al. (1997) with modifications. In-vitro starch digestion was measured immediately after cooking for conventionally cooked porridges and after addition of boiled water for extrusion cooked porridges to avoid any effect of starch retrogradation. A sample of 50 mg was used per assay. Ten (10) ml of HCl–KCl buffer was added to the sample and the mixture was homogenized using a vortex mixer. Then, 0.2 ml of a solution containing 1 mg of pepsin (Sigma-Aldrich P7000-100G) in 10 ml HCl–KCl buffer at pH 1.5 was added into each sample. This was followed by 60 min incubation at 40°C in a shaking water bath. The volume was adjusted to 25 ml by adding 15 ml tris-maleate buffer (pH 6.9).

The hydrolysis was started by addition of 5 ml tris-maleate buffer containing 2.6 IU of α -amylase from porcine pancreas with activity of 19.6 units/mg (Sigma-Aldrich A-3176) to each sample. The flasks were placed on a shaking water bath at 37 °C. Aliquots of 0.1 ml were taken at 0 and 5 min and thereafter at an interval of 30 min until 3h. Inactivation of α -amylase was by placing the tubes in boiling water for 5 minutes. Thereafter, 1 ml of 0.4M sodium-acetate buffer at pH 4.75 and 60 μ l of amyloglucosidase from *Aspergillus niger* with an activity of 64.7 U/mg (Fluka-10115) was added to hydrolyze the solubilized starch. Samples were then incubated at 60°C for 45 min.

Finally the glucose concentration was measured using glucose oxidase peroxide (Sigma-Aldrich GAGO-20). The rate of hydrolysis was expressed as a percentage of the total starch hydrolyzed at different times within 3h. White wheat bread was used as the reference sample and analyzed like the other samples within 20 min of baking to avoid retrogradation. The formula below was used to calculate starch digestibility.

Starch digestibility (%) = Mg starch digested/mg starch in porridge sample \times 100

The rate of starch digestion was expressed as the percentage of the total starch digested at different times (0, 5, 30, 60, 90, 150 and 180 minutes) (Goni *et al.* 1997). Classification of starch based on digestibility was consistent with that described by Englyst *et al.* (1992) with slight modification. Rapidly digestible starch (RDS) is the starch digested within 30 min of incubation, slowly digested starch (SDS) is that which is digested between 30 and 120 min of

incubation and resistant starch (RS) is the amount of starch not digested after 120 min of incubation. A fourth category of very rapidly digestible starch was also identified (Chung *et al.* 2006).

Estimated glycemic index

A non-linear model established by Goni *et al.* (1997) was used to describe the kinetics of starch hydrolysis:

$$C = C_{\infty}(1 - e^{-kt}) \quad (1)$$

Where C is concentration at time t, C_{∞} is the percentage of starch hydrolysed after 180 min, k is the kinetic constant (min^{-1}) and t is the time (min). The parameters k and C_{∞} were estimated for each treatment based on the data obtained from the *in vitro* hydrolysis procedure. Equation 2 used by Jaisut *et al.* (2008) was used to calculate the area under the hydrolysis curve (AUC)

$$\text{AUC} = C_{\infty}(t_f - t_0) - (C_{\infty}/k)(1 - \exp(-k(t_f - t_0))) \quad (2)$$

Where t_f is the final time (180 min) and t_0 is the initial time (time 0). Hydrolysis index (HI) is defined as the area under the hydrolysis curve of treated sample divided by the corresponding area of white bread. The glycemic index was estimated using the equation of Goni *et al.* (1997) as follows:

$$\text{GI} = 39.71 + 0.549\text{HI}$$

3.1.2.7. X-ray diffraction

Samples were prepared for X-ray diffraction (XRD) analysis using back loading method. The samples were analysed with a PANalytical X'Pert Pro Powder Diffractometer (Ostfildern, Germany), with an X'Celerator detector. The diffractometer was equipped with variable divergence and receiving slits using Fe filtered Co-K α radiation (1.78901 Å) and operated at 35 kV and 50 mA. Samples were scanned at 25 °C with 2 θ in the range 2-90°. Diffractograms were interpreted using X'PertHigh score Plus software.

To calculate total % crystallinity, X-ray diffractograms were normalized using Origin-pro 7.5, (Originlab Corporation, Northampton, USA) software. Total percentage 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 (Mutungi *et al.* 2009).

3.1.2.8 Thermal properties

Thermal analyses were done using a differential scanning calorimeter (DSC) (HP DSC 827e, Mettler Toledo, Schwerzenbach, Switzerland). Sample (5 mg) was weighed into an aluminium sample pan (40 μ l) and 15 μ l of water was added. Samples were equilibrated overnight at room temperature. The measurements were done using a heating rate of 10 $^{\circ}$ C/minute between 40 $^{\circ}$ C and 125 $^{\circ}$ C. The instrument was calibrated using indium; and an empty aluminium DSC pan was used as a reference.

3.1.2.9 Determination of colour

The colour of freshly prepared porridges was assessed using a Choma Meter CR 400 (Konica, Minolta Sensing, Osa, Japan). The CIE-LAB system for colour values L* a* and b* were recorded. The L* value gives a measure of lightness of the product from 100 for perfect white and zero for black. The a* value accounted for redness (+) and greenness (-) while b* values accounted for yellowness (+) and blueness (-), respectively. A white tile (L= 96.76, a= 0.12 and b=1.80) was used to calibrate the colour meter before use. Hue angle was calculated as $\text{Tan}^{-1} (b^*/a^*)$.

3.1.2.10 Consumer sensory evaluation

Females (n = 122) aged 20 -38 years with children aged below 2 years participated in the study. They were recruited from six peri-urban health centres in Nampula and Zambezia 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 Zambezia. Porridge (\pm 50 g) was served at 40-50 $^{\circ}$ C in 125 ml plastic cups. Plastic spoons were used to evaluate the porridges. Samples were blind-coded with three-digit random numbers. Order of serving was randomized per session; consumers (n= \pm 25) within a session evaluated all six porridges. Consumers expressed their liking of colour, consistency, smell, taste and overall acceptability using a 5-point hedonic scale: 1=dislike to 5=like very much. Water was provided at room temperature to clean the mouth between samples.

3.1.2.11 Data analysis

Analysis of variance (ANOVA) was used to determine the effect of soy flour addition and heat processing methods on nutritional attributes and parameters of kinetics of *in vitro* starch digestion using Statistica Version 9.0 (Statsoft, Tulsa, OK, USA). Cooking methods 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 analysed using one-way ANOVA. The means were separated using Fischer's Least Significant Difference (LSD) test.

3.1.3. Results

3.1.3.1. Nutrient composition and protein quality

The nutrient composition of cassava-soy porridges is shown in Table 3.1.1. As dry weight basis, the energy content of all porridges ranged between 1404KJ g /100g in conventionally cooked cassava porridge and 1682 KJ g /100g in conventionally cooked porridge with defatted soy flour and soy oil. Addition of defatted soy flour with soy oil led to 20 and 26 fold increase in extractable fat content for extrusion and conventionally cooked porridges, respectively compared to cassava porridge.

Available lysine was lower than lysine content by 22% and 11% in extruded and conventionally cooked porridges containing defatted soy flour, respectively (Table 3.1.1).

In porridges containing defatted soy flour with soy oil; the decrease in available lysine compared to lysine content was 25% and 9% in extruded and conventional cooked porridges, respectively. The IVPD of extruded porridge with defatted soy flour and with defatted soy flour and soy oil was 9% and 12% higher than in corresponding conventionally cooked porridges. The PDCAAS increased two fold in conventionally cooked composite porridges compared to cassava porridge. The PDCAAS in extruded porridges increased by 35% and 67% for porridges containing defatted soy flour, and defatted soy flour with soy oil, respectively compared to extruded porridge containing cassava only.

Table :3.1 1 Effect of adding soy flour and heat processing on total starch, fat, energy content and protein quality Effect of adding (protein content, lysine and available lysine content, lysine score, *in vitro* protein digestibility (IVPD), and Protein Digestibility Corrected Amino Acid Score (PDCAAS), of cassava complementary porridges (dry weight basis)

Type of Porridge	Total Starch g kg ⁻¹	Fat g kg ⁻¹	Energy (Mj) g kg ⁻¹	Protein (N×6.25) g kg ⁻¹	^φ Lysine (g 100 g ⁻¹ protein)	Available lysine (g 100g ⁻¹ protein)	% IVPD	Lysine score	*PDCAAS	
Cassava	870.0e ± 10.7	2.0a ± 0.5	14.0a ± 0.14	25.7a ± 0.7	2.8a ± 0.0	nd	59.9a ± 8.3	0.53	0.31	
Conventional cooking	With defatted soy flour	591.9c ± 23.6	2.2a ± 0.6	15.4c ± 0.0	164.0d ± 2.3	5.4c ± 0.2	4.8b ± 0.0	83.8b ± 5.4	1.03	0.76
	With defatted soy flour and soy oil	551.3b ± 8.4	52.3d ± 1.8	16.8d ± 0.2	137.3b ± 2.7	5.3c ± 0.2	4.8b ± 0.2	78.5b ± 7.1	1.01	0.80
Extrusion cooking	Cassava	877.6e ± 5.0	1.9a ± 0.7	14.5b ± 0.2	22.3a ± 0.7	3.3b ± 0.0	nd	86.5b ± 1.4	0.63	0.56
	With defatted soy flour	609.0c ± 14.2	2.1a ± 0.2	15.3c ± 0.9	160.2d ± 5.9	5.4c ± 0.5	4.2a ± 0.5	92.8c ± 4.3	1.03	0.83
	With full fat soy flour	563.2b ± 13.7	39.6b ± 0.5	16.6d ± 0.2	130.1b ± 7.3	5.3c ± 0.4	4.0a ± 0.2	90.7c ± 2.5	1.01	0.94
Reference	376.8a ± 30.4	45.7c ± 1.8	17.0b ± 0.1	149.8c ± 5.0	6.8d ± 0.3	6.4c ± 0.0	93.3c ± 2.2	1.30	1.00	

Values are means ± standard deviation of 3 independent experiments. Values within the same column followed by different letters are significantly different ($p \leq 0.05$)

Cassava - 100% cassava flour

With defatted soy flour - 65% cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil - 65% cassava flour, 28% defatted soy flour and 7% soy oil

Reference - Commercial ready to eat complementary porridge

nd- Not determined because amino acids Histidine and Arginine were not detected (Hurrell *et al.* 1979)

^φLysine score-Based on a 52 mg/g protein requirement for a 1-2 year old child (WHO/FAO/UNU, 2007)

*PDCAAS = Amino acid score × IVPD/100

3.1.3.2 Kinetics of starch digestion

Heat processing method and compositing significantly ($p < 0.05$) influenced starch digestion of porridges (Figure 3.1.1). Preliminary analysis indicated a rapid digestion rate in all the porridges. This prompted sampling after 5 min of digestion. The starch digestion after 5 min was 77.6, 67.7 and 50.2% in extruded cassava porridges, porridge with defatted soy flour and with defatted soy flour and soy oil, respectively. The corresponding values for conventionally cooked porridges were 66.0, 64.2 and 57.1%, respectively. The hydrolysis time to reach the maximum starch digestion was within 60 min in all the porridges.

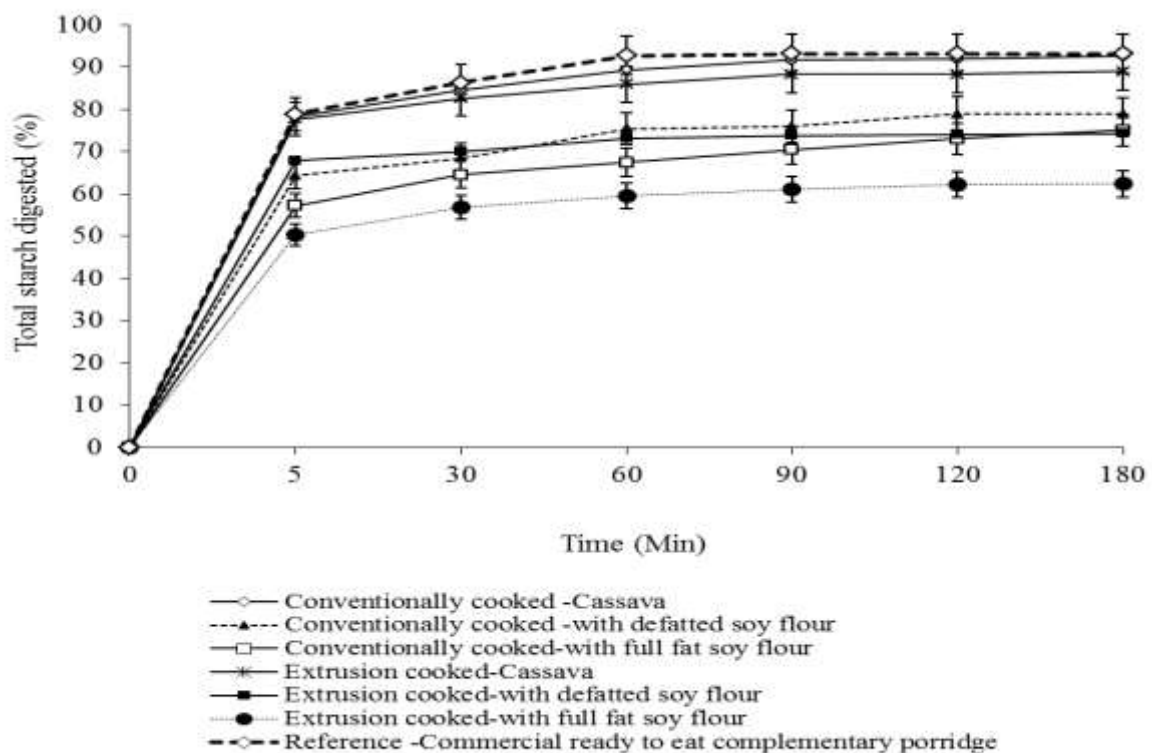


Figure 3.1. 2: Effect of adding either defatted soy flour or defatted soy flour with soy oil and heat processing methods on kinetics of starch digestion of cassava complementary porridges.

Cassava-100% cassava flour

With defatted soy flour -65% cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil - 65% cassava flour, 28% defatted soy flour and 7% soy oil

Bars are standard deviation of 3 independent experiments.

The total starch digested (TSD) was significantly ($p < 0.05$) reduced by addition of either defatted soy flour, or defatted soy flour with soy oil (Table 3.1.2). Extruded porridge with defatted soy flour and soy oil showed the lowest TSD (62%). Extruded porridges containing

defatted soy flour with soy oil showed the lowest kinetic constant (k) value (0.061) indicating the highest resistance to digestion by α -amylase. Extruded cassava porridge showed the highest k -value (0.092). The k -value can be related to glycemic index (GI) (Goni *et al.* 1997). The GI value ranged between 90 in extruded porridge with defatted soy flour and soy oil and 119 in conventionally cooked porridge with defatted soy flour.

3.1.3.4 X-ray diffractogram and thermal properties

The X-Ray diffractograms of raw formulations had peaks at $2\theta = 20.4, 22.6, 23.9$ and 29.9° (Figure 3.1.2). These peaks are a mixture of A and B polymorph starches (Mutungi *et al.* 2011). Conventionally cooked porridge seemed mainly amorphous; with no clear peaks. Extruded cassava porridge and porridge with defatted soy flour had peaks at $2\theta = 15.1$ and 23.2° . Extruded porridge with defatted soy flour and soy oil had peaks at $2\theta = 7.9, 13.0, 15.3, 20.4$ and 23.3° . Peaks at $2\theta = 7.9$ and 13° have been associated with presence of amylose-lipid complexes (Godet *et al.* 1995). The total crystallinity of uncooked formulations was 30%. For extruded cassava porridge, porridge with defatted soy flour and porridge with defatted soy flour and soy oil, the total crystallinity was 16, 17 and 19%, respectively. Total crystallinity of conventionally cooked porridges was not determined because they were mainly amorphous.

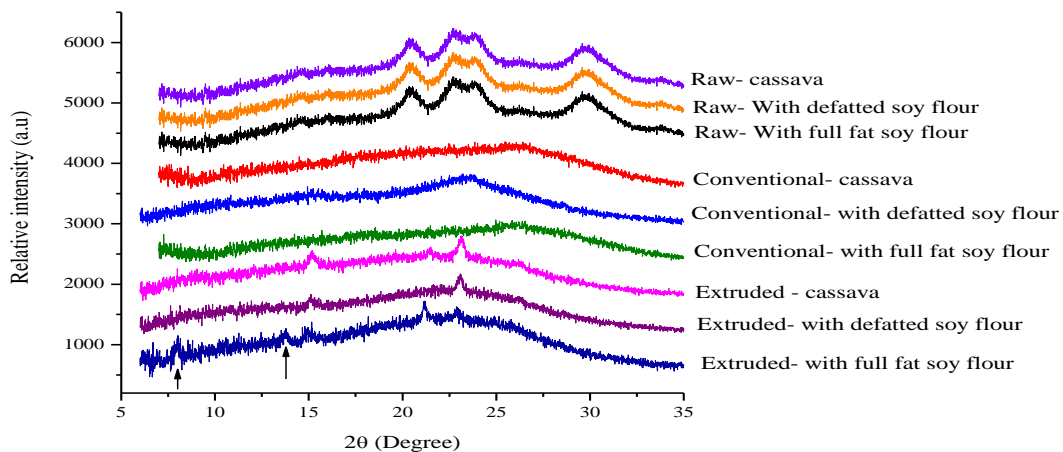


Figure 3.1. 3: Effect of adding either defatted soy flour or defatted soy flour with soy oil and heat processing methods on X-ray diffraction pattern of cassava complementary porridges

Arrows show peaks related to amylose-lipid complexes Godet *et al.* 1995; Shetha *et al.* 2010

Cassava-100% cassava flour

With defatted soy flour -65% cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil - 65% cassava flour, 28% defatted soy flour and 7% soy oil

Table 3.1 1: Effect of soy flour and heat processing methods on kinetic parameters of in vitro starch digestion of cassava complementary porridges

	Type of porridge	C_{∞} (%)	k (Min^{-1})	HI (%)	GI
	Cassava	92.5d \pm 2.0	0.091ab \pm 0.00	128.4c \pm 2.3	110.4de \pm 0.5
Conventional cooking	With defatted soy flour	78.8bc \pm 0.9	0.069ab \pm 0.00	114.0b \pm 0.9	102.7bcd \pm 1.6
	With defatted soy flour and soy oil	75.0b \pm 0.9	0.061a \pm 0.00	106.0b \pm 1.1	103.3bc \pm 2.1
Extrusion cooking	Cassava	89.3d \pm 2.8	0.092b \pm 0.01	144.9d \pm 0.7	119.2e \pm 0.5
	With defatted soy flour	73.6b \pm 1.4	0.085ab \pm 0.01	115.6b \pm 0.9	104.1cd \pm 0.5
	With defatted soy flour and soy oil	62.3a \pm 2.5	0.072ab \pm 0.00	98.8a \pm 1.1	90.1a \pm 0.5
	Reference	93.1d \pm 3.0	0.065ab \pm 0.01	142.8d \pm 1.0	118.3e \pm 0.5
	White bread	62.9a \pm 2.5	0.069ab \pm 0.01	97.7a \pm 0.3	94.6ab \pm 1.9

Values are means \pm standard deviation of 3 independent experiments. Values within the same column followed by different letters are significantly different ($p \leq 0.05$).

Cassava-100% cassava flour

With defatted soy flour -65% cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil - 65% cassava flour, 28% defatted soy flour and 7% soy oil

Reference- Commercial ready to eat complementary porridge

C_{∞} = % starch digested after 180 min

HI, k and GI were calculated from the equation: $AUC = \frac{C_{\infty}}{k} (1 - \exp(-k(t_r - t_0)))$ proposed by Goni *et al.* 1997

White bread was used as the reference for calculating GI

3.1.3.4 Thermal properties

Figure 9 shows the DSC thermograms of milled extrudates and freeze-dried conventionally cooked porridges heated from 40°C to 125 °C. A transition endotherm occurred in extruded porridge with defatted soy flour and soy oil only. The onset temperature and end set temperature were 106.5 °C and 108.5 °C, respectively. This endotherm peak has been associated with melting of crystalline amylose-lipid complex (Biliaderis and Galloway, 1989).

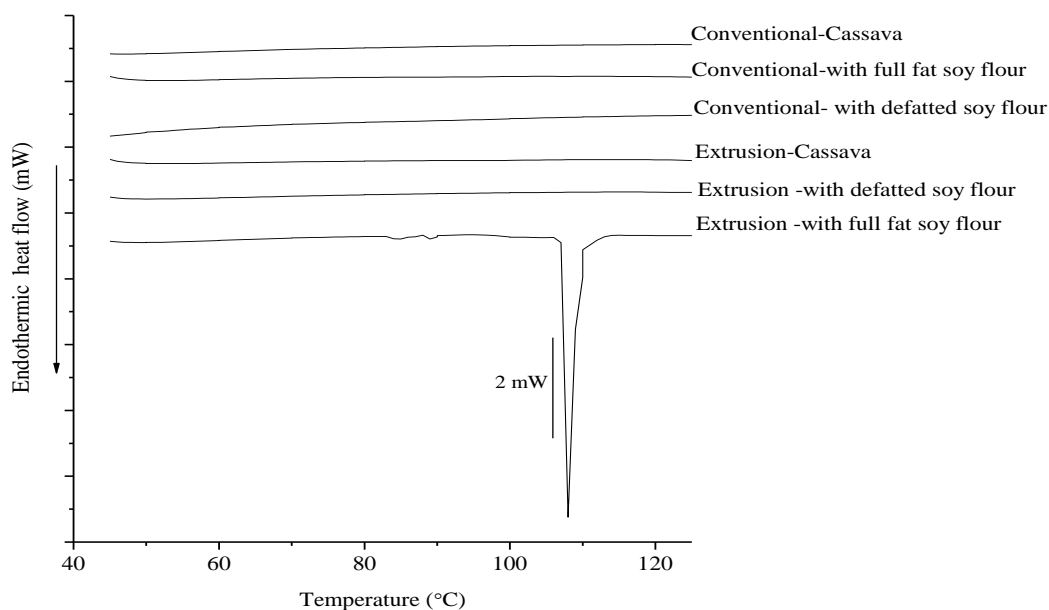


Figure 3.1. 4: Effect of adding either defatted soy flour or defatted soy flour with soy oil and heat processing methods on DSC thermogram of cassava complementary porridges

Cassava-100% cassava flour

With defatted soy flour -65% cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil - 65% cassava flour, 28% defatted soy flour and 7% soy oil

3.1.3.5. Colour (L, a, b values)

Extrusion cooked porridges had higher L, + a* and + b* values compared to the corresponding conventionally cooked porridges (Table 3.1.3). Extrusion cooked porridges with defatted soy flour and soy oil were more red and yellow (higher +a* and +b* values, respectively) than the other extrusion cooked porridges. Porridges with defatted soy flour and soy oil (both extrusion cooked and conventionally cooked) were significantly lighter ($p < 0.05$) as indicated by higher L* values, compared to the corresponding cassava porridges and

porridges with defatted soy flour. Extrusion cooked cassava had significantly lower hue angle compared to extrusion cooked porridge with defatted soy flour and with defatted soy flour and soy oil.

3.1.3.6 Porridge acceptability by mothers

The mean consumer sensory acceptability scores were three and above on a 5-point hedonic scale for all sensory attributes (Table 3.1.3). Conventionally cooked composite porridges were liked significantly more ($p < 0.05$) than cassava porridges. The average ratings for conventionally cooked porridge with defatted soy flour and with defatted soy flour and soy oil were not significantly different for all attributes. Consumers rated extruded cassava porridge higher than the composite porridges for all sensory attributes. Extruded porridge with defatted soy flour and soy oil was, on the contrary, rated significantly lower ($p < 0.05$) for all sensory attributes except overall acceptability. The overall liking of extruded porridge with defatted soy flour had the highest variability as indicated by wide distribution of scores.

3.1.4 Discussion

The decrease in available lysine compared to lysine content was higher (~10%) in extrusion cooked composite porridges compared to the corresponding conventionally cooked porridges. Reduction in available lysine (0-32 %) in sweet potato-soy flour extrudates has been reported (Iwe *et al.* 2004). The decrease could be due to occurrence of Maillard reaction between ϵ -amino group of lysine and carbonyl group of reducing sugar (Moughan and Rutherford, 2008). Low moisture content during extrusion may have favoured occurrence of higher Maillard reaction than in conventional cooking (Bjöck *et al.* 1983). The PDCAAS of cassava composite porridges (extruded and conventionally cooked) were >70%; the recommended minimum level for complementary foods (FAO/WHO, 1994). The fat content of all cooked porridges was lower than in the uncooked formulations. Formation of amylose-lipid complexes as indicated by Figure 3.1.2 and 3.1.3 could have contributed to the reduced fat recovery.

Table 3.1 2: Effect of compositing on colour and consumer sensory ratings of cassava-soy flour porridges

Type of porridge		Colour (L, a b values)				Consumer ratings (n = 122)				
		<i>L</i> *	<i>a</i> *	<i>b</i> *	<i>Hue angle</i>	Visual Colour	Consistency	Smell	Taste	Overall acceptability
Conventionally cooked	Cassava	48.8a ± 1.2	-0.1a ± 0.3	0.2a ± 0.5	63.4a ± 0.6	3.3a ± 1.0	3.2a ± 0.9	3.3a ± 1.0	3.4a ± 1.0	3.3a ± 1.0
	With defatted soy	48.9a ± 0.1	0.7b ± 0.0	2.0b ± 0.0	70.7a ± 2.6	4.3b ± 0.9	4.4b ± 0.8	4.0b ± 1.0	4.2b ± 1.1	4.1b ± 1.1
	With defatted soy flour and soy oil	53.1b ± 0.3	0.5b ± 0.1	3.7c ± 0.3	82.3 b± 2.8	4.4b ± 1.0	4.4b ± 0.8	4.2b ± 1.0	4.2b ± 1.0	4.1 b ± 1.1
Extrusion cooked	Cassava	56.6b ± 0.4	-1.4a ± 0.0	2.6a ± 0.2	61.6a ± 2.8	4.0b ± 1.4	3.9b ± 1.4	3.6a ± 1.4	3.9b ± 1.4	3.8b ± 1.5
	With defatted soy	52.1a ± 0.2	0.9b ± 0.3	5.0b ± 0.5	79.8b ± 2.6	4.2b ± 1.2	3.7b ± 1.5	3.9a ± 1.4	3.3a ± 1.5	3.1b ± 1.6
	With defatted soy flour and soy oil	58.3c ± 0.1	1.9c ± 0.1	8.8c ± 0.1	77.8b ± 1.9	3.3a ± 1.1	3.0a ± 1.1	3.2a ± 1.2	3.3a ± 1.1	3.4b ± 1.2

Values of instrumental colour measurements are means of three independent analyses ± standard deviation. Values in the same column and similar heat processing 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 defatted soy flour and soy oil-65% Cassava flour, 28% defatted soy flour and 7% soy oil

¹*L**, Lightness (0- Black, 100 - white); +*a**, red, -*a** green; +*b** yellow; -*b**, blue, Hue angle = $\text{Tan}^{-1}(b^*/a^*)$

Consumer sensory ratings were 1-5 point hedonic scales where 1=dislike very much, 3=neither like nor dislike and 5= like very much

Statistical analysis of extruded and conventionally cooked porridges was done separately

Starch digestion follows first order kinetics (Goni *et al.* 1997) whereby catalytic rate increase with additional substrate until a maximum value is reached. The rate of starch digestion reached a plateau in all porridges within 60 min (Figure 3.1.1). Addition of defatted soy flour reduced the TSD in extruded and conventionally cooked porridges compared to the corresponding cassava porridges. Reduction in *in vitro* starch digestibility has been reported in extruded durum semolina and gluten blends (Fardet *et al.* 1999). Increased physical barrier by protein that reduced accessibility of starch by α -amylase has been suggested. All porridges had high GI (Foster-Powell *et al.* 2002)

This can be attributed to high rate of starch digestibility due to disruption of starch granule during extrusion and conventional cooking. Further, cassava has low amylose/amylopectin ratio (AACC, 2000), which is associated with high digestibility and consequently high GI. These GI ranges are consistent with the literature for complementary foods (Foster-Powell, 2000).

The TSD was lowest in extruded porridge containing defatted soy flour with soy oil. Formation of amylose–lipid complexes as shown to have occurred during extrusion of porridge with defatted soy flour and soy oil (Figure 3.1.2. and 3.1.3) may contribute to the relatively low digestibility. A V-polymorph pattern of amylose-lipid complexes in extruded wheat- almond flour has been reported (De Pilli *et al.* 2008). Amylose-lipid complexes tend to reduce access of α -amylase to amylose for digestion (Cui and Oates, 1999). The limited access could be due to the compact nature of the V- crystalline pattern of amylose–lipid complexes (Pushpadass *et al.* 2009). Extruded porridge with defatted soy flour and soy oil 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 (Shi and Gao, 2011).

The mean TSD in extruded porridges was lower than the corresponding conventionally cooked porridges. This could in part be due to presence of more crystalline structure in extruded porridges compared to the conventionally cooked porridges. All extruded porridges had peaks characteristic of A-type polymorph (Mutungi *et al.* 2009). Similar findings were reported during extrusion of maize starch (Shestha *et al.* 2010). Recrystallization of starch at low water and/or high temperature as is the case during extrusion forms type A-polymorph (Shestha *et al.* 2010; Nelles *et al.* 2003). The A-type polymorph has close-packed arrangement of double helices, and is relatively resistant to digestive enzyme (Mutungi *et al.* 2009).

Table 3.1.4 shows a simulation of the amount of energy, protein and lysine (calculated based on available lysine) that can be provided by cassava-soy porridges to a child aged 6-8 months, receiving low or average quantity of nutrients from breast milk. Low or average intake of nutrients from breast milk is common in Africa (WHO/UNICEF, 1998). To calculate the nutritional adequacy of cassava-soy flour porridges, extruded porridges were assumed to contain 25% solid and the conventionally cooked porridges to contain 10%. Preliminary analysis with a rotational viscometer also suggest that extrusion cooked porridges at 25% solid had a viscous flow similar to 10 % solid for conventionally cooked porridges and commercial reference (at 25% according to manufacturer's guidelines). These solids contents were therefore also used to prepare porridges for consumer sensory evaluation.

The energy content of extruded porridges (25% solids), was between 0.9 kcal/g in cassava porridge and 1kcal/g in porridge with defatted soy flour and soy oil, which is within the recommendation of complementary foods of ≥ 0.8 kcal/g (WHO/UNICEF, 1998). If fed thrice per day, all extruded porridges can meet the energy needs of children receiving average and low energy from breast milk. At this feeding frequency, conventionally cooked porridges can 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) 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 due to low gastric capacity of children (30 g/kg body weight) (WHO/UNICEF, 1998). As the conventionally cooked porridges contain protein in excess of the requirements of 6-8 month old child, it is possible that some of the protein could be used to provide energy.

In as would be eaten basis, extruded and conventionally cooked composite porridges can exceed by 0.85 to 7 times the protein requirements of 6-8 month old children receiving low or average quantity of protein from breast milk. It would be important to review downwards the amount of protein incorporated in the composite porridges to avoid possible toxicity. Further, extruded porridge with defatted soy flour and with defatted soy flour and soy oil would meet the lysine requirements (based on available lysine) of 6-8 months old children receiving average or low quantities of lysine from breast milk.

Table 3.1. 3: Tabulation of contribution of cassava-soy flour complementary porridges to energy, protein and lysine requirements of a well-nourished 6-8 months old child if fed thice per day*(249 g per feeding)

Recommended requirement	⁹ Level & quantity of nutrient intake from breast milk	⁹ Required nutrient from complementary food	[§] Conventionally cooked (10% solid)			[§] Extrusion cooked (25% solid)			Reference (25% solids)	
			Cassava	With defatted soy	With defatted soy flour and soy oil	Cassava	With defatted soy	With defatted soy flour and soy oil		
⁹ Energy 769 (kcal/ day)	Low	217	552	269.2	289.5	317.9	689.2	722.9	784.7	807.5
	Average	413	356	269.2	289.5	317.9	689.2	722.9	784.7	807.5
⁹ Protein 9.6 (g/ day)	Low	2.3	7.3	1.7	12.2	10.2	5.0	30.0	24.3	27.8
	Average	4.5	5.1	1.7	12.2	10.2	5.0	30.0	24.3	27.8
[*] Lysine 355 (mg/ day)	Low	176	179	^φ nd	58.5	48.8	nd	125.4	97.0	178.0
	Average	335	20	nd	58.5	48.8	nd	125.4	97.0	178.0

Cassava - 100% cassava flour

With defatted soy flour - 65% Cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil - 65% Cassava flour, 28% defatted soy flour and 7% soy oil

Reference-Commercial ready to eat complementary porridge

^φ nd- Not determined because available lysine was not determined (Table 3.1.1)

⁹ Calculations of energy and protein are based on requirements of 6-8 months-old children; receiving maximum recommended feeding frequency (3 times per day) WHO/UNICEF, (1998)

^{*} Calculations were done using available lysine content of study porridges (Table 2) based on amino acid requirement of a child aged < 2 years. Median weight of 6 months- old boy child (7.9 kg) was used to calculate lysine requirements (WHO child growth standards)

[§] Calculations were based on conventionally cooked porridges containing 10% solids and extruded porridges containing 25% to mimic traditional African complementary porridges and commercial ready to eat complementary porridge, respectively

The colour lightness (L^* values) ranged from 48-58 in the six porridges. These values were within the ranges of 47-68 reported for sorghum porridges; which is one of the commonly eaten porridge in Africa (Aboubacar and Hamaker, 2000). Presence of brown colour due to Maillard browning during flour manufacture could have contributed to the higher (+) a^* , (+) b^* and hue angle values in porridge with defatted soy flour as compared to the cassava porridge. Maillard browning is a chemical reaction involving free amino groups of protein and carbonyl groups of reducing sugars (Singh *et al.* 2007). The reaction is dependent on presence of amino acids and sugars, processing conditions (time, temperature and moisture) (Cheftel, 1986). The higher (+) a^* and (+) b^* values in extrusion cooked porridges as compared to the corresponding conventionally cooked porridges could be due to additional Maillard browning during extrusion of the cassava-soy composite flours. Maillard reaction is favoured at a temperature of $>180\text{ }^\circ\text{C}$ and higher shear conditions ($>100\text{ rev/min}$) (Cheftel, 1986). Extrusion cooking was done within similar conditions, as the temperature was $120\text{ }^\circ\text{C}$ and the shear rate was 200 rpm.

In terms of consumer sensory acceptability, sensory attributes of conventionally cooked composite porridges were more liked than cassava porridge. Soy flour contains limited starch; 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 (Radhika *et al.* 2008), may have also reduced viscosity. Tuber starches are devoid of lipids and therefore have a bland taste (Radhika *et al.* 2008). Addition of soy flour could have introduced flavours associated with caramelization and Maillard reaction because it was toasted during manufacturing.

It was expected that extruded composite porridges would be more liked than extruded cassava porridge due to increased flavour and aroma volatile compounds formed during extrusion. Dimethyl disulphide and dimethyl trisulphide volatiles were categorised in extruded vegetable protein and wheat starch (Solina *et al.* 2008). Further, extrusion of starch in the presence of linoleic fatty acid has been shown to form benzaldehyde and hezanal volatile compounds (Solina *et al.* 2008). Probably the relatively lower liking could be because the volatile compounds formed during extrusion were not familiar to the consumers. There were large variations in liking of extruded composite porridges, indicating that some consumers liked the porridges while

others disliked them. Sensory profiling of these porridges is shown in section 3.3 and further informs on the drivers of consumer liking and dislike.

3.1.5. Conclusion

Extruded 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 cassava and defatted soy flour with or without added soy oil improves the protein quality of cassava complementary porridges in terms of protein content, available lysine and PDCAAS. At 35% defatted soy flour inclusion, extruded porridges if fed thrice per day meet the protein, lysine (available) and energy requirements of a child aged 6-8 months receiving low or average quantities of protein from breast milk. Cassava-soy flour porridges contain rapidly digested starch, which is desirable in young children whose digestive system is underdeveloped.

3.1.6 References

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3.2 Effect of soy flour addition (with or without soy oil) and heat processing method on rheological properties of extruded and conventionally cooked cassava complementary porridges

Abstract

The viscoelastic properties of extruded and conventionally cooked cassava-soy flour porridges were studied by frequency sweep, temperature sweep and time sweep within the linear viscoelastic range. Extrusion cooked porridges showed markedly lower viscosity at all shear rates as compared to conventionally cooked porridges. Shear rate and shear stress data fitted to power law model during measurement of flow property. All the porridges showed shear thinning behaviour ($n < 1$). The power law flow index; n -value of extrusion cooked porridges was markedly higher than in the corresponding conventionally cooked porridges. All porridges had solid-like behaviour as storage modulus (G') was consistently higher than the loss modulus (G'') at 20-70 °C during small amplitude oscillatory shear. During temperature sweep, a biphasic increase in G' was observed in all the porridges. When porridges were stored at 4 °C for 12 h, the G' values of conventionally cooked porridges were higher than in corresponding extrusion cooked porridges. This indicates that more retrogradation occurs in conventionally cooked porridges as compared to the extrusion cooked porridges. In light micrographs, conventionally cooked porridges appeared to have swollen starch granules while extrusion cooked porridges showed a continuous starch matrix. Addition of defatted soy flour with soy oil increased the relative strength of cassava pastes possibly due to the filler effect of the oil. Extrusion cooked porridge with defatted soy flour and soy oil had closely clustered small oil globules while the oil globules in conventionally cooked porridges were large and sparsely distributed. Thus, extrusion cooked porridges have limited increase in viscosity during cooling and refrigeration, which is beneficial for infant feeding as porridges of high energy density maintain consumable consistency during common handling procedures.

3.2.1. Introduction

Knowledge on the rheological properties of food pastes/porridge is needed for several purposes including quality control, product development, sensory assessment, process design and standardization (Latha *et al.* 2002). For instance, porridges may be stored at varying temperatures before they are consumed. A better understanding of their rheological properties during handling and storage may improve potential for design and product development of porridges with specific rheology and sensory properties. For example complementary porridges in particular need to have a viscosity of 1000- 3000cP (1-3 Pa.s) in order to provide adequate nutrition and a consistency that can be consumed by infants (Mosha and Svanberg, 1983). As porridges are shear thinning, Mouquet and Treche (2001) found a good correlation of the consistency at which infants usually consume porridges and that of the recommendation of Mosha *et al.* (1983), when viscosity was measured after 10 min of shearing at a shear rate of 83 s⁻¹ and porridge held at 45 °C.

While extrusion cooking could be used to produce low cost complementary porridges in developing countries (Mouquet *et al.* 2003), studies on extrusion cooking have mainly reported on physical and chemical properties of the extrudates (Ruiz-Ruiz *et al.* 2008). Recently, Hagenimana *et al.* (2006) and Pérez *et al.* (2008) reported on the flow behaviour of extruded rice flour and maize-soy flour, respectively. Wu *et al.* (2010), working on extrusion cooked flaxseed-maize blend reported on dynamic rheological properties of the pastes as affected by processing conditions. To the best of our knowledge, no literature was found on rheological properties of cassava complementary porridges or paste.

Starch paste, which consists mostly of a dispersion of amylose and amylopectin polymers in water, have the ability to behave as a viscoelastic material (Mulvihill and Kinsella, 1987). The macromolecular substances responsible for network formation in food systems are primarily polysaccharides and proteins (Tabilo-Munizaga and Barbosa-Canovas, 2005). However, presence and concentration of solutes such as salts, lipids, and sugars may also influence rheological behaviour of pastes (Yoo and Yoo, 2005). For instance, protein may reduce retrogradation of amylose during cooling to usual eating temperature (~ 40 °C). This may in turn influence textural and eating quality of starch pastes (Sun *et al.* 2008). Furthermore, depending

on the processing conditions, various macromolecules can form a single phase (mixed gel) or one of the macromolecules pastes and the other component can be dispersed as a filler (filled gel) (Eskins *et al.* 1996). Thus, the interaction of ingredients influences rheological properties of food.

In a study by Bejosano and Corke, (1999), addition of 1% amaranthus protein concentrate was found to reduce the G' of maize starch gel. Lindahl and Eliasson (1986) studied the interactions between wheat proteins and different starches based on small oscillatory rheological measurements of starch pastes. These authors found an increase in storage modulus (G') of wheat and rye starch gels when gluten was added. However, a decrease in G' was observed for maize starch while no effect was found for potato and barley starches. Wu *et al.* (2010) found values of G' and loss modulus (G'') of flaxseed-maize blend to be frequency dependent at a range of 1 to 100 rads /s and that G' was higher than G'' over the frequency range. Increase in concentration of flaxseed (0 to 20%) resulted in an increase in G' possibly due to reduced starch damage (Wu *et al.* 2010).

Using temperature and frequency sweep, Lu *et al.* (2012) showed the rheological properties of γ -irradiated potato paste during storage. These authors found an increase in G' during storage of gels for 2 h at 4 °C; which was attributed to retrogradation as shown by a transition peak around 40-60 °C using the differential scanning calorimeter. γ -irradiation reduced gel strength and retrogradation of potato paste during short and long term storage Lu *et al.* (2012). The aim of this study was to determine the effect of addition of soy flour on rheological properties of extrusion and conventionally cooked cassava complementary porridges.

3.2.2 Materials and methods

Materials described in section 3.1.2.1 and 3.1.2.2 were used in this experiment

Conventional cooking

Conventionally cooked porridges were prepared as described in section 3.1.2.3. This included addition of a smooth cold flour slurry to boiling water. Cooking continued for 15 min with stirring every 5 min.

Extrusion cooking

Extrusion cooking and milling procedure described in section 3.1.2.3 was followed. In brief, Clextral BC 45 co-rotating twin screw extruder (Clextral, Firminy, France) at a screw speed of 200 rpm, a barrel temperature of 120 °C and a retention time of 2 min was used. Extrudates were oven dried for 10 min at 100°C and then milled to a particle size of about 500 µm using a roller mill. Preparation of the reference and extrusion cooked porridges involved mixing the flour powder (either at 10%, 15 % or 25% solids content) with boiled hot water (~85 °C). The mixtures were then thoroughly mixed to a smooth paste.

3.2.2.1 Determination of rheological properties

a) Flow properties

A rotational concentric cylinder rheometer (Physica MCR 301, Anton Paar, GmbH, Ostfildern, Germany) with temperature control and data acquisition software (Rheoplus version 3) was used to determine the viscosity of porridges. Conventionally cooked porridges contained 10% solids while extrusion cooked porridges contained either 10% or 25% solids content. Immediately after preparation, porridges were cautiously transferred into the rheometer cup (CC27-SN10577) maintained at 40 °C. A thin layer of light paraffin oil was applied on top of the exposed sample surface to prevent loss of moisture through evaporation (D'Silva *et al.* 2011) and then left to equilibrate for 30 min. After equilibration, the apparent viscosity was recorded at a shear rate range of 0.01 to 1000 s⁻¹.

b) Frequency sweep

Frequency sweep was determined using the rheometer described in section on flow properties, using cup and bob system. A strain sweep test was done to establish the limit of linear viscoelastic (LVE) range (Mezger, 2006). This region was at 0.5% strain. Frequency sweep was carried out between 0.01 to 100 rad/s. Depending on the experimental conditions, porridges were introduced into a rheometer cup held at either 20, 40, 60 or 70 °C. The porridges were allowed to equilibrate for 30 min before the experiment was run. For comparison purposes, all porridges were prepared at 15% solids because at 25% solids content, conventionally cooked porridges

formed a thick paste that was not easy to handle. A light layer of paraffin oil was applied on top of the porridge to prevent loss of moisture. Storage/elastic (G') and loss/viscous (G'') moduli were obtained from the rheoplus software as a function of frequency. Loss tangent ($\tan \delta$) was calculated as G''/G' .

c) Temperature sweep

Temperature sweep was done at a frequency of 6.3 rad/s over a cooling temperature range of 90 to 15 °C at a rate of 2 °C per min. After preparation; porridges of 15% solids content were immediately cautiously introduced into a rheometer cup held at 90 °C. The porridges were allowed to equilibrate for 10 min. A thin layer of paraffin oil was applied on top of the porridge to avoid loss of moisture. Values of G' and G'' were obtained from the rheoplus software as a function of temperature. A strain of 0.5% (the LVE range) was maintained during the assay.

d) Time sweep

Time sweep was carried out at a frequency of 6.3 rad/s over 12 h at 4 °C and a strain of 0.5%. A thin layer of paraffin oil was applied on the porridge to avoid moisture loss during experiment. Porridges (15% solids content) were allowed to equilibrate for 30 min before the experiment was started. Values of G' and G'' were obtained from the rheoplus software as a function of time. $\tan \delta$ was calculated as described in earlier.

3.2.2.2 Light and confocal scanning laser microscopy

a) Light microscopy

Microscopy was done on freshly prepared porridge with 15% solids content. Iodine solution was prepared as described by Kuar and Singh, (2000). Porridge (5 g) was transferred into a plastic test tube and then 0.5 ml of iodine solution was added. The mixture was gently mixed by hand-shaking every 5 min for 15 min. Thereafter a single drop was thinly spread on a microscope slide and covered with a thin slide cover. A Nikon Digital Camera, (DXM 1200F, Japan) was used to view the samples at a magnification of 20 \times .

b) Confocal scanning laser microscopy (CSLM)

For CSLM, porridge samples (5 g) were stained with 0.5 ml of Nile red (0.1% w/v in acetone) to stain lipids. The mixture was then left for 15 min with shaking every 5 min. A single drop of the porridge mixture was thinly smeared on a microscope slide and covered with a glass slide. A CSLM, Zeiss LSM 510 Meta Confocal Scanning Laser Microscope (Zeiss SMT, Jena, Germany) was used to view the samples. The excitation and emission spectra for Nile red were 488 nm and 550-303 nm, respectively. Images were viewed with Carl Zeiss LSM 510 Version 3.2 SP2 software (Heidelberg, Germany).

3.2.2.3. Statistical analysis

Viscosity parameters of shear stress and shear strain were fitted to a power law model. The K and n values were subjected to one way analysis of variance (ANOVA) using type of composite as the independent variable and the calculated parameters as the dependent variables. Fischer's least significant differences (LSD) test was used to separate means using Statistica software version 10.0 (StatSoft, Tulsa, OK, USA) at 5%.

3.2.3. Results

3.2.3.1 Flow properties

Figure 3.2.1 and 3.2.2 shows the flow properties of extruded and conventionally cooked cassava-soy flour porridges. Extrusion cooked porridges showed a markedly lower viscosity at all shear rates as compared to their corresponding conventionally cooked porridges. For both extrusion and conventionally cooked porridges, addition of either defatted flour, or defatted soy flour with soy oil resulted in a lower viscosity as compared to the corresponding porridge containing only cassava. The range of flow properties of extrusion cooked porridges at 25% solids content was similar to that of the reference commercially available ready to eat porridge (Figure 3.2.2). Flow properties of conventionally cooked porridges were not determined at 25% solids because this concentration resulted in a thick paste (not edible by infants).

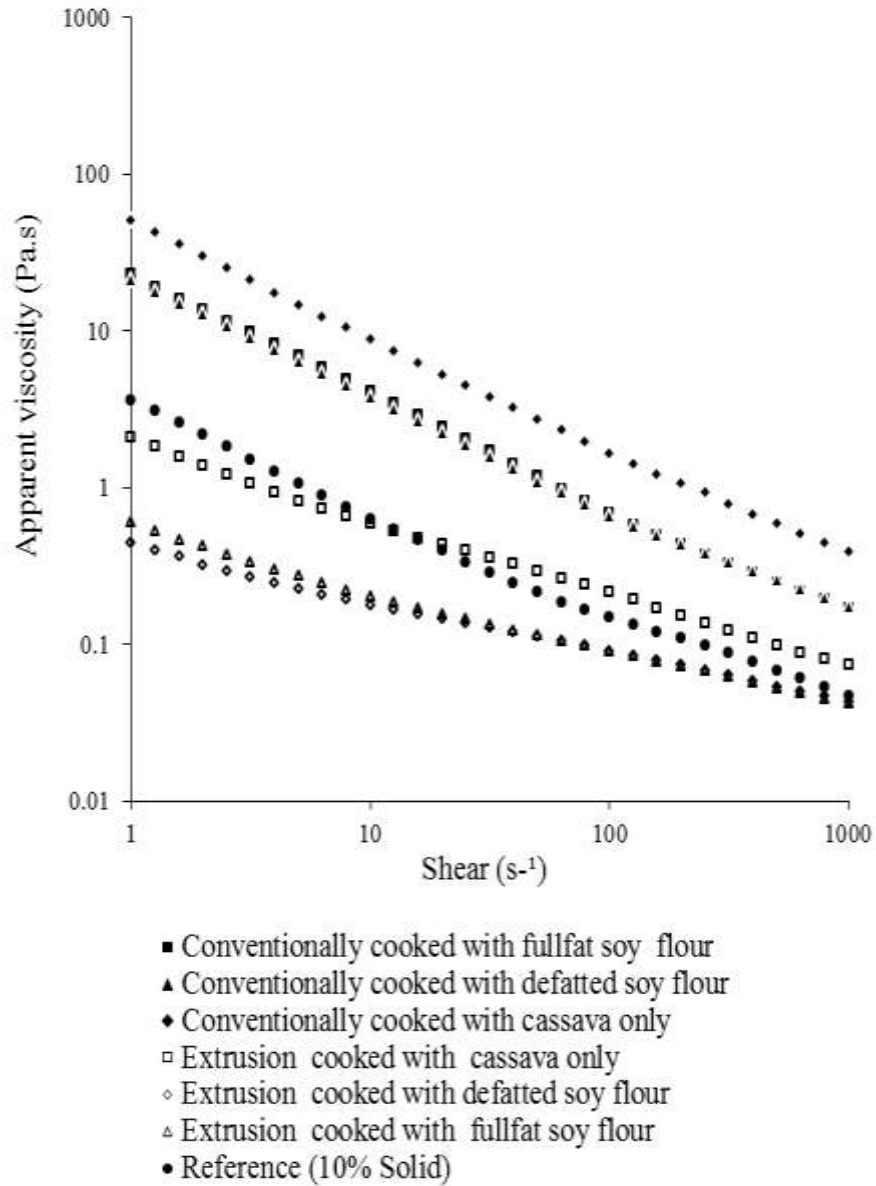


Figure 3.2. 1: Effect of adding soy flour and heat processing method on apparent viscosity of cassava complementary porridge (10 % solids) at 40 °C as a function of shear

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

Reference-Commercial ready to eat complementary porridge

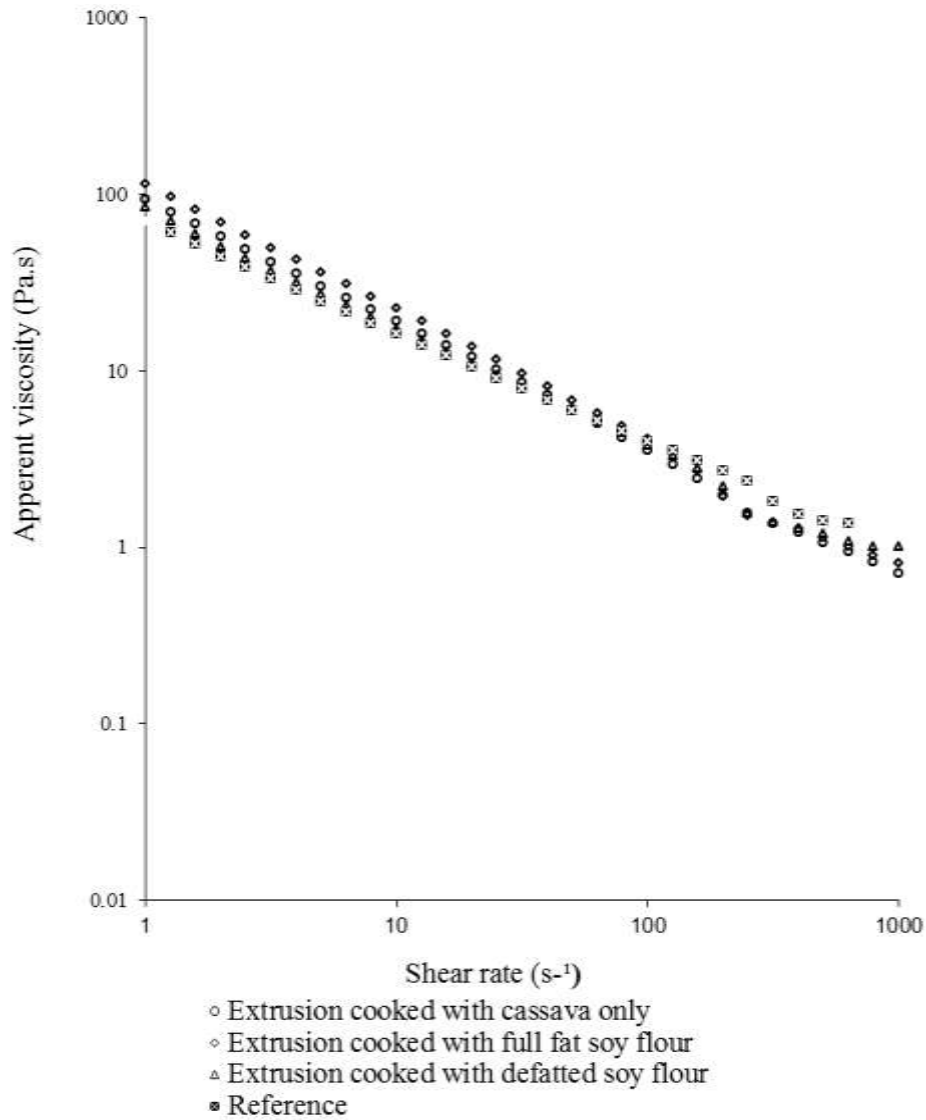


Figure 3.2. 2: Effect of adding soy flour on the apparent viscosity of extrusion cooked cassava complementary porridges (25 % solids) at 40 °C as a function of shear

With 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

Reference-Commercial ready to eat complementary food

The shear rate and shear stress data fitted well to power law equation ($\sigma = K\dot{\gamma}^n$). Where σ is the shear stress (Pa), K - value is the consistency index or the consistency coefficient (Pa.s)ⁿ, and n is the power-law index (a dimensional) (Table 3.2.1). At 10% solids content, the K - value of extrusion cooked porridges was significantly lower than the corresponding conventionally cooked porridges. K - value was significantly lower ($p < 0.05$) in composite conventionally cooked porridges as compared to conventionally cooked porridge containing only cassava flour at 10% solids content. Increase in solids content from 10% to 25% resulted in an increase in K -value for extruded porridges and the reference commercial ready to eat porridge. In extrusion cooked porridges (25% solids content), the K - value was significantly higher in porridges containing defatted soy flour, or defatted soy flour with soy oil compared to porridge containing only cassava flour. There was no significant difference in K -value for extrusion cooked porridges with defatted soy flour, and defatted soy flour with soy oil. There was also no significant difference between the reference porridge and extruded porridge containing only cassava flour, both at 25% solids content. This indicates that extrusion cooking markedly reduced the viscosity of cassava-soy porridge to the extent that solids content could be similar to commercially available ready to eat complementary porridges.

The ranges of n -value of conventionally cooked porridges containing 10% solids were the lowest (0.26 to 0.29) compared to extruded porridges either at 10% solids or 25% solids. The n - values of conventionally cooked porridges were not significantly different from each other ($p > 0.05$). There was also no significant difference between the n -values of extruded porridges.

Table 3.2.1: Effect of adding soy flour on power law parameters (K and n) of cassava complementary porridges at 40°C

	Type of composite	K -value (Pa.s) ⁿ	Power law index (n- value)
Conventionally cooked (10% solid)	Cassava	46.3c ± 3.0	0.29a ± 0.02
	With defatted soy flour	19.6b ± 1.4	0.29a ± 0.01
	With defatted soy flour and soy oil	21.9b ± 1.0	0.26a ± 0.01
Extrusion cooked (10% solid)	Cassava	1.8a ± 0.1	0.53b ± 0.01
	With defatted soy flour	0.4a ± 0.1	0.68d ± 0.04
	With defatted soy flour and soy oil	0.6a ± 0.1	0.61c ± 0.02
	Reference (10% solids)	3.2a ± 0.6	0.73d ± 0.01
Extrusion cooked (25% solid)	Cassava	81.3d ± 4.4	0.72d ± 0.07
	With defatted soy flour	97.5e ± 0.3	0.67d ± 0.10
	With full soy flour	98.1e ± 0.4	0.65d ± 0.03
	Reference (25% solids)	80.2d ± 1.2	0.83e ± 0.04

Values are means ± standard deviation. Means within a column 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 defatted soy flour and soy oil -65% cassava flour, 28% defatted soy flour and 7% soy oil

Reference -Commercial ready to eat complementary porridge

3.2.3.2 Frequency sweep

Figure 3.2.3-3.2.5, shows the dynamic frequency sweep test for the cassava-soy flour composite and the non-composited porridges at different temperatures (20, 40, 60 and 70 °C). The G' (storage modulus) and G'' (loss modulus) and $\tan \delta$ (G''/G') for all the porridges (conventionally cooked and extrusion cooked) were frequency dependent. All extrusion cooked porridges showed more frequency dependence than the corresponding conventionally cooked porridges.

The G' and G'' values of conventionally cooked porridges were higher than in extrusion cooked porridges at the frequencies recorded (0.01-100 rad/s) at all measured temperatures (20, 40, 60 and 70 °C) (Figure 3.2.3-3.2.5). This is also shown by the $\tan \delta$ values, which was lower in conventionally cooked porridges as compared to extrusion cooked porridges (Figure 3.2.6 and 3. 2.7). There was a decrease in G' and G'' with increase in temperature for all the porridges at different frequencies (0.01- 100 rad/s). Conventionally cooked porridges could be referred to as weak gel as G' was greater than the G'' and almost parallel to each other (Steffe, 1996).

Figure 3.2.6 and 3.2.7 shows the $\tan \delta$ values of the frequency sweep (0.01-100 rad/s) of extrusion cooked and conventionally cooked porridges at various temperatures (20, 40, 60 and 70 °C). All porridges (conventionally and extrusion cooked) showed a slight decrease in $\tan \delta$ between 0.01 rad/s and 0.1 rad/s. Thereafter (0.1 rad/s-100 rad/s) an increase in $\tan \delta$ was observed. Extrusion cooked cassava porridge and extrusion cooked porridge with defatted soy flour showed a cross-over (G'' became higher than the G') at a frequency of ~10 rads/s and the $\tan \delta$ exceeded 1 above this frequency rate (Figure 3.2.6). There was minimal change in $\tan \delta$ with increasing frequency for conventionally cooked porridges at all temperature conditions.

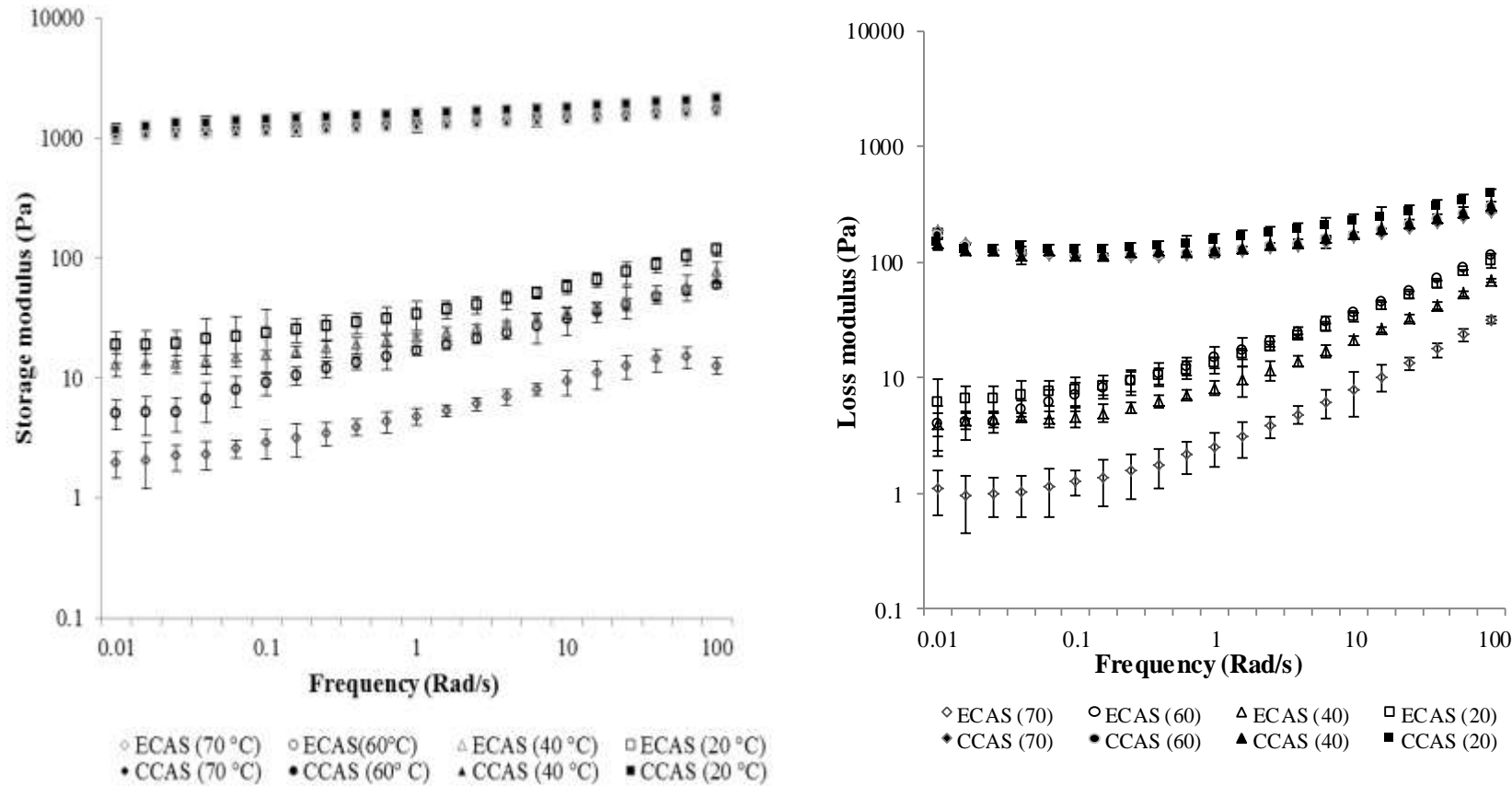


Figure 3.2. 3: Effect of temperature on storage and loss modulus of extrusion cooked and conventionally cooked cassava porridges during frequency sweep at a linear viscoelastic range of 5%

ECAS denotes extrusion cooked cassava porridge and CCAS denotes conventionally cooked cassava porridge

Holding temperature is shown in bracket

Bars indicate standard deviation

Symbols \diamond , \circ , Δ and \square are used for porridges held at 70, 60, 40 and 20 °C, respectively.

Unfilled symbols represent extrusion cooked porridges

Filled symbols represent conventionally cooked porridges

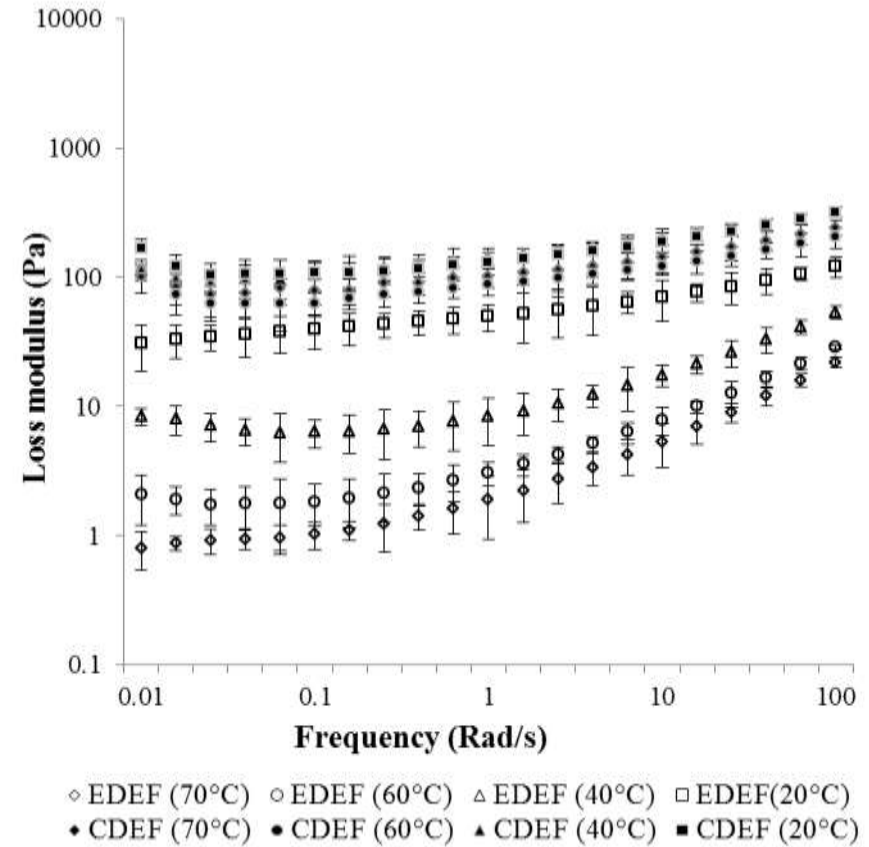
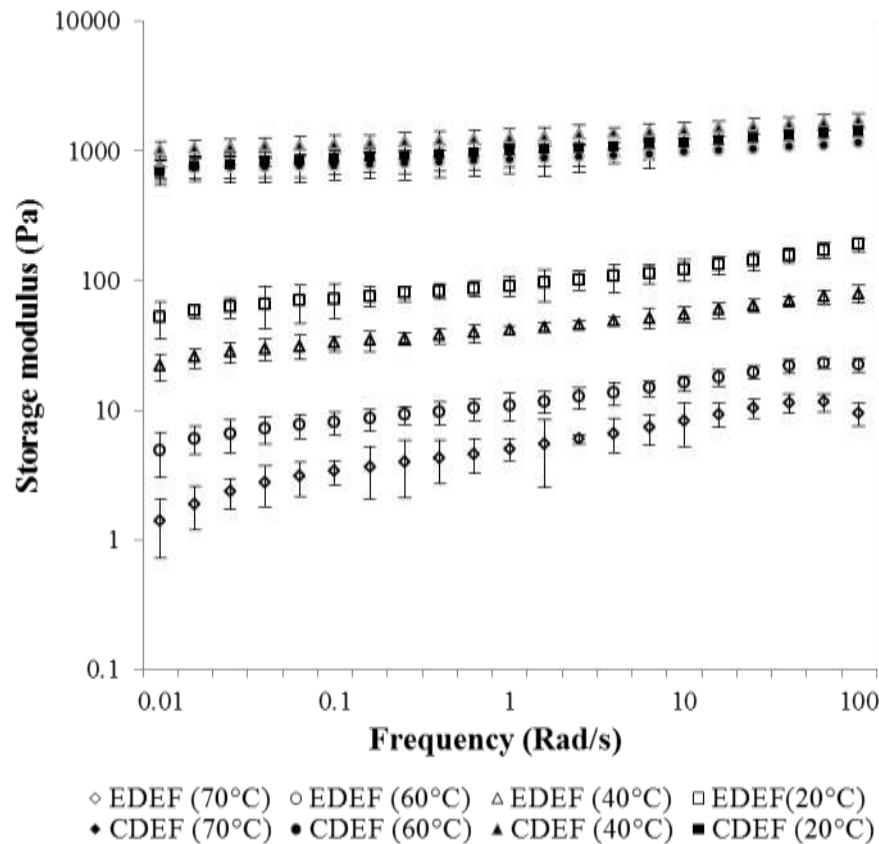


Figure 3.2. 4: Effect of temperature on storage and loss modulus of extrusion cooked and conventionally cooked porridges with defatted soy flour during frequency sweep at a linear viscoelastic range of 5%

EDEF denotes extrusion cooked porridge with defatted soy flour and CDEF denotes conventionally cooked porridge with defatted soy flour.

Holding temperature is shown in bracket

Bars indicate standard deviation

Symbols ◇, ○, △ and □ are used for porridges held at 70, 60 and 20 °C, respectively.

Unfilled symbols represent extrusion cooked porridges

Filled symbols represent conventionally cooked porridges

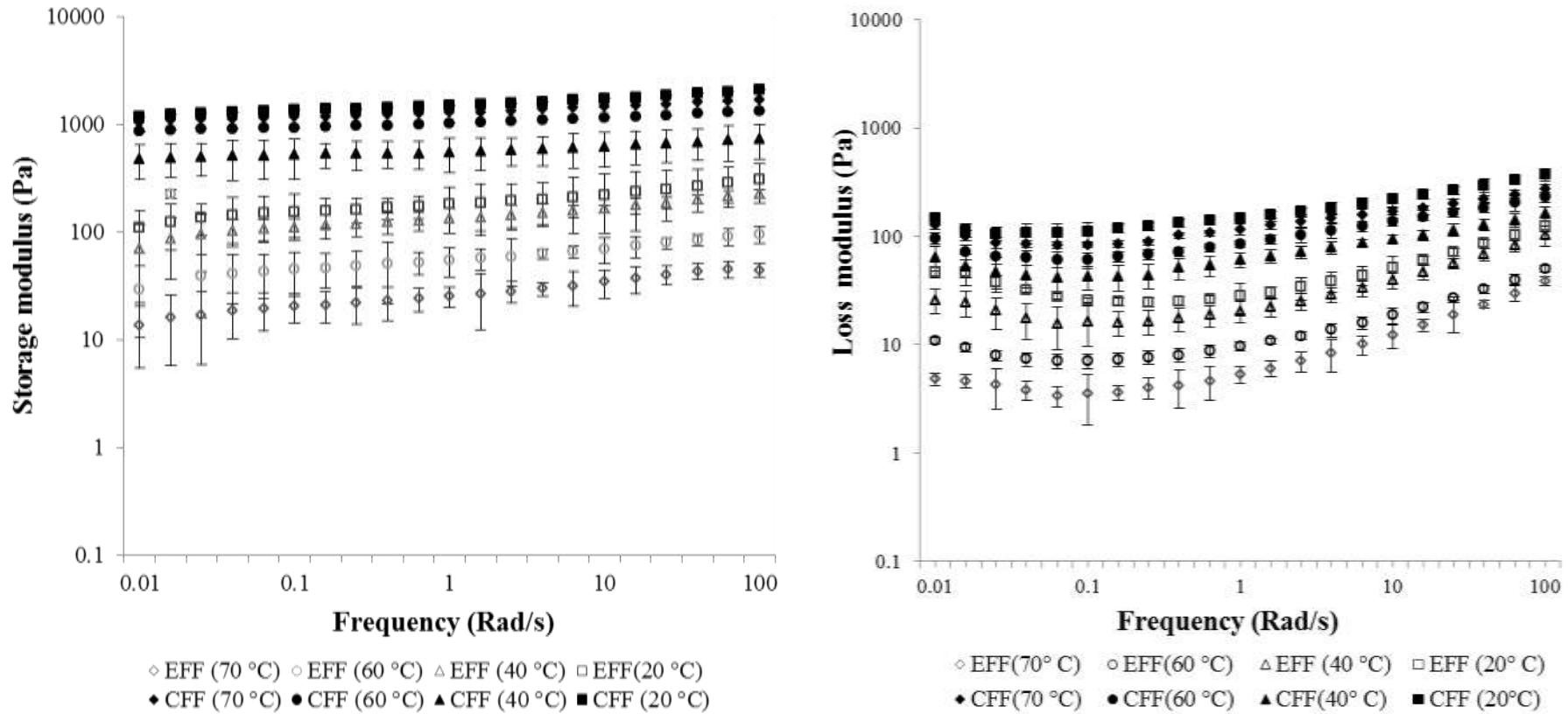


Figure 3.2. 5: Effect of temperature on storage and loss modulus of extrusion cooked and conventionally cooked porridges with defatted soy flour and soy oil during frequency sweep at linear viscoelastic range of 5%

EFF denotes extrusion cooked porridge with defatted soy flour and soy oil and CFF denotes conventionally cooked porridge with defatted soy flour and soy oil.

Holding temperature is shown in bracket

Bars indicate standard deviation

Symbols \diamond , \circ , Δ and \square are used for porridges held at 70, 60, 40 and 20 °C, respectively.

Unfilled symbols represent extrusion cooked porridges

Filled symbols represent conventionally cooked porridges

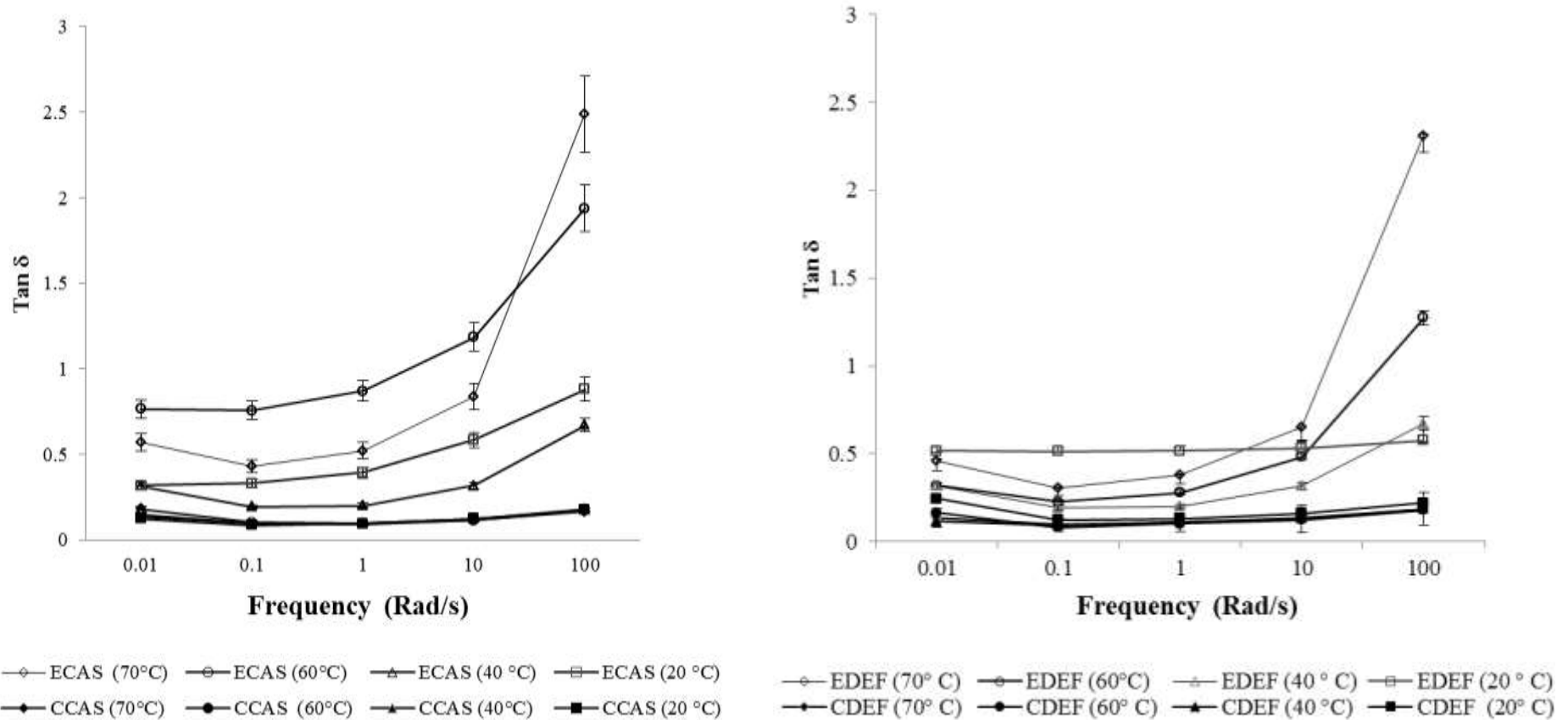


Figure 3.2. 6: Effect of temperature on tan delta values of extrusion and conventionally porridges containing cassava only and with defatted soy flour

Temperature at which the porridges were analysed is shown in brackets

ECAS denotes extrusion cooked cassava porridge and CCAS denotes conventionally cooked cassava porridge.

EDEF denotes extrusion cooked porridge with defatted soy flour and CDEF denotes conventionally cooked porridge with defatted soy flour Bars indicate standard deviation

Symbols \diamond , \circ , Δ and \square are used for porridges held at 70, 60, 40 and 20 °C, respectively.

Unfilled symbols represent extrusion cooked porridges

Filled symbols represent conventionally cooked porridges

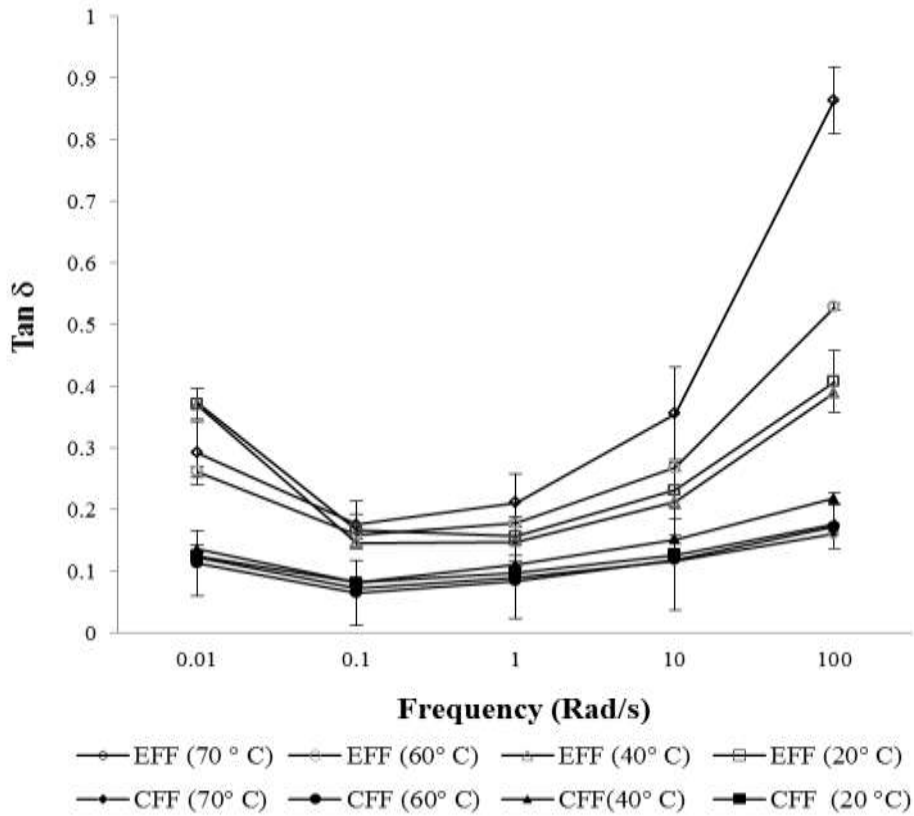


Figure 3.2. 7: Effect of temperature on tan delta values of extrusion cooked and conventionally cooked porridges with defatted soy flour and soy oil

Temperature at which the porridges were analysed is shown in brackets

EFF denotes extrusion cooked porridge with full fat flour and CFF denotes conventionally cooked porridge with full fat flour.

Bars indicate standard deviation

Symbols \diamond , \circ , Δ and \square are used for porridges held at 70, 60, 40 and 20 °C, respectively.

Unfilled symbols represent extrusion cooked porridges

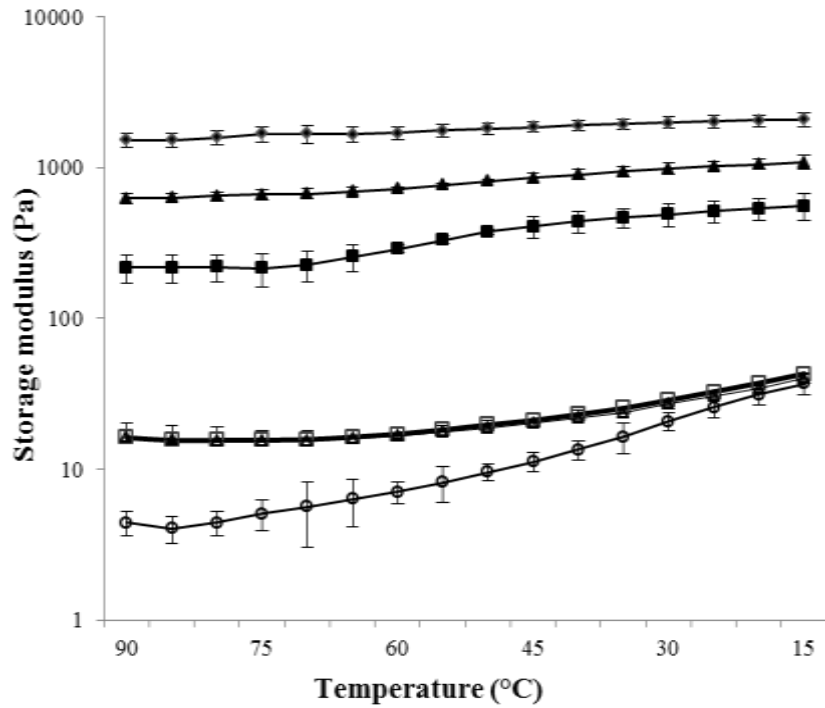
Filled symbols represent conventionally cooked porridges

3.2.3.3 Falling temperature sweep

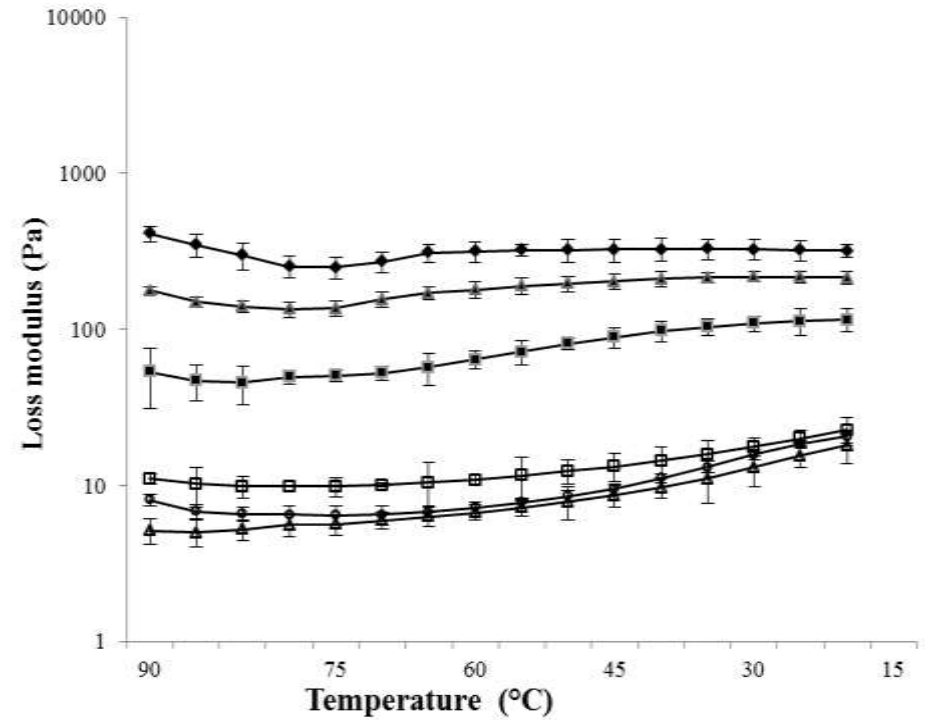
Figures 3.2.8 and 3.2.9 show the temperature sweep values of G' , G'' and $\tan \delta$ of extrusion cooked and conventionally cooked cassava porridge and cassava porridges containing either full fat or defatted soy flour. Effect of temperature sweep on storage modulus (G'), loss modulus (G'') and $\tan \delta$ was dependent on the type of composite and heat processing method. The G' and G'' values of conventionally cooked porridges were consistently higher than the corresponding extrusion cooked porridges. In both extrusion cooked and conventionally cooked porridges, G' was higher than the G'' during cooling (90-15°C).

Over the cooling temperature (from 90 °C to 15 °C), the increase in G' values were from 1515 to 2075 Pa, 215 to 555 Pa and 622 to 1081 Pa in conventionally cooked porridge containing cassava, with defatted soy flour and with defatted soy flour and soy oil, respectively. The increase in G' in extrusion cooked porridges was about 2 fold (16 to 40 Pa) in porridge containing cassava and porridges containing defatted soy flour with soy oil. Extrusion cooked porridge with defatted soy flour showed about 6 fold (4 to 37 Pa) increase in G' when cooled from 90 to 15 °C. At the end of the cooling period (15 °C), the G' was 9-fold (2075 Pa compared to 40 Pa), 33 fold (555 Pa compared to 37 Pa) and 55 fold (1081 verses 40 Pa) higher in conventionally cooked cassava porridge, porridge with defatted soy flour and porridge with defatted soy flour and soy oil compared to the corresponding extrusion cooked porridges. It seems like all porridges showed a biphasic increase in G' and G'' . Between 90 °C and ~60 °C, the porridges showed a slow increase in G' and G'' , and thereafter a high increase was observed.

Figure 3.2.9 shows the $\tan \delta$ values of extrusion cooked and conventionally cooked cassava-soy flour porridges during a falling temperature sweep (90 to 15 °C). Extrusion cooked porridges with defatted soy flour had $\tan \delta$ values greater than one. During cooling from 90 °C to about 60 °C the $\tan \delta$ value ranged from 1.2 to 1.0, thereafter the $\tan \delta$ value was less than one (0.88 at 15 °C). Extrusion cooked cassava porridges and porridge with defatted soy flour and soy oil had $\tan \delta$ values ranging from 0.68-0.60 while for conventionally cooked porridges the values were 0.25-0.15.



- ◆ Con conventionally cooked (cassava flour)
- Con conventionally cooked (65% cassava flour and 35% defatted soy flour)
- ▲ Con conventionally cooked (65% cassava flour, 28% defatted soy flour and 7% soy oil)
- ◻ Extrusion cooked (cassava flour)
- Extrusion cooked (65% cassava flour and 35% defatted soy flour)
- △ Extrusion cooked (65% cassava flour, 28% defatted soy flour and 7% soy oil)



- ◆ Con conventionally cooked (cassava flour)
- Con conventionally cooked (65% cassava flour and 35% defatted soy flour)
- ▲ Con conventionally cooked (65% cassava flour, 28% defatted soy flour and 7% soy oil)
- ◻ Extrusion cooked (cassava flour)
- Extrusion cooked (65% cassava flour and 35% defatted soy flour)
- △ Extrusion cooked (65% cassava flour, 28% defatted soy flour and 7% soy oil)

Figure 3.2. 8: Effect of temperature sweep (90 to 15°C) on storage modulus and loss modulus of cassava – soy flour porridges at 15 % solids content and strain of 0.5%

†Bars indicate standard deviation

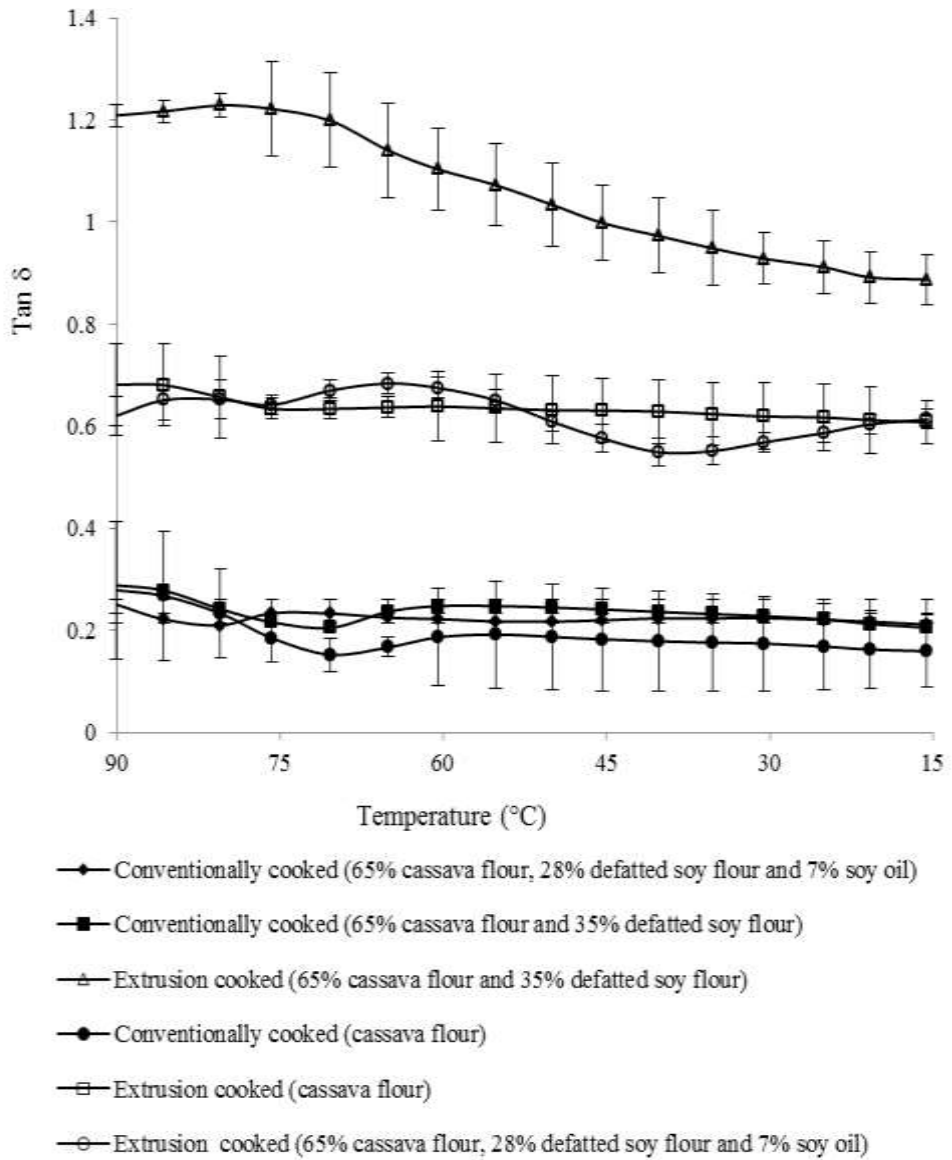


Figure 3.2.9: Effect of temperature sweep (90 to 15 °C) on $\tan \delta$ values of cassava – soy flour porridges at 15 % solid concentration and strain of 0.5% and a frequency of 6.3 rad/s

†Bars indicate standard deviation

3.2.3.4 Time sweep

The G' , G'' and $\tan \delta$ values of conventionally cooked porridges were higher than in extrusion cooked porridges during a time sweep analysis for 12 h at 4 °C (Figure 3.2.10 and 3.2.11). In extrusion cooked porridges, the values of G' after 12 h were 106, 71.9 and 78.9 Pa for porridge containing cassava only, porridge with defatted and with defatted soy flour and soy oil, respectively. The corresponding values for conventionally cooked porridges were 1880, 367 and 877 Pa for porridge containing cassava only, porridge with defatted soy flour, and defatted soy flour with soy oil respectively. Conventionally cooked cassava porridge and conventionally cooked porridge with defatted soy flour showed a slight increase in G' while the other porridges (conventionally cooked porridge with defatted soy flour and soy oil and all extrusion cooked porridges) showed a decrease in G' . Extrusion cooked porridge with defatted soy flour had the highest decrease in G' (141 Pa) (Figure 3.2.10 a) during storage at 4°C. Similarly, extrusion cooked porridge with defatted soy flour showed the highest decrease among the extruded porridges in G'' (25 Pa) during storage at 4°C, while the other porridges had limited change in G'' (Figure 3.2.10 b).

The $\tan \delta$ values of conventionally cooked porridges increased when either defatted soy flour, or defatted soy flour with soy oil was added. On the contrary, $\tan \delta$ values were reduced by addition of either defatted soy flour, or defatted soy flour with soy oil in the extrusion cooked porridges. Extrusion cooked porridges containing defatted soy flour with soy oil showed an increase (0.1) in $\tan \delta$ values throughout the 12 h of storage. The other porridges showed a decrease in $\tan \delta$ during the first hour and thereafter (2 h-12 h) limited change was observed. Over the 12 h of storage, extrusion cooked porridges had higher $\tan \delta$ values. After 12 h of storage at 4 °C, the $\tan \delta$ values of extrusion cooked cassava porridge and extrusion cooked porridge with defatted soy flour and with defatted soy flour and soy oil was 0.50, 0.32 and 0.35, respectively. After 12 h of storage at 4 °C, the $\tan \delta$ values were 0.25, 0.16 and 0.14 for conventionally cooked cassava porridge, conventionally cooked porridge with defatted soy flour and with defatted soy flour and soy oil, respectively.

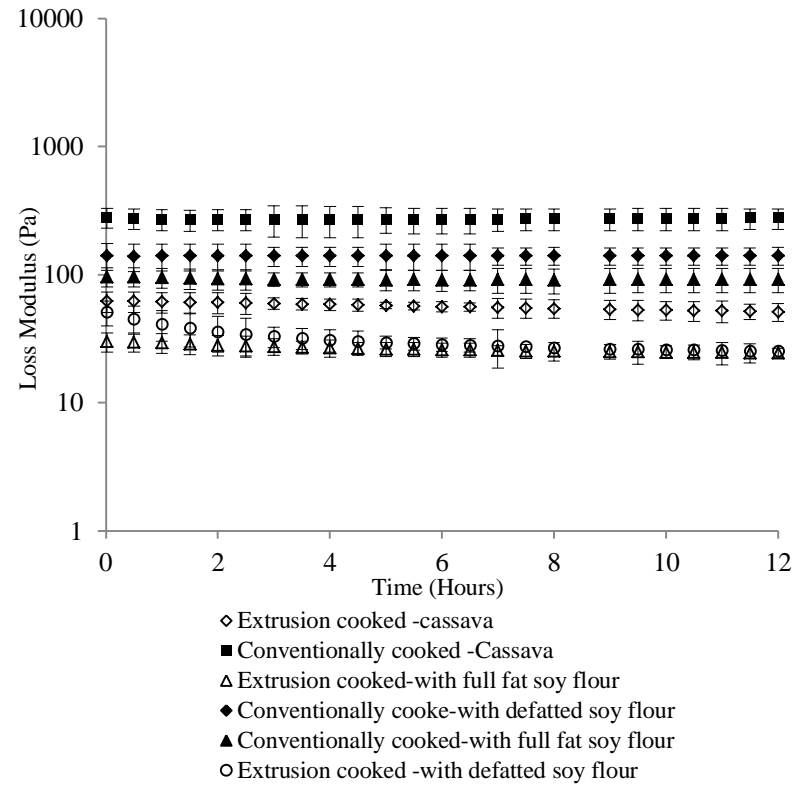
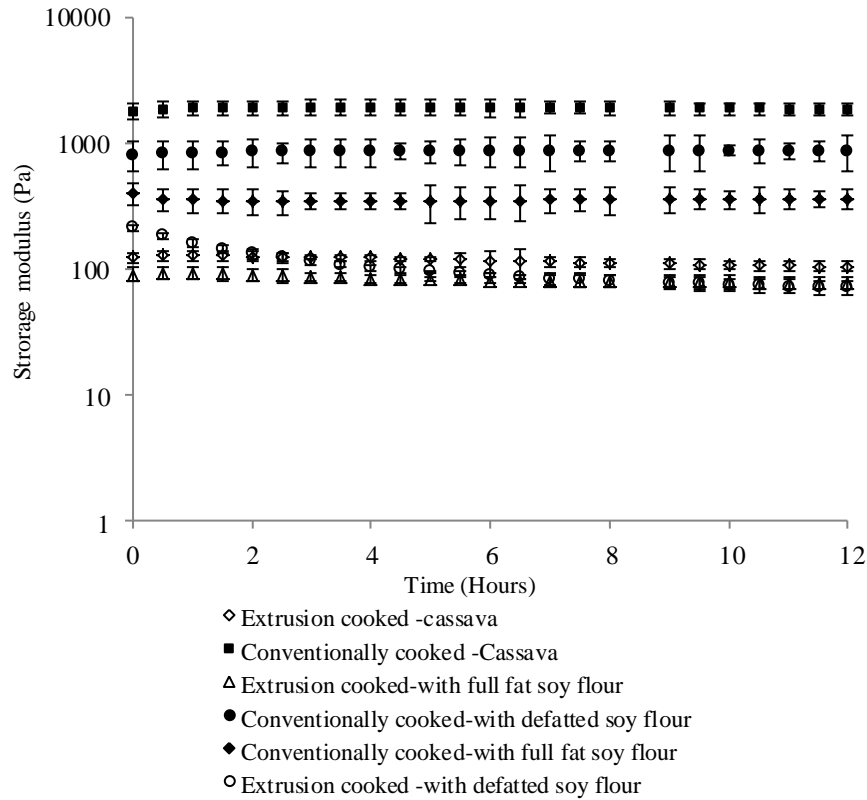


Figure 3.2. 10: Effect of storage time on storage and loss modulus of extrusion cooked and conventionally cooked cassava soy flour porridges during time sweep (4°C, 6.3rad/s)

With 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

†Bars indicate standard deviation

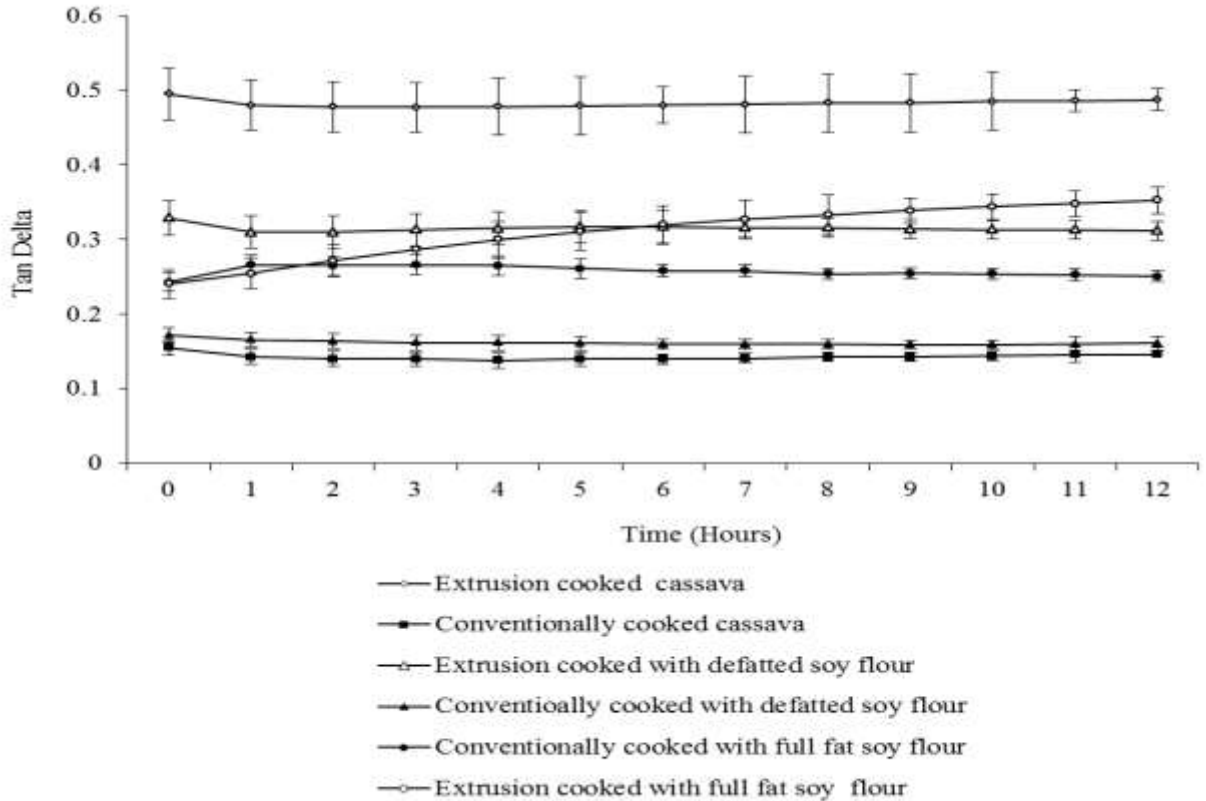


Figure 3. 2. 11: Effect of storage time on tan delta of extrusion cooked and conventionally cooked cassava soy flour porridges during time sweep (4°C, 6.3 rad/s)

With 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

†Bars indicate standard deviation

3.2.3.5 Light microscopy and confocal scanning laser microscopy

Figure 3.2.12 (a-c) shows light micrographs of conventionally cooked cassava-soy flour porridges. All three types of porridges showed clusters of perhaps swollen starch granules. For conventionally cooked porridge with defatted soy flour, and defatted soy flour with soy oil, patches of possibly soy flour seem to be embedded within the swollen matrix of starch granules. Conventionally cooked porridge with defatted soy flour and soy oil appears to have oil globules dispersed within the matrix of swollen starch.

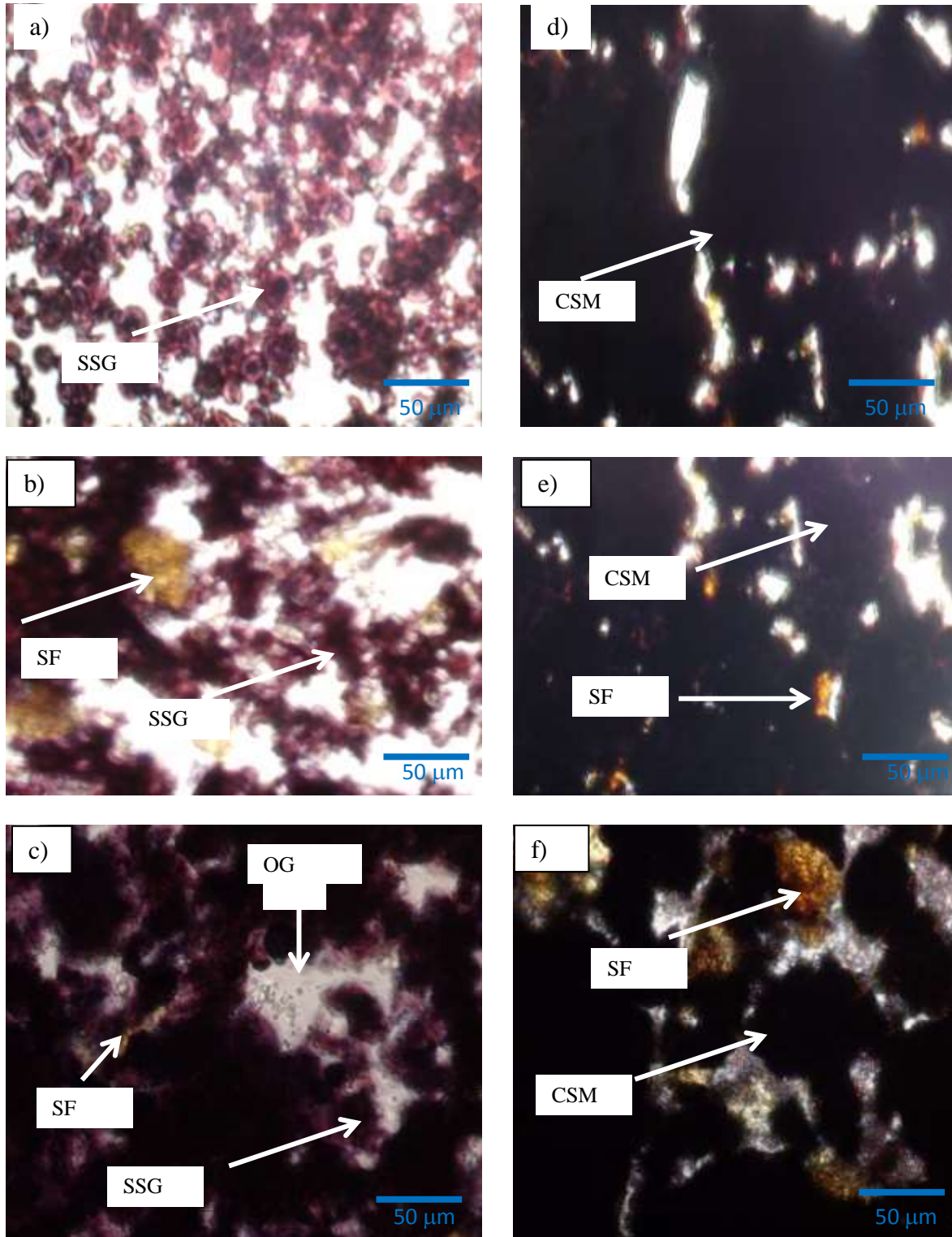


Figure 3.2. 12: Effect method of heat treatment on light micrograph of cassava-soy flour complementary porridges

*Micrographs a-c are conventionally cooked cassava porridge, porridge with defatted soy flour and porridge with defatted soy flour and soy oil, respectively

Micrographs d-f are extrusion cooked cassava porridge, porridge with defatted soy flour and porridge with defatted soy flour and soy oil, respectively

SF – Soy flour, SSG- Swollen starch granules, CSM- Continuous starch matrix, OG- Oil droplets

Figure 3.2.12 (d-f) shows the light micrographs of extrusion cooked porridges. The starch matrix of the porridges appears to be continuous. Extrusion cooked porridges with defatted soy flour, and defatted soy flour with soy oil, also showed patches of brown coloured clusters that could be the presence of soy flour. Oil globules were however not visible.

Figure 3.2.13 (a and b) shows CSLM micrographs of extruded and conventionally cooked porridge with defatted soy flour and soy oil. The oil droplets were smaller and more clustered together in extrusion cooked porridges as compared to the conventionally cooked porridges.

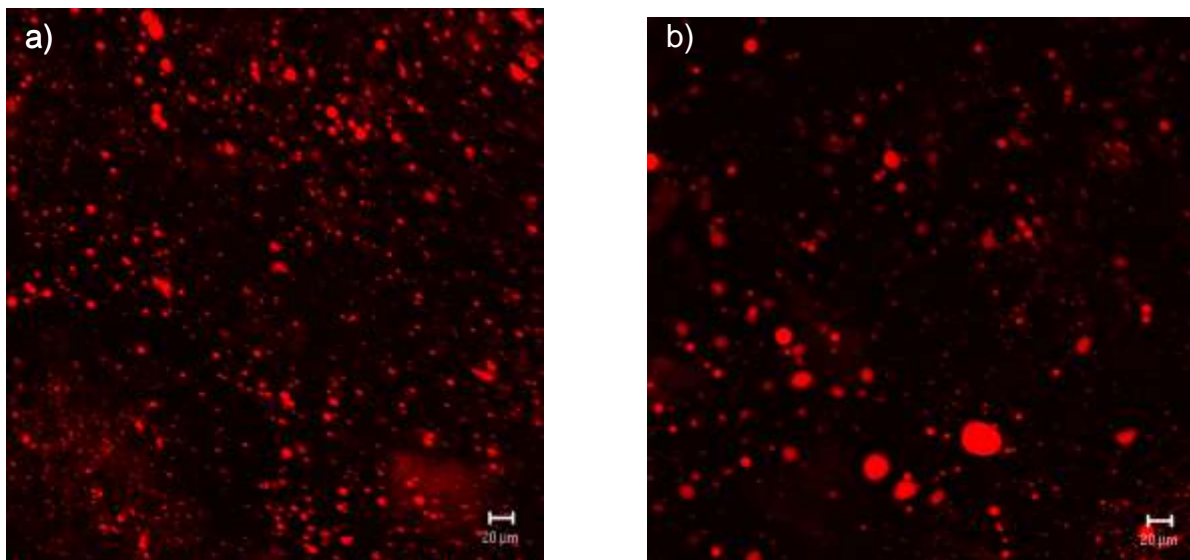


Figure 3.2. 13: Effect of method of heat treatment on confocal laser scanning micrographs of cassava-defatted soy flour with soy oil complementary porridges

Red colour indicates oil droplets .

Micrograph a and b indicate extrusion and conventionally cooked porridge, respectively

3.2.4 Discussion

3.2.4.1 Flow properties

Extrusion cooking markedly reduced the viscosity of porridges. All porridges showed shear thinning behaviour as indicated by a decrease in viscosity with increase in shear rate. Similar trends were reported by Ojijo and Shimoni (2004) for conventionally cooked finger millet porridges (3 to 8% solids content) at a shear range of 1-1000 s⁻¹. According to Larson (1999), shear thinning is an attribute of suspensions that form three dimensional ordered structures at rest.

Shear thinning commences when the shear rate is high enough to disturb from equilibrium the distribution of inter-particle spacing. Furthermore, light micrographs showed that conventionally cooked porridges are a polymer solution of dissolved amylose and remaining swollen starch granule parts (amylopectin). Xia and Callaghan, (1991), found polymer solutions to be shear thinning, with flow behaviour well explained by the power law model. At 10% solids content, the viscosity of extrusion cooked porridges were markedly lower than the corresponding conventionally cooked porridges. The low viscosity could be attributed to physical damage of starch granules during extrusion caused by mechanical shear, high temperature and pressure (Ilo and Berghofer, 1999). This results in amorphous, water soluble carbohydrates of short polymer chain, with low water binding capacity (Onyango *et al.* 2004). Similarly, Xu *et al.* (2012) working on germinated rice flour found a positive correlation between the molecular size of amylopectin and the viscosity of pastes. To facilitate a comparison between the study porridges and a commercially available ready to eat complementary porridge, extrusion cooked porridges were prepared at a solids content of 25%. At a solids content of 25%, conventionally cooked porridges were too thick (could not flow); therefore determination of flow properties was not done. Increase in solids content is desirable in complementary porridges because it results in an increase in energy density while maintaining a viscosity that can be eaten by infants (Section 2.1.3.1).

The data of shear viscosity and shear rate showed a good fit ($r^2 \geq 0.98$ to 0.99) to power law model. A fit of flow behaviour of gelatinized starch solution to the power law model has been reported for pregelatinized maize starches (Anastasiades *et al.* 2002) and extruded maize-soy bean mixtures (Peréz *et al.* 2008). All porridges showed non-Newtonian behaviour ($n < 1$) and were shear-thinning. Ahmed and Ramaswamy (2006) also reported non-Newtonian, shear-thinning behavior for sweet potato infant food. The flow behaviour index (n) and consistency index (K) values for conventionally cooked cassava porridges were 0.29 and 46.3 (Pa.s)^n , respectively. This n value was slightly lower than that reported for sweet potato dispersion (0.31) at 10% solids content while the K - value was higher (31.0 Pa.s^n) (Chun and Yoo, 2006). Mouquet and Treche, (2001) found the n -value of maize porridge (10.3% solids content) and multicomponent porridge (10.7% solids content) to be 0.54 and 0.66, respectively. This is consistent with the observation of Chen and Ramaswamy (1999) that cassava flour paste has

higher viscosity than sweet potato and maize flour paste/ porridge. The K- value of conventionally cooked porridges reduced when either defatted or conventionally cooked soy flour was added. Similar trends were observed by Mouquet and Treche (2001) when millet was composited with soy flour and conventionally cooked. Possibly the reduction in K-value could be due to a decrease in starch content present in the composite flour. Starch is the main contributor of viscosity in starchy pastes/porridges (Copeland *et al.* 2009).

3.2.4.2 Frequency sweep at different temperatures

Temperature influences cross linking and formation of junction zones of amylose in paste/gel (Morris, 1990), which may influence elastic properties of porridges. Therefore, porridges were held at various temperatures (20, 40, 60 and 70 °C) to study their viscoelastic properties at different temperature. The frequency dependent functions are storage modulus (G') and loss modulus (G''). G' is a measure of the energy stored and subsequently released per cycle of deformation per unit volume. It is the property that relates to the molecular events of elastic nature. G'' is a measure of the energy dissipated as heat per cycle of deformation per unit volume. G'' is the property that relates to the molecular events of viscous nature (Mezger, 2006). The G' and G'' of conventionally cooked porridges were higher than the corresponding extrusion cooked porridges over the entire frequency range. This increase could be due to initial formation of a stronger paste network as a result of reassociation of amylose in conventionally cooked porridges as compared to the limited reassociation in extrusion cooked porridges (Onyango *et al.* 2004). Extrusion cooking probably resulted in depolymerization of starch (Liu, 2010). Similarly, Wu *et al.* (2010) found a decrease in G' of flaxseed-maize dispersions when the severity of extrusion condition increased.

Except for extrusion cooked cassava porridge and porridge with defatted soy flour held at 60 and 70 °C, the G' and G'' values of all porridges showed an increase with frequency over the whole frequency range. Ahmed and Ramaswamy (2006) working on commercial infant sweet potato puree (11% solids) at 50°C also reported an increase in G' and G'' with increase in frequency. Similar trends were reported by Chun and Yoo (2006) for sweet potato pastes (10% solids) at 25°C. Wu *et al.* (2010) working on dispersions of extrusion cooked flaxseed-maize blends also

reported G' and G'' to increase with frequency. The increase in G' values with increase in frequency could be due to increase in paste rigidity. At high frequency (faster motion), molecular chains cannot disentangle during a single oscillation and further cross link junction points could be formed (Angiolino and Collar, 2008), thus increasing G' . The $\tan \delta$ reduced between 0.01 rads/s and 0.1 rads/s which are consistent with a decrease in G'' values at similar frequency range. These results are consistent with the observation of Singh *et al.* (2009) working on extrusion cooked potato flour paste subjected to frequency sweep at 25 °C. This indicates that at low frequency, the lost energy was reducing (Mezger, 2006); at low frequency (slow motion), there is sufficient time for networks to be relaxed and reassociated (Tabilo-Munizaga and Barbosa-Canovas, 2005). At higher frequency (10 rad/s to 100 rads/s) an increase in $\tan \delta$ was observed as G'' values also increased.

Extrusion cooked cassava porridge and porridge with defatted soy flour analysed at 70 °C and 60 °C, showed a G' - G'' cross-over; where $\tan \delta$ gradually increased to greater than 1. Bryant and McClements (2000), also found a gradual increase in $\tan \delta$ to values above 1 at high frequency (10 rad/s) while working with denatured whey protein solutions. Thus, at high frequency, extrusion cooked cassava porridge and extrusion cooked porridge with defatted soy flour studied at 60 and 70 °C were dominated by loss modulus (G''), and behaved more like liquid ($\tan \delta$ value greater than 1). In contrast, at similar temperature and frequency (60 °C and 70 °C, frequency of 0.01-100 rad/s), extrusion cooked porridge with defatted soy flour and soy oil behaved more like a solid ($\tan \delta$ less than 1). Possibly this could be due to a filler effect of packed oil droplets (Ma and Barbosa-Canovas, 1995). In addition, formation of nano-scale structures due to the presence of V-amylose (Zabar *et al.* 2009) may reduce the mobility of extrusion cooked porridges with defatted soy flour and soy oil. Formation of amylose-lipid complexes occurred in extrusion cooked porridge with defatted soy flour and soy oil (Section 3.1.3.4).

3.2.4.3 Temperature sweep

When porridges were cooled from 90 °C to 15 °C, conventionally cooked porridges showed an increase in G' values. This temperature range was selected to simulate what happens during cooling of porridge to temperature at which the porridge is eaten. Porridges are also likely to be stored at similar temperature (15 °C) especially during winter. Sun *et al.* (2008) working on rice

pastes found G' to increase with a decrease in temperature (95 °C to 20 °C) which was attributed to retrogradation of amylose that initiates reassociation through hydrogen bonding during cooling. When temperature decreases, starch paste systems tend to be steady with more rigid networks (Sun *et al.* 2008), as extensive helix-helix aggregation of amylose occurs leading to formation of crystalline domains (Gidley, 1995).

Both extrusion and conventionally cooked porridges with defatted soy flour and soy oil had higher G' than conventionally cooked porridge with defatted soy flour. Using confocal scanning laser microscopy, oil droplets were identified in both extrusion and conventionally cooked porridges to be dispersed within the starch matrix. Takahashi and Seib, (1988) found an increase in G' when wheat starch with added wheat lipids was cooled from 95 °C to 30 °C. Similar observations were also reported by Singh *et al.* (2002) during cooling of potato and corn pastes in presence of fatty acids. Addition of 1% stearic acid resulted in a 2-fold and a 4 fold increase in G' for corn and potato pastes, respectively (Singh *et al.* 2002). The findings of Singh *et al.* (2002) compare closely with those observed in conventionally cooked porridges with defatted soy flour and with defatted soy flour and soy oil as addition of 7% soy oil had a 2- fold increase in G' . Ma and Barbosa-Canovas (1994) also observed a positive correlation between oil content and G' value in mayonnaise. Possibly the increase in G' could be due to filling or packing effect of the oil droplets. Matsumuri *et al.* (1993) evaluated the filler effect of soya oil in a model system containing soy 11S globulin and concluded that soy oil acted as filler in the system, which led to increases in G' when subjected to small deformation testing. Similar observations were made by Navarro *et al.* (1997) during a study using pastes made of 7% (w/w) corn starch dispersions and 5% (w/w) sunflower oil, these authors found that gels containing sunflower oil had higher storage modulus G' values (a measurement of rigidity in the gel) than control pastes without lipids. Garzón *et al.* (2003) who evaluated the effect of soybean oil on corn starch gel hardness observed an increase in hardness in the presence of soybean oil. Possibly the relatively high G' values could be due to a filler effect from soy oil droplets as seen in CLSM micrographs.

Extrusion cooked porridges had lower G' and G'' values compared to conventionally cooked porridges. In general starch pastes may be regarded as a composite material of swollen granules

(containing mainly amylopectin) dispersed in a continuous biopolymer matrix (containing mostly amylose) (Alloncle and Doublier, 1991). Thus the overall rheological behaviour is determined by the viscoelastic properties of the dispersed phase, continuous phase and the interaction between the two phases (Alloncle and Doublier, 1991). However, extrusion cooking resulted in damaged starch granules that did not undergo pasting into the three phases when reconstituted with hot water (Copeland *et al.* 2009). As observed from the iodine stained light microscopy images, extrusion cooked porridges had a smooth distribution of starch (a continuous matrix) while conventionally cooked porridges showed traces of swollen starch granules that seem to be connected to each other. Furthermore, short chain molecules in extrusion cooked porridges have limited ability to reassociate and strengthen the paste network (Onyango *et al.* 2004). In contrast, amylose in conventionally cooked porridges undergo retrogradation through hydrogen bonding to form a three dimensional network, leading to an increase in G' .

Extrusion cooked porridges with defatted soy flour and soy oil had higher G' values than extrusion cooked porridge with defatted soy flour. Extrusion of wheat and almond flour has been reported to form amylose-lipid complexes (De Pilli *et al.* 2008). Similarly, formation of amylose-lipid complexes in extrusion cooked cassava porridge with defatted soy flour and soy oil was observed in this study (Figure 3.1.3). The high G' values in extrusion cooked porridge with defatted soy flour and soy oil could be due to the presence of amylose-lipid complexes. Amylose-lipid complexes (V-amylose) are suprastructures formed due to crystal lattice of intermolecular forces (Seneviratne and Biliaderis, 1991). The V-amylose are characterized of intra- and inter- helical contacts (hydrogen and Van der Waals bonding) that can possibly contribute to stability (Rappenecker and Zugenmaier, 1981) and thus higher G' . Furthermore, V-amylose has been suggested to pack into nano-scale structures that tend to aggregate to form micro-sized structures (Zabar *et al.* 2009).

Close aggregation of oil globules increases the effective volume of the filler resulting in high storage modulus (Sala *et al.* 2009). Possibly high mechanical shear during extrusion cooking could have enhanced the dispensability of soy oil in the extrusion cooked porridge as compared to limited mechanical shear during conventional cooking. According to Egelanddal *et al.* (2001) a positive correlation exists between oil droplet size distribution and energy input of the

homogenizer. A filler effect from soy oil droplets as indicated by confocal laser scanning images could have also contributed to the relatively high G' values in porridges with defatted soy flour and soy oil.

All the porridges (extrusion and conventionally cooked) showed a biphasic increase in G' as shown by a slow increase between 90 °C and 60 °C and thereafter a rapid increase in G' . Possibly this could be due to start of retrogradation at below 60 °C. Obanni and Bemiller (1997) investigated retrogradation of cassava starch after storage for two weeks at 4 °C using the Differential Scanning Calorimeter. These authors found an endotherm at about 60 °C. Similarly, Lu *et al.* (2012) found a transition peak at 40-60 °C in potato pastes stored at 4 °C; which was associated with retrogradation. During retrogradation, junction zones and crystallites begin to form accompanied by gradual increase in paste rigidity (Karim *et al.* 2000).

3.2.4.4 Time sweep

Time sweep was done to evaluate the effect of cold storage such as refrigeration (~4 °C) on viscoelastic properties of the porridges. At all temperatures, both extrusion cooked and conventionally cooked porridges behaved more like a soft solid because the $\tan \delta$ was less than one (Mezger, 2006). Extrusion cooked porridge with defatted soy flour and soy oil showed an increase in $\tan \delta$ during storage, an indication of paste weakening. The weakening could be due to a reduction in the amount of amylose in the aqueous phase. Amylose concentration in the continuous phase declines because of crystallization of V- complex between amylose and lipid (Takajashi and Seib, 1988). Formation of amylose-lipid complexes was shown to have occurred in the extrusion cooked cassava porridge with defatted soy flour and soy oil (section 3.1.3.4). Considering that amylose is responsible for retrogradation and paste strengthening in the short term (within hours) reduced amylose in the continuous phase may have contributed to paste weakening during storage. Extrusion cooked and conventionally cooked cassava porridge and porridge with defatted soy flour showed a decrease in $\tan \delta$ during the first hour of storage. This shows that paste strengthening possibly occurred within the first hour of storage.

Conventionally cooked porridge with defatted soy flour and soy oil had higher $\tan \delta$ values compared to conventionally cooked cassava porridge and conventionally cooked porridge with defatted soy flour during storage for 12 h at 4 °C. Singh *et al.* (2002) found a similar trend during storage of potato and corn starch pastes containing fatty acids. This indicates that, in the presence of soy oil, a weak paste network was formed during the 12 h storage period. Lipids have been reported to influence retrogradation by forming amylose-lipid interactions that reduced the loss of water from the continuous phase, which is dominated by leached out amylose in conventionally cooked pastes. According to D'Appolonia, and Morad (1981), interaction between amylose and lipids retards water distribution and hence retrogradation. Reduction in retrogradation was also suggested by D'Silva *et al* (2011) as the cause of non-gelling in teff and maize starch during prolonged pasting with added stearic acid.

3.2.5 Conclusion

The rheological properties of cassava porridge can be manipulated through extrusion and addition of either defatted soy flour, or defatted soy flour with soy oil. The flow behaviour of extrusion cooked (10% and 25% solids content) and conventionally cooked (10%) cassava-soy flour complementary porridges fits to the power law model. Addition of defatted soy flour with soy oil increases the relative strength of both extrusion and conventionally cooked porridges, possibly due to a filler effect of oil droplets. Compared to conventionally cooked porridges, all extrusion cooked porridges have a slower increase in consistency due to slower retrogradation during handling at various temperature conditions and during storage. Slow rate of increase in consistency during handling and storage of complementary porridges is desirable to ensure infants consume porridges with high nutrient density at acceptable consistency. Coupled with enhancement of nutritional value due to compositing and extrusion cooking, addition of either defatted soy flour, or defatted soy flour with soy oil to cassava flour has a potential to increase utilization of cassava complementary porridges.

3.2.6 References

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3.3 Effect of addition of defatted soy flour (with or without addition of soy oil) on sensory quality of extrusion and conventionally cooked cassava complementary porridges

Abstract

The objective of this study was to determine the sensory properties of cassava-soy complementary porridges. The sensory properties of six types of either extrusion or conventionally cooked cassava-soy porridges were described and quantified by a trained sensory panel. The sensory properties were then related to consumer preference (n =122) for the porridges using Partial Least Square (PLS) regression. Extrusion cooking allowed porridges to be prepared with a 25% solids content while maintaining a viscosity of between 1000 cP to 3000 cP (1-3 Pa.s) that can be consumed by infants. Evaluation of denseness of porridge was similar to that of instrumental viscosity measurement, which found extrusion cooked porridge with defatted soy flour and soy oil to be the most viscous. Extrusion cooking and compositing reduced the apparently negative sensory attributes of high viscosity, stickiness, translucency, jelly-appearance and bland taste that characterize conventionally cooked cassava porridge while increasing sliminess of the porridges. Extrusion cooked porridges had high overall flavour intensity, intense toasted nutty flavour, caramel aroma and toasted nutty aftertaste compared to the corresponding conventionally cooked porridges. The flavour and aroma of conventionally cooked porridges was mainly starchy. Consumer preference and liking was towards conventionally cooked porridges; possibly due to familiarity of the sensory attributes of these porridges to the consumers. It is possible that provision of information regarding nutritional value and mode of preparation of extrusion cooked porridges could increase consumer acceptance of nutritionally improved extrusion cooked porridges.

3.3.1. Introduction

Previously (section 3.1), it was demonstrated that compositing cassava and soy flour (either defatted or defatted with soy oil) and extrusion cooking can be used to produce ready to eat (instant) complementary porridges that have nutritional quality similar to commercially available ready to eat commercial cereal porridge. In addition, compositing and heat processing method influenced consumer liking of various sensory attributes of cassava-soy flour porridges. To further understand the determinants of consumer acceptability of these porridges, sensory profiling is crucial.

In sub-Saharan Africa, cassava is principally prepared as traditional foods that are consumed mainly within the producing countries such as Nigeria, Tanzania and Mozambique (Aloys and Ming, 2006; Muoki and Maziya-Dixon, 2010; Tivana *et al.* 2010). Conventionally cooked traditional cassava based foods for example *fufu* and *agbelima* (types of stiff porridge) are perceived as sticky (cohesive) a sensory characteristic that is not liked beyond cassava producing countries (Numfor *et al.* 1998).

Cassava flour contains about 80% starch (Sanchez *et al.* 2009). Cassava has a neutral flavour (Sajeev *et al.* 2003) and bland taste that has been attributed to limited lipid content (Radhika *et al.* 2008). In addition, compared to the viscosity of maize, cassava porridge has higher viscosity (Chen and Ranaswamy, 1999) due to the high swelling power of its biomolecules (Peroni *et al.* 2006). Highly viscous porridges are not desirable for complementary feeding. Infants can eat porridges of a viscosity of 1000-3000 cP (Mosha and Svanberg, 1983). Thus, processing procedures that can reduce these apparently negative sensory attributes while maintaining acceptable sensory quality are likely to increase potential utilization of cassava beyond traditional foods.

Extrusion of a mixture of starch, protein and oil may also result in development of colour, flavour and aroma compounds (Konstance *et al.* 1998; Rampersad *et al.* 2003). This could be due to the occurrence of Maillard reaction between the free ϵ - amino group of lysine and carbonyl group. Pyrazines are some of the major classes of volatiles identified in extrudates and have roasted and nutty properties (Fors and Eriksson, 1986; Maga and Sizer, 1979). Furans are oxygen

containing heterocyclics that provide a sweet or caramel-like aroma and may be formed from pyrolysis of sugars during extrusion (Riha *et al.* 1996).

No information on sensory profiling of either conventionally cooked or extrusion cooked cassava-soy complementary porridges could be found. Information on how the sensory properties influence consumer liking of porridge is also not available. Thus, the objective of this phase of the study was to determine the sensory profiles of extrusion and conventionally cooked cassava and cassava-soy complementary porridges.

3.3.2 Materials and Methods

3.3.2.1 Raw materials, formulation of composites and preparation of porridges

Raw materials and formulation of composites are described in section 3.1.2.1 and section 3.1.2.2, respectively.

3.3.2.2. Methods of heat processing

Conventional cooking

The procedure described in section 3.1.2.3 was followed.

Extrusion cooking

Extrusion cooking and milling procedures are described in section 3.1.2.3. Extrusion cooked porridges containing 10% solids (similar to conventionally cooked porridge) were runny in consistency. For this reason, only porridges with a solids content of 25% were prepared in order to match the solids content of commercial ready to eat porridge used as a reference. The higher solids content contributed to a more acceptable viscosity and was also nutritionally advantageous. Freshly prepared samples were analysed.

3.3.2.3 Determination of porridge viscosity

A rotational concentric cylinder rheometer (Physica MCR 301, Anton Paar, GmbH, Ostfildern, Germany) with temperature control and data acquisition software (Rheoplus version 3) was used to determine the viscosity of porridges. Immediately after preparation, porridges were cautiously

transferred into the rheometer cup maintained at 40 °C and then left to equilibrate for 10 min. A thin layer of light paraffin oil was applied on top of the exposed sample surface to prevent loss of moisture through evaporation (D'Silva *et al.* 2011). After equilibration, the apparent viscosity was recorded at 100 s⁻¹ to resemble the maximum shear developed in a human's mouth during mastication of pastes/porridges of a viscosity between 100 to 100000 cP (Merger, 2006; Szczecniak, 1979).

3.3.2.4 Determination of textural properties

The textural properties (firmness and stickiness) were determined using a TA-XT2 Texture Analyzer (Stable Micro Systems, Godalming, UK). The following parameters were used: mode was force in compression; pre-test speed 2.0 mm s⁻¹; test speed 0.5 mm s⁻¹; post-test speed 0.5 mm s⁻¹; sample penetration distance 5.0 mm; and a flat cylindrical PERPEX probe (20 mm diameter) was used. Porridges were allowed to cool to 40 °C in a 100 ml beaker covered with aluminium foil for 20 min to avoid evaporation of moisture. The surface layer of the porridge was cautiously scraped off prior to analysis. Firmness was the maximum force registered as the probe penetrated the porridge while stickiness was the maximum (negative force) obtained as the probe withdrew from the porridge (Liu *et al.* 2007).

3.3.2.5 Descriptive sensory evaluation

Ethical approval for the study was granted by the Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa.

a) Selection of panel members

Sensory panel members were recruited from the University of Pretoria student population. A combination of techniques was used in screening the panel. It included 1) identification of the fundamental tastes-bitter, sweet, sour, salty and umami, 2) description of four aroma compounds on filter paper strips - fat, potato, roast ham and pineapple and 3) discrimination of sensory properties of two commercial ready to eat porridges. Additional screening appraised issues of motivation, interest and availability. People allergic to soy proteins were strongly discouraged from participating.

b) Panel training

The generic descriptive sensory method described by Einstein (1991) was used in this study. During the first introductory session, panel members were given an interactive presentation on the objectives of the research project and basics of sensory evaluation. Ten sessions of 2 h each were devoted to training and group discussions to attain consensus on the sensory descriptors, references and anchors of the evaluation scales.

A preliminary list of 64 descriptors was generated by the panel. Redundant, synonymous and vague terms were eliminated by panel agreement. For example peanut butter, nutty, roasted peanut were seen to represent the same sensation and therefore toasted nutty aroma was selected to represent the sensation. To facilitate agreement on the various sensory descriptors, panellists identified products, referred to as reference standards that were presented to the panel. Reference standards have been defined as ‘any chemical, ingredient, spice or product (Reiney, 1986) and could be extended to include non-food related materials which demonstrate sensory stimuli e.g. grass for grassy (Murray, 2001). The reference standards were further used to anchor the 10 point structured line scales (Tables 3.3.1-3.3.4). At the evaluation stage, a total of 26 descriptors (Tables 3.3.1-3.3.4) were used to differentiate among the porridges.

c) Sample presentation and assessment

Nine female students (20-38 years) from University of Pretoria participated in the study. Tests were conducted in a sensory evaluation laboratory equipped with individual booths under white daylight conditions. The panel entered data directly on Compusense Five[®] Release 4.6 (Compusense Inc, Ontario, Canada). Approximately 40 g of porridge was evaluated. Pieces of carrot and filtered tap water at room temperature were provided for rinsing the mouth before and between samples. The porridges were served in glass ramekins labelled using random 3-digit codes. Each panel member evaluated six porridges within a 1 h session using stainless steel spoons. To avoid fatigue, porridges were served in two sets of three with a delay of 10 min between the two sets. The order of sample presentation was randomized over the panel. Analysis was done in triplicate over three days giving 27 data points per porridge. Ratings for individual samples were averaged over 9 panellists.

Table 3.3. 1: Sensory descriptors of appearance used by sensory panel to evaluate cassava-soy porridges: - evaluation guidelines and consensus values for reference standards

Descriptor	Definition	Procedure of evaluation	Rating scale	Reference
Glossiness	The amount of shine or gloss perceived on the surface of the product	Hold the cup bent in the direction of light	Not Glossy =0 Very Glossy =9	Mayonnaise = 5 Honey = 9
Jelly-like	Product's ability to wiggle similar to gelatin dessert/ visual evaluation of gel-like appearance of the porridge	Hold the cup bent in the direction of light and shake gently	Not jelly-like =0 Very jelly-like = 9	Moir's Jelly prepared as per manufacturer's instruction = 9
Stickiness	The degree to which a spoon adheres to the product	Use the back of the spoon to pull the porridge from the sides of the bowl	Not sticky = 0 Very sticky = 9	Johnson's baby oil = 0
Viscosity	Product's resistance to flow when stirred with a spoon	Stir the porridge in a clockwise manner once	Not viscous = 0 Very viscous = 9	Water = 1 Hulett's chocolate syrup = 9
Translucent	The degree to which a product looks translucent when poured from a spoon	Pour teaspoonful sample	Not translucent = 0 Very translucent = 9	No name Pick 'n Pay smooth Apricot jam = 9
Slimy	Degree of cohesiveness as porridge flows from a spoon		Not Slimy = 0 Very Slimy = 9	Hulett's chocolate syrup = 5 Hulett's smooth toffee sauce = 9

Table 3.3. 2: Sensory descriptors of aroma used by sensory panel to evaluate warm cassava-soy porridges using short sniffs: - rating scale and consensus values for reference standards

Descriptor	Definition	Rating scale	Reference
Starchy aroma	Aroma associated with undercooked maize porridge	Not intense =0 Very intense =9	35 % ACE maize flour stirred in boiled water without further cooking =9
Caramel aroma	Aroma associated with toasted and browned sugar without burning it	No intense =0 Very intense =9	Hulett's caramel sauce =9
Toasted nutty aroma	Aroma associated with toasted peanut	Not intense =0 Very intense =9	
Sweet aromatics	Aromatics associated with boiled herbal tea	Not intense =0 Very intense =9	Boiled Black Forest herbal tea =9
Beany aroma	Aroma associated with undercooked legumes	Not intense =0 Very intense =9	Soybeans soaked in water overnight =9
Wet bran aromatics	Aromatics associated with wetted bran	Not intense =0 Very intense =9	No name Pick 'n Pay oat bran, wetted =9
Dry grass/hay	Aromatics associated with dry grass	Not intense =0 Very intense =9	Dry grass

Table 3.3. 3: Sensory descriptors of flavour used by sensory panel to evaluate cassava-soy porridges by swirling ½ teaspoonful of sample around the mouth before swallowing: - rating scale and consensus values for reference standards

Descriptor	Definition	Rating scale	Reference
Bitter taste	Taste stimulated by solutions of caffeine or quinine	Not intense = 0 Very intense = 9	4 % w/v solution Nescafé instant coffee in boiled water =9
Cooked soy	Flavour associated with cooked soy flour	Not intense = 0 Very intense = 9	35 % defatted toasted soy flour in boiled water =9
Toasted nutty flavour	Flavour associated with toasted nuts	Not intense = 0 Very intense = 9	
Overall flavour intensity		Not intense/bland = 0 Very intense = 9	Thin maize porridge (10 % solids) =5
Starchy flavour	Flavour associated with undercooked maize porridge	Not intense = 0 Very intense = 9	35 % maize flour paste in boiled water without further heating =9
Sour taste	Fundamental taste sensation elicited by acids	Not intense=0 Very intense=9	9 % w/v tartaric acid in water = 9

Table 3.3. 4: Sensory descriptors of mouth feel and post swallowing sensation used by sensory panel to evaluate cassava-soy porridges by consuming a teaspoonful of porridge: - rating scale and consensus values for reference standards

Descriptor	Definition	Rating scale	Reference
Denseness	The degree to which food feels heavy in the mouth and does not move easily	Not intense=0 Very intense=9	
Mealiness	The perception of fine, soft, somewhat round and smooth particles evenly distributed within the product	Not intense=0 Very intense=9	Stiff maize porridge from Iwisa flour (35% flour) =5
Residual/grainy	The degree to which food leaves particles on the tongue after swallowing	No grainy particles =0 Many grainy particles =9	Stiff maize porridge from Iwisa flour (35% flour) =5
Fatty/greasy mouth coating	Feeling that the palate is coated with a fatty or starchy film	Not intense=0 Very intense=9	
Starchy aftertaste	Intensity of aftertaste associated with undercooked maize porridge	Not intense=0 Very intense=9	
Bitter aftertaste	Intensity of a lingering bitter taste	Not intense=0 Very intense=9	
Cooked soy aftertaste	Intensity of aftertaste associated with cooked soybean flour	Not intense=0 Very intense=9	35 % defatted toasted soy flour in boiled water =9

3.3.2.6 Consumer sensory evaluation

Consumer sensory evaluation was carried out as described in section 3.1.2.10

3.3.2.7 Statistical analysis

The mean descriptive sensory panel ratings, instrumental viscosity (at 100s^{-1}), textural and colour measurement were subjected to one way analysis of variance (ANOVA) using type of composite as the independent variable and the measured parameters as the dependent variables. Note that the porridges prepared using conventional cooking had lower solids contents (10 %) compared to those prepared by extrusion cooking (25 %). For this reason, separate analyses were conducted for the two cooking methods. Fischer's least significant difference (LSD) test was used to separate means using Statistica software version 10.0 (StatSoft, Tulsa, OK) at $p < 0.05$. Unscrambler ® X, version 10.1 (Camo Software) was used to regress overall acceptability scores on descriptive sensory attributes using Partial Least Squares (PLS) regression. PLS regression was also carried out to establish interrelationship between sensory attributes and consumer acceptability of the porridge samples. Sensory attributes were the X- variables while consumer scores were the Y –variables.

3.3.3 Results

3.3.3.1 Viscosity and textural properties

Table 3.3.5 shows the viscosity and textural properties of cassava-soy flour porridges. Conventionally cooked porridges with defatted soy flour and with defatted soy flour and soy oil were much less viscous ($p < 0.05$) compared to conventionally cooked cassava porridge. On the contrary, extrusion cooked porridge with defatted soy flour and with defatted soy flour and soy oil were more viscous ($p < 0.05$) compared to extrusion cooked cassava porridge. While within the acceptable viscosity for infant feeding, extrusion cooked porridge with defatted soy flour and soy oil had the highest viscosity at 25% solids content.

Textural properties (stickiness and firmness) of cassava-soy flour complementary porridges are also shown in Table 3.3.5. For extrusion cooked porridges, the porridge with defatted soy flour was the most firm and also most sticky while for conventionally cooked porridges; cassava porridge was the most firm and sticky. There was no significant difference ($p > 0.05$) in firmness between conventionally cooked porridges with defatted soy flour and with defatted soy flour and soy oil porridges. Addition of soy flour significantly ($p < 0.05$) reduced

stickiness in conventionally cooked. Reduction in stickiness due to addition of defatted soy flour with soy oil was not statistically significant for extrusion cooked porridge.

Table 3.3. 5: Effect of soy flour addition on values of shear viscosity and textural properties (firmness and stickiness) of cassava complementary porridges at 40°C

Cooking method	Type of porridge	Viscosity	Texture	
		(cP)	Firmness (N)	Stickiness (N)
Conventionally cooked (10% solids)	Cassava	1.7 b ± 0.10	0.29 b ± 0.00	-0.14 c ± 0.00
	With defatted soy	0.7 a ± 0.02	0.13 a ± 0.00	-0.05 a ± 0.00
	With defatted soy flour and soy oil	0.7 a ± 0.17	0.19 a ± 0.00	-0.08 b ± 0.00
Extrusion cooked (25% solids)	Cassava	1.5 a ± 0.35	0.10 a ± 0.03	-0.05 a ± 0.03
	With defatted soy	2.2 b ± 0.20	0.12 b ± 0.03	-0.07 b ± 0.01
	With defatted soy flour and soy oil	2.8 c ± 0.22	0.08 a ± 0.02	-0.03 a ± 0.02

Values are means of three independent analyses ± standard deviation. Values in the same column (for a 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 defatted soy flour and soy oil-65% Cassava flour, 28% defatted soy flour and 7% soy oil

Statistical analysis of extruded and conventionally cooked porridges was done separately due to difference in solid content

3.3.3.2 Descriptive sensory evaluation

Table 3.3.6 shows the average ratings for sensory attributes of conventionally cooked cassava-soy flour porridges. For conventionally cooked porridges, addition of either defatted soy flour, or defatted soy flour with soy oil reduced the scores of jelly-like appearance, stickiness, viscosity and translucency while increasing scores on sliminess. Starchy aroma was a prominent attribute for all three porridges but it was most intense in cassava porridge. Porridges with added soy flour smelled more toasted nutty. However, the intensity of other aroma attributes were not significantly ($p > 0.05$) different among the three porridges. In terms of flavour, addition of either defatted soy flour, or defatted soy flour with soy oil increased the toasted nutty flavour and toasted aftertaste, cooked soy flour flavour and overall flavour intensity as compared to the cassava porridge. Addition of either defatted soy flour, or defatted soy flour with soy oil significantly increased the mealiness of cassava porridge.

Table 3.3. 6: Effect of adding soy flour on descriptive sensory ratings of conventionally cooked cassava porridges (10% solids)

Sensory attribute ¹		Cassava	With defatted soy	With defatted soy flour and soy oil
Appearance	Glossiness	6.0b ± 0.8	6.3b ± 0.9	5.4 a± 1.0
	Jelly-like	6.4c ± 0.7	4.1b ± 1.1	3.6a ± 1.1
	Stickiness	5.1b ± 1.7	3.2a ± 1.1	3.3a ± 0.9
	Viscosity	6.5b ± 0.6	4.5a ± 0.7	4.1a ± 1.0
	Translucency	5.8c ± 1.0	4.2b ± 0.9	3.4a ± 0.9
	Sliminess	2.3a ± 0.9	3.7b ± 0.7	2.8b ± 0.7
Aroma	Starchy	5.8b ± 1.4	5.0a ± 1.3	5.0a ± 1.4
	Caramel	2.4a ± 1.1	2.4a ± 1.0	3.0a ± 1.2
	Toasted nutty	2.0a ± 0.8	2.8b ± 1.4	3.3b ± 1.5
	Sweet aromatics	3.5a ± 1.2	3.0a ± 1.3	3.2a ± 1.4
	Wet bran	2.8a ± 1.1	3.0a ± 1.1	2.8a ± 1.2
	Dry grass/hay	2.7a ± 1.1	2.8a ± 1.1	2.7a ± 1.1
Flavour	Cooked soy flour	2.4a ± 1.2	3.2b ± 1.4	4.1c ± 1.2
	Toasted nutty	2.4a ± 1.4	3.1b ± 1.5	3.3b ± 1.5
	Overall flavour	3.3a ± 1.2	3.7b ± 1.0	4.1b ± 1.1
	Starchy	1.5a ± 1.3	1.9a ± 1.1	2.4a ± 1.2
	Sour	1.1a ± 0.6	1.2a ± 0.7	1.2a ± 0.7
Mouth feel	Denseness	3.4a ± 1.6	2.6a ± 1.1	2.7a ± 1.0
	Mealiness	3.8a ± 1.5	4.6b ± 1.1	4.8b ± 1.2
	Residual/grainy	4.9a ± 1.3	4.4a ± 1.4	4.4a ± 1.1
	Oily mouth coating	1.9a ± 0.7	2.0a ± 0.8	2.5a ± 1.3
Post swallowing sensation	Toasted nutty aftertaste	2.0a ± 1.2	2.6b ± 1.2	2.9b ± 1.2
	Bitter aftertaste	1.3a ± 1.1	2.3b ± 1.3	1.9ab ± 1.3

Values are mean ratings for a trained panel (n=9) ± standard deviation. Values within the same row 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 defatted soy flour and soy oil = 65% Cassava flour, 28% defatted soy flour and 7% soy oil

The lowest value was 0, indicating not viscous, not glossy, not translucent, not jelly, not slimy, and not intense

The highest score was 9 indicating very glossy, very jelly-like, very sticky, very translucent, very slimy very many and very intense

¹Definitions of attributes are available in Tables 10 to 13

Table 3.3.7 shows the descriptive sensory attributes of extrusion cooked cassava-soy flour porridges. Under appearance, attributes of glossiness and sliminess were rated high (5.8 to 6.5) while jelly-like and translucent were rated low (2 to 2.5) for all porridges. Translucency and jelly-like appearance were significantly higher in cassava porridge as compared to the composite porridges. Aroma attributes were within the medium score ranges (4.0 to 5.5) except for wet bran and dry grass, which were rated lower 2.2-3.0. A toasted nutty aroma was significantly higher ($p < 0.05$) in composite porridges while the porridges were not significantly different for all the other aroma attributes. Flavour attributes of cooked soy flour, toasted nutty and overall flavour were rated high (5.0-6.0) while starchy flavour was of low intensity (1.5-1.7). Cooked soy flour flavour and toasted nutty flavour were significantly higher ($p < 0.05$) in the composite porridges with defatted soy compared to the cassava porridges. Mealiness, denseness and oily mouth coating were clearly observed in the three porridges but in a similar manner. Toasted nutty aftertaste was significantly higher ($p < 0.05$) in the composite porridges as compared to the cassava porridge.

Thus, the panel identified clear differences between extrusion cooked porridges and the corresponding conventionally cooked porridges. For instance, despite containing 2.5 times more solids content, extrusion cassava porridge, porridge with defatted soy and porridge with defatted soy flour and soy oil were scored as less viscous by 1 to 3 units as compared to the corresponding conventionally cooked porridges. Jelly-like and translucent appearance were also scored lower in all extrusion cooked porridges as compared to the corresponding conventionally cooked porridges. However, sensory attributes of denseness and oily mouth coating were scored higher (by 2 to 3 units) in all extrusion cooked porridges as compared to the corresponding conventionally cooked porridges. Scores for overall flavour intensity, cooked soya and toasted nutty flavour in extrusion cooked porridges were about double compared to the corresponding conventionally cooked porridges.

Table 3.3. 7: Effect of soy flour addition on descriptive sensory ratings for extrusion cooked cassava complementary porridges (25% solids)

Sensory attribute ¹		Cassava	With defatted soy	with defatted soy flour and soy oil
Appearance	Glossiness	6.0a ± 1.1	6.3a ± 0.9	5.8a ± 0.9
	Jelly-like	2.0b ± 1.0	1.4a ± 0.8	1.5a ± 0.8
	Stickiness	3.8a ± 1.4	3.4a ± 1.3	3.8a ± 1.4
	Viscosity	3.7a ± 1.2	3.6a ± 0.9	3.3a ± 1.0
	Translucency	2.5b ± 0.8	1.2a ± 0.6	1.5a ± 0.8
	Sliminess	6.4a ± 1.2	6.5a ± 1.0	6.5a ± 1.1
Aroma	Starchy	4.1a ± 1.2	4.0a ± 0.9	4.0a ± 1.3
	Caramel	4.3a ± 1.3	4.5a ± 1.6	4.3a ± 1.5
	Toasted nutty	4.5a ± 1.6	5.5b ± 0.9	5.0b ± 0.5
	Sweet aromatics	4.2a ± 1.5	3.9a ± 1.8	4.2a ± 1.5
	Wet bran	2.7a ± 1.5	3.0a ± 1.4	3.0a ± 1.4
	Dry grass/hay	2.3a ± 1.2	2.3a ± 1.1	2.2a ± 1.1
Flavour	Cooked soy flour	5.4a ± 1.0	6.0b ± 1.0	5.7ab ± 1.0
	Toasted nutty	5.1a ± 1.0	6.0b ± 1.0	5.5ab ± 1.4
	Overall flavour	5.5a ± 0.6	6.1a ± 0.7	5.6a ± 1.0
	Starchy	1.7a ± 0.9	1.7a ± 0.9	1.5a ± 0.9
	Sour	1.3a ± 0.8	1.2a ± 0.9	1.2a ± 0.8
Mouth feel	Denseness	5.5a ± 1.1	5.7a ± 1.1	5.5a ± 1.0
	Mealiness	6.5a ± 1.7	6.5a ± 1.6	6.4a ± 1.5
	Residual/grainy	1.7a ± 0.9	1.7a ± 0.9	1.6a ± 0.8
Post swallowing sensation	Oily mouth coating	5.1a ± 2.1	5.1a ± 2.4	5.1a ± 2.3
	Toasted nutty aftertaste	3.8a ± 1.0	4.4b ± 1.0	4.5b ± 1.3
	Bitter aftertaste	1.5a ± 1.1	1.5a ± 1.1	1.5a ± 1.0

Values are means of three independent analyses ± standard deviation. Values in the same column and similar heat processing method followed by the same letter are not significantly different ($p \leq 0.05$)

Cassava -100% cassava flour

With defatted soy flour - 65% cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil -65% Cassava flour, 28% defatted soy flour and 7% soy oil

The lowest value was 0, indicating absence and low intensity.

The highest score was 9 prominent presence or high intensity.

¹ Definitions of attributes are available in Tables 10 to 13

3.3.3.3 Relating consumer liking to sensory attributes

Ratings by individual consumers were mapped using partial least squares (PLS) regression to evaluate interrelationships with sensory attributes (Figure 3.3.1 and 3.3.2). The first two factors accounted for 98% of the X variance (sensory descriptors) and 38% of the Y variance (consumer rating). The first factor and the second factor accounted for 91% and 7% of the X variance, respectively. Conventionally cooked porridges clustered together on the right side of the plot and are characterised by sensory attributes namely grainy texture, translucent appearance, sticky mouth feel and jelly appearance. Extrusion cooked porridges clustered together on the left side of the plot and were characterised by sensory attributes of more intense cooked soy flavour, toasted nutty flavour, higher overall flavour intensity, oily mouth coating and denseness.

Factor one explained 20% of the variance in consumer acceptance and shows that consumer preference is towards porridges on the right side i.e. conventionally cooked porridges. Factor two explained an additional 18% of the variance in consumer acceptance and demonstrated that most consumers preferred conventionally cooked porridges containing either full fat or defatted soy flour. The third factor explained a further 25% of Y-variance (consumer rating), making the total explained variance 62%. The third factor shows a fair distribution of liking towards porridges located on top of the plots (extrusion cooked cassava porridge and conventionally cooked porridge with defatted flour).

3.3.4 Discussion

Extrusion cooking allowed for an increase in solids content of porridge up to 2.5 times while maintaining a viscosity of between 1 to 3 Pa.s. Porridges with a viscosity of 1 to 3 Pa.s have been identified as suitable for infant feeding (Mosha and Svanberg, 1983; Treche and Mborne, 1999). Compositing also allowed the functional addition of a protein source soy that greatly increased the nutritional value of the porridges. However, these improvements affected the sensory properties of the porridges.

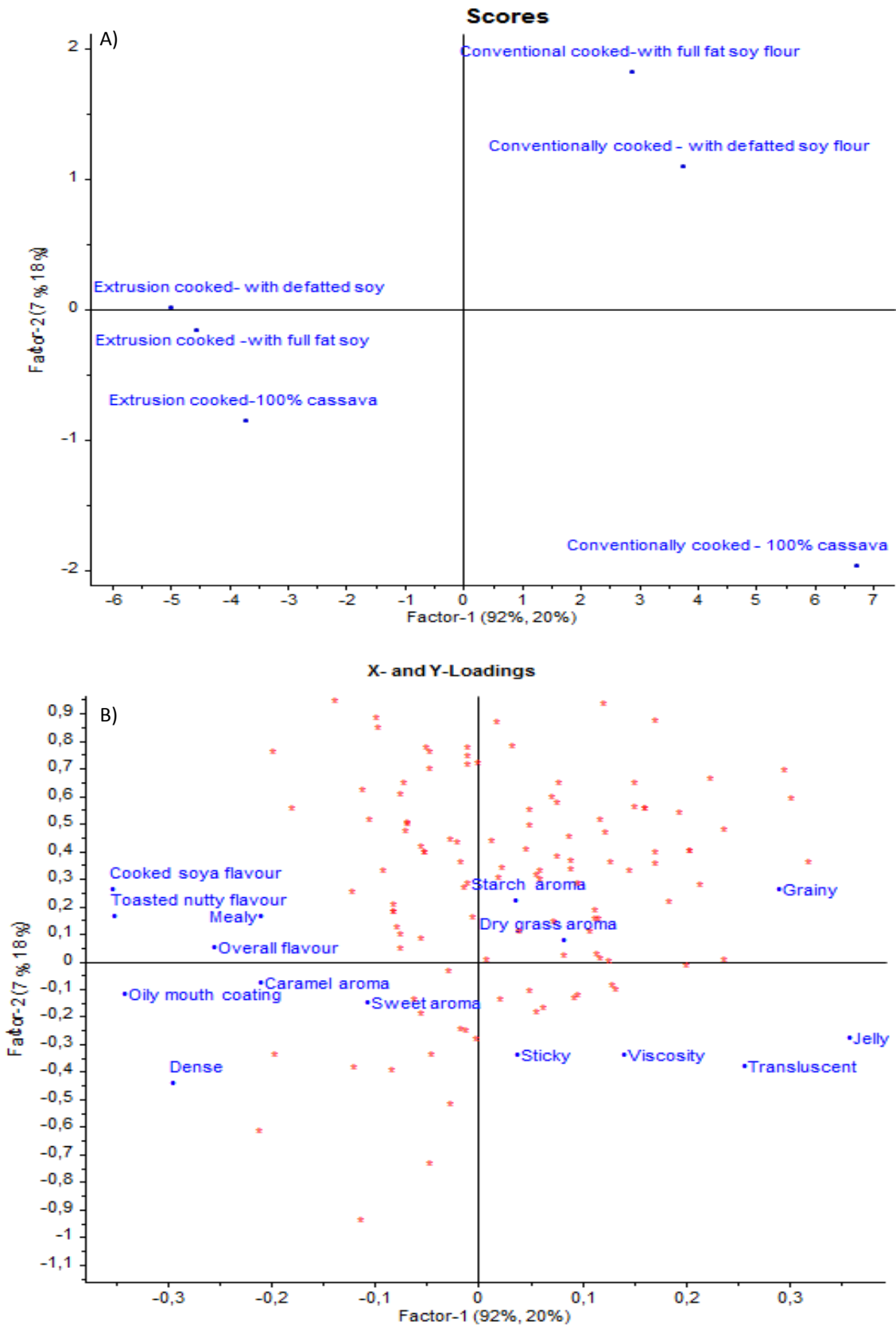


Figure 3.3. 1: Partial Least Square (PLS) regression of extrusion and conventionally cooked cassava-soy flour porridges Plot (A) is of the first two factors of scores of porridges while plot (B) is the first two factors of X (sensory descriptors) and Y (consumer scores) loading. Red dots represent the preferred direction of liking of each consumers (n =122).

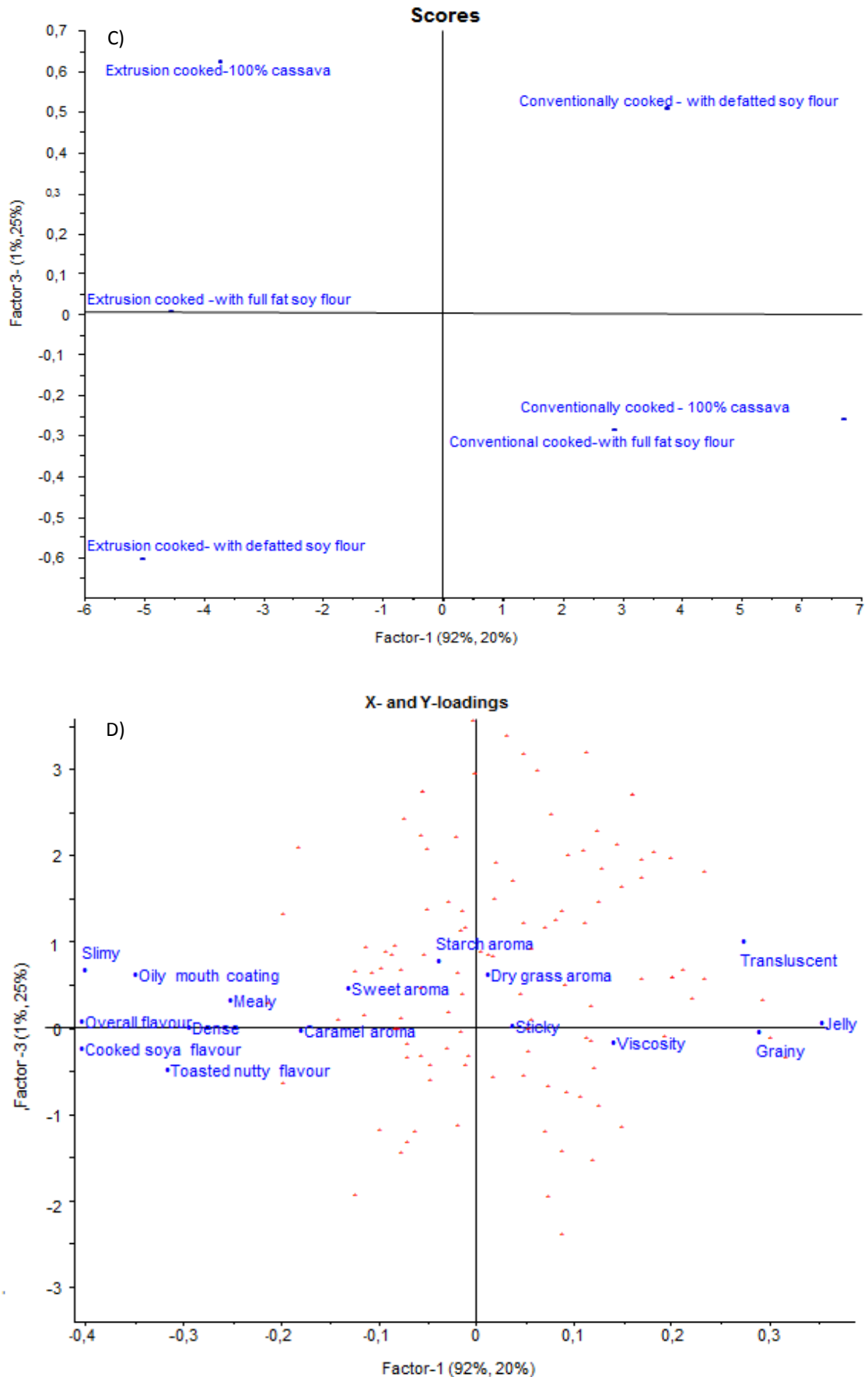


Figure 3.3. 2: Partial Least Square (PLS) regression of extrusion and conventionally cooked cassava-soy flour porridges. Plot (C) is the first and third factors of scores. Plot (D) is the first and third factors of X (sensory attributes) and Y (consumer rating) loading. Red dots represent the preferred direction of liking of each consumers (n =122).

Addition of either defatted soy flour, or defatted soy flour with soy oil to conventionally cooked cassava porridge reduced viscosity. Reduction in viscosity due to addition of soy flour would be beneficial for preparation of traditional complementary porridges of high energy density, with a viscosity that young children can masticate and swallow. Kayitesi *et al.* (2010) also reported a reduction in porridge viscosity when sorghum flour was substituted with defatted heat treated marama high protein legume flour, which is low in starch. Starch is the main component participating in gelatinization/pasting and viscosity development. Thus, reduction in viscosity when soy flour was added could be attributed to limited contribution of soy flour to viscosity.

The trained panel rated extrusion cooked porridges generally lower in viscosity than conventionally cooked porridges. For viscosity measurement, the panel used visual observation of resistance to flow when the porridge is stirred in a clockwise manner using a teaspoon. The perception that extrusion cooked porridges are less viscous is advantageous because extrusion cooked porridges had higher solids content and hence are more nutrient dense than conventionally cooked porridges. During normal porridge preparation, mothers of infants use visual observations to judge the viscosity of porridges (*Personal observation*).

Ratings of denseness by the trained panel followed a similar pattern as those of viscosity as measured using the rheometer; for instance, the extruded porridges were generally denser than conventionally cooked porridges and also the most viscous as per viscometer measurement. Furthermore, the definition provided by the panel for denseness relates to instrumental measurement of viscosity; a measure of a fluid's resistance to flow as applied in physical science.

Addition of defatted soy flour with soy oil reduced stickiness in conventionally cooked porridge according to sensory panel and using the texture analyzer. However, reduction in stickiness due to addition of defatted soy flour with soy oil in extrusion cooked porridges was not statistically significant while using a texture analyser and was not detected by the trained panel. Similarly, others have found that addition of 2% oil reduced the stickiness of sorghum couscous (Aboubakar and Hamaker, 2000). Kuar *et al.* (2005) found a decrease in swelling power and solubility of corn and potato starches with the addition of glycerol monostearate. Addition of a lipid compound to wheat starch was suggested to increase the hydrophobicity of starch granules. Increased hydrophobicity would lead to low water uptake and reduced

granule swelling (Richardson *et al.* 2003). In the presence of emulsifiers, the elastic quality of the paste is diminished because the starch molecules cannot establish enough junction zones of adequate size to give an elastic network (Ghiassi *et al.* 1982), possibly due to formation of amylose-lipid complexes.

Formation of oil droplets within the starch aqueous matrix as observed by Eskins *et al.* (1996) in corn starch and soy oil composites, may have also contributed to low stickiness. A reduction in stickiness of porridges would be beneficial to infant feeding because motor function of their tongue is underdeveloped until the age of 2 years (Carruth and Skinner, 2002) limiting manipulation of sticky food mass in the mouth. At the age of 6 months, infants can move their tongue laterally when food is put in their mouth, by 8 months the tongue can move from the centre of the mouth to the sides. After the age of 2 years, the tongue is able to make a smooth midline transfer of a food bolus (Carruth and Skinner, 2002). Furthermore, a less sticky porridge would be easier to handle by caregivers as the porridge will not stick to the bowl and spoon.

There was a significant reduction in firmness of conventionally cooked porridges due to addition of either defatted soy flour, or defatted soy flour with soy oil as measured by the texture analyzer at 40°C. This observation is consistent with the findings of Colombo *et al.* (2007) evaluating wheat gel firmness in the presence of soy protein and corn and Kuar *et al.* (2005) working with potato noodles and glycerol monostearate. Gel firmness is mainly caused by retrogradation of starch gels and depends on the extent of the junction zone formation (Miles *et al.* 1985). According to Ring *et al.* (1987), the initial firmness of starch gels during retrogradation is due to amylose matrix formation, the resulting firmness increase during storage is due to crystallization of amylopectin. After porridge preparation, porridges were allowed to cool for 20 min before textural measurements. Thus, textural properties should have been predominantly affected by the short term effects of amylose retrogradation as this time was not long enough for amylopectin to associate (Ranaweera *et al.* 2007).

The relatively low firmness in the extrusion cooked porridges despite containing higher solids content (2.5 times higher) could be because extrusion caused depolymerization of amylopectin. According to Ozcan and Jackson, (2005), degraded short amylopectin branches do not readily reassociate to form a gel network. Thus when extrusion cooked starch is

pasted, the degraded molecules dissolve quickly and develop an initial cold viscosity but do not form a gel upon cooling. Porridges with low firmness are desirable for infant feeding because these porridges would have low viscosity at eating temperature (~40°C).

Conventionally cooked cassava porridge was more translucent compared to the conventionally cooked composite porridges. Low starch paste clarity indicates the presence of swollen starch granules within gelatinized starch (Craig *et al.* 1989). Sanchez *et al.* (2009) reported clarity of cooked cassava starch to be low (45.2%) as measured using a spectrophotometer at 650 nm against a water blank. Cassava flour contains ~80% starch (Sanchez *et al.* 2009). The relatively high translucent rating for cassava porridge could be attributed to low paste clarity. Furthermore, a gelatinized starch suspension such as cassava porridge may be structurally considered as a three dimensional network of swollen starch granules embedded in a continuous phase of predominantly solubilized amylose molecules (Ojijo and Shimoni, 2004). Similarly, light microscopy of cassava porridge showed presence of swollen starch granules that are connected together. Addition of soy flour reduced translucency possibly by decreasing the amount of starch in the porridges as soy flour contains limited amount of starch. On the contrary, extrusion cooking involves starch depolymerization through mechanical shearing at high temperature and low moisture (Harper, 1989), which causes reduction of amylopectin to low molecular weight molecules (Liu, 2010). In addition, extrusion cooking results in starch depolymerization (Harper, 1989). This may explain why extrusion cooked cassava porridge was less translucent.

The flavour of ready to eat, extrusion cooked porridges were characterized by more intense overall flavour, caramel aroma and toasted nutty flavour. Possibly the intense flavour development could be due to occurrence of Maillard reaction and oxidation of fatty acids in soy oil (oleic, linoleic and linolenic acids) during extrusion cooking to produce volatile compounds such as furans, pyrazines and hexanal, respectively. In contrast, conventionally cooked porridges were characterized by bland starchy aroma and less intense overall flavour. Fadel and Faruok (2002) reported enhanced volatile compounds e.g. furans and pyrazines during heat treatment of maltose and the amino acid, alanine. Further, extrusion of starch in the presence of linoleic fatty acid has been shown to form benzaldehyde and hexanal volatile compounds (Solina *et al.* 2007).

The direction of consumer preference for cassava- soy porridges was mostly towards conventionally cooked porridges. Possibly this could be due to lack of familiarity with the sensory attributes related to extruded cassava porridges and soy composited porridges, which were new products to the consumers. Several studies have reported consumer preference to be dependent on familiarity of stimuli (Hetherington *et al.* 2000; Hetherington *et al.* 2002; Stallberg-White and Pliner 1999). Furthermore, the most familiar flavour is usually also the most preferred when consuming it for the first time in a test situation (Porcherot and Issanchau, 1998). Possibly consumer preference of extrusion cooked porridges could have been enhanced if information on nutritional value and the convenience of porridge preparation was provided to the consumers.

3.3.5 Conclusions

Extrusion cooked, nutritionally optimized cassava-soy flour porridges can be prepared at 25% solids providing a viscosity that could easily be masticated and swallowed by infants during complementary feeding because of depolymerization of starch. Compositing and extrusion cooking seem to reduce the apparent negative attributes typical of conventionally cooked cassava porridge e.g. stickiness, high viscosity, translucency and jelly-like appearance while increasing flavour and aroma intensity. Extrusion cooked, cassava-soy flour porridges have considerable potential as a complementary food in regions where cassava is a staple food. Extrusion cooked cassava-soy porridges have high energy density and protein quality, with acceptable sensory properties.

3.3.6 References

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4.0 GENERAL DISCUSSION

This chapter will first provide a critical review of methodologies used in this study. Secondly, the effect of adding soy flour and heat treatment on nutritional, rheological and sensory properties of cassava porridge will be discussed. Finally approaches for disseminating the information on cassava-soy porridges in Africa and other developing countries for improved child nutrition are proposed.

4.1 Methodology

4.1.1 Selection and handling of raw materials

Ideally, the ingredients of low cost complementary foods must be derived from dietary staples of the targeted region because they are readily available in sufficient quantities (De Pee and Bloem, 2009). In this study, complementary porridges were formulated from cassava and soy flour.

Cassava is grown in 39 out of 52 African countries, of which Nigeria, Democratic Republic of Congo, Ghana, Angola and Tanzania are among the top 10 producers in the World (FAO, 2007). Thus, cassava is a major food security crop in Africa particularly due to its biochemical adaptability to drought and has low demand for nutrients; it can produce acceptable yields even under marginal environmental conditions (Cock, 1982 as cited by Stupak, 2006). In addition, the commercial price of cassava flour is 31% cheaper than maize flour in Nampula, Mozambique (*Personal observation*).

However, use of cassava flour for infant food may be disadvantageous. Inadequate processing of cassava flour may result in high amounts of residual cyanide. Consumption of high quantities of cyanide from inadequately processed cassava flour has been implicated in causing Konzo, an irreversible paralysis of the legs in children and women of child-bearing age (Ministry of Health Mozambique, 1984). Nonetheless, simple household processing procedures like soaking (Cumbana *et al.* 2007) reduce cyanide to safe levels of < 10ppm (FAO/WHO, 1991).

To formulate a composite of cassava- full fat soy flour, addition of soy oil to defatted toasted soy flour to produce full fat soy flour was selected to avoid variations in protein configuration. This is because the commercial preparation of defatted soy flour differs from the preparation of full fat soy flour in that it involves additional steps of flaking, solvent extraction and desolvenizing (Mustakas, 1971). Mustakas *et al.* (1981) found these steps to reduce the protein solubility index and trypsin inhibitors by 27% and 19%, respectively. Thus, use of commercially available full fat soy flour would mean that the raw materials would have different properties from that of commercial defatted soy flour, which may hinder comparison of results.

4.1.2 Analytical methods

4.1.2.1 Protein quality

Protein quality evaluation aims to determine the capacity of food protein sources and diets to satisfy the metabolic demand for amino acids and nitrogen (WHO/FAO/UNU Expert consultations, 2002). Assessment of protein quality was done to assess adequacy of cassava-soy flour porridges in meeting protein needs of infants. Reduction in protein quality due to processing was also detected. There are various ways of determining protein quality of food; ways used in this study are discussed below.

Available lysine

Lysine is an essential amino acid and is often the first limiting amino acid of common staples such as cereals, roots and tubers. During processing, the ϵ - amino group of lysine can react with other compounds to become nutritionally unavailable (Hurrell *et al.* 1979). The ϵ - amino group is a chemically reactive amino acid. The ϵ - amino group is susceptible to chemical modification during processing and prolonged storage. In particular, the carbonyl group of reducing sugars can react with free ϵ - amino groups of lysine molecules in proteins to form compounds of no or limited nutritional value (Moughan and Rutherfurd, 2008). Maillard reaction results in products such as ϵ -N-deoxyketosyllsine and Schiff base (Moughan and Rutherfurd, 2008), which have limited nutritional value. For instance, metabolic utilization of ϵ -N-deoxyketosyllsine is negligible (Moughan and Rutherfurd, 2008).

Moughan, (2003) defined ‘available amino acid’ as the amount of an amino acid in a diet or food that is absorbed from the digestive tract in a chemical form that the body can potentially use for body protein synthesis. In the case of lysine, “biologically available” and “chemically reactive” is used to describe lysine molecule that has not undergone any form of structural change and therefore available for physiological use.

A number of assays to determine available (reactive) lysine have been developed. Among them, the flurodinitro-benzene (FDNB) method (Capenter, 1960) and the dye-binding lysine method (DBL) (Hurrell *et al.* 1979) are commonly used. The DBL method was used in this study. It involves shaking a protein food in a solution of Acid Orange 12 to allow the dye to bind with the basic amino groups. After the reaction has reached equilibrium, the amount of dye is calculated by measuring the extinction of the dye remaining in solution. This method requires two measurements of dye binding capacity; A) on the sample unmodified and B) on the sample after it has been treated with propionic anhydride, which neutralizes the basicity of the free ϵ -NH₂ group of lysine unit in proteins by propionylation. Thus, the first measurement A, gives the amounts of Histidine + Arginine + Lysine and the second measurement B, gives Histidine + Arginine. Therefore the difference between measurement A and B gives lysine alone. For measurement ‘A’, a sample containing ~ 15 mg of Histidine + Arginine+ Lysine is used while for measurement ‘B’, a sample containing ~15 mg of Histidine and Arginine is used.

Although the DBL method is simple and uncomplicated for determination of available lysine; the need to use different sample weights based on the content of basic amino acid may limit the rapid universal application of this method. Sample weight was calculated based on the content of the three amino acids in order to achieve 15 mg of the various amino acids for determination of A and B as described above. The need to have previous knowledge of the amino acid profile of test food may as well render this method expensive due to the additional cost of amino acid analysis.

More recent methods of analyzing reactive lysine could be considered in future. The guanidation method described by Moughan and Rutherford (1996) overcomes the challenge of a possibility of overestimating available lysine in diets due to unavailable lysine reverting to lysine during acid hydrolysis. The guanidation reaction converts chemically reactive lysine

to acid stable derivative, homoarginine (Moughan and Rutherford (1996). However, this method is relatively time consuming as the assay involves incubation of the sample for 7 days in 0.6 M O-methylisourea (P^H 6.0) at 21°C in shaking water bath. Moughan and Rutherford (1996).

Protein digestibility

Protein digestibility may be determined using biological or enzymatic methods. Enzymatic methods include pepsin digestion and three-enzyme protein digestion. The pepsin method proposed by Hamaker (1987) was used in this study. The method involves first determination of protein content in test food followed by digestion using pepsin at specific conditions. The residual protein content in the digested food is determined and expressed as a percentage of the original protein content.

The multi-enzyme technique for determination of protein digestibility closely mimics protein digestion in humans. It uses pancreatic trypsin, chymotrypsin and porcine intestinal peptidases (Hsu *et al.* 1977). Possibly the multi-enzyme technique could have detected the effect of trypsin inhibitors on protein digestibility. However, the levels of trypsin inhibitor were found to be low (~ 1.5 trypsin inhibitor units) in defatted, toasted soy flour used to composite cassava flour. The multi-enzyme technique is a pH shift method and involves use of strong buffers that may affect measurement of protein digestibility (Hsu *et al.* 1977). This method was not used in this study.

Amino acid score

The amino acid score, also referred to as chemical score determines the effectiveness with which absorbed dietary nitrogen can meet the indispensable/essential amino acid requirement at the safe level of protein intake (FAO/WHO/UNU 2007). This is achieved by a comparison of the content of the limiting amino acid in the protein or diet with its content in the requirement pattern (FAO/WHO/UNU 2007):

$$\text{Amino acid score} = \frac{\text{mg of amino acid in 1 g test protein}}{\text{mg of amino acid in requirement pattern}}$$

The nutritionally essential amino acids (EAA) are the amino acids that cannot be synthesized by human tissues in rates commensurate with metabolic needs and so must be supplied via an exogenous source (diet or breast milk) (FAO/WHO/UNU, 2007).

Amino acid score assumes that protein synthesis will be limited unless all amino acids are present in a dietary protein in the least amount relative to the amount required (Moughan, 2005). However, protein determination by this method may not be sufficient as it does not take into account digestibility of protein, which may affect the pattern of amino acid that can actually be used for protein synthesis.

Protein Digestibility Corrected Amino Acid Score (PDCAAS)

To elucidate the overall protein quality, PDCAAS was used. PDCAAS is based on comparison of the essential amino acid content of a test protein with that of a reference essential amino acid pattern and corrected for differences in protein digestibility as determined using a rat assay (Schaafsma, 2005; WHO/UNU/FAO, 2007).

Thus, $PDCAAS (\%) = \text{Protein digestibility} (\%) \times \text{Amino acid score}$.

In this regard, protein digestibility refers to true digestibility (TD). TD is true fecal digestibility of the test protein, as measured in a rat assay.

There was a modification to this method because protein digestibility was determined using the pepsin method and not by biological assay. A good correlation has been reported between the pepsin protein digestion method and digestion in human (Axtell *et al.* 1981). Use of animal assays is not only costly but also time consuming (Smith, 2003). Biological assays also face concerns of ethics regarding use of animals (European Union, 1986).

The PDCAAS method has some weaknesses. For instance, the current amino acid reference is based on essential amino acid. Essential amino acids are those that have carbon skeleton that cannot be synthesized to meet body needs from simpler molecules, and therefore must be provided in the diet (FAO/WHO/UNU, 2007). These amino acids include histidine, isoleucine, leucine, lysine, methionine, phenylalanine, theonine, tryptophan and valine. However, PDCAAS does not involve amino acids cysteine, tyrosine, glycine, arginine, glutamine and proline that become essential under specific physiological conditions (Schaafsman, 2005). For instance in newborn child, it has been suggested that only alanine,

aspartate, glutamate, serine, and asparagine are truly non- essential amino acids (Pencharz and Ball 2003).

Secondly, PDCAAS values have a cut off point of 100% in all foods. This may lead to loss of useful information especially regarding animal source foods. For instance, it has been recommended that the PDCAAS of milk be 123, 123 or 120 if lysine, theonine and methionine and cysteine are considered as the first limiting amino acid, respectively (Reeds *et al.* 2000). Such information as compared to a cut off value of 100 for milk would also aid in selection of ingredients for product development especially for populations with special needs such as infants.

4.1.2.2 Energy quality/starch digestibility

Starch digestibility

Starch is the main source of calories for humans. The calories provided by a specific carbohydrate food cannot be accurately assessed based on its quantity alone due to variations of the rate and extent of its digestion and absorption (Jenkins *et al.* 1981; Englyst *et al.* 2003). There are several *in vitro* methods for measuring important starch fractions: for examples the Englyst *et al.* (1992) method, the Goni *et al.* (1997) method and the Guraya *et al.* (2001) method.

In this study, Goni *et al.* (1997) method of *in vitro* starch digestion was used to determine kinetics of starch digestion. This method not only allows for determination of the three important fractions of starch, it also provides equations for estimation of glycemic index. The method uses α - amylase and amyloglucosidase enzymes to digest starch while protein is digested using pepsin. The α - amylase breaks down starch (both α 1-4 and 1-6 glucosidic bonds) into dextrans and oligosaccharides, which are further broken down by amyloglucosidase to glucose. This combination of enzymes closely simulates starch digestion in the small intestine, where most of starch digestion takes place (Hasjim *et al.* 2010). However, perhaps *in vitro* methods of starch digestion could be improved by including lipase because amylolysis *in vivo* occurs in the small intestine simultaneously with fat digestion in the presence of bile (Woolnough *et al.* 2008).

Aliquots were sampled at various intervals (5, 30, 60, 90, 120, 150 and 180 min). Enzymes were inactivated using boiling water, which stopped further breakdown of dextrans and oligosaccharides to glucose. Sampling at 5 min was a slight modification to the method. This was prompted by the observation that starch digestion occurred much more rapidly before the first sampling time of 30 min as suggested by Goni *et al.* (1997). Sampling of aliquots was within 120 min, the time reported to be sufficient to obtain an extended release of glucose (Englyst *et al.* 1992; Jeskins *et al.* 1981).

Glucose oxidase was used to aid in determination of glucose present in aliquots sampled at the various intervals. The principle of this method is that, glucose is oxidized to gluconic acid and hydrogen peroxide by glucose oxidase. Hydrogen peroxide reacts with O-dianisidine in the presence of peroxidase to form a coloured product (Oxidised o-Dianisidine). Sulphuric acid was added in order to form a more stable Oxidised o-Dianisidine (pink) that was analyzed using a spectrophotometer. The amount of starch digested at each interval was calculated using a factor of 0.9 in order to adjust D-glucose to hydro D-glucose as it occurs in starch.

Resistant starch was determined as the difference between total starch before digestion and the total starch digested after 180 min. This was a deviation from the Goni *et al.* (1997) method but similar to the procedure used in Englyst *et al.* (1992) method. Resistant starch refers to starch and its degradation products that are not absorbed in the small intestine by healthy individuals (Asp and Björck, 1992). Using volunteers, Englyst *et al.* (1992) found 120 min to be sufficient to obtain extended release of glucose. Use of 180 min therefore allowed for any very slow starch digestion to be identified. A plateau (state of no or limited starch digestion) occurred after 60 min of digestion (Figure 3.1.1).

The Goni *et al.* (1997) method uses a rather lengthy procedure to determine resistant starch. This method includes incubation of the sample in α -amylase for 16 h to hydrolyze digestible starch. The residual is then treated with 2 M KOH to solubilize resistant starch. A further incubation is done using amyloglucosidase followed by determination of glucose using glucose-oxidase assay (Goni *et al.* 1997).

The use of Goni *et al.* (1997) method to determine important starch fractions may be limited because it does not take into account the influence of aspects related to food and human physiological factors; for example, gastric emptying rate, digesta viscosity and transit time in the gastrointestinal tract affect starch digestion (Turnbull *et al.* 2005). An *in vivo* study would better explain kinetics of starch digestion; however, it is worth noting that the Goni *et al.* (1997) method was closely correlated to an *in vivo* study among 30 healthy volunteers ($R^2 = 0.952$) (Goni *et al.* 1997). Furthermore, similarities in trends of *in vitro* and *in vivo* starch digestion have been reported (Englyst *et al.* 1996).

Goni *et al.* (1997) method does not involve chewing of samples by volunteers, who may introduce salivary α -amylase thus negatively impacting on the precision of findings. Other authors use mechanical methods such as grinding, homogenization and milling at the oral stage of *in vitro* analysis (Woolnough *et al.* 2008). Mechanical methods too may negatively affect study findings due to changes in structure of starch particularly due to depolymerization. In part, chewing and use of other mechanical procedures was avoidable considering the nature of the samples. Possibly the kind of mixing with saliva that occurs at the oral phase may have been sufficiently provided by a shaking water bath that was used in this study.

Glycemic index

Glycemic index (GI), is a classification of the blood glucose raising potential of carbohydrate food (Wolever *et al.* 2003). It is defined as the incremental area under the blood glucose response curve elicited by a 50 g carbohydrate food expressed as a percentage of that after 50 g carbohydrate from a reference food (e.g. glucose or white bread) taken by the same subject (Jenkins *et al.* 1981). White bread was used as a reference in this study. The bread was analyzed immediately after baking to avoid retrogradation that could have led to formation of resistant starch, thus reducing GI.

The GI of the complementary foods was determined in order to give an indication of the effect of consuming cassava-soy flour porridges postprandial glycemia. The rate of small intestinal digestion of starch determines the GI of the food. Slowly digested foods have been associated with improved diabetes control (Fortvieille *et al.* 1992), reduced blood lipids (Jenkins *et al.* 1981) and reduced colonic cancer (Silver *et al.* 1995). In infants, foods with high GI would be desirable as these foods facilitate weight gain (Brand –Miller *et al.* 2002),

which is one of the growth indicators for infants. However, the high GI values of the porridges could have been due to low starch hydrolysis that occurred in bread (62.5%). Possibly retrogradation occurred during handling and sample preparation of the bread thus reducing the amount of digestible starch.

4.1.2.3 Thermal properties

Thermal properties of the porridges were studied using a Differential Scanning Calorimetry (DSC). The measuring principle of a DSC is to compare the rate of heat flow to the sample and an empty pan. Changes in the sample associated with absorption or evolution of heat cause a change in differential heat flow that is recorded as peak (Biliaderis, 1983). The DSC can be used to show the presence of gelatinized, non-gelatinized, retrograded starch and amylose-lipid complexes (Biliaderis, 1983).

Presence of retrograded starch would also have caused reduction in starch digestibility. Similarly, retrograded starch has an endothermic transition at about 40-90°C (Hasjim and Jane, 2009). To minimize on occurrence of retrogradation, porridges were immersed in liquid nitrogen immediately after preparation and then freeze dried for three days. No endothermic peak indicative of retrogradation was observed in both conventionally cooked and extrusion cooked porridges (Figure 3.1.3).

4.1.2.4 Sensory properties

Food acceptability is determined largely by the sensory perception of the product and physiological capability of the consumers (particularly for infants). For example, the recommended viscosity for complementary porridge is 1000 cP to 3000 cP (1 to 3 Pa.s) (Mosha and Svanberg, 1983; Treche and Mborne, 1999).

Porridges were analyzed by a trained panel in the form they would be eaten. That is, conventionally cooked porridges contained 10% solids while extruded porridges contained 25% solids. In addition, instrumental measurement of viscosity was done at similar solids content, to verify compliance with the recommended viscosity. At similar solids content (25%), extrusion cooked porridges were found to be of acceptable consistency to mothers of infants. Calculation of adequacy of porridges in meeting nutritional needs of children receiving low and moderate energy from breast milk was thus possible (Table 3.1.4) based on the acceptable solids content.

Instrumental data was compared to the descriptive sensory data and consumer sensory acceptability of complementary porridges. A combined approach, whereby instrumental measurements (physico-chemical characteristics) and sensory evaluation by humans (either trained or untrained) has been used to inform on the drivers of consumer liking/dislike (Aboubakar and Hamaker, 2000; Kayitesi *et al.* 2010; Kebakile *et al.* 2007).

Consumer sensory evaluation was conducted in an open setting (not in individual booths) Individual booths provide experimental control during evaluation as interference to panellists/consumers is limited (Kennedy *et al.* 2004). Possibly evaluating the porridges in an open setting could have sources of error due to interference and peer influence. This was minimized by allowing a distance of about 2 meters between the consumers. In part booths were not used because they were not available within rural community setting of Mozambique, where this study was conducted. Furthermore, individual booths as in laboratory setting were found to reduce consistency in consumer sensory ratings (Kennedy *et al.* 2004).

Possibly information gained from consumer liking scores would have been further enhanced by providing consumers with information on the nutritional value of the porridges. For instance, in section 3.1, Table 3.1.4, it was demonstrated that extrusion cooked porridges could be fed only three times in order to meet the protein and energy needs of a low and moderately breastfed 6-8 month old child. At similar feeding frequency, conventionally cooked porridges did not meet the nutritional needs of this age group because of low nutrient and energy density.

In addition, perhaps information on the solids content of extrusion cooked porridge (25% solids) versus the solids content of conventionally cooked porridges (10% solids) could have also influenced consumer liking of the various porridges. Knowledge on nutritional value of complementary foods is likely to influence acceptability scores among mothers; mother's choice of complementary foods is principally aimed at providing healthy/nutritious food to their infants (*Personal communication with mothers of children below 2 years*). Adherence to proper child growth curve (weight gain) as monitored monthly by health care givers is the main indicator of child nutrition among rural communities (Kruger and Gericker, 2003; *Personal observation*).

While sensory attributes of extrusion cooked cassava-soy porridges (with defatted soy flour, and defatted soy flour with soy oil) seem to be relatively undesirable ‘drivers’ of first time exposure consumer liking, these porridges were of superior nutritional value compared to the corresponding conventionally cooked porridges. It is possible that repeated exposure to the porridges may increase liking. Maier *et al.* (2007) found up to 70% liking of initially disliked complementary vegetable when it was fed for eight subsequent meals. A direct extrapolation of mothers’ liking of the cassava soy flour porridges to liking by infants (6-24 months) may not be a reliable or valid indication of acceptance by infants. The liking of the porridges by mothers could have been influenced by previous experiences and preconditioning related to the expected sensory attributes of porridges. Considering that complementary foods are the first foods introduced to an infant, infants’ acceptance of foods is not preconditioned or dependent on previous experience (Nicklaus *et al.* 2004). Essentially, during the first months of complementary feeding, infants tend to accept even quite bitter tasting formulae easily (Mennella and Beauchamp, 2005). In addition, infants’ acceptance of a novel food increase after repeated exposure to that food (Sullivan and Birch, 1994). Thus, although the hedonic ratings of nutritionally improved extrusion cooked cassava-soy flour porridges were slightly lower than for conventionally cooked porridges as rated by mothers, it does not mean that these porridges will not be acceptable to infants. Furthermore, marketing campaigns of nutritionally improved products often involve information regarding nutritional value and mode of preparation. It is likely these marketing messages may enhance mothers’ acceptance of extrusion cooked cassava-soy flour porridge, which is nutritionally optimized and does not involve lengthy preparation procedures.

Moreover, if consumers received the information that the extrusion cooked porridges were instant (only requiring to be reconstituted with hot water) probably this could have changed the overall liking of the porridges. Developing countries such as Mozambique are experiencing urbanization and more women are participating in formal employment. It is expected that convenient foods such as extrusion cooked complementary porridges will be more attractive especially to women working in the formal sector due to time constraint.

4.1.2.5 Viscoelastic measurements

Small-amplitude oscillatory shear analyses were used to determine the viscoelasticity of porridges. The analysis was within the linear viscoelastic (LVE) range to ensure that the

biopolymer network was not destroyed (Rao *et al.* 1997). Coaxial cylinder (bob and cup configuration) was used to determine rheological properties of porridges. Porridges were cautiously transferred to the cup to avoid formation of air bubble. Conventionally cooked porridges at 25% solids content could not flow; therefore viscoelastic measurements were not done at this solids content. Thus, 15% solids content was used for both extrusion and conventionally cooked porridges. A layer of paraffin oil was spread on top of the sample to avoid moisture loss. Samples were allowed to equilibrate before the test was conducted.

In general starch pastes may be regarded as a composite material of swollen granules (amylopectin) dispersed in a continuous biopolymer matrix (amylose) (Alloncle and Doublier, 1991). Thus the overall rheological behaviour is determined by the viscoelastic properties of the dispersed phase, continuous phase and the interaction between the two phases (Alloncle and Doublier, 1991). However, presence and concentration of solutes such as protein, salts, lipids, and sugars may also influence rheological behaviour of pastes (Yoo and Yoo, 2005).

Three types of dynamic tests were conducted to obtain useful properties of cassava-soy flour porridges during storage. These included frequency sweep, temperature sweep and time sweep studies. The frequency sweep determines G' and G'' as a function of frequency at fixed temperature. Time sweep determines G' and G'' as a function of time with the frequency and temperature held constant while temperature sweep determines G' and G'' as a function of temperature at a fixed frequency (Rao *et al.* 1999). These tests allowed for the behaviour of the porridges during cooling to eating temperature and storage as in the case of refrigeration to be determined. The relative strength of interaction polymer molecules of porridges at various temperatures was also established using frequency sweep, within the linear viscoelastic range.

4.2.1.6 Confocal scanning laser microscopy (CSLM)

CSLM is a relatively new powerful optical tool for the visualization of the structure of biopolymer mixtures (Tromp *et al.* 2001) and products (Blonk and Aalst, 1993). In CSLM, images of food components such as protein and lipids are produced by using laser to excite a selective fluorescent dye introduced in the food system during sample preparation (Brooker, 1991). In this study, Nile red fluorescent dye was used to localize lipids (Auty *et al.* 2001) in

the complementary porridges. The dye diffused into the lipid components of the complementary porridges and became fluorescent when it was excited at 633 nm. The molecules of the dye spread over the sample according to local accessibility and affinity (Velde *et al.* 2003).

The use of CSLM was advantageous over the other microscopy techniques such as Scanning Electron Microscopy and Transmission Electron microscopy because its sample preparation procedure is less laborious, is not time consuming and not likely to change the structure of sample; visualization is at ambient temperature (Dürrenberger *et al.* 2001). Further, samples used in CSLM are not restricted by thickness (Dürrenberger *et al.* 2001) as compared to light microscopy, which gives blurred images if too thick samples are used (McKenna, 1997). This is because the CLSM does not depend on transmitting light through the sample. Furthermore, CLSM allows for interior components of the sample to be localized, which makes a good representation of the sample.

4.2 Research findings and future work

4.2.1 Nutritional properties

As shown in Table 3.1.1, addition of soy flour; either defatted or full fat and extrusion cooking markedly improved the nutritional value of cassava porridge as a complementary food. Table 4.1 is a summary of key determinants of nutritional quality of complementary foods. Extrusion cooked composite porridges met the recommendations of lysine score, PDCAAS, gross energy, energy density (WHO/FAO, 1998) and viscosity (Mosha and Svanberg, 1983).

Addition of defatted soy flour with soy oil resulted in about 20 to 25 times higher fat content as compared to the porridge with defatted soy flour (Table 3.1.1). Fat provides energy; indeed it is the most energy dense macronutrient with 1 g providing 38 kJ. In addition, the constituents of soy oil contain essential fatty acids (linoleic and linolenic) that support neurodevelopment, visual development and absorption of fat soluble vitamins (Lunn and Theobald, 2009). An association between α -linolenic acid intake and length gain in infants has been suggested (Adu-Afarwuah *et al.* 2007).

However, soy oil contains a high content of triglycerides, which are rich in unsaturated fatty acids. Extruded porridge containing defatted soy flour with soy oil would therefore be susceptible to rancidity within a few days of storage. Rancidity is caused by lipolysis and subsequent oxidation of the resulting de-esterified unsaturated fatty acids (Malcolmson *et al.* 1996). Fat rancidity is significant in product development because taste and smell acceptability is negatively correlated to rancidity (Hansen, 1996). Rancidity results in formation of volatile secondary products such as hexanal and heptanol, which have off smell and bitter taste (Heinio *et al.* 2000). However, soy oil contains high levels of natural antioxidants especially tocopherols that would delay occurrence of rancidity in extrusion cooked porridges containing defatted soy flour with soy oil.

Extrusion cooked porridges had relatively lower starch digestibility as compared to the corresponding conventionally cooked porridges. Food extrusion in the presence of high moisture may favour retrogradation of extrudates resulting in reduction in starch digestibility (Mahasukhonthachat *et al.* 2010) due to formation of type III resistant starch (Englyst *et al.* 1992). Storage of extrudates at low temperature may also favour nucleation of extrudates and impact on percentage of retrograded starch thus reducing starch digestibility (Hagenimana *et al.* 2006). All extruded cassava-soy flour porridges had slight total crystallinity of 16-19% as shown by X-Ray Diffractogram (Figure 3.1.2). Conventionally cooked porridge was mainly amorphous. Possibly retrogradation was minimized because extrudates were rapidly oven-dried after extrusion. Extruded porridge containing defatted soy flour with soy oil showed a marked decrease in starch digestibility (11%), compared to cassava porridge. The low starch digestibility was attributed to formation of amylose-lipid complexes as shown in Figure 3.1.3.

4.2.2 Functional properties

Extrusion cooked porridge with defatted soy flour and soy oil was the least sticky (Table 3.3.5). Formation of oil droplets within the starch aqueous matrix as observed by Eskins *et al.* (1996) in maize starch and soy oil composites, may have contributed to low stickiness. Similarly, formation of oil droplets within the aqueous matrix of porridge as shown using CSLM and light microscopy (Figure 3.2.12 and 3.2.13) could have reduced stickiness of porridge.

Reduction in stickiness is beneficial for complementary foods because infants' motor tongue function is under-developed until the age of 2 years (Carruth and Skinner, 2002). Besides, a

study among 98 infants showed that infants aged 13 to 17 months attempted self-feeding (Carruth and Skinner, 2002). Thus, less sticky infant food is desirable as it would support infants' motor development. In addition, reduced stickiness would facilitate easiness in eating as stickiness contributes to stretching flow, which has a positive correlation with the sensed difficulty in swallowing (Chen and Lolivret, 2011).

Table 4. 1: Summary of key nutritional and physical properties of cassava-soy flour porridges as compared to recommendations available in literature

	Type of Porridge	Protein (N×6.25) (g kg ⁻¹)	% [‡] IVPD	Lysine score	*PDCAAS	Gross Energy (kJ / 100 g db)	Kcal/g	Fat (g kg ⁻¹)	Total starch digested	GI	Viscosity (Pa.s)
Conventional cooking	Cassava	25.7	59.9	0.53	0.31	1404.0	0.3	2.0	92.5	110.4	1.7
	With defatted soy flour	164.0	83.8	0.99	0.76	1544.8	0.4	2.2	78.8	102.7	0.7
	With defatted soy flour and soy oil	137.3	78.5	1.00	0.80	1682.5	0.5	52.3	75.0	103.3	0.7
Extrusion cooking	Cassava	22.3	86.5	0.64	0.56	1455.5	0.9	1.9	89.3	119.2	1.8
	With defatted soy flour	160.2	92.8	0.83	0.83	1539.7	0.9	2.1	73.6	104.1	2.3
	With full fat soy flour	130.1	90.7	1.00	0.94	1666.3	0.9	39.6	62.3	90.1	2.8
Reference		149.8	93.3	1.20	1.00	1706.6	1.0	45.7	93.1	118.3	2.0
Recommended				‡≥ 0.65	‡≥ 70	‡≥750	‡≥0.8				†1-3

Cassava - 100% cassava flour

With defatted soy flour - 65% cassava flour and 35% defatted soy flour

With defatted soy flour and soy oil - 65% cassava flour, 28% defatted soy flour and 7% soy oil

Reference - Commercial ready to eat complementary porridge

nd- Not determined

[‡]Lysine score = Based on a 52mg/g protein requirement for a 1-2 year old child⁷

[‡]IVPD-*In vitro* protein digestibility

^{*}PDCAAS = Amino acid score × IVPD/100

[‡] WHO/FAO, (1998)

[†]Mosha and Svanberg, (1983)

Conventionally cooked porridge containing 100% cassava flour was described by the sensory panel as translucent and jelly-like in appearance (Table 3.3.6). This was attributed to presence of swollen starch granules as shown by the light microscopy micrographs (Figure 3.2.12). This is consistent with the observation that starch pastes such as porridges contains swollen granules (amylopectin) dispersed in a continuous biopolymer matrix (amylose) (Alloncle and Doublier, 1991), also depicted in the schematic diagram of gelatinization and pasting during conventional cooking (Figure 4.1). Addition of either defatted soy flour, or defatted soy flour with soy oil reduced on this seemingly negative attributes. Consistency of the composite conventionally cooked porridges was also more preferred compared to that of 100% cassava.

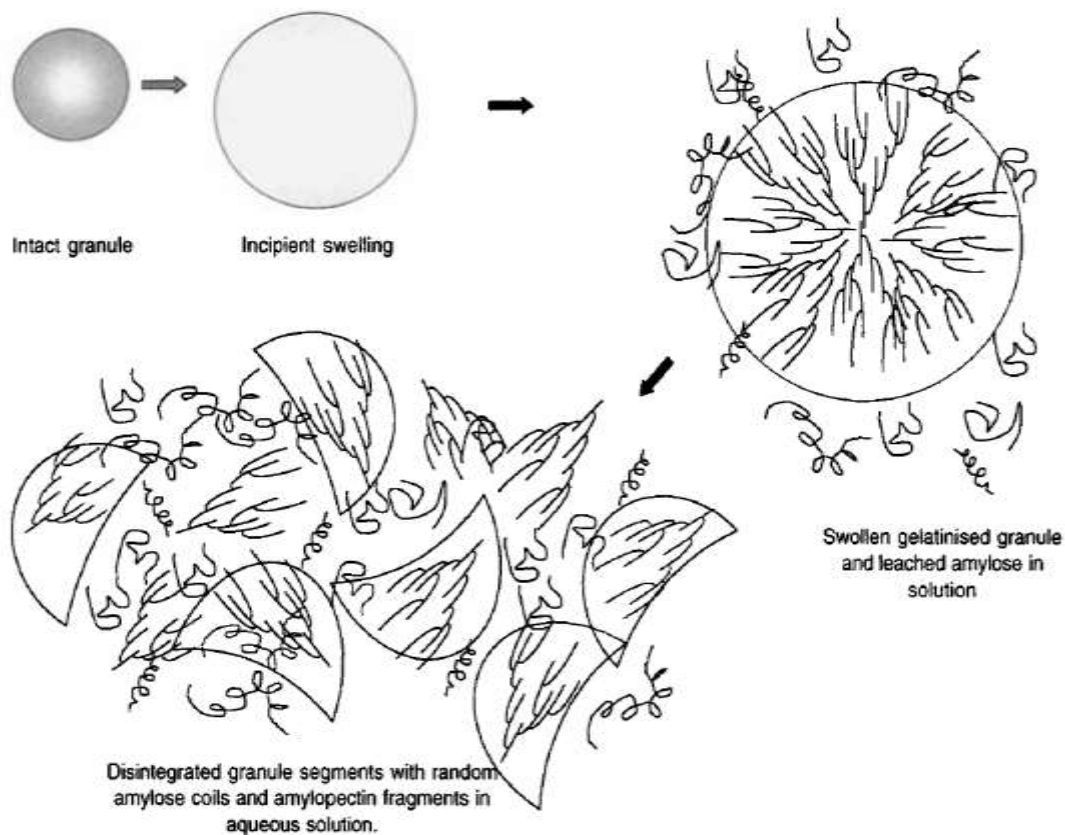


Figure 4. 1: Idealized diagram of the swelling and gelatinization of starch granule in the presence of water (Adapted from *Tester et al.* 2004)

In contrast, extrusion cooking is a high temperature, short time process in which moistened food materials are plasticized and cooked in a tube by a combination of moisture, pressure, temperature and mechanical shear resulting in depolymerization of starch (Riaz, 2001). Figure 4.2 is a schematic diagram of starch depolymerization during extrusion. Possibly this is the reason why extruded porridges were perceived as slimy (Table 3.3.7) due to presence of fine flour particles.

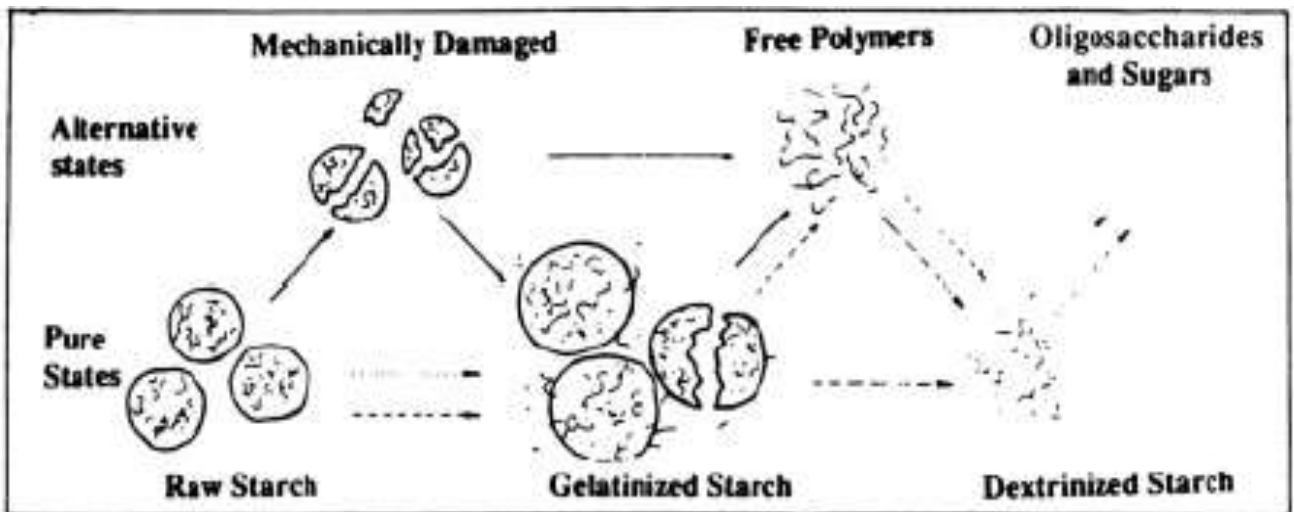


Figure 4. 2: Schematic representation of starch depolymerization under shear and temperature (Lai and Kokini, 1991)

Continuous arrows indicate shear
 Broken arrows indicate heat

Conventionally cooked porridge containing 100% cassava flour was the most viscous at 10% solids content as assessed visually by a trained panel (Table 3.3.6). Rasper (1969) working with 14 types of starches found cassava to have the most swelling power at 95°C. The high swelling power was attributed to low degree of molecular association in cassava starch granules as compared to other types of starch (Rasper, 1969). Cassava starch also showed the highest viscosity and behaved more like waxy starch as measured during normal pasting using rapid viscoanalyser (Debet and Gidley, 2006). Addition of soy flour, which contains limited starch, resulted in significant reduction of porridge viscosity. Obanni and Bemiller (1997) working with blends of various starches suggested that blending could be used to modify properties of starch.

Extrusion cooked porridges were characterized by the trained panel as slimy (Table 3.3.7). This could be attributed to presence of depolymerized starch, mainly dextrans due to extrusion cooking. Liu *et al.* (2010) suggested that extrusion cooking leads to size dependent depolymerization of starch as observed by highest depolymerization rate at the beginning of extrusion and gradual slowing down as the size of the polymer became smaller. Similar trends were confirmed by a progressive reduction in large molecules while the small molecules remained unchanged, thus a narrowing of size distribution results (Liu *et al.* 2010). As the depolymerization rate decreased, the size of the polymer decreases, eventually the polymer would be sheared down to a minimum size (Liu *et al.* 2010). Mua and Jackson (1998) working on maize starch pastes found stringiness increased with a decrease in M_w . The slimy consistency of extruded porridges was acceptable to mothers of infants although the scores were slightly lower than those of conventionally cooked composite porridges.

Extrusion cooked porridges also showed to have less shear thinning properties (Figure 3.2.1) as compared to the corresponding conventionally cooked porridges. Shear thinning occurs due to the disentanglement of polymer chains (Mezger, 2006). Mua and Jackson (1997), working on amylose and amylopectin fractions of maize found amylopectin fractions of low M_w to be shear thinning.

To determine the appropriateness of cassava-soy flour porridge as a complementary food, viscosity was determined at a shear rate of 100 s^{-1} . This is the maximum shear rate that is developed by humans during mastication of porridges (100-100 000 cP). Considering that infants' motor function is still underdevelopment (Carruth and Skinner, 2002), use of this shear rate may not be appropriate. Further, comparison of viscosity data available in literature (Table 2.2) is rather difficult considering that factors such as temperature, shear rate, and shear time affect viscosity. Thus, future research may focus on standardization of procedures (either instrumental or descriptive) that would take into consideration evolution of motor development in infants during the period of complementary feeding (6-23 months).

Extrusion cooked porridges also showed lower tendency to retrogradation during cooling and storage (Figure 3.2.8 and 3.2.10). This behaviour could be attributed to presence of low molecular weight dextrans as discussed earlier. Sterling (1978), reported β -amylase treated amylopectin (reduced to 2-3 glucose) retrograded less readily than native starch. Low retrogradation potential is beneficial for infant feeding as porridges do not develop high viscosity, that exceed infants' ability to masticate at usual temperatures of eating (40°C). Figure 4.3 is an illustrative summary relationship between structural and sensory properties of extrusion and conventionally cooked cassava-soy porridges.

In summary, there exists a relationship between the sensory and structural properties of cassava-soy flour porridges. The principal sensory properties of conventionally cooked porridges included high stickiness, jelly and translucent appearance as well as high viscosity, which are undesirable for infant feeding. Addition of soy flour and extrusion cooking reduced these apparently negative sensory properties. However, extrusion cooking increased the intensity of sensory attributes of denseness and sliminess (Figure 4.3).

The sensory properties of conventionally cooked porridges could be attributed to the microstructural properties of the porridges such as presence of swollen starch granule and high tendency to retrograde. Similarly, sensory properties of extrusion cooked porridges could be explained by the microstructural properties. For instance, limited tendency to retrograde may contribute to low viscosity of porridges at usual eating temperature (~ 40 °C). In addition, reduction of jelly-like and translucent appearance could be due to presence of continuous starch matrix in extrusion cooked porridges (Figure 4.3).

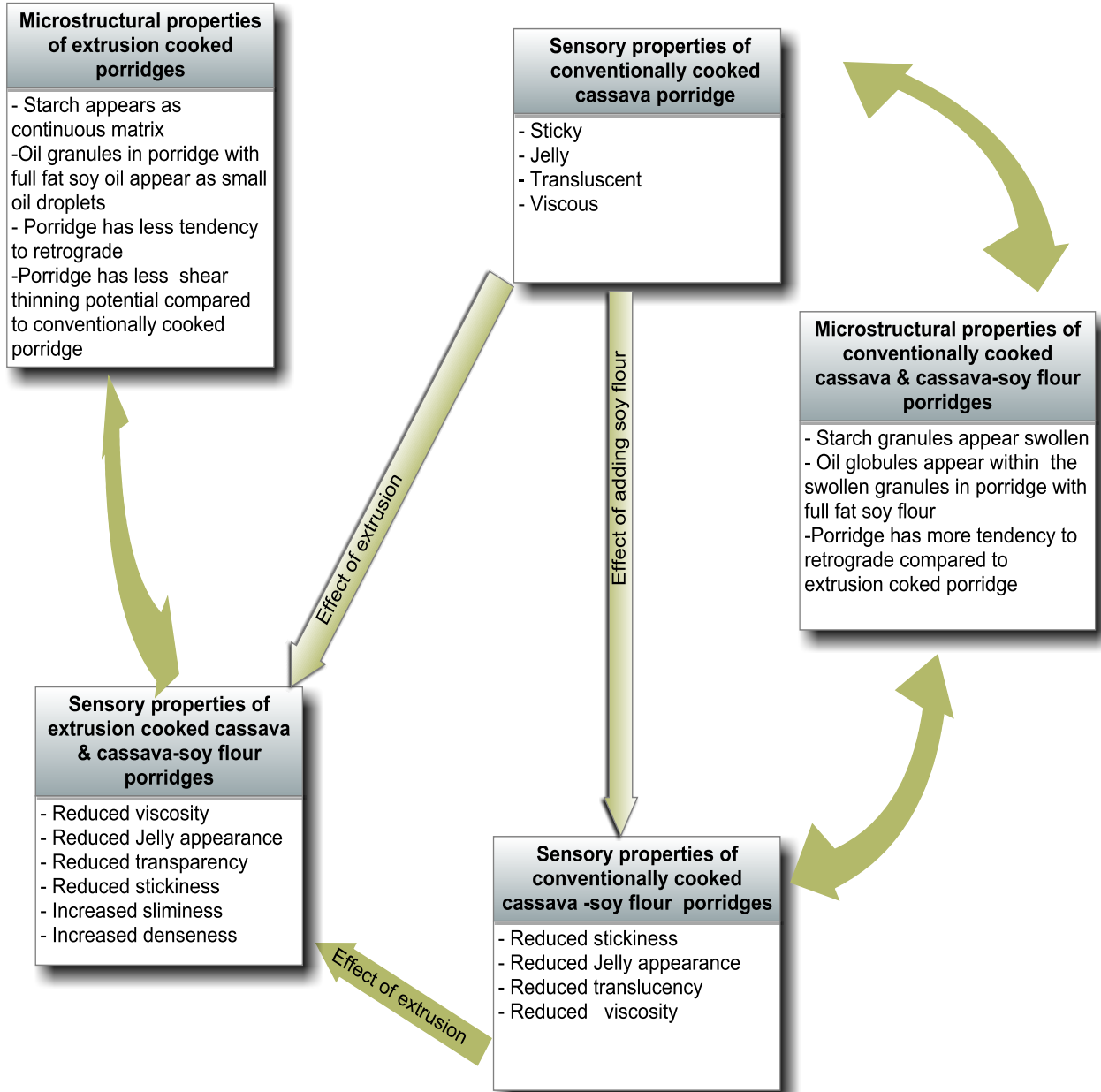


Figure 4. 3: Relationship between structure and sensory properties of extrusion and conventionally cooked cassava-soy flour porridges

4.3 Dissemination of low cost cassava-soy complementary porridge

Extruded cassava-soy flour porridge may be viewed as a low cost, protein and energy rich complementary food. Cassava as a carbohydrate source is low priced compared to other carbohydrate sources such as maize, sorghum and millet (Phillips *et al.* 2004). On the other hand, soy flour is a plant-based legume that is high in protein and would appropriately complement for limiting amino acids in starchy staples such as cassava. Soybeans also have high PDCAAS (90%), which is similar to that of beef (91%) (Michaelsen *et al.* 2009). Thus soybean is a good replacement to high cost animal source protein. Table 4.2 shows the estimated cost of producing nutritionally optimized extruded cassava- soy flour and the cost of meeting the nutritional need of an infant receiving low energy from breast feeding per day. Comparison with the cost of commercial ready to eat complementary porridge is also illustrated.

The estimated cost of extruded cassava-soy flour porridges was markedly increased when the cost of vitamin and mineral mixes were added. Addition of vitamin and mineral mix after extrusion cooking of starchy staples for complementary porridge has been recommended. Owino *et al.* (2007) working on extruded maize-legume complementary porridge found that vitamin and mineral mix accounted for 60% of the total cost of production. Iron, zinc and vitamin A deficiency are also significant health problems in developing countries (Diaz *et al.* 2003). Thus a complementary porridge that not only meet the protein and energy needs at infancy but also iron, zinc and vitamin A would be more preferred.

Iron fortification could be done using ferrous sulfate, ferrous fumarate, or NaFeEDTA (Hurrell *et al.* 2000). NaFeEDTA has been suggested as an ideal Fe fortificant for foods since EDTA moiety protects Fe from phytic acid (International Nutritional Anemia Consultative Group, 1993). Furthermore, NaFeEDTA is delivered in the small intestine, which is the site of absorption (Bothwell, 1999). NaFeEDTA also prevents Fe-catalyzed fat oxidation reactions during storage of foods (Hurrell, 1997). NaFeEDTA thus covers the shortfalls of FeSO₄ and ferrous fumarate. FeSO₄ is prone to Fe-oxidation while ferrous fumarate is susceptible to poor bioavailability in the presence of phytic acid (Hurrell *et al.* 1997). Furthermore, possibly further work could determine the content and adequacy of minerals in cassava-soy flour porridges. Depending on variety and

agronomic conditions, soybeans contains substantial amounts of iron (18.7%) and zinc (11.5%) (Paucar-Menacho *et al.* 2010).

Table 4. 2: Estimation of cost of extruded cassava-soy flour porridge and a comparison with the cost of commonly used commercial ready to eat complementary porridge

Production cost	Cost per ton (US\$)	
	<i>Porridge with defatted soy flour</i>	<i>Porridge with defatted soy flour and soy oil</i>
Cassava flour	5200\$ (6500kg×0.8\$)	5200\$ (6500kg×0.8\$)
Defatted soy flour	4900\$ (3500×1.4\$)	3920\$ (2800kg×1.4\$)
Defatted soy flour with soy oil	-	1470\$ (700L×2.1\$)
¹ Man h	10\$ (2.5×4\$)	10\$ (2.5h×4\$)
¹ Machine h	42\$ (6×7\$)	42\$ (6h×7\$)
Total Basic cost/ Ton	10 152.0	10590.0
¹ Indirect costs and losses (15% of total basic cost)	1523.0 (10152×15%)	1589.0 (10590×15%)
¹ Cost of minerals and vitamins (60% of the total cost of production)	7005.0 (11675×60%)	7320.0 (12179×60%)
Total production cost /Ton	11675.0 (10152+1523)	12179.0 (10590+1589)
¹ Profit Margin (15% of total production cost)	1751.0 (11675×15%)	1827.0(12179×15%)
Cost of 1 Ton	13426.0 (11675+1751)	14006.0(12179+1827)
Cost including 14% VAT /Ton	15306.0(13426×114%)	15967.0 (14006×114%)
Retail price per kg	US\$ 15.3	US\$ 16.0
² Retail price of reference commercial ready to eat porridge per kg	US\$24	
<i>Cost of supplying adequate nutrients during infancy (Child receiving low nutrient from breast milk)</i>		
³ Gastric capacity	350g/meal	
³ Frequency of feeding	3 times	
⁴ Solids content of porridge	25%	
Amount of extruded powder required per feeding	25% ×350g= 90g	
Total amount eaten per day	90g × 3times = 270g	
Cost of feed fed per day	4.1 (US\$ 15.3 Per kg × 270g)	4.3 (US\$ 16 per kg × 270)
Cost of feed fed per day (reference porridge fed at similar amounts)	6.48 (US\$ 24per kg ×270g)	

¹Owino *et al.* (2007)

²Own observation from retail shops in Nampula, Mozambique

³ UNICEF/WHO, (1998)

⁴Muoki *et al.* (2012)

⁵Packaging, distribution and storage costs not included

Section 1.0 described the significance of child malnutrition and the possible approaches to producing nutritionally optimized porridges with acceptable sensory properties. Causes of child malnutrition are multifaceted and would therefore need a combination of approaches to ensure access, affordability and consumption by vulnerable population. Figure 4.4 is a four -tiered model of a combination of approaches aimed at improving child nutrition in Africa and other developing countries. Stage (1) the overall aim would be to develop an optimized infant food that is socio-culturally acceptable. Stage (2) to ensure adequate supply of nutrients and that infant can eat the porridge; the complementary foods would need to be nutritionally and rheologically optimized. Stage (3) to guarantee affordability, use of low-cost processing technologies, locally produced materials, packaging in small units and appropriate market promotion would be desired. Stage (4) for effective uptake, nutrition education, continued breast feeding, adherence to appropriate feeding frequency and adherence to basic hygiene/ reduced incidence of diseases would be crucial.

Infancy stage is characterized by increased energy needs that cannot be met though breast feeding alone (Walker, 1990). According to WHO/UNICEF, (1998) guidelines, complementary foods that provide $\geq 0.8\text{kcal/g}$ would meet energy if at least three meals are eaten per day. As shown in Table 3.1.4, extruded composite porridges would provide the energy, protein and lysine requirements of infants (6 to 8 months) receiving either low or average breast milk. Provision of low and average energy from breast milk is common in developing countries (WHO/UNICEF, 1998). To meet this nutritional adequacy, porridges would need to be prepared at 25% solids content (Table 3.1.4). This information would need to be delivered to populations at risk of child malnutrition. According to Bruyeron *et al.* (2010), use of exists networks such as women unions and community volunteers would help in reaching rural community.

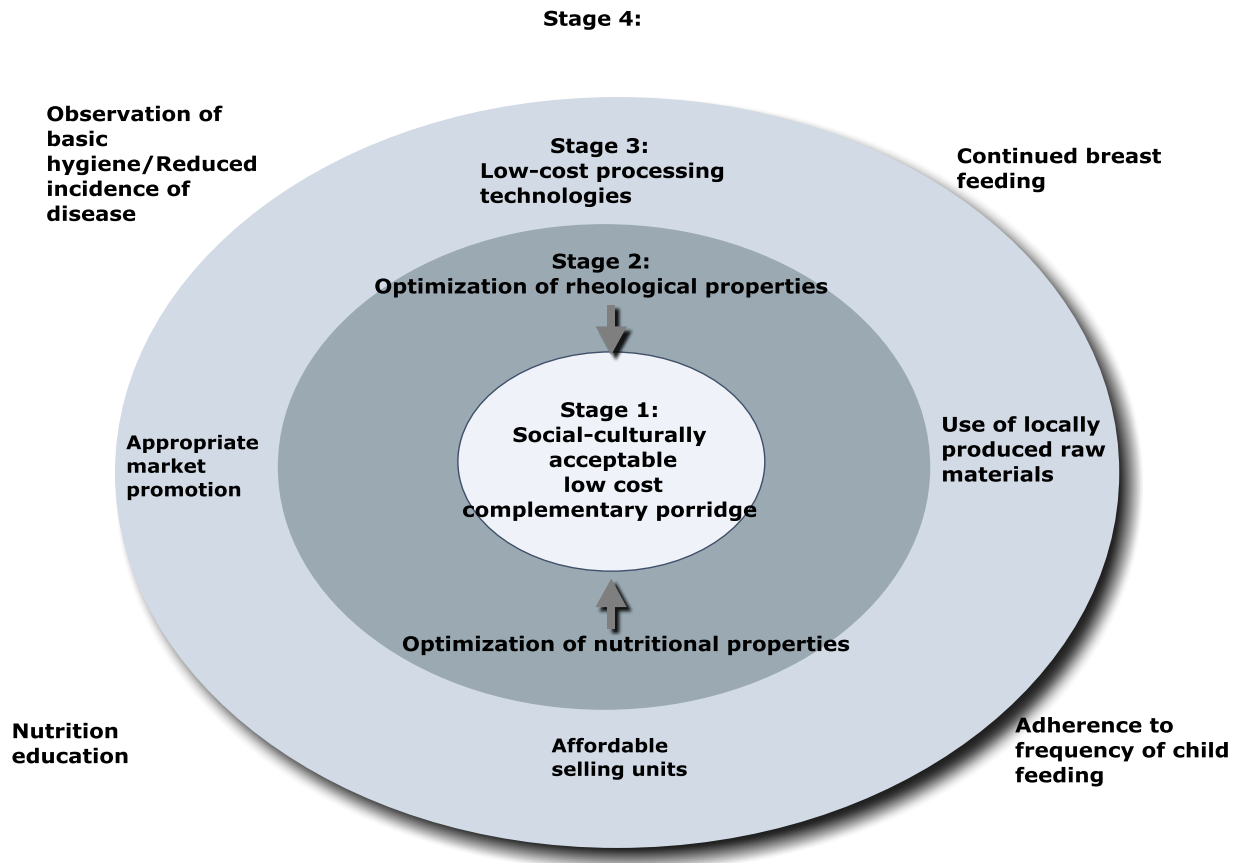


Figure 4. 4: Four-tiered dissemination approach to enhance child nutrition using a low cost complementary porridge

5.0 CONCLUSIONS AND RECOMMENDATIONS

Extrusion cooking and addition of soy flour improves the nutritional quality of cassava complementary porridges. Extrusion cooking allow for up to 2.5 times greater solids content as compared to conventionally cooked porridges while maintaining a consistency that is edible by infants. Thus extrusion cooking increases energy density and this can be due to depolymerization of starch during extrusion cooking. Extrusion cooked porridges containing either defatted soy flour, or defatted soy flour with soy oil, meet the nutrient needs of infants at the prime age when malnutrition typically starts (6-8 months) assuming the infant gets either low or average energy intake from breast milk

Extrusion cooking and addition of soy flour also improve the protein quality of cassava complementary porridges in terms of available lysine. It seems that extrusion cooking conditions used in the study allows for limited occurrence of Maillard reaction. Extrusion cooked cassava-soy flour porridges also have protein digestibility values within the recommendations for complementary foods.

Extrusion cooking of cassava and defatted soy flour with soy oil leads to formation of amylose-lipid complexes. Presence of amylose-lipid complexes seems to lower starch digestibility of porridge possibly due to limited access of α - amylase to starch during digestion. However, all porridges are rapidly digested, which is beneficial for infants' underdeveloped digestive system.

The consistency of extrusion cooked cassava-soy porridges do not increase much in consistency during cooling to the temperature at which these are usually eaten and during refrigeration/storage. This is possibly due to limited retrogradation as a result of starch depolymerization into small molecules that have limited ability to re-associate and increase viscosity. This is favorable for infants because they have limited ability to masticate highly viscous food.

Extrusion cooking and addition of soy flour reduce typical sensory characteristics of conventionally cooked cassava porridge such as stickiness, high viscosity, jelly-like appearance

and translucency. Reduction in stickiness particularly improves the applicability of cassava as a complementary porridge because it makes eating easier for infants whose motor function is not well developed. Future studies may include feeding trials among infants to establish possible correlations between handling and overall acceptability of cassava- soy porridges. Further, acceptability of the extruded porridges could be evaluated over a long-term study compared with the conventionally cooked porridges.

Extrusion cooked cassava-soy flour porridges are acceptable to Mozambican mothers who use cassava as a staple food. However, compared to conventionally cooked porridges, extrusion cooked porridges are slightly less preferred. Possibly the sensory attributes developed due to occurrence of limited Maillard reaction (intense flavour and aroma) are not familiar to Mozambican mothers who mainly use conventionally cooked porridges.

Future research could improve on the mineral and vitamin content of cassava-soy flour porridges. Iron, zinc and vitamin A are also health problems in areas where cassava is a staple food. Inclusion of minerals and vitamins would better respond to nutrition health problems as deficiencies of these exists in conjunction with PEM. Possibly use of cassava varieties bio fortified with beta-carotene, iron and zinc could also be another alternative.

Production of complementary foods using other locally available non-cereal starchy crops such as sweet potato, irish potato and yams can be experimented on. These will be beneficial in ensuring complementary foods are produced using locally produced raw materials rather than reliance on imported raw materials. Reliance on imported raw materials often renders processed complementary foods unaffordable to households vulnerable to malnutrition. Use of locally produced raw materials will also create markets for local farming households.

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