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SENSORY AND NUTRITIONAL QUALITY OF MARAMA-SORGHUM COMPOSITE FLOURS AND PORRIDGES

By

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DECLARATION

I declare that the dissertation herewith submitted for the degree MSc (Agric) Food Science and Technology at the University of Pretoria, has not previously been submitted by me for a degree at any other university or institution of higher education.

Eugenie Kayitesi

DEDICATION

In loving memory of my late mother Mrs. Murebwayire Agnes

To my father Mr. Nkurunziza Francis and my Aunt Jane

And to the Almighty God for the gift of life

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ABSTRACT

Sensory and nutritional quality of marama-sorghum composite flours and porridges

by

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Marama bean (*Tylosema esculentum* (Burch) A. Schreib) is an underutilised, drought-tolerant legume native to the semi-arid areas of Botswana, Namibia and South Africa. The edible seeds of marama beans are good sources of protein and fat, and its flours can potentially enhance the nutritional quality of sorghum porridge, a staple in many African countries. Sorghum has a low protein content and is deficient in lysine. Compositing sorghum with lysine-rich marama flour when preparing porridges would address this problem. Utilisation of marama flour in composite porridge depends on sensory acceptance. In this study nutritional and sensory quality of marama-sorghum composite flours and porridges are investigated. Full fat and defatted flours from unheated and dry heated (150 °C /20 min) marama beans were composited with condensed tannin-free sorghum meal (30:70). Marama flours, sorghum meal, marama-sorghum composite flours and porridges were analysed for proximate composition, amino acid composition, energy value, fatty acid composition, total phenolic content and antioxidant activity. Porridges (10% solids) were subjected to descriptive sensory analysis, consumer acceptance test (n=52), texture analysis, pasting profiles and colour measurements.

Sorghum porridge and porridge composite with full fat marama flour from heated beans were more acceptable than other composite porridges. Compositing sorghum meal with marama flour reduced the cooked sorghum aroma/flavour intensities prominent in sorghum porridge. Dry heating marama beans prior to milling resulted in a roasted nutty flavour in the final product. Porridges from heated marama beans were darker in colour than porridges from unheated beans. This could be attributed to flavour and colour development due to Maillard reaction during dry heating. Composite porridges from full fat marama flours were described as buttery/creamy. A bitter taste and aftertaste was perceived in porridges from defatted flours. Presence of fat seems to mask bitterness in porridges. Marama-sorghum composites and *Tsabotlhe* porridges were less viscous than sorghum porridge. This was confirmed by pasting profiles (low final viscosities) and texture analysis indicating reduced firmness. Starch contributes greatly to the textural properties of sorghum porridge. Marama flour has no starch. Compositing the flour with sorghum reduced starch levels in the composite porridges. This explains the reduction in viscosity and firmness of the porridges.

Compositing sorghum meal with marama flours significantly increased protein and fat contents in flours and porridges. The fat content in marama-sorghum flours was in the range of 5.6 to 14.6%. Protein increase ranged from 61% to 96% in marama-sorghum composite porridges compared with sorghum porridge. There was 11-24% energy value increase in marama-sorghum composite porridges compared with sorghum porridge. Porridges composited with full fat flours contributed to higher energy values than those composited with defatted flours. This is because of fat energy contribution. Lysine content in marama flour was significantly higher than sorghum meal. Lysine content was 3 to 4 times higher in marama-sorghum porridges than in sorghum porridge. Unsaturated fatty acids were the most present in both marama-sorghum composite porridges and sorghum porridge. There was an increase in oleic acid as marama flour was composited with sorghum.

Marama flours had higher levels of total phenolics than sorghum flour. Marama flour has high levels of tyrosine which could react with the Folin Ciocalteu reagent thus leading to an increase in measurable phenols. Marama flours from dry heated beans had higher total phenolic content and antioxidant activity than flours from unheated beans. Heating may have increased phenolic compound extractability due to release of bound phenolics. There was a positive correlation between the total phenolic content and antioxidant activity ($r = 0.80$, $p < 0.05$) in all samples. Findings from this study indicate that marama flour can potentially be used to improve the nutritional quality of sorghum porridges. Furthermore this study shows that use of full fat flour in marama-sorghum composite porridges give more acceptable sensory properties.

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1. INTRODUCTION

Tylosema esculentum (Burch) A. Schreib known as morama or marama bean in Setswana and Gemsbok bean in Afrikaans is found in Botswana (around the Central Kgalagadi area), Namibia as well as the Limpopo, the North-West and Gauteng provinces of South Africa. Marama bean is potentially a valuable crop for semi-arid countries (Hartely, Tshamekang and Thomas, 2002) and has long been identified as a food source (Amarteifio and Moholo, 1998). It is consumed by the rural communities especially people of the Kalahari desert. Marama bean is boiled as green vegetables similar to green peas. The dry beans are roasted and eaten as snacks (Mmonatau, 2005). Recently, because of its high protein and fat content and other constituents such as phenolic compounds, known to have potential health benefits, research on domestication, utilisation and chemical composition of marama bean is being undertaken (Marama I and II European Union projects). Value added marama flour has been developed by Maruatona (2008). Food processing applications of marama flour in food systems have not been exploited.

According to Amarteifio and Moholo (1998), marama bean is a good source of protein (34%) and fat (34%). It can potentially be used to enhance the nutritional quality of cereals such as sorghum. *Sorghum bicolor* (L.) Moench is a major staple food in many African countries where agricultural and environmental conditions are unfavourable for the production of other crops (Rooney and Serna-Saldivar, 1990). However sorghum, like other cereals, has low protein content, and is deficient in the essential amino acid lysine. Compositing sorghum with marama flour may contribute to a better amino acid balance, increased protein content and improved energy value hence helping to alleviate protein energy malnutrition, a problem in many developing countries.

Potential utilisation of marama flour in food systems such as marama-sorghum composite porridges will not only depend on the potential contribution to nutrition, but also on consumer acceptance based on sensory properties of the food products. Marama bean seeds are not eaten raw as they are tasteless with an unpleasant slimy texture, but after heating they have a delicious nutty flavour, resembling roasted peanuts (Mmonatau, 2005). This may be due to the formation and release of flavour compounds due to Maillard reaction as a result of heating. The sensory properties of marama bean flour from heated and unheated beans, and when applied in food systems such as marama- sorghum porridges have not been described.

Marama bean constituents such as phenolic compounds are believed to have antioxidant properties. These are suggested to play an important role in protecting food from oxidative degeneration (Nandutu, Clifford and Howell, 2007). Reports indicate that diets rich in phenolic compounds may play a role in the prevention of various diseases associated with oxidative stress such as cancer, cardiovascular and neurodegenerative diseases (Anderson and Wolf, 1995). Phenolic content and antioxidant activity of marama-sorghum composite flours and their porridges have not been investigated.

This study therefore aims at evaluating the potential of marama bean flour in improving the nutritional and sensory quality and potential health promoting quality of sorghum porridges. Furthermore the effects of heating of the beans prior to preparation of marama bean flour and defatting the flour on the nutritional and sensory quality, phenolic compounds and antioxidant activity of sorghum-marama composite flours and porridges were investigated.

2. LITERATURE REVIEW

In this review, focus is put on the chemical composition of marama bean as well as the effect of processing (dehulling, dry heating and oil extraction) on the nutritional, sensory, functional and health promoting quality (phenolic compounds and antioxidant activity) of marama flours. Marama bean will be compared with other legumes such as soya bean. This is because limited published information is available on marama beans, particularly in the area of food processing applications. Soya bean has been exploited more extensively therefore a study of its literature would be relevant to marama bean. The chemical composition of marama bean will also be compared to sorghum to demonstrate the need for compositing sorghum meal with marama flour to improve the nutritional quality of the end-use product (marama-sorghum composite porridges).

2.1 Introduction

Research efforts are being directed towards the study of underexploited legumes that are well adapted to adverse environmental conditions. Among these is *Tylosema esculentum* (Burch) A. Schreib known as marama bean. Marama bean is a creeper plant which has branches that grow up to six metres long and the seeds are contained in pods. Between October and March (spring to summer in the region) (Coetzer and Ross, 1977) golden yellow clusters of flowers appear and the fruit ripens between March and April (autumn). The pods usually contain two seeds (Figure 2.1) but can produce as many as six seeds each weighing approximately 2.4 g when mature. The ripe seeds are chestnut brown and spherical, the inner flesh comprising of the two cotyledons that are firm and cream coloured (Mmonatau, 2005).

Figure 2.1: Picture of marama bean pods and dry seeds

The growth distribution of Marama bean (*Tylosema esculentum)* in southern Africa is shown in Figure 2.2

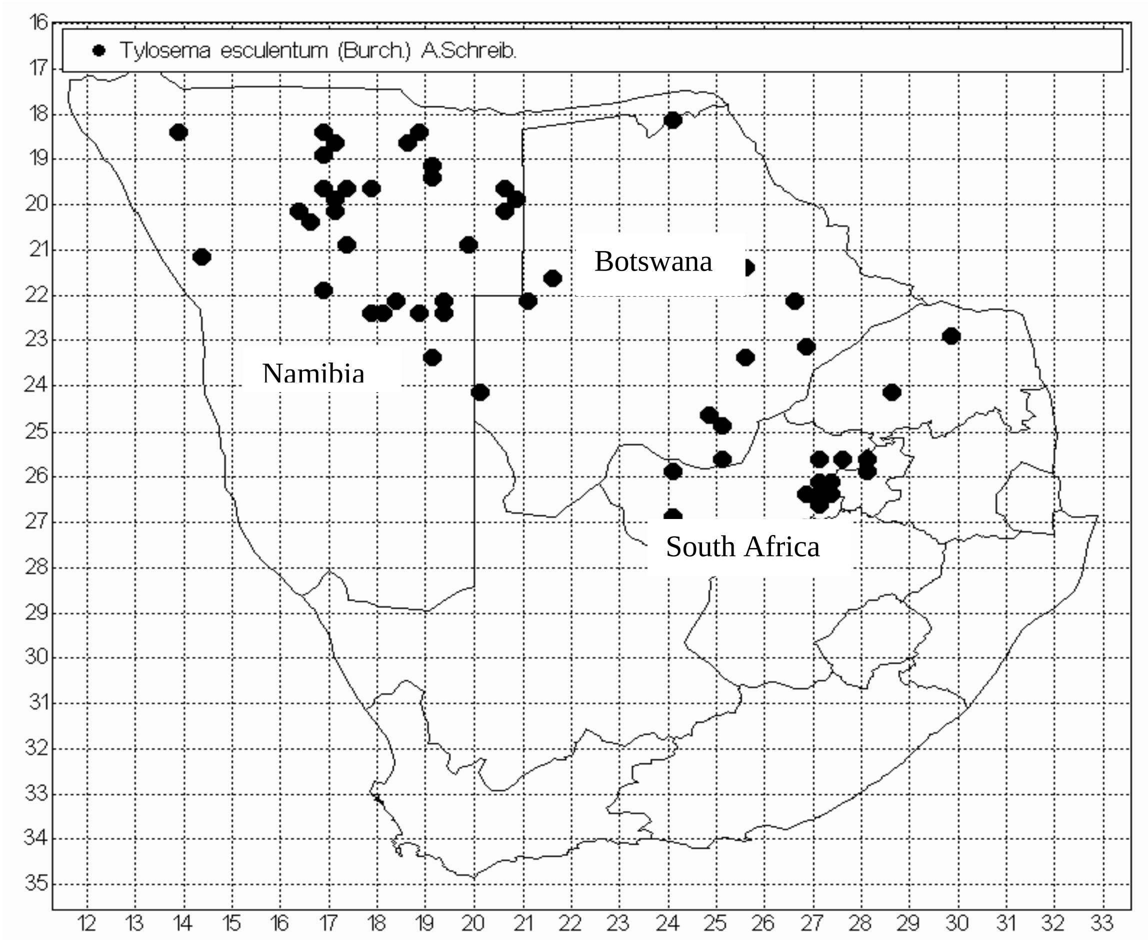

Figure 2.2: Geographical distribution of *Tylosema esculentum* in Southern Africa [South African National Biodiversity Institute (SANBI), SA]

An updated geographical distribution of marama beans in South Africa (Gauteng, North-west and Limpopo provinces), is shown in Fig. 2.3

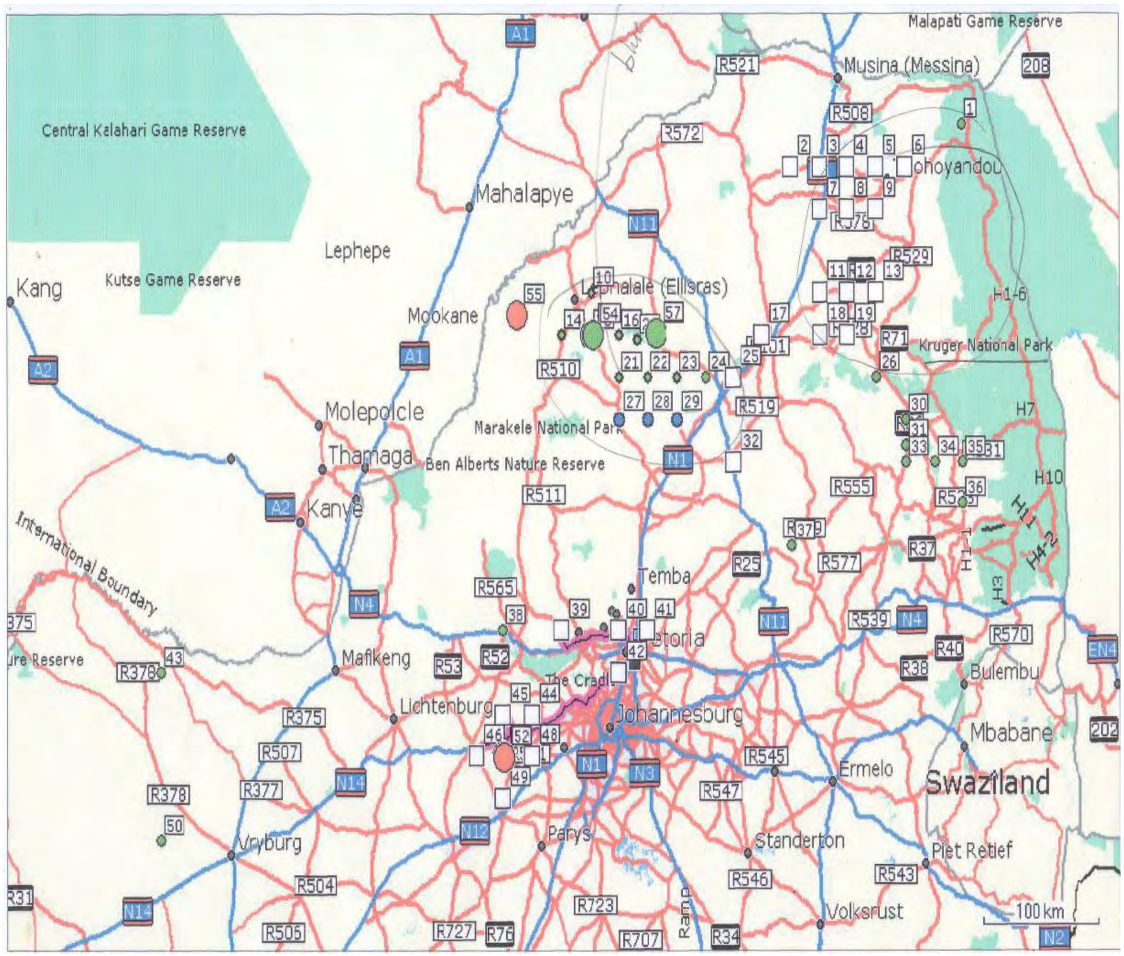

Figure 2.3: Distribution of *Tylosema esculentum* (Burch) A.Schreib and *Tylosema fassoglense* (Kotschy ex Schewinf.) Torre & Hillc in Gauteng, North-west and Limpopo provinces of South Africa (Maruatona, 2008)

Key:

Red dots – *Tylosema esculentum* (Burch) A.Schreib

Green dots - *Tylosema fassoglense* (Kotschy ex Schewinf.) Torre & Hillc

Marama bean belongs to the family Fabaceae; subfamily Ceasalpinoidae and genus *Tylosema* (Hartley *et al.*, 2002). There are four species of *Tylosema* in Africa. Figure 2.4 shows the taxonomic position of *Tylosema esculentum.*

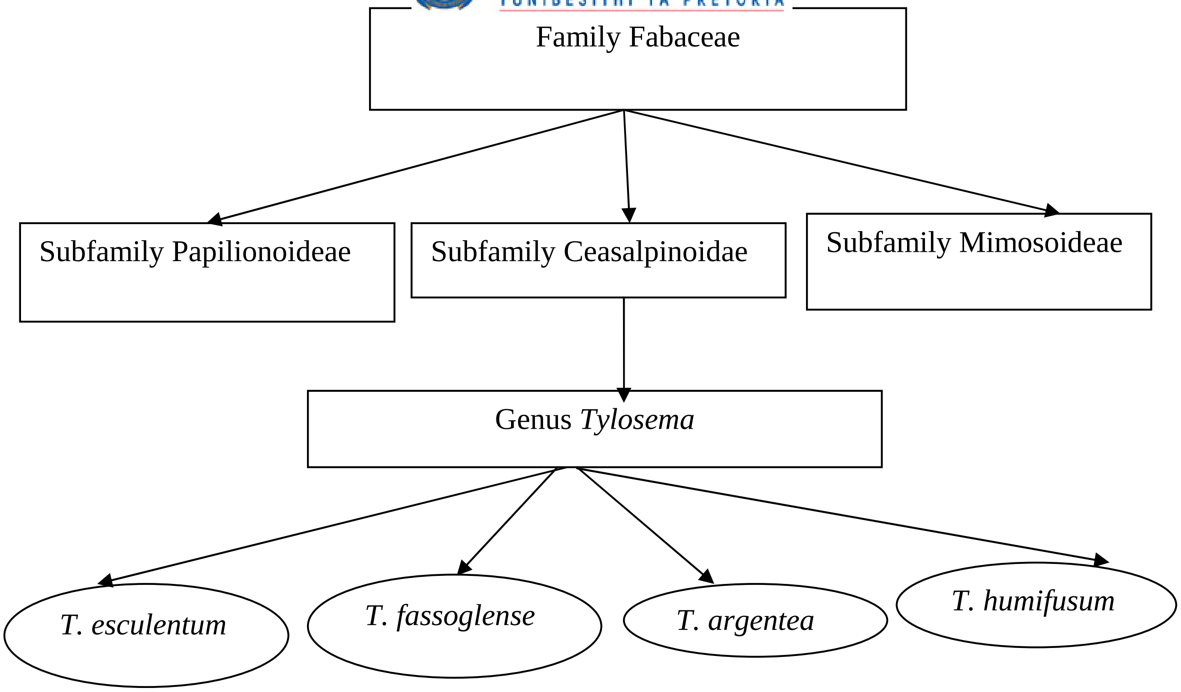

Figure 2.4: Taxonomy of *Tylosema esculentum* adapted from Hartley *et al. (*2002)

2.2 Relevant chemical composition of marama and soya bean and sorghum grains

Marama bean has high nutritional value as indicated in Table 2. 1. The protein content is comparable to that of soya bean. The oil content of marama bean is much higher than that of soya beans, and compares favourably with oilseeds such as ground nuts (45-55%), sunflower seeds (22-36%) and rape seeds (22-49%) (Salunkhe and Kadam, 1989). Though sorghum is considered a subsistence crop because of its drought tolerance and adaptation to dry tropical and subtropical conditions, sorghum like other cereals has low protein content (Table 2. 1). As a result, it does not supply adequate protein for satisfactory growth of infants and children, nor for bodily maintenance of adults. Marama beans can potentially be used to enhance the nutritional value of sorghum-based products, such as marama-sorghum porridges increasing their protein and fat content and improving energy value.

Table 2.1 Comparison of the proximate composition (%) of marama, soya beans and sorghum grain

Nutrient (%)	Marama bean (Amarteifio and Moholo, 1998)	Soya bean (Stauffer, 2005)	Sorghum (Klopfenstein and Hoseney, 1995)
Crude protein	34.0	36	10.9
Crude fat	33.5	20	3.2
Carbohydrates	24.0	28	73.0
Ash	3.7	5	1.6

2.2.1. Protein and amino acid composition

Plant proteins are classified based on their solubility pattern: albumins soluble in water; globulins soluble in dilute salt solutions; prolamins soluble in alcohol–water mixtures, and glutelins soluble in dilute acids and bases (Osborne, 1924). Bower, Hertel, Oh and Storey (1988) reported globulins as the most abundant proteins (53%) in marama beans followed by albumins (23.3%), prolamins (15.5%), alkali-soluble glutelins (7.7%) and acid-soluble glutelins (0.5%). Soya bean proteins contain about 90% globulins and 10% albumins (Gueguen, 1983). The major storage proteins (kafirins) in sorghum grain are soluble in alcohol–water mixtures and therefore defined as prolamins (Osborne, 1924). The other proteins contained in relatively lower quantities in sorghum grain are the glutelins, albumins and globulins.

The protein quality of any given food depends on its essential amino acids pattern (Friedman, 1996). There are 20 amino acids found in nature; 8 of them cannot be synthesised by the human body and are known as essential amino acids (De Valle, 1981). These include isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. The Food and Agricultural Organisation and World Health Organisation (FAO/WHO) has developed suggested human amino acid requirements using beef as a reference pattern (Table 2.2). The protein quality of any food can be determined by comparing the levels of amino acids of the test protein with corresponding levels in the reference pattern**.** Table 2.2 indicates that marama bean and soya bean have higher lysine content than sorghum that meets FAO suggested amino acid requirements. Glutelins, albumins and globulins are richer in lysine than prolamins (Taylor and Schüssler, 1986). Sorghum proteins (kafirins) are poor in lysine, and this explains low levels of lysine in sorghum. Legume proteins (marama bean protein by implication), are valuable for their amino acids that complement cereal proteins. Therefore marama flour can potentially be used to enhance the nutritional quality of sorghum porridges.

Table 2.2 Essential amino acid composition (%) of marama, soya bean and sorghum proteins

Amino acid	Marama bean	Soya bean	Sorghum	FAO Reference Pattern
	Mmonatau, (2005)	Vaidehi & Kadam, (1989)	Taylor & Schüssler, (1986)	Snyder & Kwon, (1987)
Leucine	5.5	7.8	13.3	4.8
Lysine	4.1	6.4	2.6	4.2
Methionine	0.7	1.1	1.7	2.2
Cysteine	0.4	1.4	ND	4.2
Phenylalanine	3.3	5.0	4.4	2.8
Threonine	3.4	3.9	3.4	2.8
Tryptophan	ND	1.4	ND	1.4
Valine	4.3	4.6	5.6	4.2
Histidine	1.9	2.6	2.6	ND
Isoleucine	3.4	4.6	4.0	6.4

ND Not detected

Table 2.3 Fatty acid composition (%) of oils from marama and soya beans

Fatty acid (%)	Marama bean (Bower *et al*, 1988)	Soya bean (Wolf & Cowan, 1970)
Myristic (14:0)	1.3	0.1
Palmitic (16:0)	13.8	11.0
Stearic (18:0)	9.7	4.0
Arachidic (20:0)	2.8	0.3
Palmitoleic (16:1n-9)	1.7	0.1
Oleic (18:1n-9)	48.5	23.4
Linoleic (18:2n-6)	19.2	53.3
Linolenic (18:3n-2)	2.0	7.9
Behenic (22:0)	ND	0.1

ND Not detected

2.2.3. Phenolic compounds and antioxidant activity

Phenolic compounds are a class of low molecular weight secondary plant metabolites found in most plants (Nandutu *et al.*, 2007). Chemically they are substances possessing an aromatic ring bearing one or more hydroxyl (OH) groups. Phenolic compounds are broadly grouped as tannins, phenolic acids and flavonoids (Shahidi & Naczk, 2004). Phenolic compounds are believed to have antioxidant properties (Nandutu *et al.*, 2007). They scavenge free radicals by donating hydrogen atoms to free radicals and hence they may protect cell constituents against oxidative damage and limit the risk of various degenerative diseases associated with oxidative stress (Anderson and Wolf, 1995). Generally the higher the number of phenolic hydroxyl groups in a phenolic compound, the greater the antioxidant activity (Rice-Evans *et al.*, 1996).

The total phenolic content in marama bean cotyledon is quoted as 28% (Van Zyl, 2004). According to this report phenolic acids (protocatechuic, sinapic, caffeic and vanillic) and flavonoids (fisetin, rutin, quercetin, kaempferol, myricetin and catechin) were the most abundant in marama bean cotyledon. Sinapic, caffeic and vanillic were also reported in soya bean (Hoppe, Jha and Egge, 1997). Marama bean cotyledon contained higher levels of phenolic acids than flavonoids (Van Zyl, 2004). This is in agreement with the results for lentils and peas as reported by Dueñas, Hernández and Estrella (2006).

Among cereals, sorghum has the highest levels phenolic compounds, up to 6% (w/w) in some varieties (Beta, Rooney, Marovatsanga and Taylor, 1999; Awika and Rooney, 2004a). Phenolic compounds in sorghum fall into three broad classes namely phenolic acids, flavonoids and tannins (Hahn, Rooney & Earp, 1984). Phenolic acids are found in all sorghum types and exist as benzoic acid or cinnamic acid derivatives to form hydroxybenzoic and hydroxycinnamic acids, respectively (Dykes & Rooney, 2006). The major classes of flavonoids studied in sorghum are the 3-deoxyanthocyanidins which are the most common. Tannins of sorghum are of the condensed type (proanthocyanidins). Condensed tannins are high molecular weight polymers that consist of polymerised flavan-3-ol and/or flavan-3,4-diol units linked by C4→C8 interflavan bonds and are called B-type proanthocyanidins (Dykes & Rooney, 2006). Tannins occur only in the pericarp and testa layers of sorghums contain dominant B_1 and B_2 genes (Hahn & Rooney, 1986). Sorghum types that do not contain dominant B1 and B2 genes do not have condensed tannins and are referred to as "non tannin sorghums". Tannins are reported to cross-link with proteins by reacting with lysine or methionine residues, making them unavailable during digestion (Anderson and Wolf, 1995). In sorghum (Awika *et al.*, 2003b) as well as in marama bean (Van Zyl, 2004), phenolic content correlates strongly with antioxidant activity measured by various methods indicating that phenolics are largely responsible for antioxidant activity. Use of marama based foods such as marama-sorghum porridges rich in phenolic compounds (phenolic acids and flavonoids), would be of importance to consumers because they could exhibit health promoting qualities mainly due to the antioxidative properties.

2.3 Marama flour production

The suggested procedure of producing marama flour (Maruatona, 2008) is shown in Figure 2.5. Processes include dehulling, heat treatment, oil extraction (for defatted flour) and milling.

2.3.1. Heat treatment

Marama beans prior to flour production are dry heated which is accomplished by use of a forced convection continuous tumble roaster (Maruatona, 2008). Heat treatment of marama beans inactivates protease inhibitors such as trypsin and chymotrypsin inhibitors which interfere with protein digestion (Liener, 1986). The continuous tumble roaster has four main components (Fig. 2.6 and 2.7), namely the control system, seed hopper, drum (perforated cylinder and screw conveyer) and a holding unit.

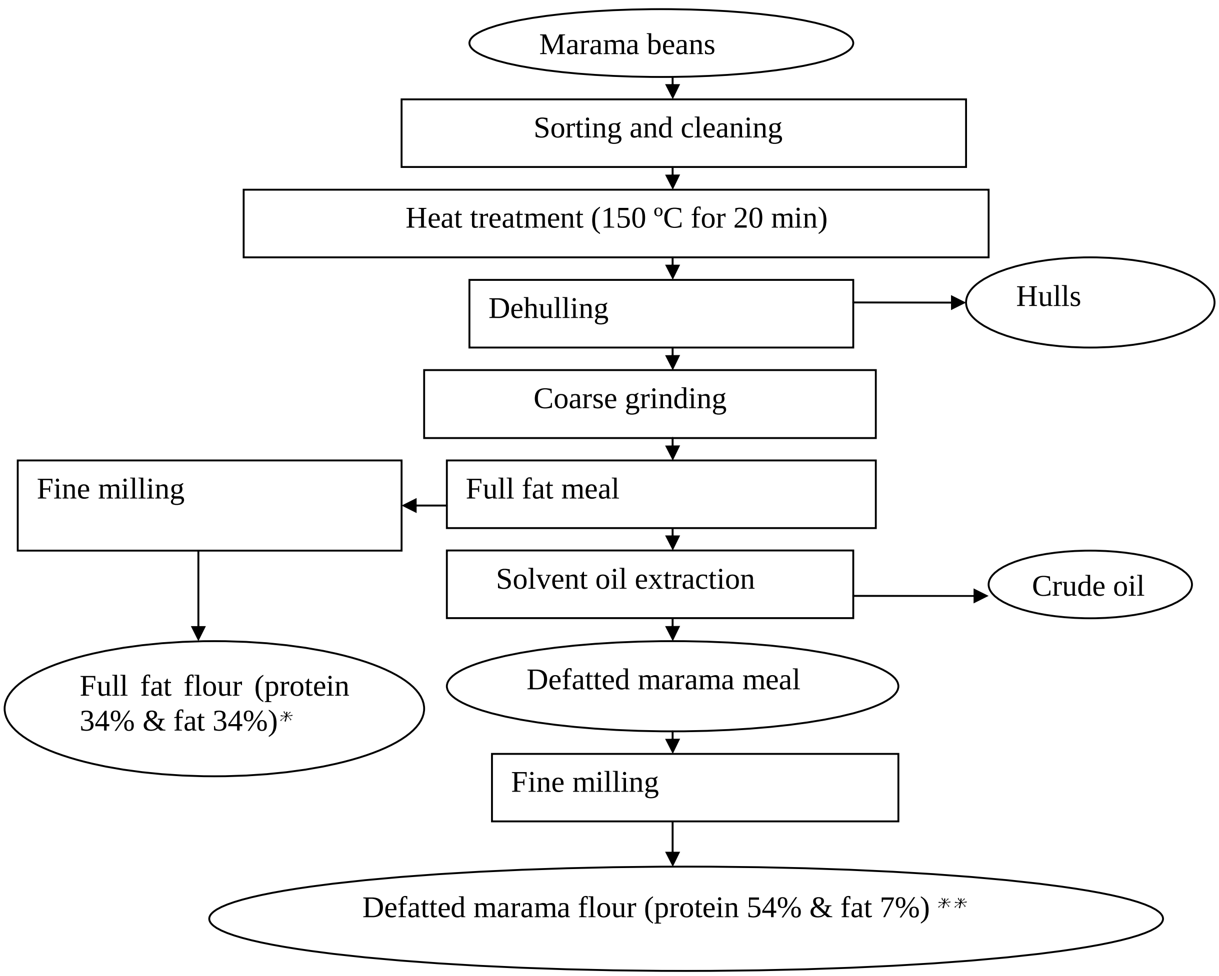

Figure 2.5: Processing procedure for marama flour (adapted from Maruatona, 2008)

***Amarteifio and Moholo (1998); **Maruatona (2008**

Figure 2.6: Picture of the forced convection continuous tumble roaster used for drying whole marama beans (Roastech, South Africa)

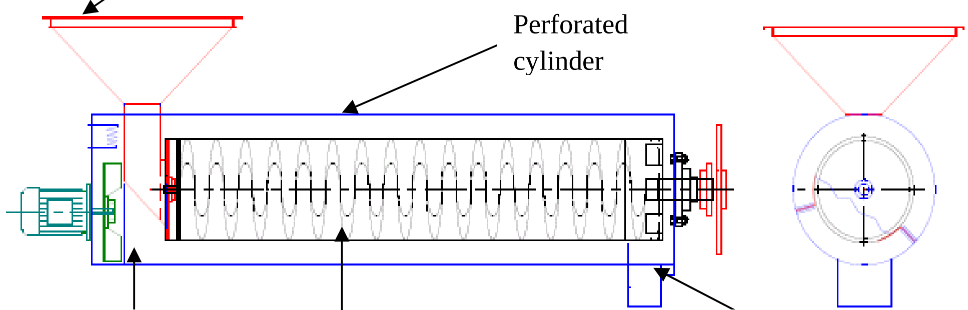

Figure 2.7: Schematic diagram of the forced convection continuous tumble roaster used for drying whole marama beans (Roastech, South Africa)

2.3.2. Dehulling

Marama bean hulls are hard and not consumed. Dehulling therefore involves the separation of the hulls from the cotyledons. Marama beans can be dehulled using a DF sample cracker (Fig. 2.8). The cracker has two discs carrying blades, in which one of the discs rotates and the other remains stationary. A groove machined into the stationary disc channels the beans to a seat carrying the only blade on this disc. The rotating disc, on the other hand, has four knives, all made of High Speed Steel. As this disc rotates, the blades cut through the bean for as long as it still remains on the stationary disc (Maruatona, 2008). The dehulled beans are then milled into flour.

2.3.3. Milling

Milling can be accomplished by using a conventional hammer mill or pin mill. However, to process flours with finer particle size, impact turbo mills or high-speed pin mills are used (Snyder and Kwon, 1987). The milling equipment used influences paste functionality and end product quality because milling affects particle-size distribution of the flour.

Figure 2.8: DF sample cracker used for dehulling marama beans

2.3.4. Oil extraction

In the soya bean industry, oil extraction is mostly achieved by use of two processes: the screw-press (expeller) process and extraction by solvents (Berk, 1992). Solvent oil extraction has been used to produce defatted marama flour. Oil extraction of marama flour and other oilseeds such as soya, increases their protein content and make them less susceptible to lipid oxidation leading to longer shelf-life. Oil extraction increased marama flour protein content from 34% (Amarteifio and Moholo, 1998) to 52.7% (Maruatona, 2008). Fat reduced from 33.5% (Amarteifio and Moholo, 1998) to 7% (Maruatona, 2008). Oil extraction in marama beans is achieved by firstly coarse grinding the dehulled beans into a meal. This is followed by defatting using *n*-hexane in the ratio of 1 part meal: 3 parts hexane. The meal-hexane mixture is stirred for 1 h and is allowed to stand for 30 min and hexane is decanted off. The defatted meal is then left in a fume cupboard overnight to evaporate hexane (Maruatona, 2008).

2.4 Effect of processing on the quality of the legume flours and end use products

2.4.1. Effect of processing on the sensory quality

Legume-based foods are becoming increasingly important components of the human diet. However, its effective utilisation in the diet depends, to a large degree, upon consumer acceptance of its sensory characteristics. Marama bean seeds are not often eaten raw as they are tasteless with an unpleasant slimy texture, but after roasting they have a delicious nutty flavour, resembling roasted peanuts (Mmonatau, 2005). Flavour development may be due to development of flavour compounds via Maillard reaction, caramelisation, and lipid–Maillard product interactions when heating marama beans as described by Sacchetti, Pinnavaia, Guidolin and Rosa (2004) for products such as chestnuts. An undesirable bitter taste in roasted marama beans was reported by Mmonatau (2005) due to overheating at 150ºC for 40 min. Sacchetti *et al* (2004) reported that high temperatures lead to development of off flavour in chestnut flour. The high processing temperatures enhance the Maillard reaction, causing the occurrence of browning phenomena, and flavour development that could be desirable or undesirable depending on the extent of heating. The undesirable bitter taste may relate to off-flavour development compounds from Maillard reactions such as furan and caramel compounds (Bemiller and Whistler, 1996).

The Maillard reaction is a non-enzymatic reaction that takes place on heating and is related to aroma, flavour and colour development in food products such as roasted coffee and cocoa beans and many baked cereal products (Martins *et al*., 2001). The Maillard reaction involves condensation of reducing sugars with a free amino group such as lysine forming N-substituted glycosylamine (Figure 2.9). N-substituted glycosylamine is unstable. With increased temperatures because of its instability it undergoes the amadori rearrangement forming ketosamines (Martins *et al*., 2001).

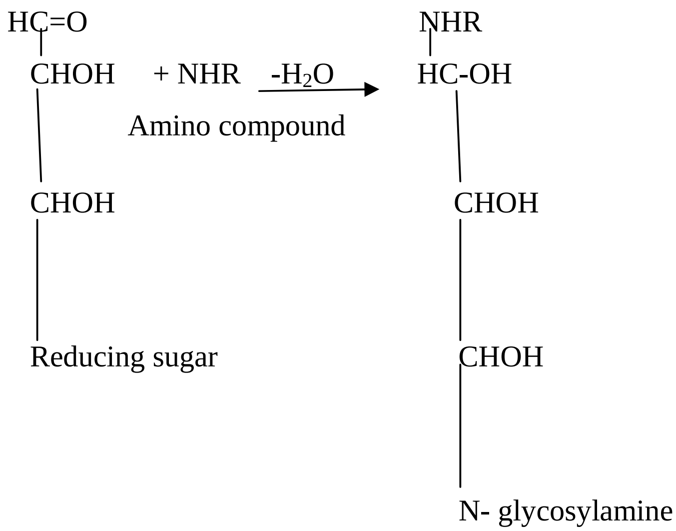

Figure 2.9: Reaction of a reducing sugar and an amino group forming N-substituted glycosylamine (Martins *et al*., 2001)

Further reaction with amino acid forms brown nitrogenous polymers and copolymers known as melanoidins that may result in undesirable flavours such as bitterness or a burnt aroma. On the other hand melanoidins may give caramels which are desirable in some food products. The final products of the Maillard reaction are melanoidins and they are also responsible for the brown colour development (Morales, 2005),

Clark and Proctor (1994) have also reported unpleasant sensory properties in raw defatted soya flour which were described as grassy, cooked beany, astringent and bitter. The descriptions given to the flavour of soya bean protein products are fairly consistent: beany, bitter, nutty and toasted as reported by Rackis, Cowan and Wolf (1973). The nutty and roasted flavours are due to physical treatments such as dry heating. Bitter and beany are two flavours generally agreed upon for raw soya bean flour, and beany was reported most frequently as a predominant odour (Rackis, Sessa and Honig, 1979). Evidence that measurable amounts of lipid material remain in defatted soya meal from hexane-extracted soybean flour suggests that oxidation of lipid components may be a factor in the flavour problems of soya bean protein products. Removal of much of the flavour and lipid material by extraction of dehulled, defatted soybean flakes with alcohols supports this suggestion (Rackis *et al.*, 1973).

Unpleasant flavour in raw peanut flour has been reported (Rackis *et al.*, 1979). Raw peanuts have a grassy flavour that can be eliminated by dry heating. This is due to protein denaturation that leads to irreversible binding of flavour constituents that may reduce the intensity of off-flavours (Rackis *et al.*, 1979) and desirable flavour development due to enhancement of Maillard reaction (Sacchetti *et al*., 2004). However, depending upon time and temperature of dry heating, a bitter taste may develop. Phenolic compounds have been reported to be responsible for bitter taste in soya beans (Drewnowski and Gomez-Carneros, 2000). This could possibly also explain bitterness in marama bean.

2.4.2. Effect of processing on the nutritional quality

Heat treatment may bring about several changes in the nutritional qualities of marama bean flour and end products. Heat treatments of legumes, which can be accomplished by dry heating, denature heat-labile protease or trypsin inhibitors. Trypsin inhibitors interfere with the digestion and absorption of proteins when consumed by humans (Snyder & Kwon, 1987). Heat treatment of marama beans prior to flour production therefore improves bioavailability of proteins hence improving the protein quality. Maruatona (2008) reported higher trypsin inhibitor activity in marama flour from unheated marama beans (250.8 TUI/ ml extract) compared with soya flour from unheated beans (57.6 TUI/ ml extract). Dry heating of whole marama beans at 150 ^{o}C for 20 min significantly reduced the trypsin inhibitor activity in its defatted flour to 3.3 TUI/ ml extract. This means up to 98.7% reduction in trypsin inhibitor activity.

According to Maruatona (2008) the *in-vitro* protein digestibility of marama flour from heated beans was 2.7% higher than that of marama flour from unheated marama beans. The improvement in the protein digestibility of flours prepared from heated beans could probably be due to the unfolding of the proteins during heating, thus making them more accessible and easier to be hydrolysed by proteases (Hsu *et al*. 1977).

Excessive heat however may have negative effects on the nutritive value of marama bean proteins. Maruatona (2008) reported a reduction in lysine content (11.9%) upon heating. Maillard browning reactions of the ε-NH_2 group of lysine with carbonyl groups of reducing sugars produce fructosyl-lysine and cross-linking of lysine to form lysinoalanine and conversion of L- to D-lysine may lead to a loss in lysine (Friedman and Brandon, 2001). Maruatona (2008) also reported a reduction in threonine, tyrosine, alanine, proline, phenylalanine, valine, glycine and leucine upon dry heating.

2.4.3. Effect of processing on the phenolic content and antioxidant activity

As indicated in the previous section, marama bean is a good source of phenolic compounds. Phenolic compounds are believed to have antioxidant properties (Nandutu *et al*., 2007). Dehulling marama bean prior to milling reduces the total phenolic content of marama beans. Van Zyl (2004) reported that phenolic compounds were mainly concentrated in the seed coat with lower levels in the cotyledon. Dehulling involves removal of marama bean seed coat hence loss of the phenolic compounds.

Awika *et al*. (2003a), working with sorghum, reported an increase in monomeric and tetrameric tannins on baking but a reduction in polymeric tannins which may be attributed to complexation of tannins with other macromolecular constituents such as protein. Increase in the levels of monomers and tetramers may be associated with high molecular weight polymers broken down into low molecular weight constituents (Awika *et al*., 2003a).

Phenolic content correlates strongly with antioxidant activity (Awika *et al.*, 2003b). Logically as phenolic content is reduced due to different forms of processing, antioxidant activity also decreases. Complexation of phenols with macromolecules on heating reduces phenolic availability and extraction. This may affect the antioxidant activity. Heating however may induce production of Maillard reaction products, especially melanoidins, which have been reported to have antioxidant activity through scavenging oxygen radicals or chelating metals (Michalska, Amigo-Benaventb, Zielinski & Dolores Del Castillo, 2008). Maillard reaction products (MRP) from histidine are said to have the highest antioxidant activity. MRP obtained from heated histidine and glucose exhibit copper ion binding ability (Michalska *et al*., 2008).

2.4.4. Effect of processing on the functional quality

The processing procedures involved can modify proteins and other components. This affects not only its nutritional and sensory quality as explained previously, but the functionality as well. Functionality is defined as any property of a food ingredient except the nutritional value that affects its utilisation (Fennema, 1985). Functional properties are however often used to denote any property of proteins that affect their use, either as processing aids or as a direct contributor of product attributes (Gilbertson and Porter, 2001). Proteins can bind water or oil, stabilise foams, form films, form emulsions, form gels and aggregates. All these functionalities result from the amphipathic nature of proteins i.e. their ability to bind both hydrophobic and hydrophilic materials (Gilbertson and Porter, 2001).

Heat treatment affected the functionality of marama flour. According to Maruatona (2008) heat treatment reduced nitrogen solubility index by 28.6%. This could probably be because of protein denaturation followed by a subsequent increase in surface hydrophobicity and aggregation of proteins through hydrophobic, electrostatic and disulphide interactions (Morr, 1990).

The interactions of water and oil with proteins are very important in food systems because of their effects on the flavour and texture of foods. Intrinsic factors affecting water binding capacity of food proteins include amino acid composition, protein conformation, and surface polarity/hydrophobicity (Barbut, 1999). However, food processing methods have important effects on the protein conformation and hydrophobicity. A decreased oil absorption capacity was reported by Maruatona (2008).

The formation and stability of emulsions is very important in food systems such as salad dressings. Proteins are composed of charged amino acids, non charged polar amino acids and nonpolar amino acids, which makes protein a possible emulsifier (Yu et al., 2007). Dry heating of marama beans significantly decreased the emulsion capacity of marama bean flour (Maruatona, 2008). It has been reported that emulsion capacity generally depends largely on protein solubility (Carvalho, Garcia, and Amaya-Farfan, 2006). This is because emulsion formation depends on the rapid adsorption, unfolding and reorientation of the proteins at the oil-water interface; thus proteins with low solubility have a decreased capacity to act as surface-active agents and to adsorb at the oil/water interface (Morr, 1990).

The formation of foams is analogous to the formation of emulsions. In the case of foam, water molecules surround air droplets, and air is the non-polar phase. Theoretically, the amphipathic character of protein makes them good foaming agents that work at air–water interface to prevent bubble coalescence. Dry heating of marama beans did not have a significant effect on the foaming capacity of marama bean flour Maruatona (2008).

2.5 Sorghum porridges

In most developing countries the first food to be introduced in a child's diet is porridge prepared from cereal flour. According to Taylor and von Ascheraden (1997) porridge made from sorghum was traditionally the staple diet of the black people of southern Africa. Sorghum, maize, and pearl millet thick porridge are popular in many semi-arid regions. Porridge may be prepared soft or thick. A soft porridge is a thin, easily flowing product with low solids, while a thick porridge is a stiff product with high solids. Porridge can be made by souring and fermenting the flour before cooking or cooked in water without fermentation (Pelembe, 1998).

Starch is the primary carbohydrate in sorghum grain and is normally embedded in a protein matrix (Klopfenstein and Hoseney, 1995). Sorghum starch contains 70-80% amylopectin and 20-30% amylose (Klopfenstein and Hoseney, 1995). When starch granules are heated in water, amylose molecules are released into the solution, and upon cooling they re-associate rapidly by cross-linking with each other through hydrogen bonding to form a gel thus determining the textural changes in the starch paste (Moris, 1990). Starch contributes greatly to the textural properties of sorghum porridge.

Wet cooking of sorghum also greatly reduces protein digestibility and lysine availability due to insolubilisation of kafirins and greater cross-linking with disulphide bonds (Kirleis, 1990). When sorghum is wet-cooked, enzymatically resistant protein polymers are formed through disulphide bonding of the β- and γ-kafirins (Rom *et al*.,1992; Oria *et al*., 1995), and possibly other proteins which are located on the outside of the protein body (Duodu *et al.*, 2003). The disulphide cross-linked proteins thus formed would then prevent access to and restrict digestion of the more digestible and centrally located α-kafirin within the protein body (Rom *et al*.,1992; Oria *et al*., 1995 ; Hamaker *et al*., 1994).

The major objective of compositing cereals such as sorghum with legumes is because legumes are limiting in cystine and methionine but contain sufficient lysine therefore can be used to overcome lysine deficiency of cereals. A positive correlation between lysine content and availability has been reported by Copelin *et al.* (1978). Compositing cereals with legumes improve the nutritional value of cereal-legume composite foods (Klopfenstein and Hoseney, 1995). However in composite porridges with high lipid content starch molecules form helical inclusion lipid-amylose complexes, which cause high pasting temperatures and low paste viscosities (Mishra and Rai, 2006). As a result composite porridges become less firm (Fliedel, 1995).

2.6 Gaps in knowledge

This review shows that marama bean is a good source of fat, protein and the essential amino acid lysine that is deficient in cereals. Furthermore marama bean constituents such as phenolic compounds are believed to have antioxidant properties. Marama bean protein content is comparable to that of soya bean. The oil content of marama bean is much higher than that of soya beans, but compares favourably with oilseeds such as ground nuts, sunflower seeds and rape seed. Legumes such as soya bean are used to complement cereals to increase protein content, amino acid balance and energy. Marama beans can potentially be used to enhance the nutritional value of sorghum-based products. However no information is available on the potential application of marama bean flour in food systems, for example its use in compositing cereal based products such as sorghum-marama composite porridge.

Processing procedures such as dry heating and oil extraction may affect the nutritional quality, phenolic content and antioxidant activity, warranting research to be done. Furthermore potential utilisation of marama bean flour in food systems such as marama-sorghum composite porridges will not only depend on their potential contribution to nutrition but also on consumer acceptance based on sensory properties of the food products. The sensory properties of marama bean flour from heated and unheated beans, and when applied in food systems such as marama-sorghum porridges have not been profiled. Therefore there is need to study the potential of marama bean flour in improving the nutritional and sensory quality of sorghum porridge. Furthermore the effect of different processing steps on the nutritional and sensory quality of marama-sorghum composite flours and porridges as an end use product should be investigated.

2.7 Hypotheses

- The sensory characteristics of sorghum porridge and marama-sorghum composite porridges from flour produced from dry heated and unheated marama beans will differ. During heating of marama beans Maillard browning will result in colour changes (darkening) and development of toasted, nutty flavours which may be detected in the porridge. The differences in sensory characteristics of the porridges will also have an effect on the consumer acceptance of the porridges. Porridges composited with full fat flour will possibly be more acceptable than porridges composited with defatted flours. This is because of the contribution of the fat inherent flavours (Ohmes, Marshall and Heymann, 1998).

- Compositing sorghum meal with marama flour will improve the nutritional quality of the meal and resultant porridges. Sorghum has lower protein content and its protein is limited in the essential amino acid lysine (Klopfenstein and Hoseney, 1995). Marama flour will positively contribute to protein and lysine content due to its high protein content 34-37% (Amarteifio and Moholo, 1998 ; Mmonatau, 2005) and improve the energy values because of its high oil content of 35-37% (Amarteifio and Moholo, 1998 and Mmonatau, 2005).

- Dry heating of marama beans will result in higher total phenolic content in marama flour. Phenolic compound extractability will increase because of an increase in the levels of monomers and tetramers associated with high molecular weight polymers broken into low molecular weight constituents (Awika *et al*., 2003a). Phenolic content will correlate strongly with antioxidant activity thus dry heating will also increase antioxidant activity (Awika *et al*., 2003b). Dry heating may also lead to the formation of Maillard reaction products such as hydroxymethylfurfuraldehyde (HMF) which exhibit high antioxidant activity (Michalska, 2008).

2.8 Objectives

- To determine the effects of dry heating marama beans, defatting and compositing the resultant flours with sorghum meal on the sensory quality and acceptance of the porridges.
- To determine the effects of dry heating marama beans, defatting and compositing the resultant flour with sorghum meal on the nutritional quality in terms of protein and fat content, amino acid composition, fatty acid composition and energy value of marama-sorghum flours and porridges.
- To determine the effects of dry heating marama beans and compositing the resultant flour with sorghum meal on the total phenolic content and antioxidant activity of the flours and porridges.

2.2.2. Lipid composition

Lipid composition of food is important in human nutrition, as it is known that fat forms a vital component of body cell constituents; it is also a good source of energy. Fat also acts as a functional ingredient in improving the sensory quality of processed food products and is a carrier of fat soluble vitamins (Salunkhe, Cha, Adsule and Kadam, 1992). Table 2.3 shows the fatty acid composition of oil from marama and soya bean. Oils from marama bean and soya bean (like other plant oils) are rich in unsaturated fatty acids. Oleic acid (48.5%) is the most abundant fatty acid in marama bean oil, followed by linoleic acid (19.2%). On the other hand linoleic acid (53.3%) is the most abundant in soya bean oil. From a food oxidation point of view, lipids with high levels of unsaturated fatty acids such as oleic acid, linoleic and linolenic acid are important. Oil from marama and soya beans both contain high levels of these fatty acids that make them prone to oxidation. However oleic acid in marama oil is two times higher than that in soya oil. This means that marama bean oil would probably be less susceptible to oxidation than soya bean oil. This is because it has less 1,4 penta-diene structure in linoleates. This structure has been reported by Nawar (1996) to be more susceptible to oxidation by a factor of about 20 than the propene of oleate because it has two double bonds in the cis form as opposed to the propene structure in oleate which has one double bond (Nawar, 1996). It is also important to note that food sources with high oleic acid contents e.g. olive oil, have cardio-protective effects (Hu, Manson and Willet, 2001). Saturated fatty acids palmitic acid and stearic acid are higher in marama bean than in soya. This makes marama oil more stable than soya oils.

3. RESEARCH

This research chapter is divided into two chapters. Figure 3.0 show the experimental design of both research chapters.

3.1 Effects of dry heating marama beans, defatting and compositing the resultant flours with sorghum meal on the sensory quality of their porridges (To be submitted to the Journal of the Science of Food and Agriculture)

3.2 Effects of dry heating marama beans, defatting and compositing the resultant flour with sorghum meal on the nutritional quality and antioxidant activity of sorghum-marama porridges

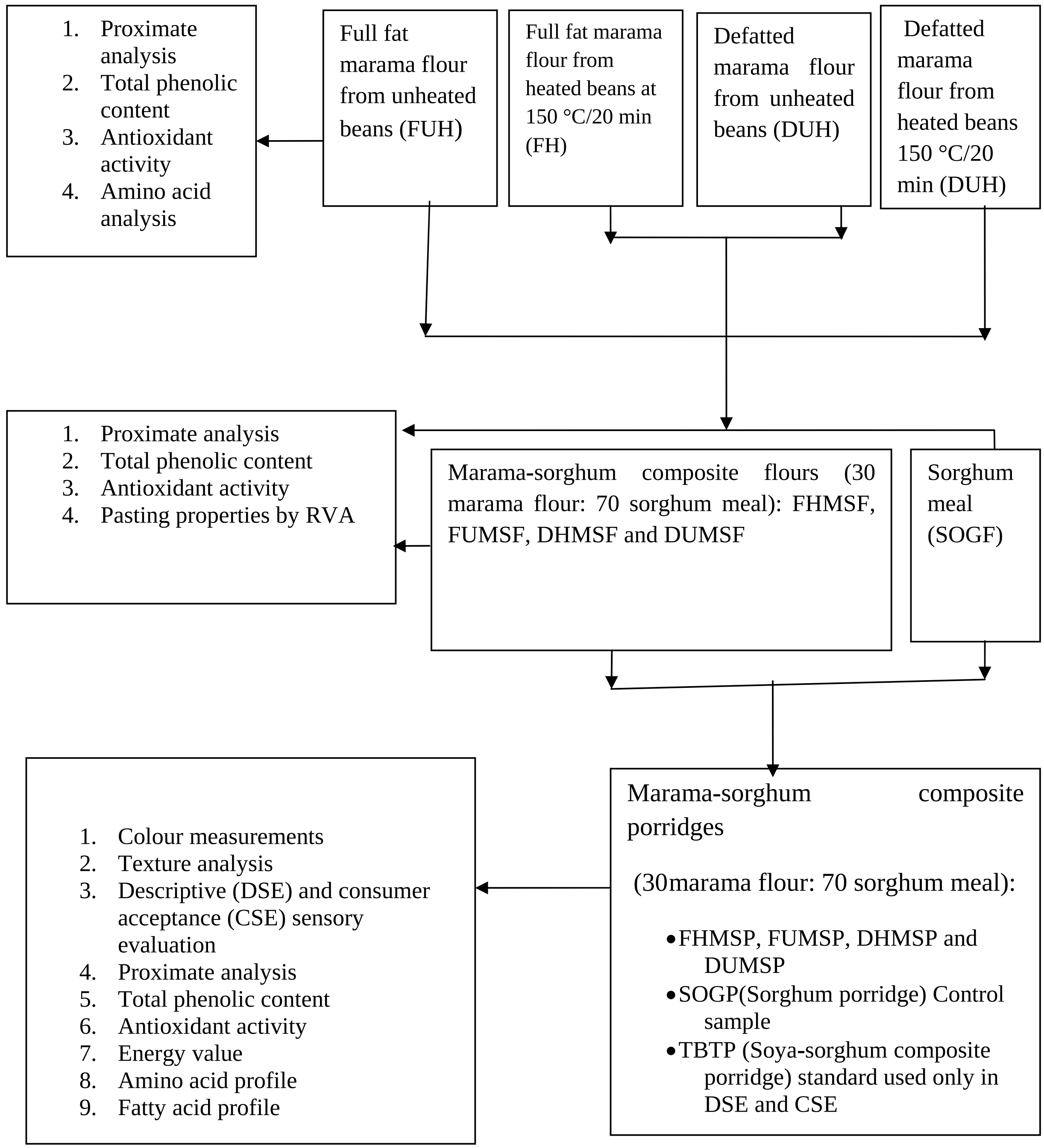

Figure 3.0: Experimental execution of sensory and nutritional quality evaluation of marama-sorghum composite flours and porridges

3.1. Effects of dry heating marama beans, defatting and compositing the resultant flours with sorghum meal on the sensory quality of their porridges

ABSTRACT

The edible seeds of marama beans are good sources of protein and fat and can potentially enhance the nutritional quality of sorghum porridge. Utilisation of marama flour in composite porridge depends on sensory acceptance. Six porridges (10% solids) were prepared from: full fat and defatted flours from heated and unheated marama beans composited with 70% sorghum meal, 100% sorghum meal and *Tsabotlhe* (a commercial sorghum-soya composite) used as a standard. Porridges were subjected to descriptive sensory analysis, a consumer acceptance test (n=52), texture analysis, pasting and colour measurements. Compositing with marama flour reduced the cooked sorghum aroma/flavour intensities prominently in sorghum porridge. Dry heating marama beans prior to milling resulted in a roasted nutty flavour. This was perceived in both full fat (12.7 % fat) and defatted (2.9 % fat) composite porridges but more prominently perceived in defatted samples. Marama-sorghum porridges from unheated samples and *Tsabotlhe* were characterised by a strong boiled nut aroma/flavour. Composite porridges from full fat marama flours were described as buttery/creamy. A bitter taste and aftertaste were perceived in porridges from defatted flours. Marama-sorghum composites and *Tsabotlhe* porridges were less viscous than sorghum porridge. This was confirmed by pasting profiles (low final viscosities) and texture analysis indicating reduced firmness. Porridges from unheated marama beans were brighter in colour than porridges from heated beans. Sorghum porridge and porridge composite with full fat marama flour from heated beans (FHMSP) were more acceptable than other composite porridges.

3.1.1. INTRODUCTION

Marama bean (*Tylosema esculentum* (Burch) A. Schreib) is a wild underutilised legume in southern Africa (Hartely *et al*., 2002). The edible seeds are good sources of protein and fat (Amarteifio and Moholo, 1998), and can potentially enhance the nutritional quality of sorghum porridge, a staple in many African countries (Rooney and Serna-Saldivar, 1990). Sorghum has low protein and is deficient in the essential amino acid, lysine. Therefore compositing sorghum meal with marama flour would improve the nutritional quality of the composite porridges. Utilisation of marama flour in composite porridges will not only depend on nutritional quality but also on sensory properties that affect consumer acceptability of the porridge.

Different processing procedures are used in production of marama flour which may affect the sensory quality of the end products such as marama-sorghum porridges. Marama bean is rich in unsaturated fatty acids (Mmonatau, 2005) and could also be susceptible to oxidation. Defatting of marama flour is done to improve its storage stability. However removal of fat may lead to loss of its inherent richness and creaminess. This may affect the acceptability of the final product such as porridges in this application. Marama flour processing involves dry heating of marama beans. This operation aims at deactivation of protease inhibitors such as trypsin inhibitors which have a negative effect on digestion of proteins by humans (Liener, 1986). Heat treatment of marama beans leads to flavour and colour development which make them more palatable (Mmonatau, 2005).

This study aimed at evaluating the effects of compositing sorghum meal with different types of marama bean flour (full fat and defatted marama flours from dry heated and unheated beans) on sensory quality of the porridges.

3.1.2. MATERIALS AND METHODS

3.1.2.1. Preparation of marama flour

Marama flours were prepared using the procedure described by Maruatona (2008) with modifications. Dry heating of marama beans was achieved by use of a forced convection continuous tumble roaster (Roastech, Bloemfontein, South Africa). The continuous tumble roaster has four main components, namely the control system, seed hopper, drum (perforated cylinder and screw conveyer) and a holding unit. A speed set of 290 rpm was selected because it resulted in a heating time of 20 min (first bean) to 23 min (last bean) at 150 °C (Maruatona, 2008). Heating marama beans at 150 °C for 20 minutes was found to inactivate trypsin inhibitors (Maruatona, 2008).

A DF cracker (WMC Metal Sheet Works, Tzaneen, South Africa) was used to dehull marama beans prior to milling. The latter was achieved by using a laboratory Waring blender (Lasec, Johannesburg, South Africa), for coarse grinding and a laboratory mill (IKA Werke, Germany) for fine milling. Dehulled marama beans were coarsely ground and oil was extracted using hexane. Coarsely ground marama flour with hexane (1:3) was stirred using a magnetic stirrer for 2 h, whereafter the hexane was decanted off, the procedure was repeated 3 times. After oil extraction the flour was left in a fume cupboard for 24 h and milled again to pass through a 1000 µm mesh. Four marama flour samples were prepared, vacuum packed and stored at 4°C until used to make marama-sorghum composite flours. The percentage yield of the four types of marama flours obtained is shown in Table 3.1.1.

Table 3.1.1 Yield of the flour from the processed marama beans

Processing steps	**Type of flour**			
	Full fat unheated (g)	**Full fat heated (g)**	**Defatted unheated (g)**	**Defatted heated (g)**
Unprocessed beans	2000	2000	3000	3000
Dry heating	N/A	1876	N/A	2875
Dehulling	845	833	1285	1225
Milling	827	827	1271	1191
Defatting + milling	N/A	N/A	805	661
Flour yield (%)	**41**	**41**	**27**	**22**

N/A Not applicable

3.1.2.2. Preparation of marama-sorghum composite flours

Commercial sorghum meal (Monati super Mabele, Nola foods Randfontein, South Africa) was purchased at a supermarket in Pretoria, South Africa. Full fat and defatted marama flours from heated and unheated marama beans were composited with sorghum meal at a ratio of 30% marama flour: 70% sorghum meal, vacuum packed and stored at 4 ºC until used to make porridges**.**

3.1.2.3. Pasting properties of the flours

Pasting properties of flour suspensions containing 4 g flour in 25 g of water were studied using a series 3 D Rapid Visco Analyser (RVA) (Newport Scientific, Warriewood, Australia). The RVA was programmed to rapidly stir each freshly mounted suspension at 900 rpm for 20 s, where after the sheer rate was decreased and held constant at 160 rpm for the remainder of the test period. The temperature profile entailed holding initially at 50ºC for 2 min, then increasing to 92ºC over a 5 min period and holding at 92ºC for 7 min and then cooling to 50ºC over 5 minutes and holding for 2 min. Pasting peak viscosity (PV- peak viscosity at the start of the 92ºC holding period), holding strength (the trough at minimum hot paste viscosity), final viscosity (the viscosity after the test, after cooling to 50ºC and holding at this temperature), setback viscosity (final viscosity minus holding strength) and break down (peak viscosity minus holding strength) were determined for each flour suspension from the RVA plots obtained. Each sample was analysed in triplicate.

3.1.2.4. Descriptive sensory evaluation of porridges

Preparation of the porridges

Six porridges (10% solids) were prepared: sorghum meal (100% sorghum) denoted as (SOGP), full fat flour from unheated marama beans composited with 70% sorghum meal (FUMSP), full fat flour from heated marama beans composited with 70% sorghum meal (FHMSP), defatted flour from unheated marama beans composited with 70% sorghum meal (DUMSP), defatted flour from heated marama beans composited with 70% sorghum meal (DHMSP) and *Tsabotlhe* porridge (TBTP a commercial sorghum-soya composite flour from Foods Botswana) used as a standard.

A Botswana porridge-making process (Kebakile *et al.*, 2008) with modifications was used for the preparation of soft sorghum porridges. The cooking process entailed first mixing 200 ml of cold water with the flour (80 g) to make a slurry. The slurry was gradually added, while stirring to avoid lump formation, to 600 ml of boiling water in a small (2 L) stainless steel saucepan. The porridge was simmered at low heat (on a hot plate) for 20 min, stirring every 5 min.

Recruitment and screening of the panel

University of Pretoria students, who were willing to consume sorghum porridge, and did not suffer from any food allergies and that had some experience of descriptive sensory evaluation, were invited through emails and telephone calls to apply for the descriptive sensory panel. Nineteen individuals responded and attended an introduction session. Ten persons were already trained panellists: of these 6 confirmed their availability. The nine remaining untrained persons were screened for sensory acuity over two days using three different screening methods (1 h per method), i.e. identification of basic tastes (sweet, sour, salty, bitter and umami), identification of aromas on aroma smelling strips and identification of sensory attributes that describe taste, aroma, flavour and appearance differences of roasted peanuts. A final panel of seven judges, five previously trained and two new recruits, were selected and used.

Training of the panel

Training of the panel was done in 9 h, 1 h per day following the generic descriptive analysis method as described by Einstein (1991). During the training, each panellist described the differences between the six porridge samples at least three times. Descriptive terms and scale anchors were developed, defined and agreed upon for evaluation. Before the actual evaluation the panellists' performance was check at least three times and the FCM® tool in Compusense five ® was used to facilitate training.

Sample evaluation

Cooked porridge (40 g portions) was served in glass ramekins covered with aluminium foil, and kept warm on a warming tray at 50°C. The sensory evaluation of the porridge was conducted in a sensory evaluation laboratory with individual booths equipped with computers for direct data entry using Compusense five ® release 4.8 (Compusense Inc., Guelph, Canada). Panellists evaluated all samples in triplicate during three days with one session per day. Each panellist received 6 samples of porridge on a white tray, with six stainless steel teaspoons, a serviette and a plastic disposable cup filled with filtered tap water for rinsing the mouth before and between tasting the samples. To avoid fatigue, 3 samples were tasted and after a 10 min break, the other 3 samples kept warm on a warming tray at 50°C, were tasted. The order of sample presentation was randomised over the panel. Red light in the tasting booths was used to mask the colour of the porridges for the panellists in order to concentrate on aroma, texture and flavour properties. The panel used sixteen descriptive terms, grouped under aroma, flavour, texture and aftertaste attributes. Aroma was evaluated immediately after removing the foil cover using short sniffs. Then a full spoon of the porridge was chewed in the mouth to test for flavour and texture properties. After swallowing the panellists analysed the aftertaste properties. Table 3.1.2 shows the definitions of the terms developed by the panellists. Nine-point line scales were used to measure the intensity of each attribute for a given sample. The minimum value was 1 denoting not perceived, not coarse or not thick. The maximum point was 9 denoting strongly perceived, very coarse or very thick.

3.1.2.5. Textural properties of porridges

The textural properties (firmness and stickiness) of five porridges (10% solids) prepared from sorghum flour (100% sorghum), full fat flour and defatted flour from unheated and heated marama beans composited with 70% sorghum meal were determined using the TA-XT2 Texture Analyser (Stable Micro Systems, Godalming, UK). The following instrument test parameters were used: mode was force in compression; option return to start; pre-test speed was 2.0 mm/sec; test speed was 2.0 mm/sec; post test speed was 10.0 mm/sec; sample penetration distance was 10.0 mm; trigger type was auto-0.05 N; and a flat cylindrical perplex probe (20 mm diameter) was used.

displayed using Compusense five ® release 4.8 (Compusense Inc., Guelph, ON, Canada). Consumers were also prompted to provide comments on the reasons why they liked or disliked the different porridges.

3.1.2.8. Statistical analyses

With the exception of the consumer acceptability test which was not repeated, all the other analyses were conducted in triplicate per repeat. The effects of heating marama beans, defatting the flour and compositing the resultant flours with sorghum meal on the porridge sensory properties, texture measurements, pasting properties and colour measurements were evaluated using analysis of variance (ANOVA) based on a 5% level of significance. Statistica was used for data analysis (Statistica Version 8.0, Statsoft, Tulsa, USA). Significant differences between means were determined using Fisher's least significant difference test (LSD). Furthermore Principal Component Analysis was performed to evaluate and identify the variations between the samples based on the sensory attribute loadings. For consumer acceptability test box and whisker plots were used to demonstrate score distributions for the porridges.

3.1.3. RESULTS

Under this section, results of the effects of heating marama beans, defatting and compositing the resultant flours with sorghum meal on the sensory quality of the porridges are shown. Referring to the results on nutritional quality evaluation (research chapter 2, Table 3.2.1 pp 59), the fat and protein contents of the porridges were as follows: SOGP (11.7% protein and 1.4% fat), FUMSP (18.8 % protein and 12.5 % fat), FHMSP (18.8% protein and 12.7% fat), DUMSP (22.9% protein and 2.9% fat) and DHMSP (22.6% protein and 2.7 % fat) respectively.

3.1.3.1. Pasting properties

Table 3.1.3 shows the effects of heating marama beans, defatting and compositing the resultant flour with sorghum on the pasting profile of marama-sorghum composite porridges.

Table 3.1.2 Terms used by descriptive sensory panel to describe the sensory attributes of the porridges

Attributes	Definitions	References	Rating scale
Aroma			
Overall aroma strength	The overall aroma intensity of the porridge		Bland = 0, strong = 9
Cooked sorghum porridge aroma	Intensity of aroma associated with cooked sorghum	Cooked sorghum porridge (Nola monati super Mabele) (rated 8)	Not perceived = 0, Strongly perceived = 9
Boiled nut aroma	Intensity of aroma associated with boiled nut	Boiled whole marama beans (boiled for 45 min) (rated 7)	Not perceived = 0, Strongly perceived = 9
Roasted nutty aroma	Intensity of aroma associated with medium-roasted nut and having fragrant character such as methyl pyrazine	Roasted marama beans (150 ºC for 20 min) rated 8	Not perceived = 0, Strongly perceived = 9
Flavour			
Overall flavour strength	The overall aroma intensity of the porridge		Bland = 0, strong = 9
Cooked sorghum porridge flavour	Intensity of flavour associated with cooked sorghum	Cooked sorghum porridge (Nola monati super Mabele) (rated 8)	Not perceived = 0, Strongly perceived = 9
Boiled nut flavour	Intensity of flavour associated with boiled nuts	Boiled whole marama beans (boiled for 45 min) (rated 7)	Not perceived = 0, Strongly perceived = 9
Roasted nutty flavour	Intensity of flavour associated with medium-roasted nuts and having fragrant character of methyl pyrazine	Roasted marama beans (150 ºC for 20 min) rated 8	Not perceived = 0, Strongly perceived = 9
Butter creamy flavour	Intensity of flavour associated with butter	Unsalted butter (rated 7)	Not perceived = 0, Strongly perceived = 9
Salty	Basic salt taste associated with sodium chloride (table salt)	0.35% sodium chloride in spring water (rated 9)	Not perceived = 0, Strongly perceived = 9
Bitter	Basic bitter taste associated with caffeine or quinine	0.15 % caffeine solution in spring water (rated 9)	Not perceived = 0, Strongly perceived = 9

Table 3.1.2 Terms used by descriptive sensory panel to describe the sensory attributes of the porridges (continued)

Attributes	Definitions	References	Rating scale
Texture			
Coarseness	Extent to which grittiness or graininess of porridge caused by small particles could be perceived in the mouth		Not coarse = 0, Very coarse =9
Viscosity	Force required to draw a liquid from a spoon over the tongue	Thick maize porridge (12% solids)(rated 9)	Not thick = 0, Very thick = 9
Oily/creamy	Intensity of mouth feel associated with fatty oily products such as dairy cream		Not perceived = 1, Strongly perceived = 9
After taste/mouth feel			
Sorghum aftertaste	Intensity of aftertaste associated with cooked sorghum porridge perceived after swallowing the porridge	Cooked sorghum porridge (Nola monati super Mabele)(rated 6)	Not perceived = 1, Strongly perceived = 9
Bitter	Basic bitter taste associated with caffeine or quinine	0.15 % caffeine solution in spring water (rated 7)	Not perceived = 0, Strongly perceived = 9
Sour	Basic sour/acidic taste associated with citric acid	0.08% citric acid solution in spring water (rated 9)	Not perceived = 0, Strongly perceived = 9
Sweet aromatic nutty after taste	Sweet nutty after taste associated with roasted peanuts	Roasted peanuts (rated 7)	Not perceived = 0, Strongly perceived = 9

Porridge samples (10% solids) were prepared gradually adding flour slurry (50 g in 100 ml water) to 400 ml boiling water in a small stainless steel saucepan, stirring continuously to avoid lump formation. An electric stove with twin hotplates set on low heat was used to cook the porridge. The porridge was simmered for 15 min (stirring after every 5 min) and was immediately filled into 3 sample tubes (50 ml volume and 30 mm diameter). The tubes were covered with aluminium foil and were held at 50ºC for 90 min. To determine the texture of the porridges the aluminium foil was removed from the tube and the surface layer of the porridge was scraped off. The tube was then firmly secured centrally on the texture analyser stage. The test cycle was then started immediately, and the force-time curve was recorded. Two parameters were derived from the curve: the porridge firmness, defined as the maximum force obtained as the probe penetrated the porridge; and the stickiness of the porridge, defined as the maximum force as the probe withdrew from the porridge. Porridges were analysed in triplicate.

3.1.2.6. Colour measurements of the porridges

Colour of porridges were measured using a Chroma Meter CR-400 (Konica Minolta Sensing, Inc. Japan) and expressed in terms of lightness (L*), red-green characteristics (a*-value) and blue-yellow characteristics (b*).

3.1.2.7. Consumer sensory evaluation of the porridges

The same six porridge samples were prepared and presented to the consumers in the same way as for descriptive sensory analysis. Consumers (n = 52), 30 male and 22 female, were invited from the community and the students of the University of Pretoria using trained field workers. Consumer screening selected for South African citizens that consumed sorghum porridge at least once a week and have no food allergies. No training was required. Each porridge sample was tested for overall acceptability (rated based on the degree of liking) on a nine-point hedonic scale (Peryam and Pilgrim, 1957). The nine structural levels range from 9 “like extremely”, through 5 “neither like nor dislike”, to 1 “dislike extremely”. The overall acceptability of the porridges was determined from the scores. Questions and scales were

Table 3.1.3 Pasting properties (Rapid visco units) of marama-sorghum composite porridges and sorghum porridge

Type of porridge	Peak viscosity	Trough	Break-down	Setback	Final viscosity
SOGP	245.6^{e} (4.5)	218.2^{c}(5.1)	27.4^{b}(9.2)	290.9^{c}(21.4)	509.1^{c}(16.5)
FUMSP	90.2^{b}(0.6)	73.8^{b}(0.5)	16.4^{ab}(0.3)	109.8^{ab}(3.2)	183.6^{ab}(3.7)
FHMSP	72.8^{a}(3.6)	63.0^{a}(2.1)	9.7^{a}(1.5)	106.6^{ab}(4.8)	169.6^{a}(6.9)
DUMSP	109.3^{c}(1.8)	76.8^{b}(0.9)	32.5^{b}(0.9)	92.0^{a}(0.9)	168.7^{a}(1.9)
DHMSP	122.4^{d}(10.0)	73.0^{b}(4.9)	49.4^{c}(5.2)	135.9^{b}(7.5)	208.9^{b}(12.4)

^{abc} = mean values within a column with different letters differ significantly (P<0.05), SD = Standard deviation given in parentheses RVU= Rapid visco units, SOGP = Sorghum porridge, FUMSP = Full fat unheated marama - sorghum porridge, FHMSP = Full fat heated marama- sorghum porridge, DUMSP = Defatted unheated marama – sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge

The pasting profiles of marama-sorghum composite porridges displayed the same general pattern showing small variations. Peak viscosity, trough, breakdown, seatback and final viscosities of marama- sorghum composite porridges were significantly lower (p<0.05) than that of sorghum porridge.

3.1.3.2. Descriptive sensory analysis

Compositing marama flour with sorghum meal affected the aroma and flavour of the porridge. Sorghum porridge (SOGP) had more intense cooked sorghum aroma and flavour (Table 3.1.4) compared to the composite porridges. DHMSP and FHMSP were significantly higher in roasted nut aroma and flavours than DUMSP, FUMSP, TBTP and SOGP. The aroma and flavour of DUMSP and FUMSP were described as boiled nut. The latter porridges were closely comparable to TBTP in terms of overall aroma and flavour strength. Introduction of legume flours (marama or soya flour) significantly increased buttery/creamy flavours and oily mouth feel in composite porridges.

Table 3.1.4 Effect of dry heating marama bean, defatting and compositing the resultant flour with sorghum flour on aroma and flavour attributes of marama-sorghum porridges

Attributes	SOGP	TBTP	FUMSP	FHMSP	DUMSP	DHMSP
Overall aroma strength	4.6^{a}(1.2)	5.2^{bc}(0.8)	5.0^{b}(0.8)	5.2^{bc}(0.9)	4.9^{ab}(0.8)	5.4^{c}(0.9)
Cooked sorghum porridge aroma	5.2^{b}(1.2)	2.7^{a}(1.3)	2.7^{a}(1.3)	2.4^{a}(1.1)	2.9^{a}(1.2)	2.8^{a}(1.1)
Boiled nut aroma	1.0^{a}(1.3)	3.5^{d}(1.5)	4.3^{e}(0.9)	2.7^{bc}(1.3)	3.3^{cd}(1.6)	1.9^{b}(1.5)
Roasted nut aroma	0.8^{a}(0.9)	1.7^{b}(1.0)	1.1^{ab}(0.7)	3.9^{c}(1.7)	1.1^{ab}(1.1)	4.4^{c}(1.7)
Overall flavour strength	4.1^{ab}(1.1)	4.5^{b}(1.0)	4.1^{ab}(0.8)	4.5^{b}(0.7)	3.9^{a}(0.8)	4.5^{b}(0.9)
Cooked sorghum porridge	5.7^{c}(0.7)	3.4^{b}(1.4)	2.3^{a}(1.3)	2.1^{a}(1.0)	2.4^{a}(0.9)	1.9^{a}(1.1)
Boiled nut flavour	0.8^{a}(0.8)	3.2^{c}(1.0)	4.6^{e}(0.8)	2.3^{b}(0.8)	3.9^{d}(1.2)	1.7^{b}(1.0)
Roasted nut flavour	0.7^{a}(0.8)	1.7^{b}(1.1)	0.8^{a}(0.7)	5.1^{c}(0.8)	1.1^{a}(0.9)	5.1^{c}(1.1)
Buttery/creamy flavour	1.0^{a}(0.9)	3.8^{c}(1.2)	3.2^{bc}(1.6)	3.5^{bc}(1.5)	3.1^{b}(1.2)	3.0^{b}(1.2)
Salty	0.6^{a}(0.7)	2.5^{c}(1.7)	0.8^{ab}(0.7)	1.1^{b}(0.8)	0.8^{ab}(0.7)	1.1^{ab}(0.9)
Bitter	0.8^{a}(0.7)	0.8^{a}(0.6)	1.0^{ab}(0.7)	0.9^{a}(0.7)	1.2^{bc}(0.8)	1.3^{c}(0.8)

^{abcde} = mean values within a row with different letters differ significantly (p<0.05), SD = Standard deviation given in parentheses, SOGP = Sorghum porridge, TBTP = Tsabotlhe (Sorghum-soya porridge) commercial product from Botswana, FUMSP = Full fat unheated marama -sorghum porridge, FHMSP = Full fat heated marama- sorghum porridge, DUMSP= Defatted unheated marama –sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge, for scaling refer to Table 3.1.2

TBTP was perceived as salty. Bitterness was perceived in DUMSP and DHMSP. These are porridges which were composited with defatted marama flours.

Composite porridges had lower viscosity (Table 3.1.5) than the sorghum porridge. TBTP had the lowest viscosity scores. A sweeter aromatic nutty after taste was perceived in marama-sorghum composite porridges than in sorghum porridge.

FHMSP and FUMSP (porridges composited with full fat flour) and TBTP were coarser than other porridges.

Table 3.1.5 Effect of dry heating marama bean, defatting and compositing the resultant flour with sorghum flour on texture/mouth feel and after taste attributes of marama-sorghum porridges

Attributes	SOG	TBTP	FUMSP	FHMSP	DUMSP	DHMSP
Porridge viscosity	6.0 ^{c}(1.0)	3.3 ^{a}(0.7)	4.3 ^{b}(0.8)	4.4^{b}(0.7)	4.1 ^{b}(1.2)	3.9^{b}(0.9)
Coarseness	2.6 ^{a}(0.9)	3.9^{b}(1.3)	5.3 ^{c}(0.7)	4.2^{b}(0.8)	2.5 ^{a}(0.9)	2.2^{a}(1.0)
Oily mouth feel	0.9 ^{a}(0.8)	2.9^{bc}(1.0)	3.5 ^{c}(1.3)	3.5^{c}(1.6)	2.6 ^{b}(0.9)	3.0^{bc}(1.3)
Sorghum flavour after taste	4.5 ^{c}(1.2)	3.0 ^{b}(1.5)	2.4^{ab}(1.3)	2.4^{a}(1.8)	2.5^{ab}(1.2)	2.3 ^{a}(1.2)
Sweet aromatic nutty after taste	0.9 ^{a}(0.8)	2.8^{bc}(1.0)	3.9 ^{d}(1.1)	3.7^{d}(1.0)	2.7 ^{b}(1.0)	3.3^{cd}(1.3)
Sour after taste	0.7 ^{a}(0.7)	0.7 ^{a}(0.7)	0.7 ^{a}(0.8)	0.7^{a}(0.7)	0.7 ^{a}(0.7)	0.7^{a}(0.7)
Bitter after taste	0.8 ^{a}(0.7)	0.8 ^{a}(0.6)	0.8 ^{a}(0.7)	0.9^{a}(0.9)	1.0^{ab}(0.8)	1.2 ^{b}(0.9)

^{abcde} = mean values within a row with different letters differ significantly (p<0.05), SD = Standard deviation given in parentheses, SOGP = Sorghum porridge, TBTP = Tsabotlhe (Sorghum-soya porridge) commercial product from Botswana, FUMSP = Full fat unheated marama -sorghum porridge, FHMSP = Full fat heated marama- sorghum porridge, DUMSP= Defatted unheated marama –sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge, for scaling refer to Table 3.1.2

Principal Component Analysis (PCA) was used to summarise the variation in the descriptive sensory attributes of the porridges. Figure 3.1.1(A) shows the projection of scores of the porridges and Figure 3.1.1(B) illustrates loading projections of the sensory attributes. The first two principal components described 76% of the total variation in sensory attributes of the porridges.

The first principal component (PCA 1) explained 52 % of the total variation. Sorghum porridge on the right side of the plot was differentiated from marama-sorghum and soya-sorghum composite porridges. Cooked sorghum aroma, flavour and after taste were strongly perceived in sorghum porridge and furthermore the sorghum porridge was more viscous than the composite porridges. Porridges on the left side of the plot included full fat and defatted marama-sorghum porridges from dry heated and unheated marama beans which were characterised by the attributes roasted nut and boiled nut aroma and flavour, buttery/creamy flavour, oily mouth feel and sweet nutty aromatic aftertaste.

The second principal component (PCA 2) added 24 % to the explanation of variation and separated DHMSP and FHMSP with more roasted nut aroma and flavour, overall aroma and flavour strength on the top of the plot from DUMSP and FUMSP which were characterised by the attributes boiled nut aroma and flavour. The score for the standard soya-sorghum porridge (TBTP) on PCA 1 and PCA 2 were close to zero indicating that these 2 PC’s did not adequately differentiate this porridge from the others.

The third principal component (Figure 3.1.2 C and D) explained an additional 13 % (making the total of 89 %) of the variation and differentiated marama-sorghum porridges composited with defatted flour which were slightly bitter compared to others. The third principal component showed that TBTP was more salty compared to other porridges

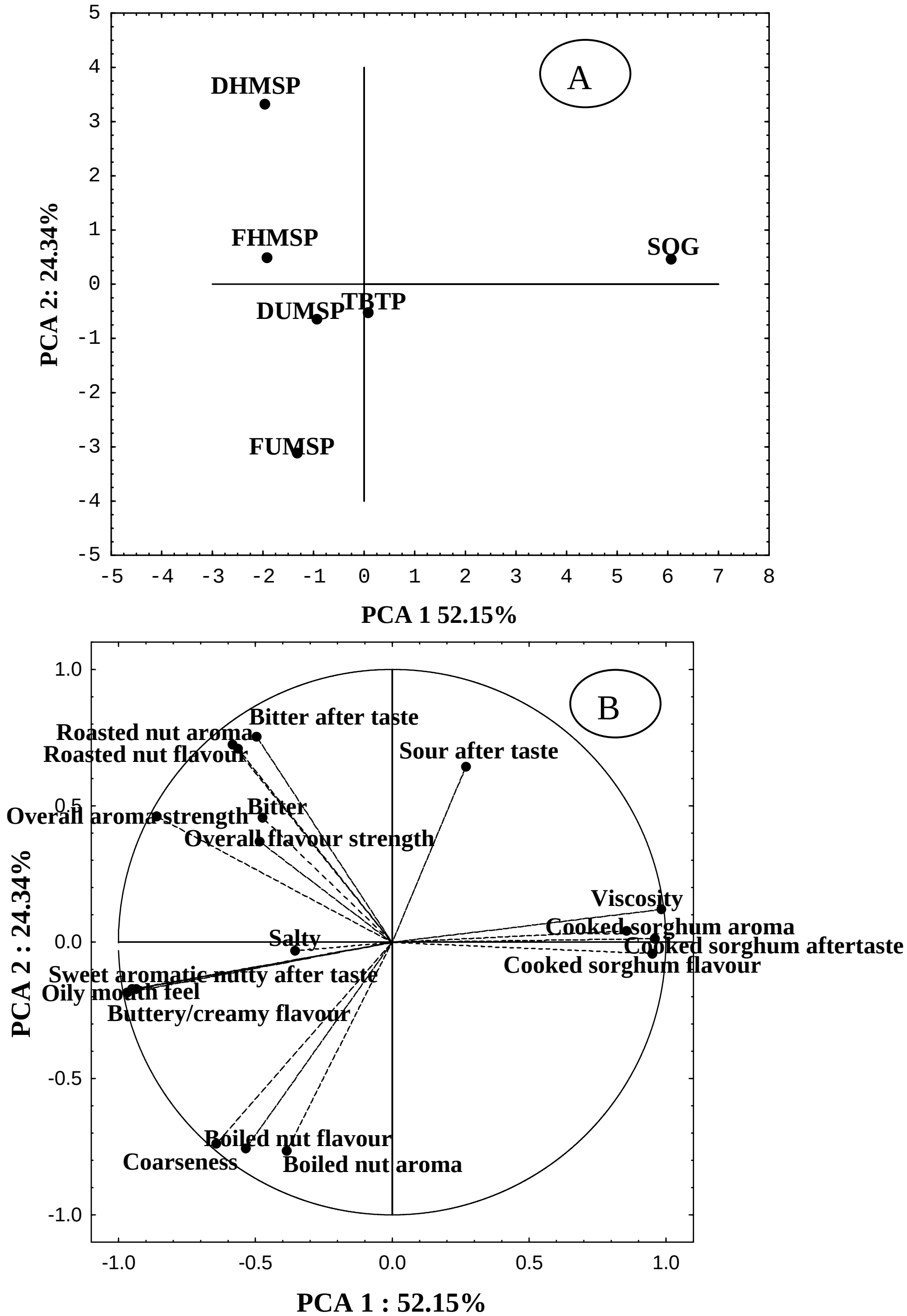

Fig 3.1.1: Principal Component Analysis of the porridges (A) Plot of the first two principal component scores of the porridges (B) Plot of the first two principal component loading projections of the sensory attributes SOG = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, DUMSP= Defatted unheated marama –sorghum porridge, TBTP = Tsabotlhe (Sorghum-soya porridge) commercial product from Botswana, FHMSP = Full fat heated marama-sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge

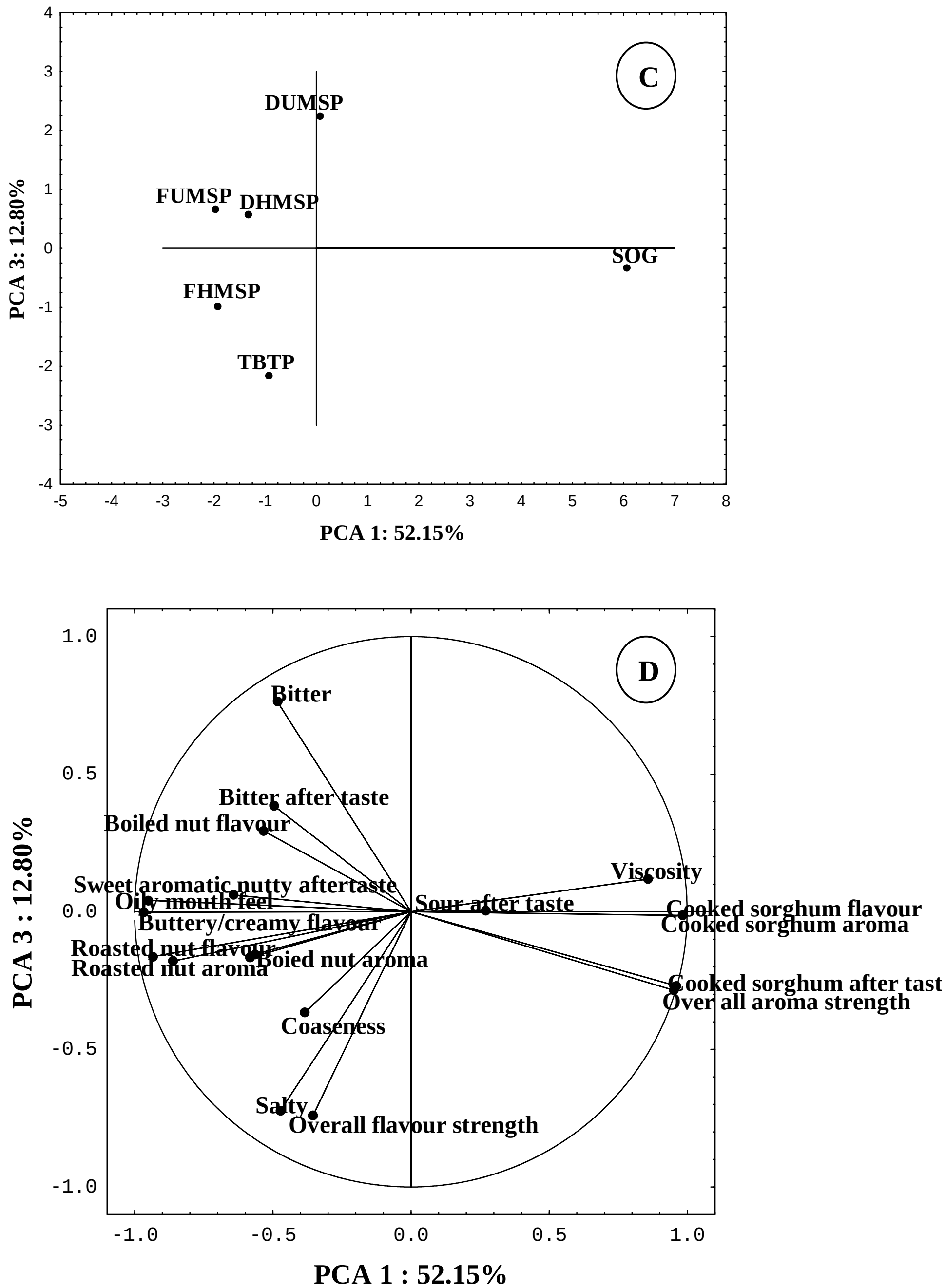

Fig 3.1.2: Principal Component Analysis of the porridges (C) Plot of the first and third principal component scores of the porridges (D) Plot of the first and third principal component loading projections of the sensory attributes SOG = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, DUMSP= Defatted unheated marama –sorghum porridge, TBTP = Tsabotlhe (Sorghum-soya porridge) commercial product from Botswana, FHMSP = Full fat heated marama- sorghum porridge, DHMSP = Defatted heated marama –sorghum porridges

3.1.3.3. Textural properties

Composited marama–sorghum porridges were softer than sorghum porridge. Figure 3.1.3 shows that heating marama beans, defatting the flour prior to compositing and preparing composite porridges did not have much effect on firmness of the porridges. There was no big difference in the stickiness of the porridges but sorghum porridge was slightly stickier than the composite porridges.

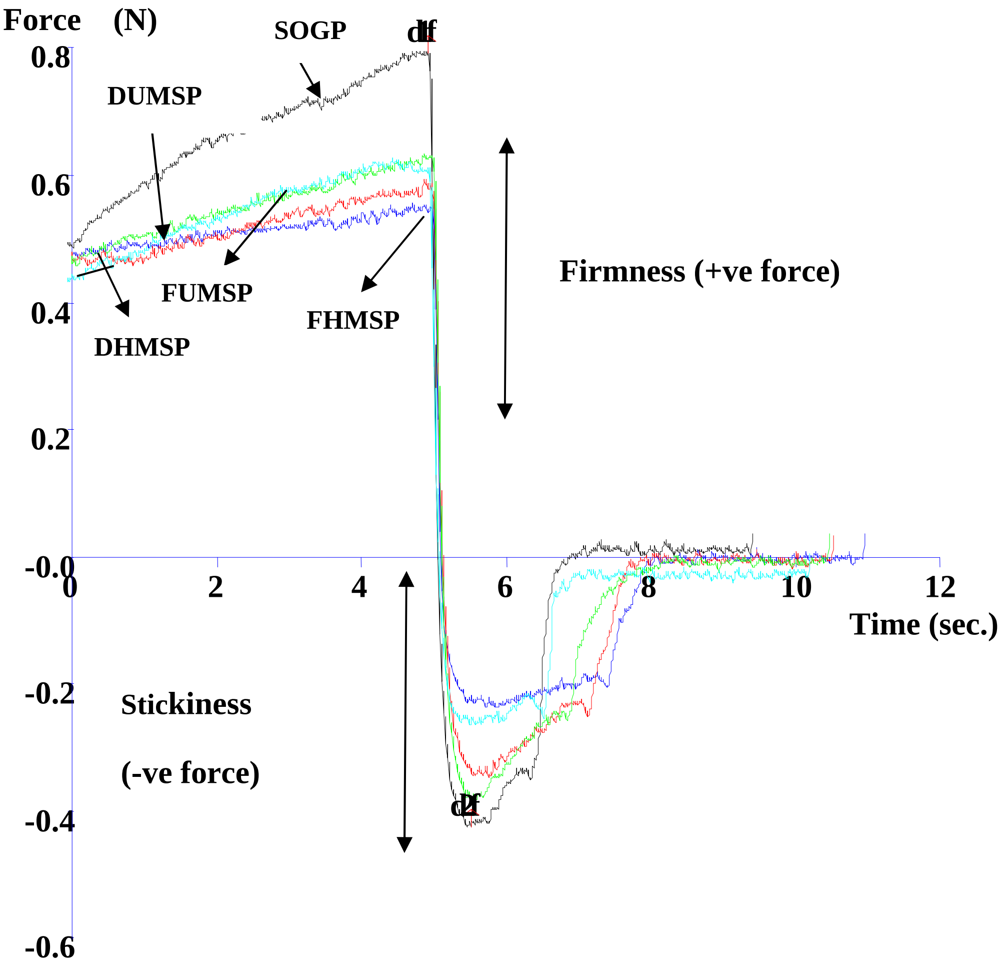

Figure 3.1.3: Firmness and stickiness of marama- sorghum composite and sorghum porridges

Porridge firmness: Defined as the maximum force (N) obtained as the probe penetrated the porridge, Porridge stickiness: Defined as the maximum force (N) recorded as the probe withdrew from the porridge SOGP = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, DUMSP = Defatted unheated marama –sorghum porridge, FHMSP = Full fat heated marama- sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge

3.1.3.4. Colour

DUMSP and FUMSP were significantly lighter (as indicated by L values) than DHMSP and FHMSP that are from heated marama beans, but generally all marama composite porridges were lighter than the sorghum porridge. Table 3.1.6 shows that FHMSP and DHMSP which were relatively darker, also had higher b values than DUMSP and FUMSP.

Table 3.1.6 Effect of dry heating of marama beans, defatting and compositing the resultant flour with sorghum meal on the colour of the porridges (L*, a*, b* values)

Type of porridge	L*	a*	b *
SOGP	58.8^{a} (0.5)	2.8^{a} (0.3)	5.1^{a}(0.2)
FHMSP	62.1^{b}(0.4)	4.5^{c} (0.4)	12.5^{d} (0.5)
FUMSP	67.4^{d}(0.7)	2.9^{a} (0.2)	8.4^{c} (0.5)
DHMSP	63.2^{c}(0.4)	3.9^{b} (0.1)	13.0^{d} (0.2)
DUMSP	68.5^{e}(0.8)	2.2^{a} (0.2)	7.1^{b} (0.4)

L* = Lightness (0=black, 100=white), +a* = red -a* = green,

+b* = yellow, -b* = blue,

^{abc} = mean values within a column with different letters differ significantly (P<0.05), SD = Standard deviation given in parentheses RVU= Rapid visco units, SOGP = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, FHMSP = Full fat heated marama- sorghum porridge, DUMSP = Defatted unheated marama –sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge

3.1.3.5. Consumer acceptability

Mean ratings illustrating the effects of dry heating marama bean, defatting and compositing the resultant flour with sorghum flour on overall consumer acceptability of the sorghum-marama porridges are presented in (Figure 3.1.4). The comments on why the consumers liked some porridges more than others are listed in Appendix A. The distribution along the bar line on the graph explained the agreement among consumers, the shorter the score distribution the more the agreement. Sorghum porridge (100%) scored higher (6.6) and was accepted similarly as porridges composited with full fat flour from heated marama beans (FHSMP) that scored (5.8).

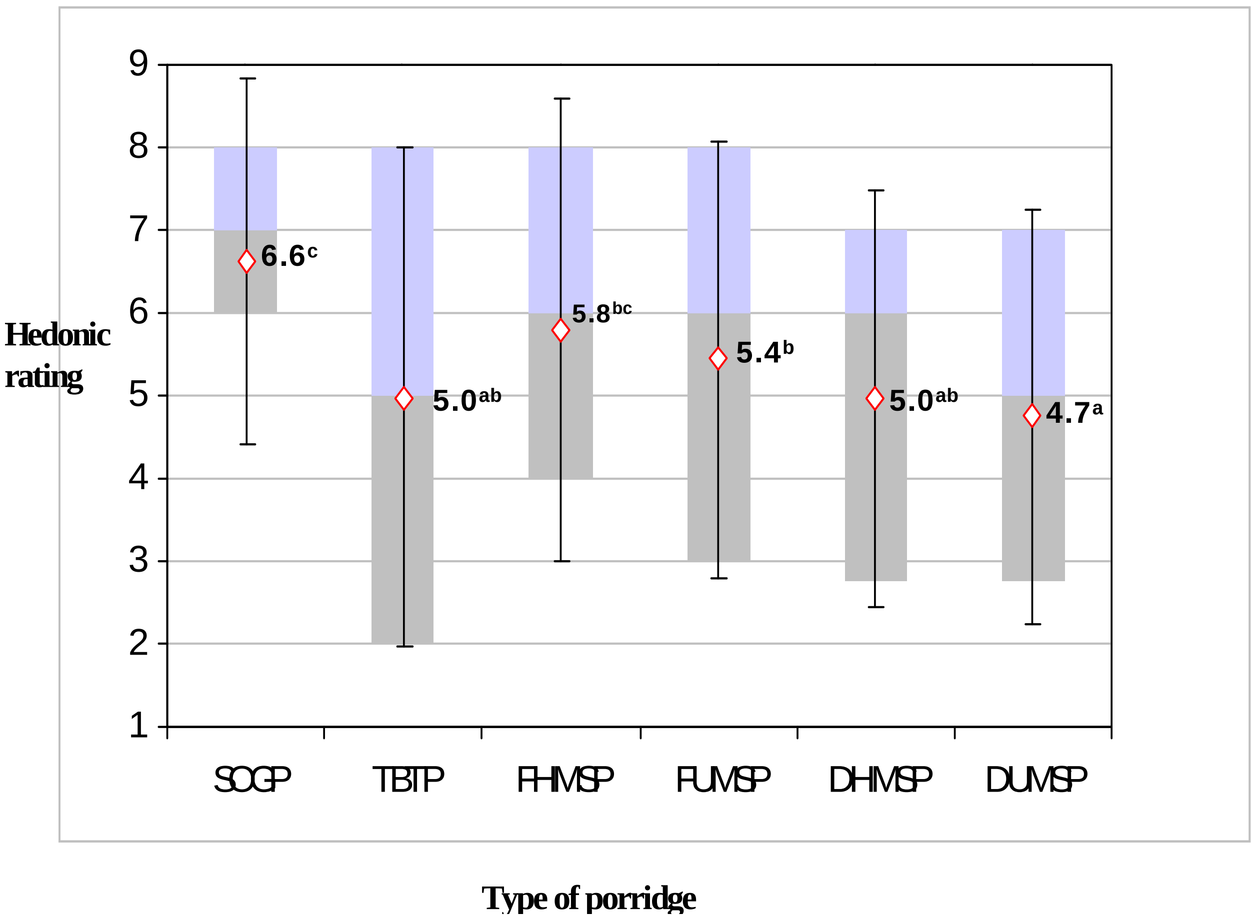

Figure 3.1.4 Consumer acceptability of marama-sorghum porridges, sorghum porridges and Tsabotlhe porridge

[abc] =, mean values with different letters differ significantly ($P<0.05$), SOGP = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, DUMSP = Defatted unheated marama –sorghum porridge, TBTP = Tsabotlhe (Sorghum-soya porridge) commercial product from Botswana, FHMSP = Full fat heated marama- sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge. The lighter shaded area is the higher percentile and the bottom represents the value above which 75% of the ratings fell, the darker shaded area is the lower percentile and the top represents the value above which 25% of the rating fell. The median is the border between the two shaded areas. On the scale 1= Dislike extremely, 5= neither like nor dislike and 9= like extremely.

3.1.4. DISCUSSION

Results from descriptive sensory analysis and instrumental analyses (pasting profiles, texture analysis and colour measurements) show that consumer acceptability of the porridges was much dependent on the sensory attributes of the porridges in terms of flavour, aroma, colour and texture. Sorghum porridge and marama-sorghum porridge composited with full fat flour made from heated beans (FHMSP) were the most acceptable. This may be because the sensory properties of sorghum porridge were more familiar to the consumers as it is at present the product consumed mostly. FHMSP was probably more acceptable because of its rich, buttery, creamy flavours. Fat is a carrier of many flavour compounds and contributes its own natural richness and creaminess (Ohmes *et al.*, 1998). Roasted nut aroma and flavour and sweet aromatic nutty after taste characterised FHMSP and DHMSP porridges from heated beans. This is attributed to desirable flavour development due to Maillard reaction products such as pyrazines produced during dry heating (Sacchetti *et al.*, 2004).

Bitter taste and after taste were present although at low levels in DUMSP and DHMSP. These are porridges composited with defatted flours. Decrease in fat content induces an increase in flavour release of the high-molecular weight compounds (Guichard, 2002). Removal of fat probably unmasked the bitter taste perceived in these porridges. Bitterness might also be associated with the presence of phenolic compounds that causes bitterness in legumes as reported by Drewnowski and Gomez-Carneros (2000). Bitterness was more prominent in porridge from heated sample. Bitterness due to excessive heat treatment in marama beans was reported by Mmonatau, (2005). Bitterness may also relate to off-flavour compounds from Maillard reactions such as furan and caramel compounds (Bemiller and Whistler, 1996).

Darker colour development was observed in FHMSP and DHMSP porridges from heated beans and was confirmed by use of a colour meter. This may be due to non-enzymatic browning from Maillard-type reaction products developed during heating (Martins *et al*., 2001). A dark colour development in marama flour from heated beans was reported by Maruatona (2008). FUMSP and DUMSP porridges from unheated beans were lighter.

The lighter colour in the marama-sorghum composite porridges from unheated beans was appreciated by most of the consumers in their comments as an improvement to the normal brownish colour of sorghum porridge. Light coloured sorghum porridges from white sorghum are usually preferred by consumers (Aboubacar *et al.*, 1999).

Marama-sorghum composite porridges and TBTP were less viscous compared to sorghum porridge. A reduction in viscosity of composite porridges was identified by the descriptive sensory panel and confirmed by pasting profile measurement. Similar reduction in hot peak viscosity of sorghum porridge when composited with peanut flour was reported by Singh and Singh (1991). Texture measurements showed that sorghum porridge was firmer than the composite porridges. Starch greatly contributes to the textural properties of sorghum porridge. Marama flour has no starch (Van Zyl, 2007); therefore introduction of marama flour decreases the starch levels in composite porridges. This may explain the reduction in viscosity and firmness of porridges. Furthermore high pasting temperatures and low paste viscosities have been reported in composite porridges with high lipid content. Starch molecules form helical inclusion lipid-amylose complexes (Morrison and Boyd, 1983; Mishra and Rai, 2006). As a result composite porridge become less firm (Fliedel, 1995). Firmness of sorghum porridge may have contributed to its acceptability. Most consumers that participated in the consumer acceptability test recommended sorghum porridge for its firmness. Porridges composited with full fat marama flour were coarser than other porridges. Marama has high fat content and milling the beans resulted in a paste-like meal making it difficult to attain flour with homogeneous particles.

Cereal based porridges are the first solid foods to be introduced in a child's diet in most developing countries. Their energy density is often low due to large volumes of water added during preparation to achieve a thin, drinkable consistency for infants (Stephenson *et al.*, 1994). It has been reported that the higher viscosity porridges constrains the amount that can be consumed by infants (Stephenson *et al.*, 1994). Compositing sorghum meal with marama flour would be recommended to obtain high energy density and less viscous porridges. Thus could be suitable for children in places where both marama and sorghum grows.

3.1.5. CONCLUSIONS

The sensory attributes of sorghum porridges composited with marama flour are clearly different from traditional sorghum porridge. Sensory properties of the porridges affect their acceptability. Porridges composited with marama flour from heated beans have roasted nut aroma and flavour. Composite porridges are less viscous compared to sorghum porridge. Sorghum and FHMSP porridges are more acceptable. This is because sorghum porridge is familiar to the consumers. FHMSP has rich, buttery and creamy flavours contributed by fat and sweet aromatic nut flavours due to dry heating. Compositing sorghum meal with full fat marama bean flour has potential to provide acceptable sensory appeal and could improve the nutritional status of persons using sorghum as a staple.

3.2. Effects of dry heating marama beans, defatting and compositing the resultant flour with sorghum meal on the nutritional quality and antioxidant activity of sorghum-marama porridges

ABSTRACT

Marama beans are a good source of protein, fat and phenolic compounds known to have potential health benefits. Full fat and defatted flours from unheated and dry heated marama beans (150 °C /20 min) were composited with condensed tannin-free sorghum meal (30:70). Marama flours, sorghum meal, marama-sorghum composite flours and porridges were analysed for proximate composition, amino acid composition, energy value, fatty acid composition, total phenolic content and antioxidant activity. Compositing sorghum meal with marama flours significantly increased protein and fat contents in flours and porridges. Energy values of marama-sorghum composite porridges were 11-24% higher than sorghum porridge. Lysine content was 3 to 4 times higher in marama-sorghum porridges than in sorghum porridge. Unsaturated fatty acids were approximately 3 times higher than saturated fatty acids in both marama-sorghum composite porridges and sorghum porridge. There was an increase in oleic acid as marama flour was composited with sorghum. Marama flours had significantly higher levels of total phenolics (3.0 - 5.7 mg CE/100 mg) than sorghum meal (0.7 mg CE/100 mg). There was a positive correlation between the total phenolic content and antioxidant activity ($r = 0.80$, $p < 0.05$) in all samples. Use of marama flour in sorghum composite flours and porridges improved nutritional quality and antioxidant activity.

3.2.1. INTRODUCTION

Marama bean *Tylosema esculentum* (Burch) A. Schreib is a wild underutilised legume in southern Africa and is used as a food source by the rural communities of the Kalahari desert) (Amarteifio and Moholo, 1998). Marama bean is a good source of protein (34%) and fat (33.5%) (Amarteifio and Moholo, 1998). It can potentially be used to enhance the nutritional quality of cereal products such as sorghum.

Sorghum bicolor (L.) Moench is a major staple food in many African countries where agricultural and environmental conditions are unfavourable for the production of other crops (Rooney and Serna-Saldivar, 1990). However sorghum, like other cereals, has low protein content, and is deficient in the essential amino acid lysine. Compositing sorghum with marama flour may contribute to better amino acid balance, increased protein content and energy value and could help alleviate protein energy malnutrition in developing countries.

Other marama bean constituents such as phenolic compounds are believed to have antioxidant properties. Reports indicate that diets rich in phenolic compounds may play a role in the prevention of various diseases associated with oxidative stress such as cancer, cardiovascular and neurodegenerative diseases (Anderson and Wolf, 1995; Nandutu, Clifford and Howell, 2007). Marama bean cotyledon is reported to have 2.8 mg CE/100g total phenolic content (Van Zyl, 2004). Phenolic content and antioxidant activity of sorghum-marama composite flours and their porridges have not been investigated.

Production of marama flours involves processes such as dry heating the beans (roasting), oil extraction and milling (Maruatona, 2008). These processes can affect the nutritional quality of the resultant flour. This will in turn affect the nutritional value of composite flours and porridges if marama flour is used in composite foods. Such processing can also affect phenolic content and antioxidant activity. This study aims at evaluating the potential of marama bean flour in improving the nutritional quality of sorghum porridge, and also the effect on phenolic content and antioxidant activity.

3.2.2. MATERIALS AND METHODS

3.2.2.1. Preparation of full fat and defatted marama bean flour from heated marama beans

Marama beans were dry heated using a forced convection continuous tumble roaster (Roastech, Bloemfontein, South Africa). The continuous tumble roaster has four main components, namely the control system, seed hopper, drum (perforated cylinder and screw conveyer) and a holding unit. A speed set of 290 was selected because it resulted in a heating time of 20 min (first bean) to 23 min (last bean) at 150°C (Maruatona, 2008). A DF sample cracker (WMC Metal Sheet Works, Tzaneen, South Africa) was used to dehull marama beans (dry heated and unheated) prior to milling. Marama beans were coarse ground and oil was extracted using hexane (1 part ground four to 3 parts hexane) for 2 h. The hexane was decanted off, and the procedure was repeated 3 times. After oil extraction the flour was left in a fume cupboard for 24 h and milled again to pass through a 1000 µm mesh. Four marama flour samples were obtained and were denoted full fat flour from heated marama beans (FH), full fat flour from unheated marama beans (FUH), defatted flour from heated marama beans (DH) and defatted flour from unheated marama beans (DUH). Marama flours were vacuum packed and stored at 4°C.

3.2.2.2. Preparation of marama-sorghum composite flours and porridges

Commercial sorghum meal (Monati super Mabele, Nola foods Randfontein, South Africa) was purchased at a supermarket in Pretoria, South Africa, and blended with marama flours (70 parts sorghum meal to 30 parts marama flour) to make composite flours (Figure 3.2.1). These were vacuum packed and stored at 4°C until used to prepare porridges. A typical Botswana porridge-making process was used for the preparation of soft sorghum porridges (Kebakile *et al*, 2008). The cooking process entailed first mixing 200 ml of cold water with the flour (80 g) to make a slurry. Then the slurry was gradually added, while stirring to avoid lump formation, to 600 ml of boiling water in a small (2 l) stainless steel saucepan. The porridge was simmered at low heat (on hot plate) for 20-30 min, stirring every 5 min. Once ready, the porridges were freeze dried, vacuum packed and stored in the cold room until analysed.

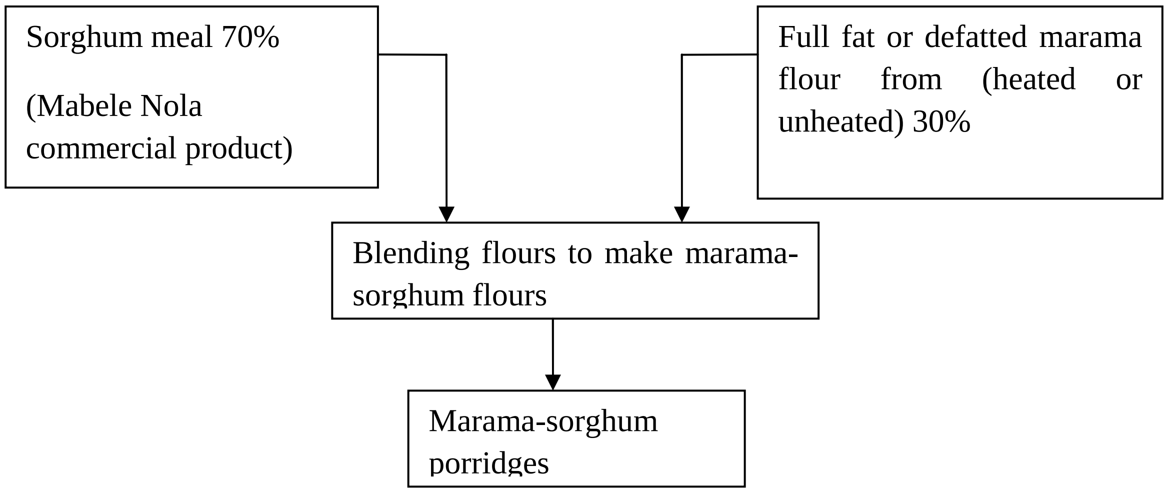

Figure 3.2.1 Preparation of marama-sorghum composite flours

3.2.2.3. Proximate analysis of flours and porridges

Moisture

Moisture was determined using the AACC Method 44 – 15A (American Association of Cereal Chemists – AACC, 1999). Moisture tins were dried in a forced draught oven at 103°C for 1 h. The tins were then cooled in a dessicator for about 10 min. The tins were weighed and 2 g of milled sample weighed into the tins and dried in a forced draught oven for 4 h at 103°C. The samples were cooled for 10 min and weighed. The moisture content (%) was calculated as follows:

$$\% \text{ moisture} = \frac{[(\text{mass food} + \text{tin}) - (\text{mass tin})] - [(\text{mass dry food} + \text{tin}) - (\text{mass tin})]}{[(\text{mass food} + \text{tin}) - \text{mass tin}} \times 100$$

Crude protein

Crude protein was determined using the thermal combustion (Dumas) method with the Leco FP – 528 Protein/Nitrogen Analyzer (Leco Corporation, USA). This procedure is a three-phase analysis where the nitrogen in the protein is released through chemical decomposition by heat (combustion). The phases are as follows:

- *Sample drop purge phase*: The encapsulated samples are placed in the loading head, sealed and purged of any atmospheric gases that have entered during sample loading. The ballast volume and gas lines are also purged.
- *Burn phase*: The sample is combusted at 850 °C in a stream of oxygen.
- *Analyse phase*: Nitrogen containing compounds are converted to nitrogen which is oxidized to oxides of nitrogen; water produced is condensed and removed. Oxides of nitrogen are carried by helium gas to a thermal conductivity detector and reduced to nitrogen for estimation. The carbon dioxide and sulphur dioxide formed are removed by selective absorption.

The nitrogen content was converted to % protein by using a protein conversion factor of 6.25.

Crude fat

Crude fat was determined by extraction of 3 g of the sample with 40 ml petroleum ether (boiling point 40-60°C) for 4 h according to AACC method 30-25 (1983) using a Soxhlet test apparatus. The ether was then removed from the collection flask at low temperature volatilization before oven drying. The residue fat were dried in an oven at 100 °C for 30 min. Percent fat was calculated using the following formula

$$\% \text{ Fat} = \frac{[(\text{mass of beaker} + \text{mass of extracted fat}) - (\text{mass of beaker})]}{\text{Mass of sample}} \times 100$$

Ash

AACC method 08 – 01 (1999) was used to determine the ash content. Ash is the material remaining after oxidative combustion of all the organic matter in food. “Ash” is therefore a measure of the food’s mineral content. Silica crucibles were dried for 5 h in a muffle furnace oven, allowed to cool in the muffle furnace oven, and then transferred to a dessicator using metal tongs. The crucibles were weighed to the nearest 0.1 mg using an analytical balance. Approximately 2 g of the finely milled sample was transferred into the crucible and spread as a thin layer. The crucibles containing the sample were then re-weighed. The crucibles were placed on a tripod and gauze and heated until the samples were charred. The samples were then placed in the muffle oven and heated at 550 °C for

5 h. The ash samples were cooled in a dessicator and weighed soon after room temperature was attained. Percentage ash was calculated as follows:

$$\% \text{ Ash} = \frac{(\text{mass ash + crucible}) - (\text{mass crucible})}{(\text{Mass food + crucible}) - (\text{mass crucible})} \times 100$$

Carbohydrate content

Total carbohydrate was calculated by difference.

% Carbohydrate = 100 – (% Moisture + % Ash + % Crude fat + % Crude protein)

3.2.2.4. Determination of amino acid composition of flours and porridges

Sample preparation

Two to three milligrams of each sample were weighed and analysed in a tared glass ampoule. After 1.0 ml of 6 N HCl was added, samples were centrifuged at 15000 rpm for 5 min and then dried under vacuum for 1.5 to 2 h. The pH of the samples was adjusted by adding 20 µl solution of ethanol: water: triethylamine in the ratio of 2:2:1 and then dried for a further 1.5 to 2 h. The resulting sample was derivatised by adding 20 µl derivatising solution of ethanol: water: triethylamine: phenylisothiocyanate in the ratio of 7:1:1:1. The mixture was allowed to react at room temperature for 10 min prior to drying under vacuum (minimum of 3 h).

HPLC conditions

Analysis of the amino acids was performed with a Waters C18 column (3.9 x 150 mm). The gradient solution was the same as that described by Bidlingmeyer, Cohen, and Tarvin (1984). The solvents utilized were the sodium acetate buffer (A) and acetonitrile (B) (300 mL ACN, 200 ml water, 0.2 ml CaEDTA). The columns used were application-specified Pico-Tag columns. The sample was resuspended in 200 µl of Picotag sample diluent and an 8 µl sub-sample was then injected for separation by HPLC (2X Model 510 pumps, Model 440 Absorbance detector, 717 plus Autosampler (Waters Corporation, MA, USA). A gradient which runs for the separation consisted of 10% A traversing to 51% B in 10 min using a convex curve. The amino acid composition was expressed as g/100 g sample on a dry basis.

3.2.2.5. Determination of fatty acid composition of porridges

The fatty acid composition was determined using a modification of the methods described by Alonso *et al*. (2004) and Genet *et al*. (2004). Ten millilitres phosphate buffered saline was added to 1.0 g of the sample in a 30 mL test tube and 1000 µl internal standard (1 mg/ml Pentadecanoic acid in methanol). The sample was homogenised in a mechanical homogeniser at low speed for ± 30 s and then at maximum speed for ± 30 s or until the sample was fully homogenised. It was then centrifuged for 15 min in a bench top centrifuge at maximum speed. Five millilitres of the supernatant was aspirated into a clean, labelled 10 ml test tube, 2 ml chloroform and 1 ml 0.1N HCL were added, mixed and the phase allowed to separate. Chloroform (lower layer) was transferred into a clean, labelled 10 ml tube and closed with a Teflon lined screw cap. The extraction was repeated with 2 ml aliquot chloroform and combined with the previous chloroform extract. The chloroform was evaporated to dryness under a gentle stream of nitrogen. Methanolic KOH (1 ml of 1N) was added to the extract, closed and heated at 60ºC for 20 min. It was allowed to cool, then 1 ml BF_3 in methanol was added, closed and heated at 60ºC for 30 min. After cooling 1 ml saturated NaCl in water and 1 ml hexane were added and mixed by vortex. The phases were allowed to separate and the hexane (upper) layer was aspirated into a clean, labelled 1 ml autosampler vial containing 100 mg (1 mm layer) anhydrous Na_2SO_4. This was allowed to stand for 10-15 min and kept in the freezer until analysed. Samples were analysed using a Varian 3300 Gas Chromatograph, with an FID detector. A Varian column WCOT fused silica coating (CP-Sil 88, 100 m x 0.25 mm DF 0.2 µm) column was used (Scientific Supply Services Johannesburg, South Africa). Initial column temperature and column hold time was 140°C and 5 min respectively. Final column temperature was 240°C and holding time was 25 min. The injector temperature and detector temperature was 250°C. Fatty acid methyl esters (FAMES) were identified by comparing the retention times to those of the standard Fame mixture. The results were expressed as mol % fatty acid (as is basis).

3.2.2.6. Determination of the gross energy of porridges

Gross energy was determined using the water bomb calorimeter (MC-1000). The sample analysed was placed in a clean metal crucible and weighed to be approximately 0.5 g. The bomb was prepared by making sure that the water tap connected to the bomb and oxygen bottle were opened, thereafter the bomb and computer were switched on before placing a sample inside the bomb and the fuse wire between the two electrodes of the bomb cap was strung to make sure that the wire is not loose. The metal crucible was placed on the o-ring of the cap, a wool string was attached to the wire between the electrodes and the other points inserted in the crucible and covered with the sample. The wool string helped in the ignition of the sample. The bomb cap together with the sample in the metal crucible was then placed in the bomb. The lid of the bomb was closed and the red light was on. Before ignition of the samples the bomb goes through different stages that is testing temperature, pre-period 1 and 2, bomb fired, main period, cooling and washing the bomb. Thereafter it ran for 5 min to ignite the sample and results were shown on a computer screen. The results were expressed in kJ/100 g of porridge (dry basis).

3.2.2.7. Total phenolic content and antioxidant activity determination of flours and porridges

Sample preparation

Acidified methanol (1% HCl in methanol) was used as the extracting solvent for determination of total phenolic content and antioxidant activity of the flours and porridges. Duplicate samples were extracted with 30 ml solvent in three phases as follows: 10 ml solvent was added to 0.3 g of the sample in a conical flask and completely covered with aluminium foil and stirred for 2 h, transferred to 40 ml plastic centrifuge tubes, centrifuged at 3500 rpm for 10 min (25ºC) using a Rotanta 460 R centrifuge (Labotech T., Johannesburg, South Africa) and decanted, keeping the supernatant. The sample residue was rinsed again with 10 ml of the solvent, stirred for 20 min, centrifuged again as above and decanted, keeping the supernatant. This step was repeated as in the second time and the supernatants were combined and stored in a glass bottle covered with aluminium foil and kept in a cold room until analysed.

Determination of total phenolic content

The total phenolic content of the flours and porridges extracts was determined using the Folin-Ciocalteu method (Singleton & Ross, 1965) as described by Waterman & Mole (1994). The Folin-Ciocalteu method quantifies the total concentration of phenolic hydroxyl groups present in the sample being assayed (Waterman & Mole, 1994). The reagent reacts with phenols to form chromogens that can be detected spectrophotometrically. The blue color development is due to the reduction-oxidation reaction in which the phenolate ion is oxidized at basic pH, while reducing the phosphomolybdic/phosphotungstic acid complexes in the reagent to form chromogens (Waterman & Mole, 1994). The methanolic phenolic extract (0.5 ml) was added to a 50 mL volumetric flask containing 10 mL distilled water. Folin-Ciocalteu's phenol reagent (2.5 ml) was added and mixed. After 2 min, 7.5 ml sodium carbonate (Na_2CO_3) solution (20 g/ 100 ml) was added and the content was mixed and made up to volume with deionised water. The volumetric flask was then stoppered and mixed thoroughly by inverting several times and allowed to stand for 2 h from the addition of sodium carbonate. The absorbance was measured at 760 nm using a Lambda EZ150 spectrophotometer (Perkin Elmer, USA) and the estimation of total phenolics in the extracts was carried out in duplicate for all the samples. Catechin was used as a standard and the results were expressed as catechin equivalents (CE, mg catechin equivalents/100 mg sample) on dry matter basis

Determination of antioxidant activity

The free radical scavenging activity of the methanolic extracts of the flours and porridges was determined using the Trolox Equivalent antioxidant capacity (TEAC) assay ($ABTS^{\cdot+}$ free radical scavenging) as described by Awika, Rooney, Wu, Prior and Cisneros-Zevallos (2003) with modifications. This spectrophotometric technique measures the relative ability of hydrogen-donating antioxidants to scavenge the 2, 2'-azinobis (3-ethyl-benzothaizoline-6-sulfonic acid) radical cation chromogen ($ABTS^{\cdot+}$) in comparison with the antioxidant potency of Trolox, the water soluble vitamin E analogue and this gives the TEAC value of the antioxidants (Awika, *et al*., 2003). The ABTS radical cation ($ABTS^{\cdot+}$) was prepared by mixing equal volumes of 8 mM ABTS and 3 mM potassium persulphte ($K_2S_2O_8$) using deionised water. The solution was allowed to react for at least 12-16 h in the dark at room temperature before use. A phosphate buffer solution (pH 7.4) was prepared by mixing 0.2 M Na_2HPO_4 (40.5 ml), 0.2 M $Na_2H_2PO_4$ (9.5 ml) and 0.877g NaCl and filling up to 1000 ml with deionised water. $ABTS^{\cdot+}$ solution (2.5 ml) was added to phosphate buffer solution (72.5 ml) to prepare a working solution. The working solution (2.9 ml) was added to methanolic extracts (0.1 ml) or Trolox standard (0.1 ml) in a test tube and mixed. The test tubes were allowed to stand for 30 min. The absorbance of the standards and samples was measured at 734 nm using a Lambda EZ150 spectrophotometer (Perkin Elmer, USA). The results were expressed as µM Trolox equivalent/100 mg sample, on dry matter basis.

3.2.2.8. Statistical analyses

The analyses were performed in triplicate. Data obtained was analysed by one-way ANOVA. Mean differences were evaluated at the 95% significance level ($p \leq 0.05$) using the least significant difference test. The statistical analyses were performed using Statistica Version 8.0 (Statsoft, Tulsa, USA).

3.2.3. RESULTS AND DISCUSION

3.2.3.1. Proximate composition

Defatted and full fat marama bean flours were higher in protein, fat and ash contents compared to sorghum meal (Table 3.2.1). Defatted marama flours (DH, DUH) were higher in protein and lower in fat content than full fat marama flours (FH, FUH). Oil extraction reduced fat in the flours, and concentrated other constituents, hence the higher protein content in defatted flours. Full fat marama flours had similar protein and fat contents to those reported by Amarteifio and Moholo (1998) and Mmonatau (2005). Defatted flour from dry heated marama beans (DH) had higher protein content and lower fat content than defatted flour from unheated marama beans (DUH). A difference in fat content of defatted marama flour from dry heated beans (1.9 %) compared with defatted flour from unheated beans (7.0%) was also reported by Maruatona (2008). This is explained by the disruption of lipid bodies of the marama beans upon heating allowing the oil to be more readily expelled.

Table 3.2.1 Proximate composition of flours and porridges (g/100g) dry basis

	Protein	Fat	Ash	Carbohydrates
Flours				
SOGF	9.9^{a} (0.2)	3.0^{b} (0.2)	1.4 ^{a} (0.1)	85.7^{l}(0.0)
FUH	34.3^{g} (0.5)	38.1^{j} (0.0)	2.7^{cd} (0.0)	24.8 ^{b}(0.1)
FH	34.6^{g} (0.7)	39.1^{k} (0.0)	2.9^{d} (0.0)	23.3^{a} (0.0)
DUH	50.0^{h} (0.5)	15.3^{i} (0.1)	4.2^{e} (0.1)	30.5^{c} (0.0)
DH	53.2^{i} (1.5)	11.2^{e} (0.0)	4.7^{f} (0.1)	31.2^{d} (0.0)
Composite flours				
FUMSF	17.8 ^{c} (0.5)	14.2^{g} (0.0)	1.8 ^{b}(0.1)	66.2 ^{f} (0.1)
FHMSF	17.9 ^{c} (0.7)	14.6 ^{h} (0.0)	1.9^{b} (0.0)	65.5^{e} (0.2)
DUMSF	22.6 ^{e} (0.5)	6.9^{d} (0.0)	2.3 ^{c} (0.1)	68.2 ^{h} (0.1)
DHMSF	23.8 ^{f} (1.5)	5.6 ^{c} (0.0)	2.4^{c} (0.0)	68.1 ^{h} (0.0)
Composite porridges				
SOGP	11.7 ^{b} (0.1)	1.4^{a}(0.1)	1.5 ^{a} (0.2)	85.4 ^{k} (0.0)
FUMSP	18.8 ^{d} (0.3)	12.5 ^{f} (0.2)	2.0 ^{b} (0.1)	66.8 ^{g} (0.1)
FHMSP	18.8 ^{d} (0.3)	12.7^{f} (0.1)	2.10 ^{b} (0.0)	66.4 ^{ef} (0.0)
DUMSP	22.9 ^{e} (0.2)	2.9 ^{b} (0.2)	2.4 ^{c} (0.2)	71.8 ^{j} (0.1)
DHMSP	22.6 ^{e} (0.17)	2.7 ^{b} (0.1)	2.6 ^{c} (0.1)	72.1 ^{i} (0.0)

^{abcde} = mean values within a column with different letters differ significantly ($p<0.05$), Standard deviations are given in parentheses DUH: Defatted flour from unheated marama beans, DH: Defatted flour from heated marama beans, FH: Full fat flour from heated marama beans and FUH: Full fat flour from unheated marama beans and SOGF: Sorghum meal, FHMSF: Full fat marama-sorghum composite flour from heated marama beans, DHMSF: Defatted marama-sorghum composite flour from heated marama beans, FUMSF: Full fat marama-sorghum composite flour from unheated marama beans, DUMSF: Defatted marama-sorghum composite flour from unheated marama beans, FHMSP: Marama-sorghum porridge composited with full fat flour from heated marama beans, DHMSP: Marama-sorghum porridge composited with defatted flour from heated marama beans, FUMSP: Marama-sorghum porridge composited with full fat flour from unheated marama beans and DUMSP: Marama-sorghum porridge composited with defatted flour from unheated marama beans and SOGP: Sorghum porridge

The relatively lower fat content of DH contributes to concentrating its protein content compared to DUH. Though the fat content of FH (39.1 g/100 g) and FUH (38.1 g/100 g) was statistically different, this may not be of practical significance since the two values are close to each other.

Compositing sorghum meal with marama bean flour nearly doubled protein content of marama-sorghum composite flours (compared with sorghum meal). The fat content in marama-sorghum flours was higher than sorghum meal. Increase in protein (24.5%) and fat (12.9%) contents in maize composite flours when composited with African oil bean flour compared to maize flour has been reported by Enujiugha (2006). Compositing sorghum meal with marama flours significantly increased protein and fat contents in marama-sorghum composite porridges. Protein increases in marama-sorghum composite porridges ranged from 61% in porridges composited with full fat flours (FHMSP and FUMSP) to 96% in porridges composited with defatted flour (DHMSP and DUMSP) compared with sorghum porridge. Fat increases ranged from 92.8% in DHMSP and DUMSP to 807% in FHMSP and FUMSP compared with sorghum porridge. This is because marama flour has high protein and fat content and thus contributes to increased levels of fat and protein in composite porridges. Increase in protein in cereal-legume composite foods has been reported by Solomon (2005).

Protein is an essential macronutrient for growth and maintenance of body tissues and its requirement is highest during the first year of life (FAO/WHO, 1985). Increase in fat content of the porridges is also important because fat increases the energy density of the porridges, provides essential fatty acids and facilitates the absorption of fat-soluble vitamins. In addition fats slow gastric emptying and intestinal motility thus affecting satiety (Mosha and Vicent, 2005). Thus use of marama flour in sorghum composite flours enhances the energy density of the porridges.

Compositing marama bean flour with sorghum meal significantly reduced the carbohydrate content. Marama bean stores energy as fat and has low carbohydrate content. On the other hand sorghum stores energy as carbohydrate, therefore compositing sorghum meal with marama had a diluting effect on the carbohydrate content of sorghum meal.

Marama-sorghum composite flours composited with defatted flour as the legume component had significantly higher protein and lower fat contents than composite flours with full fat flours as the legume component. This is possibly because of the differences in protein and fat contents of defatted and full fat marama flours prior to compositing 30% marama flour with sorghum meal. Heating marama beams prior to defatting and compositing the flour with sorghum meal did not significantly affect the protein and fat contents in composite porridges.

3.2.3.2. Energy value

The energy values of marama-sorghum porridges and sorghum porridge are summarised in Table 3.2.2. The energy values of the porridges were in accordance with the recommendations of FAO/WHO (1985) which specify 1.0 Kcal/g or 4.19 kJ/g for children 2 to 5 years. There was 11-24% increase in energy value in marama-sorghum composite porridges compared to sorghum porridge.

Table 3.2.2 Energy value of sorghum porridge and marama-sorghum composite porridges (kJ/100g) dry basis

Type of porridge	Gross Energy	Percent increase in energy value (%) (compared with SOGP)
SOGP	1724.1^{a} (0.1)	NA
FUMSP	2130.2^{d} (0.7)	23
FHMSP	2134.0^{d} (0.1)	24
DUMSP	1959.4^{c} (0.2)	14
DHMSP	1918.8^{b}(0.4)	11

^{abcd} = mean values within a column with different letters differ significantly (p<0.05), Standard deviations are given in parentheses FHMSP: Marama-sorghum porridge composited with full fat flour from heated marama beans, DHMSP: Marama-sorghum porridge composited with defatted flour from heated marama beans, FUMSP: Marama-sorghum porridge composited with full fat flour from unheated marama beans and DUMSP: Marama-sorghum porridge composited with defatted flour from unheated marama beans and SOGP: Sorghum porridge, NA: Not applicable

Marama-sorghum composite porridges with full fat marama flours were significantly higher in energy values than porridges composited with defatted marama flours. This is possibly because of their high fat content that increased energy density of the porridges. DUMSP however had significantly higher energy value than DHMSP. The difference in their fat content explains the observed differences in their energy values. Formulations of composite food mixtures of cereal, legumes and oil seeds have been proposed as a practical and sustainable approach for improving macronutrient and energy status of weaning foods in developing countries (Mosha and Vincent, 2005).

3.2.3.3. Amino acid composition

Table 3.2.3 shows the amino acid composition of defatted marama bean flour from unheated (DUH) and heated (DH) marama beans compared with sorghum meal (SOGF). Essential and nonessential amino acid contents of the flours were determined except for tryptophan. The total amino acid content was higher in marama bean flours (DUH 47.4% and DH 51.7%) than in SOGF (8.9%). Marama bean flours were higher than sorghum meal in all amino acids except for cysteine. Glutamic acid and tyrosine were the most abundant amino acids in marama bean flours.

Lysine is a major limiting amino acid in sorghum. Lysine content in DUH (2.8%) and DH (2.7%) was significantly higher than SOGF (0.2%). The lysine content in marama bean flours was similar to that reported by Maruatona (2008) in defatted flour from unheated marama bean (3.1%) and defatted flour from heated marama bean (2.8%). Compositing sorghum meal with marama flour would be expected to increase lysine content hence its nutritional quality. Dry heating marama beans prior to flour processing reduced lysine by 3.7% but this may be considered practically insignificant. The reduction of lysine in marama bean flour as a result of dry heating the beans has also been reported by Mmonatau (2005) and Maruatona (2008). This may be attributed to Maillard reactions of the ε-NH_2 of lysine with reducing sugars.

Methionine and cysteine contents were very low both in marama flours and sorghum meal. This is possibly because acid hydrolysis of protein, the method used to determine the amino acid content destroys a large amount of these amino acids (Eka, 1978).

There was a considerable improvement in amino acid profile of sorghum marama composite porridges compared with sorghum porridge (Table 3.2.4). Improvement in amino acid content of sorghum gruels when composited with peanut and SUA-90 bean flours was reported by Mosha and Vicent (2005). Leucine, phenylalanine, isoleucine, valine and tyrosine were significantly higher in marama-sorghum composite porridges compared to sorghum porridge (Table 3.2.4).

Table 3.2.3 Amino acid composition of marama flours and sorghum meal g/100 g flour (dry matter basis)

AMINO ACID	SOGF	DUH	DH
Essential amino acids			
Histidine	0.2[a]	1.3[b]	1.4[b]
Isoleucine	0.4[a]	2.2[b]	2.9[b]
Leucine	1.2[a]	3.0[b]	3.3[b]
Lysine	0.2[a]	2.8[c]	2.7[b]
Methionine	0.2[a]	0.4[b]	0.4[b]
Phenylalanine	0.5[a]	2.1[b]	2.3[b]
Threonine	0.3[a]	1.5[b]	1.6[b]
Valine	0.4[a]	2.2[b]	2.4[c]
Non-essential amino acids			
Alanine	0.8[a]	1.6[b]	1.7[b]
Arginine	0.4[a]	3.3[b]	3.5[c]
Aspartic acid	0.5[a]	4.0[b]	4.4[c]
Cysteine	0.1[a]	0.1[a]	0.1[a]
Glutamic acid	1.8[a]	7.7[b]	8.3[c]
Glycine	0.3[a]	3.0[b]	3.2[c]
Proline	0.8[a]	3.6[b]	4.0[c]
Serine	0.4[a]	2.6[b]	2.9[c]
Tyrosine	0.4[a]	6.0[b]	6.6[c]

[abc] = mean values within a row with different letters differ significantly ($p<0.05$), SOGF = Sorghum meal, UMF = Marama flour from unheated beans, HMF= Marama flour from heated beans (150°C for 20 minutes) marama flours were partially defatted prior to amino acid analysis

Table 3.2.4 Amino acid composition of sorghum porridge and marama-sorghum composite porridges (g/100g porridge dry basis)

AMINO ACID	SOGP	FUMSP	FHMSP	DUMSP	DHMSP
Essential amino acids					
Histidine	0.3[a]	0.4[b]	0.4[b]	0.5[c]	0.5[c]
Isoleucine	0.4[a]	0.8[b]	0.8[b]	1.0[c]	1.0[c]
Leucine	1.4[a]	1.6[a]	1.5[a]	1.8[b]	1.8[b]
Lysine	0.2[a]	0.7[b]	0.7[b]	0.9[c]	0.9[c]
Methionine	0.2[a]	0.2[a]	0.2[a]	0.2[a]	0.2[a]
Phenylalanine	0.5[a]	0.8[b]	0.8[b]	1.0[c]	1.0[c]
Threonine	0.4[a]	0.5[ab]	0.7[b]	0.7[b]	0.7[b]
Valine	0.5[a]	0.9[b]	0.8[b]	1.0[c]	1.0[c]
Non-essential amino acids					
Alanine	1.0[a]	1.0[a]	1.0[a]	1.2[b]	1.1[ab]
Arginine	0.5[a]	1.0[b]	1.0[b]	1.3[c]	1.3[c]
Aspartic acid	0.5[a]	1.3[b]	1.2[b]	1.6[c]	1.7[c]
Cysteine	0.1[a]	0.1[a]	0.1[a]	0.1[a]	0.1[a]
Glutamic acid	1.2[a]	3.2[b]	3.3[b]	4.1[c]	4.0[c]
Glycine	0.4[a]	0.9 [b]	0.9[b]	1.2[c]	1.2[c]
Proline	1.0[a]	1.4[b]	1.4[b]	1.8[c]	1.8[c]
Serine	0.5[a]	0.9[b]	0.9[b]	1.2[b]	1.1[b]
Tyrosine	0.4[a]	1.6[b]	1.6[b]	2.3[c]	2.3[c]

[abcd]= mean values within a row with different letters differ significantly ($p<0.05$), SOGP = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, DUMSP= Defatted unheated marama –sorghum porridge, FHMSP = Full fat heated marama- sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge

Compositing a lysine deficient sorghum meal with high lysine-legume significantly increased lysine content in marama-sorghum composite porridges. Lysine content was 3 to 4 times higher in marama-sorghum porridges than in sorghum porridge. Amino acid contents in marama-sorghum composite porridges from defatted flour were significantly higher than composite porridges prepared from full fat flours. This is possibly because oil extraction concentrated protein and amino acid content of marama-sorghum porridges composited with defatted flour.

3.2.3.4. Fatty acid composition

The fatty acid composition of marama-sorghum composite porridges and sorghum porridge are shown in Table 3.2.5. Generally unsaturated fatty acids were the most abundant in both marama-sorghum composite porridges and sorghum porridge. There was an increase of up to 18 to 43 % in oleic acid as marama flour was composited with sorghum meal. According to Bower *et al.* (1988) oleic acid (48.5%) is the most abundant fatty acid in marama bean. This explains the higher oleic acid content in marama-sorghum composite porridges than in sorghum porridge. Food sources with high oleic acid levels such as olive oil have been reported to have cardio-protective effects (Hu, Manson and Willet, 2001). Dry heating marama beans prior to flour processing did not have a significant effect on the fatty acid contents of marama-sorghum composite porridges.

Total saturated fatty acids ranged from 25-26% in marama-sorghum composite porridges and 28 % in sorghum porridges. Palmitic acid and Stearic acid were the most abundant saturated fatty acids both in sorghum and marama-sorghum composite porridges. Myristic acid was not detected in the composite porridges. The ratio of unsaturated: saturated fatty acid was calculated and is shown in Table 3.2.5. The ratio is used to express the health value of a fat. The balance is important with respect to coronary heart disease (Anderson, 2004). This is exemplified by the fact that saturated acids elevate serum cholesterol and LDL, while unsaturated lowers serum cholesterol (FAO/WHO, 1998). Additionally, essential fatty acids are vital for normal fetal development and infant growth, since infants generally utilise the essential fatty acids to synthesise other long chain PUFA used extensively for the central nervous system membrane and photoreceptor cell development during the first year of life (Fernandez *et al.*, 2002).

Table 3.2.5 Fatty acid composition of sorghum porridge and marama-sorghum composite porridges (mol % fatty acid as is basis)

Fatty acid	SOGP	FUMSP	FHMSP	DUMSP	DHMSP
C14:0 Myristic acid	1.6(0.2)	ND	ND	ND	ND
C16: 0 Palmitic acid	22.5^{c}(0.8)	18.5^{ab}(0.3)	18.0^{a}(0.3)	19.5^{b}(0.1)	19.4^{b}(0.1)
C16:1Palmitoleic acid	0.8^{ab}(0.1)	0.8^{ab}(0.0)	0.7^{a}(0.0)	0.9^{b}(0.0)	0.9^{b}(0.1)
C18:0 Stearic acid	4.7^{a}(0.2)	4.7^{a}(0.0)	4.7^{a}(0.0)	5.2^{b}(0.1)	5.4^{b}(0.0)
C18:1n9C Oleic acid	29.5^{a}(0.3)	42.3^{d}(0.2)	42.2^{d}(0.3)	36.9^{c}(0.1)	34.8^{b}(0.4)
C18:2n6C Linoleic acid	39.5^{d}(0.0)	31.5^{a}(0.0)	31.4^{a}(0.1)	35.7^{b}(0.2)	37.3^{c}(0.0)
C18:3n3 Linolenic acid	1.3^{c}(0.0)	0.2^{a}(0.0)	0.2^{a}(0.0)	0.4^{b}(0.0)	0.5^{b}(0.1)
C20:0 Arachidic acid	ND	1.0^{b}(0.0)	1.2^{c}(0.0)	0.9^{a}(0.0)	1.0^{b}(0.0)
C20:1 cis-11-Eicosenoic acid	ND	0.3^{a}(0.0)	0.3^{a}(0.0)	ND	0.3^{a}(0.0)
C22:0 Behenic acid	ND	0.6^{b}(0.0)	0.7^{c}(0.1)	0.5^{a}(0.0)	0.5^{a}(0.0)
C24:0 Lignoceric acid	ND	0.2^{a}(0.0)	0.4^{b}(0.0)	ND	0.2^{a}(0.0)
Saturated fatty acids	28	25	25	26	26
Unsaturated fatty acids	71	75	75	74	74
Ratio of unsaturated : saturated fatty acids	2.5	3	3	2.8	2.8

[abcd]= mean values within a row with different letters differ significantly ($p<0.05$), Standard deviations are given in parentheses, ND= Not detected SOGP = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, DUMSP= Defatted unheated marama –sorghum porridge, FHMSP = Full fat heated marama- sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge

3.2.3.5. Total phenolic content and antioxidant activity

Total phenolic content (TPC) and antioxidant (free radical scavenging) activity of marama flours, sorghum meal, sorghum porridge, marama-sorghum composite flours and porridges are summarised in Table 3.2.6. Marama flours were significantly higher by 328.6 to 714% in total phenolics content than sorghum meal. Antioxidant activity was also significantly higher in marama flours than in sorghum meal (370 to 427 % higher). Marama flour has high tyrosine content which reacts with the Folin-Ciocalteu reagent thus increasing levels of measurable phenols and L-tyrosine also exhibits antioxidative properties (Meucci and Mele, 1997).

Total phenolic contents were significantly higher in defatted marama flours than in full fat flours. This could possibly be due to oil extraction in defatted flour that concentrated other constituents hence an increase in total phenolics. Total phenolic content of FUH (3.0 mg CE/100 mg) is similar to 2.8 mg CE/100 mg in marama cotyledon reported by Van Zyl (2004).

Dry heating marama beans prior to flour processing increased total phenolic content and antioxidant activity of the flours. Increase in total phenolic content and antioxidant activity following roasting peanuts has been reported by Talcott, Passeretti, Duncan and Gorbet (2005). Disruption of the cell wall through heating or the breakdown of insoluble phenolic compound could have led to better extractability of these compounds. Dewanto, Wu and Liu (2002) reported that thermal processing may release bound phenolics from breakdown of cellular constituents. Additionally, heating induces production of Maillard reaction products, especially melanoidins, which have been reported to have antioxidant activity (Michalska, 2008).

Marama-sorghum composite flours and porridges had higher total phenolic content and antioxidant activity than sorghum meal and porridge Table 3.2.3.6. Porridges and flours composited with defatted marama flours had significantly higher total phenolic content and antioxidant activity than porridges and flours composited with full fat flours.

Table 3.2.6 Total phenolic content and antioxidant activity of flours and porridges (dry basis)

	TPC* (mg CE/100mg)	Antioxidant activity** (μMTE/100mg)
Flours		
SOGF	0.7[a] (0.1)	3.0[a] (0.7)
FUH	3.0[d] (0.2)	14.1[d] (1.1)
FH	3.8[e] (0.4)	14.3[de] (1.3)
DUH	4.8[f] (0.5)	14.5[e] (1.5)
DH	5.7[g] (0.6)	15.8[e] (1.3)
Composite flours (30:70)		
FUMSF	1.8[bc] (0.1)	9.5[b] (0.9)
FHMSF	1.8[bc] (0.1)	10.8[b] (1.3)
DUMSF	2.0[c] (0.1)	12.4[c] (1.54)
DHMSF	2.1[c] (0.1)	13.1[cd] (1.43)
Porridges		
SOGP	0.5[a] (0.2)	2.3[a] (0.4)
FUMSP	1.5[b] (0.2)	10.6[b] (1.7)
FHMSP	1.6[b] (0.2)	11.1[bc] (1.7)
DUMSP	2.1[c] (0.2)	13.6[d] (2.1)
DHMSP	2.2[c] (0.1)	13.7[d] (2.2)

[abcde] = mean values within a column with different letters differ significantly ($p<0.05$), Standard deviations are given in parentheses DUH: Defatted flour from unheated marama beans, DH: Defatted flour from heated marama beans, FH: Full fat flour from heated marama beans and FUH: Full fat flour from unheated marama beans and SOGF: Sorghum meal FHMSF: Full fat marama-sorghum composite flour from heated marama beans, DHMSF: Defatted marama-sorghum composite flour from heated marama beans, FUMSF: Full fat marama-sorghum composite flour from unheated marama beans, DUMSF: Defatted marama-sorghum composite flour from unheated marama beans, FHMSP: Marama-sorghum porridge composited with full fat flour from heated marama beans, DHMSP: Marama-sorghum porridge composited with defatted flour from heated marama beans, FUMSP: Marama-sorghum porridge composited with full fat flour from unheated marama beans and DUMSP: Marama-sorghum porridge composited with defatted flour from unheated marama beans and SOGP: Sorghum porridges.* expressed as mg catechin equivalent per 100 mg sample and **expressed as micro molar trolox equivalent per 100 mg of the sample

There was a significant positive correlation ($r = 0.80$, $p < 0.05$) between the total phenolic content and antioxidant activity of the flours and the porridges. This means high phenolic content led to high antioxidant activity. Free radicals and other reactive oxygen species contribute to the development of many diseases (Shahidi & Naczk, 2004). Phenolic compounds scavenge free radicals by donating hydrogen atoms to free radicals; hence may protect cell constituents against oxidative damage and limit the risk of various degenerative diseases associated with oxidative stress (Anderson *et al.,* 1995).

3.2.4. CONCLUSIONS

Marama-sorghum composite porridges have improved nutritional quality compared with sorghum porridge in terms of protein content, essential amino acids, fatty acids and energy densities. Marama-sorghum composite porridges are important not only for their nutritional contribution but also for potential anti-oxidative benefits associated with their high levels of phenolic compounds. Use of full fat flours in compositing sorghum meal is recommended to achieve high nutrient content and protein complementarity, which in turn improves both protein and energy utilisation.

4. GENERAL DISCUSSION

This chapter is divided into two sections. The first section critically discusses the experimental approach and methodologies used in this study. The objective is to reveal the strengths and weaknesses in the application, as well as making suggestions for applying the methods better in the future. The second section critically evaluates the sensory and nutritional quality of marama-sorghum composite flours and porridges.

4.1. Critical evaluation of experimental design and methodologies used

Marama beans used in this study were harvested in 2008 in Botswana and Namibia. Marama beans were not easily available in sufficient quantities during the research period and this was the main limitation encountered in this study. This is because marama beans are seasonal, they grow in the wild and their availability is highly dependent on environmental conditions prevailing. There was abundant rainfall in the areas where marama grows before flowering which may have affected seed growth and development. Marama beans are collected by the local people from the wild during the harvesting period. Wrong timing of the harvesting period may also have contributed to the low quantities of beans harvested. In South Africa, most of the areas where marama bean plants were previously found are now used for commercial game farming. Thus since these farms are private properties, it is difficult for local people to have access to the marama beans.

Some of the marama beans were dry heated using a continuous forced convection roaster prior to flour production. Heat treatment inactivates trypsin inhibitors, thus improving the nutritional quality of the beans. The heat treatment reduces trypsin inhibitors effectively (Maruatona, 2008).

A DF cracker developed by WMC Metal Sheet Works (Tzaneen, South Africa) was used to crack the beans, separation of the hulls from cotyledon was done manually by hands. This makes it time consuming. Marama beans could not be fully cracked. The process had to be repeated several times, separating the cracked cotyledons from hulls with hands. It was difficult to sort very small pieces of cracked cotyledons and seed coats, thereby decreasing the yield. Use of a cracker that can effectively separate cotyledons from the hulls by aspiration could be recommended for further studies.

Defatting marama flour is required to improve its stability. Marama bean contains a high percentage of unsaturated fatty acids (Ketshajwang *et al.*, 1998). Full fat marama bean flour could be susceptible to oxidation, thus affecting its keeping quality. Furthermore defatting marama flour increases it protein content (Maruatona, 2008). This could be important in flour food processing applications where protein related functional properties are required. Defatted soya flours are used in a wide variety of food applications such as bakery, meat and beverage products to impart desirable functional properties. Marama bean cotyledons were coarsely ground using a Waring blender and defatted by solvent extraction to obtain a defatted meal, which was milled again to obtain defatted marama flour. Defatting was done manually on a laboratory scale. The oil content in the defatted flour was up to 11% in flour from heated beans and 15% in flour from unheated beans. The values above indicate that the method was not effective; the oil was not completely extracted. Therefore in the future the oil extraction process should be done repeatedly and the fat content determined after each repetition to ensure that oil is completely extracted. Flour yield losses were experienced because some of the flour was decanted with the hexane. Use of an oil expeller would be recommended to avoid flour loss.

Tannin free sorghum meal (commercial product), was intentionally selected to be able to evaluate the contribution of potential health benefits of marama flour in marama-sorghum composite flours and porridges. A typical Botswana porridge-making process was used for the preparation of soft sorghum porridges (Kebakile *et al*, 2008). This is because sorghum porridge is most consumed as staple food in Botswana, in the areas where marama grows.

The sensory quality which made use of descriptive sensory evaluation, consumer acceptability test, pasting properties (flour), texture and colour measurements of marama-sorghum composite porridges and sorghum porridge (control sample) were evaluated. A sorghum-soya composite porridge (*Tsabotlhe*) was introduced as a standard sample for only descriptive and consumer sensory evaluation. *Tsabotlhe* was selected to be used in this study because it was an already existing product in the Botswana market, therefore would be of importance to compare its sensory properties and acceptability with marama-sorghum composite flours and porridges. Furthermore as part of the bigger marama project, a willingness to pay evaluation was conducted therefore a need to include a product on the market. Other analyses were not done on *Tsabotlhe* because no information was available on its formulation and composition and could not be compared to marama-sorghum composite flours and porridges.

Einstein (1991) defines Descriptive Sensory Evaluation as “the identification, description and quantification of sensory attributes of a food material or product using human subjects who have been specifically trained for this purpose”. As such, the success of the descriptive sensory analysis depends primarily on the collective ability of the descriptive sensory panel to reliably and precisely grade the sensory attributes of the product. Because they are human subjects they can be affected by different forms of setbacks e.g. emotional, social and physical conditions. Training sessions help the panel to become familiar with the product. In this study panellists identified the differences between porridges quantitatively using a linear scale. They determined the intensity of the sensory attributes in the porridge. Though six porridges were evaluated, three samples were served followed by a 10 min break to avoid fatigue. In this study the panel was reliable and were able identify the differences between the porridges.

The rapid visco analyser (RVA) is widely used for studying starch pasting properties (Bao and Corke, 2002). Pasting is a process which follows gelatinisation, involving swelling of starch granules, leaching and alignment of granule components and disruption of starch granules (Newport Scientific 1998). In this study the total solids (16%) used for RVA measurements were different from 10% solids porridge used in the descriptive sensory test. In the preliminary tests marama-composite porridges were fluid resulting in poor pasting properties (there was no gelatinisation), therefore a need to increase the total solids.

Consumer sensory evaluation requires a minimum of 50 consumers (Lawless and Heymann, 1999). In this study 52 consumers, 30 male and 22 female evaluated porridge samples. The panel was made up of young people most of them were students, which may not be representative of all sorghum porridge consumers. In the future considering the balance of young and old people would be advised. Each porridge sample was tested for overall acceptability (rated based on the degree of liking) on a nine-point hedonic scale (Peryam and Pilgrim, 1957). Consumers were also prompted to provide comments on the reasons why they liked or disliked the porridge (attached in appendix A). As a motivation consumers were rewarded for the participation in the test.

The amino acid composition of marama flour, sorghum flour, sorghum and marama-sorghum composite porridges were determined using a modification of the method described by Bidlingmeyer *et al*. (1984). This method involves three main steps: acid hydrolysis of the proteins and peptides to yield constituent amino acids; derivatization of amino acids and analysis by reverse phase HPLC. This method is sensitive, rapid, efficient and specific for both primary and secondary amino acids in protein hydrolysates (Bidlingmeyer *et al*., 1984). However acid sensitive amino acids such as tryptophan and cysteine may be lost due to acid hydrolysis. As a result tryptophan was not reported in amino acid composition results and low levels of cysteine were detected. Specific methods to determine tryptophan can be used.

Acidified methanol was used for the extraction of phenolics from the marama bean in this study. Due to the chemical nature of food phenolics, no completely satisfactory solvent extraction procedure is suitable for extraction of all phenolics in foods. Solubility of phenolics is dependent on the type of solvent (polarity), degree of polymerisation of phenolics, interaction of phenolics with other food constituents and formation of insoluble complexes (Waterman & Mole, 1994). Acidified methanol has been recommended for the extraction of phenolics in beans (Madhujith & Shahidi, 2005). However most of the phenolics in plants occur in bound and esterified form. Therefore extensive hydrolysis procedures are required to release the bound phenolics (Robbins, 2003).

The Folin-Ciocalteu method used to determine total phenolic content quantifies the total concentration of phenolic hydroxyl groups present in the sample being assayed (Waterman & Mole, 1994). The reagent reacts with phenols to form chromogens that can be detected spectrophotometrically. The blue color development is due to the reduction-oxidation reaction in which the phenolate ion is oxidized at basic pH, while reducing the phosphomolybdic/phosphotungstic acid complexes in the reagent to form chromogens (Waterman & Mole, 1994).

Folin-Ciocalteu method however is not specific and detects all phenolic hydroxyl groups in extracts. Aromatic amino acids such as tyrosine also react with the Folin Ciocalteu reagent thus increasing the measurable phenols. Use of other methods such as high performance liquid chromatography (HPLC) that identifies and quantifies specific phenolic compounds would be recommended.

Antioxidant activity in this study was measured using the Trolox equivalent antioxidant activity (TEAC). This assay measures the ability of antioxidant to scavenge free radicals (Awika *et al*., 2003). The antioxidants reduce the radicals depending on the antioxidant activity, concentration of the antioxidants and the duration of the reaction. This method is preferred for its simplicity and speed of analysis. It can be used over a wide pH range (Lemaska, Szymusiak, Tyrakowska, Zielinski, Soffer and Rietjens, 2001).

4.2. Critical evaluation of sensory and nutritional quality of marama-sorghum composite flours and porridges

As expected the protein content of sorghum meal was lower than that of marama flours (Fig.4.2). Because of low protein content, cereal grains, sorghum by implication, do not supply adequate protein for satisfactory growth of infants and children or for bodily maintenance of adults (Sarwar, Peace and Botting, 1993). Lysine is a major limiting amino acid in sorghum meal. This demonstrates a need for compositing sorghum meal with marama flour, to increase the protein and lysine content in the composite porridges. Apparently marama flour protein content was not affected by dry heating, as nitrogen is notaffected.

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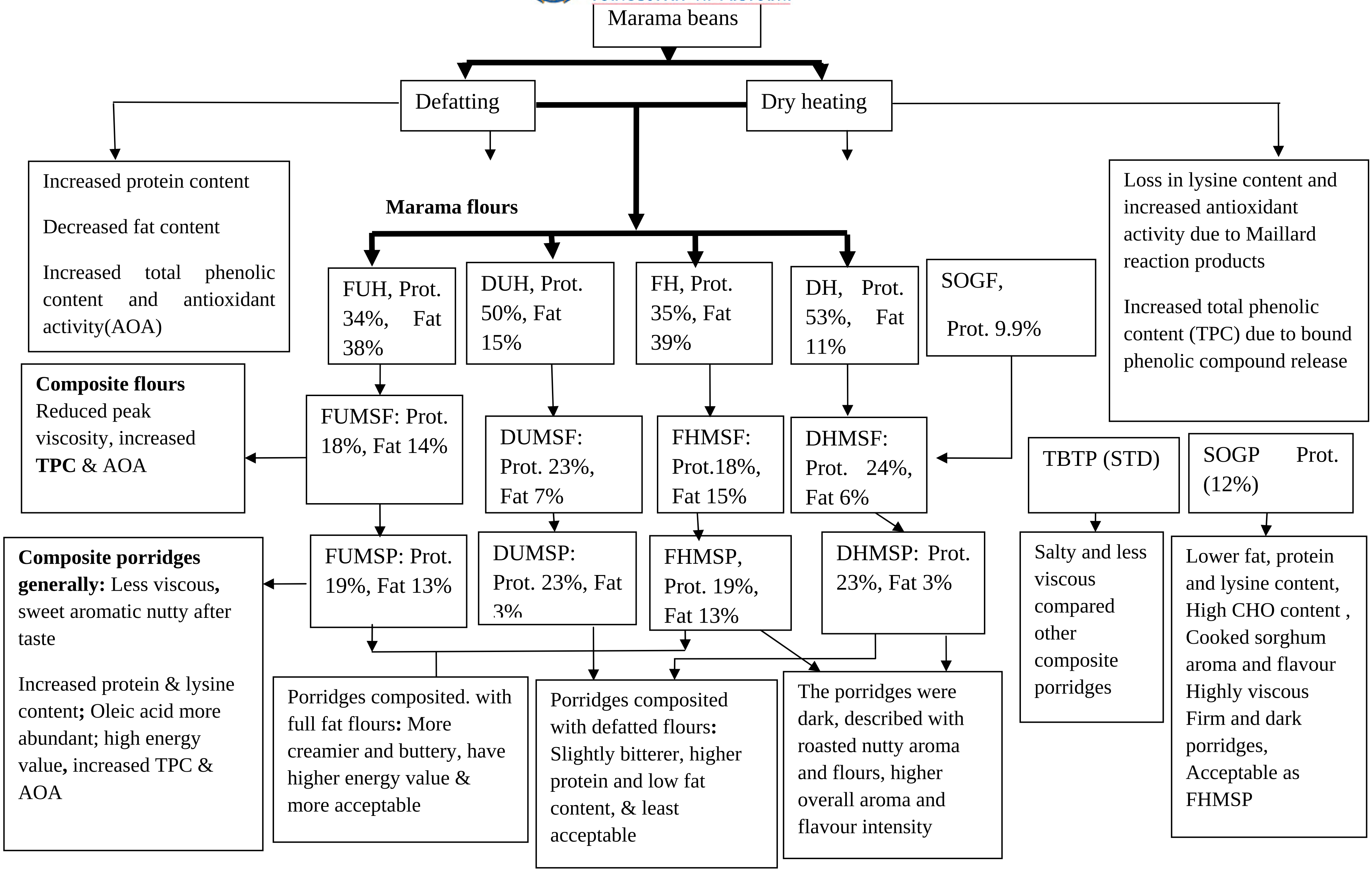

Figure 4.2: Effects of dry heating marama beans, defatting, and compositing resultant flour with sorghum meal on the sensory and nutritional quality of sorghum porridges.

Heat treatment led to 3.7% reduction in lysine content. Destruction of essential amino acids such as lysine due to heat has been reported by Del Valle (1981). Severe treatment may change the structure of the proteins by hydrolysis of peptide bonds, modification of amino acid side chains, and formation of new covalent isopeptide cross-links (Stanley, 1989). It has also been reported that the formation of Mallard browning reaction products is positively correlated with a decrease in lysine availability (Friedman, 1996).

The chemical mechanisms involved in the initial stages of the Maillard reaction have been studied in some detail and involve the condensation of the carbonyl group of the reducing sugar with the amino compound to give a glycosylamine. During thermal processing this breaks down to various sugar dehydration and degradation products. These compounds interact with other reactive components such as amines, amino acids, aldehydes, hydrogen sulphide and ammonia, and it is these interactions which provide the basis for the colours and aromas which characterise cooked foods (Martins *et al.*, 2001). The presence of Maillard reaction products therefore explains the darker colour in porridges composited with flour from dry heated beans and a lighter colour in porridges composited with flour from unheated beans. The products of the initial and intermediate stages of the Maillard reaction are colourless or pale yellow. Colour formation is attributed to the final stage of the reaction, where condensation between carbonyls (especially aldehydes) and amines occurs to give high molecular mass, coloured products known as melanoidins (Michalska, 2008).

Maillard reaction is also responsible for the desirable roasted nut aroma and flavour perceived by the descriptive sensory panel in marama-sorghum porridges composited with flours from heated beans. The final stage of the reaction is of great importance for flavour formation when carbonyl compounds react with each other, as well as with amino compounds and amino acid degradation products, such as hydrogen sulphide and ammonia. It is these interactions that lead to the formation of flavour compounds, including important heterocyclics, such as pyrazines, pyrroles, furans, oxazoles, thiazoles and thiophenes (Mottram, 1991).

Defatting marama flours resulted in an increase in protein of the flour and reduced fat content. Oil extraction in soya flour has been reported to increase its protein content from 40% to 50% (Lusas & Riaz, 1995). Defatted flours may also ensure a long shelf life by reducing the susceptibility of the fat to oxidative rancidity and formation of off-flavour due to reduced fat content. Compositing sorghum meal with defatted marama flour significantly increased the protein content in composite flours and porridges.

Marama–sorghum porridges composited with full fat marama flour were significantly higher in fat content. This is attributed to the fact that fat content in full fat marama flour was up to 3 times higher than defatted flour and 13 times more than in sorghum meal. Fat also forms a vital component of many cell constituents and acts as a carrier of fat soluble vitamins. Furthermore fat increases energy density, and this explains the observed 24% increase in energy value in marama-sorghum porridges composited with full fat flour. Fat provides essential fatty acids such as n-3 and n-6 polyunsaturated fatty acids needed to ensure proper neural development (Salomon, 2005).

Oleic acid levels were increased on compositing sorghum meal with marama flours. It is important to note that food sources rich in oleic acid such as olive oil have cardio-protective effects as opposed to dietary fat rich in saturated fatty acids associated with increased risk of cardiovascular diseases (Hu *et al*., 2004). From a storage stability point of view, peanut with high oleic acid has been reported to have improved stability against lipid oxidation that could lead to adverse flavours (Mugendi, Sims, Gorbet and O'keefe, 1998)

Linoleic acid was abundant in all the porridges. Currently linoleic acid is of particular interest (Enser, Hallet, Hewitt, Fursey, Wood and Harrington, 1998). It is associated with a range of potential health benefits, which include functioning as an anti-carcinogenic, aiding in the utilisation of energy for muscle production instead of adipose tissue production, protection from atherosclerosis and modification of the immune response (Krummel, 2004).

Fat contributes significantly as a functional ingredient in improving the sensory quality of several processed food products. Marama-sorghum porridges composited with full fat flour were creamier and more buttery. This is because fat is the main carrier of flavour for many compounds (Ohmes *et al.*, 1998). Fat affects the flavour by contributing its own natural richness and creaminess, contributing flavours acquired through hydrolysis, oxidation or processing and by modifying the perception of flavourful substances in the product (Ohmes *et al.*, 1998). The effect of defatting was noticeable by sensory analysis. Bitter taste and aftertaste were perceived by the descriptive sensory panel in the descriptive sensory results of marama-sorghum porridges composited with defatted flour. Bitterness might be associated with the presence of phenolic compounds that cause bitterness in legumes as reported by Drewnowski and Gomez-Carneros (2000). In this study bitterness was prominent in marama-sorghum porridges composited with defatted flour prepared from dry heated marama beans. This may be related to off-flavour compounds from Maillard reactions such as furan and caramel compounds (Bemiller and Whistler, 1996).

Compositing marama flour with sorghum meal significantly reduced carbohydrate contents in composite flours and porridges. This affected their textural and pasting properties. In a preliminary experiment done by Maruatona (2008), the RVA did not give any viscosity measurements when a flour suspension of 10% (m/v) concentration in water was used because the defatted marama bean flour settled at the bottom of the metal container to form dough-like strands which coiled around the spindle paddle during mixing with water. Although a low viscosity reading was observed when a flour suspension of 20% (m/v) was used, this still did not give a better understanding of the possible pasting properties of the defatted marama bean flour. This is possibly because of the absence of starch in marama beans (van Zyl, 2007a). This also explains low viscosities of marama-sorghum composite porridges described by the sensory panel. Apart from reduction in starch levels, low viscosities in marama-composite porridges could be explained by starch (amylose fraction contributed by sorghum) complexes with other porridge components such as lipids that may affect the gelatinisation or disordering of starch granules and their swelling and retrogradation behaviour (Morrison and Boyd, 1983). As a result composite porridges became less firm (Fliedel, 1995).

Consumer acceptability of a food product depends not only on flavour and colour but also on texture. For adults firmness is important in porridges and largely affects acceptability of the porridges (Mohamed, Hamaker and Aboubacar, 1993). This may explain why sorghum porridge was slightly more acceptable than the composite porridges. Compositing marama flour with sorghum meal reduced the firmness and viscosity of the porridges. A positive aspect of this is that solid contents could be easily increased for infant consumption without excessive increase in viscosity (Lorri, 1993). However other factors like the percentage of solids in the porridge, how much an infant can eat have to be considered for a product to be a weaning food.

Another reason for the overall acceptability of sorghum porridge is its familiarity to the consumers. Several studies have linked consumer preference to familiarity (Lévy and Köster, 1999; Stallberg-White and Pliner, 1999; Hetherington, Bell and Roll, 2000; Hetherington *et al*., 2002). Porcherot and Issanchou (1998) found that most familiar flavours are usually also the most preferred. Also increased liking was reported with repeated exposure of the unfamiliar food products (Pliner, 1982). The optimal arousal level theory of Berlyne (1970) states that experience with a specific product influences consumers' attitude towards this product. Experience with a product may lead to either an increase or decrease in acceptability. These changes in acceptability may depend on how high the arousal potential of the initial experience is compared to a person's optimal arousal level. A high arousal potential will lead to increased liking. Marama-sorghum composite porridges with time as they are exposed to the consumer might become less or more acceptable. Further studies on the effect of repeated exposure of the porridges to the consumers should be carried out in the future.

Marama flours were significantly higher in total phenolic content and antioxidant activity than sorghum flour. Marama flour is high in tyrosine as reported earlier. Aromatic amino acids such as tyrosine react with Folin Ciocalteu reagent thus increasing measurable phenols (Schnaith, 1989). Tyrosine also has been observed to present high ABTS antioxidant activity at very low concentrations (Perez-Jimenez and Saura-Calixto, 2006). Meucci and Mele (1997) reported that tyrosine showed an inhibition pattern similar to that found in the presence of human serum albumin, i.e. a strong decrease of the absorbance of the radical cation ABTS. Thus tyrosine probably played a significant role in the high total phenolic content and antioxidant activity of marama flours, marama-sorghum composite flours and porridges.

Marama flours from dry heated beans were significantly higher in total phenolic content than those from unheated beans. Heat-induced Maillard reaction products have been reported to interfere with total phenolic content and exhibit antioxidant activity measurements (Michalska, 2008). The interfering compounds may be implicated in oxidative-reduction reaction resulting in products such as melanoidins which may contribute to the absorbance measurement by Folin-Ciocalteu method (Asami et al., 2003; Lindenmeier and Hofmann, 2004).

5. CONCLUSIONS AND RECOMMENDATIONS

Marama-sorghum composite porridges have improved nutritional quality in terms of protein content, essential amino acids, fatty acids and energy densities compared to sorghum porridge.

Defatted flours have higher protein contents than the full fat flours. Therefore defatted marama flours could be further applied in food systems for supplementation when combined with other plant proteins such as cereals (e.g. baking industry) for nutritional purpose as well as its protein related functional properties. Further studies on bioavailability of the protein are required in the future to evaluate the quality of marama bean protein in food systems.

In marama-sorghum composites, use of full fat marama flours in compositing sorghum meal is recommended to achieve higher nutrient content and protein complementarity, which in turn improves both protein and energy value. However flour storage stability studies are required in the future.

Marama flours have higher total phenolic content than sorghum meal. Tyrosine seems to contribute to the analysis of total phenolics and antioxidant activity of marama flours and their composites. Further investigation of the role of tyrosine as an antioxidant in marama flour and when applied in food a system is required. Marama flours from dry heated beans have high total phenolic content and antioxidant activity than flours from unheated beans. Thermal processing releases bound phenolics as a result of breakdown of cellular constituents. Additionally, heating induces production of Maillard reaction products, which exhibit antioxidative properties.

Sensory properties of sorghum porridge and the four different marama composite porridges are different in terms of flavour, aroma, colour and texture. These properties directly affect the acceptability of the porridges. Porridges composited with marama flour from heated beans have roasted nut aroma and flavour. Composite porridges are less viscous compared to sorghum porridge. Sorghum and FHMSP porridges are more acceptable. This is probably because sorghum porridge is familiar to the consumers. FHMSP has rich, buttery and creamy flavours contributed by fat and sweet aromatic nut flavours due to dry heating. Compositing sorghum meal with full fat marama bean flour has potential to provide acceptable sensory appeal and could improve the nutritional status of persons using sorghum as a staple.

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7. **APPENDIX A** (Comments are presented verbatim, spelling and grammar errors not corrected)

7.1. Consumer comments on the acceptability of sorghum porridge (SOGP)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
1	It was tasteful and thick.	It tastes like the ordinary meals that i' ve eaten, nothing new about it.
2	It is thick and looks delicious before even tasting.	More sourness can make it really good
3	The colour, richness, thickness and the taste is excellent	None
4	No	The colour is terrible and doesn't entice a person to eat it
5	It was nice and thick	It was a bit bland
6	A typical breakfast for a busy day	
7	Taste good with sugar added, I doubt that with out sugar it will not be tasteful	None
8	Taste very good	The colour when cooked
9	It's got this smooth taste	Little granules left in the mouth
10	Colour and that it is more solid than the previous samples	It tastes a bit bland and that with the added sugar it is still bland.
11	Nothing	Jelly looking and colour bad
12	It does not have an after taste and after swallowing you dont get the grains left in the mouth	I like everything about it
13	Its taste is acceptable	Its colour
14	Not really, it just tastes nice as I have been exposed to a lot it in my upbringing.	No.
15	It tastes like normal white maize porridge. There is no after taste.	The colour is not attractive to the consumer.
16	The crystals are smooth	The colour, and its hard
17	Well done and very rich just the way i like my porridge	Nothing

Consumer comments on the acceptability of SOGP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
18		Colour is too dark too granular that you have thing to spit out there is some after taste that i cannot identify. It's like something is missing.
19	Is so thick it does not have that after taste and it really delicious	Nothing at all
20	-	It is tasteless, The color is bad
21	Taste very good	
22	Nothing	The porridge is too soft and feels like eating sand with water
23	I like the fact that it is silent and nice colour	Nothing
24	The taste	The colour
25	The colour is great and less brown	Is has some black spot in it
26	It is delicious	Nothing much
27	The colour and the tenderness of the porridge	The small wheat seeds that are left insight the mouth after eating
28	Soft, easy to swallow, no fibrous residue leftover on palate	
29	Is strong and healthy	Nothing at all
30	I t had a traditional (mabele) taste i loved it	
31		
32	Smooth, has normal taste or flavour of porridge	Looks horrible, the colour is too dark and weird
33		It's too thick and it doesn't taste good
34	It tastes different as compared to the others	But too soft
35	Everything about it.	Not a thing.
36	Taste	None
37	It tastes very nice	Nothing at all

Consumer comments on the acceptability of SOGP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
38	Very testy, well cooked	None
39	It tastes good and i like the way it is made	No comment
40	No after taste,	The colour
41	Nothing	Taste, appearance & the smell
42	No	It does not look good and food is all about appearance.
43	No, it just tastes nice	
44	Thickness	None
45		It has got a very dark grey colour
46	It taste nice	Its colour is a bit scary...1 might not want to eat it
47	It was very nice	I know we don't eat the colour but when people see that it too dark they won't even try to test it.
48	It tastes nutritious	I love the taste but it looks more like something you take when you are sick
49	I like the colour and the thickness	It has a sour taste ,even if you put in sugar it is still there
50	Nice ideal soft texture preferred normal taste	Nothing
51	Very soft porridge and good in terms its softness and test ok.	The porridge will not alleviate hunger immediately ,it will require you to take more porridge
52	Rich in fibre	Colour

7.2. Consumer comments on the acceptability of *Tsabolthe* (TBTP)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
1	It is not bad or good	It is not bad or good. Makes me indifferent.
2	I do not like it at all.	It taste like a baby food
3	No	It's to watery and weak
4	No	It tastes like oats it doesn't really taste like porridge
5	It was simple to taste but I'm sure it has all the nutritional benefits necessary	A bit watery
6	It's not too soft and the taste is good	Nothing
7	None	It is too oily and has less maize in it.
8	Nothing	Too light and does not taste very good
9	Not at all!	Taste bas for me, just not nice more of taking maize and adding cold water and you drink it!
10	The porridges taste somehow uncooked and very translucent.	The sorghum granules are not well cooked can actually taste the granules , Very translucent and powdery
11	Better texture	The taste is very bad
12	Do not like anything about it.	It has oil-like feel i the mouthing and the grains are too much giving out a doom taste.
13	It tastes good.	It is not thick
14	Not at all.	The taste is bad and I could not keep the porridge in my mouth for long. It is also weak appearance; therefore it looks like it would not last long in the stomach.
15	No	I taste like breast milk and the colour is not attractive to the consumer.
16	Nothing	It's too soft, too watery and it taste bad.
17	Nothing	Not rich very watery

Consumer comments on the acceptability of TBTP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
18	It’s a tastes i have acquired	Too granular
19	Nothing at all	It got too much water
20	Not really	Its salty
21	Taste creamier, seems like milk is poured	Nothing at all
22	Nothing at all	The taste is strange and it doesn't taste like healthy porridge
23	It has a soft flavour i will say while it made of hart maize	Nothing i think i good
24	It taste nice and too soft	It is too thick and taste as if there is something oily added into it.
25	It looks like purity, baby bottled food that you buy in store	I think is baby food, isn’t it?
26	I don't like it	It is too wet and soft
27	Sweet taste	None
28		Heavy overbearing raw flavour even after addition of sugar
29	Nothing	Is so soft. i don’t like it
30	It had a smooth taste	
31		Too soft
32	No	Too weak, tastes funny, it is watery
33	Its taste better and l think its good for your health	
34	Nothing at all	It got too much water
35	I don’t like it	Everything about it
36	Softness	None
37	It is not liquid, is can keep you filled up for a long time. it is nice	Nothing at all
38	Slightly testy	Taste like there is salt
39	Well prepared	No comment

Consumer comments on the acceptability of TBTP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
40	Reminds me of home	I like it totally
41	Nothing	Taste, appearance & the smell
42	No	It does not look good and food is all about appearance.
43	No, it just tastes nice	
44	Thickness	None
45		It has got a very dark grey colour
46	It taste nice	Its colour is a bit scary...1 might not want to eat it
47	It was very nice	I know we don't eat the colour but when people see that it too dark they won't even try to test it.
48	It tastes nutritious	I love the taste but it looks more like something you take when you are sick
49	I like the colour and the thickness	It has a sour taste ,even if you put in sugar it is still there
50	Nice ideal soft texture preferred normal taste	Nothing
51	Very soft porridge and good in terms its softness and test ok.	The porridge will not alleviate hunger immediately ,it will require you to take more porridge
52	Rich in fibre	Colour

7.3. Consumer comments on the acceptability of marama –sorghum composite porridge with full fat flour from dry heated beans (FHMSP)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
1	It has a different taste, a little compelling.	Nothing.
2	It is a bit thick	The added flavour it's nice but restricted. It makes one to develop a dislike of the whole porridge.
3	Richness and the thickness	Taste
4	No	It tastes terrible
5	Nice colour	It also tasted nutty
6	It tastes like normal porridge I am used to	It's too soft
7	It is tasteful and i can eat it with Sugar	None
8	Did not notice anything different.	Don't know if it's the cooking or not but it's very watery, very light.
9	Nothing	Too weak ,not smooth enough, doesn't hold its watery
10	Color and that it is well cooked	taste has a nutty taste that is a bit off
11	Nothing	The look, the taste and the texture
12	It is sweet and tasty	I liked everything about it
13	The colour of the sample	The taste of the sample
14	It has a nice aftertaste.	No.
15	It tastes bad. Its not nice at all.	It tastes bad. It really isn't nice.
16	I like the after taste	It's too alkaline
17	Not really	The smell
18	Colour is ok. Not too dark nor light granule not too much	Doesn't taste that good
19	It taste extremely good	Nothing

Consumer comments on the acceptability of FHMSP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
20	Not really	Its tasteless
21	Taste very deliciously and soft	Nothing to criticised about it
22	The porridge is sort of heavy	It feels like too much work to eat it
23	First the colour make u to want to eat and further more is delicious	Nothing
24	It taste nice and rich	Nothing
25	Salt inside	The black spot losses the appetite
26	It is delicious	Nothing
27	The tenderness and cooked maize	It leave after taste insight the mouth
28	Soft, easy to swallow, nice peanut-buttery flavour	
29	Is great	Nothing
30		It tasted like peanut butter and absolutely hate the taste of peanut butter
31	Is good	Too soft
32	No	Tastes like there is peanuts or peanut butter, looks ugly
33		
34	The peanuts	None
35	Everything about it, it has a great taste	I don't at all
36	It taste good	None
37	Tastes better	No dislikes
38	Too much taste of peanuts	Not that testy
39	It is very nice and it tastes good	Try to make it a bit thicker, otherwise it is okay

Consumer comments on the acceptability of FHMSP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
40	The natural taste	None
41	Taste	The colour
42		It tastes like morvite and i grew up eating a lot of that which i would rather not consume anymore.
43	No	Just doesn't taste nice
44	Milky like taste	After taste
45	It has got a very milky taste.	
46	It's so delicious!! It taste like caramel	No not really
47	Is good	Is not cooked properly. It smells like it was burned.
48	Looks great and the taste i just delicious....	No
49	That it leaves a last long taste after you have tried it. That is a great thing	They still need to work on the taste factor. It still has that taste like it is powder, the taste that you get before it is ever cooked.
50	The nuttiness	Sour after taste
51	Nothing	The porridge doesn't test ok at all.
52	Taste like peanut butter	Its taste its horrible

7.4. Consumer comments on the acceptability of marama –sorghum composite porridge with full fat flour from unheated beans (FUMSP)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
1	Nothing	It is tasteless.
2	Nothing, I don't like it at all	Taste foreign, it like is not meant to be consumed by human beings.
3	The colour and its smoothness	Its weak or too watery
4	No	It doesn't look appealing at all & the after taste is terrible
5	It wasn't as sour as the others and it was quite soft	It was slightly watery
6	Not a bad taste and too soft	It's a bit bitter can one can handle the bitterness even kids
7	None	It is too watery
8	Taste very good, looks appealing and it's not light.	Nothing.
9	Very smooth and tasty	Doesn't have that desire to eat it when you look at it
10	It is well coked and not so translucent (watery)	It is a bit light in appearance
11	Nothing	The nutty taste
12	No	It leaves out grains after swallowing, and it has a bad sour taste and mostly it has an after taste
13	No	What was put inside the porridge (something like beans)
14	No.	No, it is just a new taste to me and that is all.
15	The colour is fine. It tastes ok.	No
16	Its soft, taste great	Nothing
17	Not very thick	
18	Taste is not too bad	Smell

Consumer comments on the acceptability of FUMSP (continued0

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
19	It taste good, and is so reach as if i put milk on it	Nothing at all
20	Not really	Its tasteless
21	Softly	Something that actually taste like peanut
22	It is crunchy but not too heavy	It tastes like grain porridge and I do not like grain porridge at all
23	Do not like	It is silent nothing special about it
24	Taste nice	Nothing
25	It looks like it has milk inside	Doesn't taste good as it looks.
26	It is soft and simple	It is not that healthy compared to other porridge
27	None whatsoever	The taste of the maize
28		Rubbery
29	Those little nuts makes it very nice	Nothing
30		
31	Taste good	Nothing
32	No	Looks weird, has these funny little particles
33		
34	None	Large pieces of 'particles', whatever they are called
35	I don't at all	It really doesn't have a great taste
36	None	It taste funny
37	It got taste	I have to give attention in order to feel its taste
38	Smooth	No comment
39	It is well made	No comment
40		No taste

Consumer comments on the acceptability of FUMSP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
41	The taste	Nothing
42	No	The beads were too much....
43		Everything
44	Taste with sugar	None
45	It goes down well	
46	The taste is ok	It has this white things inside i don't like
47	Is one of the second best compared to sample 798	Nothing to dislike.
48	It feels like i have tasted it before	No
49	When you put the sugar it taste very well	No
50	The nutty feeling when being masticated.	Extremely sour, highly not desirable for my porridge.
51	It is like Batswana porridge called ting which is little bit sour.	No
52	Taste good	Nothing

7.5. Consumer comments on the acceptability of marama –sorghum composite porridge with defatted flour from dry heated beans (DHMSP)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
1	It is almost nice to eat...	It has a bitter after-taste.
2	It is a bit thicker	The taste does not correspond with the looks
3	The taste, colour and smoothness	No
4	No	It has a bitter taste
5	It was soft	It tasted like peanut butter
6		Its sour and too soft
7	It is soft, thick and smooth. very enjoyable	None
8	Nothing	Taste and texture
9	Nothing	Don't like the colour, it does not have this outstanding taste for me more like flour with hot water added dont like it at all!
10	Nothing	Taste and colour it taste like mabele beer
11	Better texture	Tastes burnt
12	It taste nice, and it does not leave grains in the mouth	It has a sour-like taste that made me think if i were to it a lot or enough to fill my tummy it would be bad.
13	It has a good colour and I could taste something like peanuts	Like baby's porridge
14	No.	It has a bad aftertaste.
15	I like the taste after swallowing.	The feeling when reaching the tongue.
16	Nothing	Taste bad, the after taste is worse
17	A bit rich in taste	Not as rich as i like my porridge
18	Smooth colour is ok	Does not smell too good leave a bitter taste on the tongue
19	It's delicious and it give you strength especially if you take it in the morning	Nothing other than saying it good for babies

Consumer comments on the acceptability of DHMSP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
20	Not really	The taste is unlike a taste of a porridge
21	Nothing special just fine	I don't its taste but any way nothing much to worry about
22	It is easier to eat at any specific time	The ingredients in the porridge are probably what I do not like
23	Nothing	I dislike the colour then the taste is even worse
24	Nothing	Colour and the taste
25	They is a peanut butter inside	The taste still left on the tongue after.
26	The colour, sweet and soft	Nothing much
27	The brownish colour and the little bit of the sweetness	None whatsoever
28	Thick, consistent (good texture in the mouth)	Flavour slightly weak
29	Nothing	Is not that great
30		It tasted raw and it left an after taste
31		The taste is not that good.
32	No	Tastes sour, smells funny
33	The ingredients that are in the sample taste nice and it gives you more energy because there is some vitamins in peanut batter	Non that i can think of
34	The taste of peanuts, i love it	What i dislike it that it has maize taste that i like
35	None	What i don’t like about it is that is not thick the way i like it
36	Good taste	It has less taste
37	It is too liquid and less taste	Not too smooth and not that much tasty
38	No taste	It should be a bit thicker

Consumer comments on the acceptability of DHMSP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
39	It is nice not bad	It tastes like its not ready
40		Taste
41	The smell	The after taste
42	No	Not really
43	Tastes like baby food	Sour like taste
44	None	
45	It doesn't have an after-taste	Yes it requires me to put in too much sugar, it required too much sugar for me to actually get the taste
46	Yes, it tastes like my mom’s!!!It reminds of home	It was burned.
47	It’s more like good.	Tastes more like baby food
48	No	When i swallow it. It takes time to pass the mouth area
49	I like the colour and that it is not too thick	Bitter after taste even after sugar was added
50	Soft texture	It also test like burned porridge ,i think it will be good for the children
51	Its colour	
52	The porridge tastes fine and soft	It taste like burnt porridge

7.6. Consumer comments on the acceptability of marama –sorghum composite porridge with defatted flour from unheated beans (DUMSP)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
1	Nothing!	It is bitter!
2	I like its thickness and also has nice flavour	Lacks the sour taste I require
3	Thickness, richness and the taste	The colour
4	No	The taste is appalling
5	It has an inviting light colour	It is bitter even after adding sugar
6		Its slightly sour and somehow soft, which might get you hungry just after eating it
7	None	It taste a bit sour and has after taste
8	Good taste	Don't know
9	Nothing	Don't like the " texture" would like it with less granules
10	Well cooked and the sorghum granules are also well cooked	The colour and that with the added sugar it still tastes a bit bland
11	Nothing i like	Taste is bad
12	I do not like anything about it.	It is tasteless, it has grains that have a doom taste as if you've drank warm water
13	No	The taste doesn't do it for me
14	No.	No.
15	The colour is fine.	It doesn't taste nice.
16	Nothing	The taste is bad
17		The taste is very dull it is not rich
18	Nothing at all	It does not have taste even if you put sugar on it
19	Not really	Its tasteless

Consumer comments on the acceptability of DUMSP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
20	All ingredient added up are good	No complain
21	There is less grain in it yet it taste like grain porridge	It is grain porridge according me
22	The fact that with sugar is better than alone	If you are not suppose to eat sugar in my case you will hate this
23	Taste nice and natural.	Nothing
24	The taste left on the tongue after	The colour is not good
25	I don't like it	It is not soft
26	None	The ingredients not well cooked and still taste the row maize
27	Thick, but maintaining its softness and consistency	Remnants leftover in mouth after swallowing
28	Is good	Need to be strong
29		It had to many clots in it
30	You can eat it without sugar	Nothing!
31	No	Looks ugly, too much rough particles
32		Don’t like the taste
33	None	Not good tasting
34	It is very tasty in way that i would love to have it again	It’s not that thick
35	It has no good taste	Taste
36	Its good got the taste	Nothing much, just can’t really feel its taste.
37	Has energy and it is tasty too	Too light
38	Very tasty and well done	No comment
39	Its natural taste	The grains....
40	The stuff that remains on my tongue	The smell

Consumer comments on the acceptability of DUMSP (continued)

Consumers	Anything specific that you really like about the sample	Anything specific that you really dislike about the sample
41	Not really it just tastes like the normal porridge we have at home	It's slightly different.
42	It tastes like morvite	Not really it just doesn't taste very nice
43	None	Too soft
44		It has a very light colour and taste like it's a bit off
45	No	It taste bad
46	It taste divine.	Nothing to dislike about it. If u dislike it means u don't know what u want.
47	Looks great for something i can eat in the morning but tastes more like the first two samples.	No
48	It taste familiar and that it can be enjoyed	It needs to be cooked a little bit longer
49	No	Bitterness and sourness.
50	Nothing	The porridge is sour
51	Its rich in fibre	Nothing
52	Looks great for something i can eat in the morning but tastes more like the first two samples	Nothing

SOGP = Sorghum porridge, FUMSP = Full fat unheated marama -sorghum porridge, DUMSP= Defatted unheated marama – sorghum porridge, TBTP = Tsabotlhe (Sorghum-soya porridge) commercial product from Botswana, FHMSP = Full fat heated marama- sorghum porridge, DHMSP = Defatted heated marama –sorghum porridge