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Development of a Protein-rich Composite Sorghum–Cowpea Instant Porridge by Extrusion Cooking Process

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To develop an instant high protein porridge, various ratios of sorghum and cowpeas were extruded at 130 and 165 °C and a water content of 200 g/kg using a twin-screw extruder. An increased proportion of cowpeas resulted in an increase in protein content, nitrogen solubility index (NSI), yellow colour, water absorption (WAI) and solubility (WSI) indexes and in a decrease in total starch (TS), enzyme-susceptible starch (ESS), expansion ratio (ER), and porridge firmness. The higher extrusion temperature gave lower NSI, TS and WAI. ESS, ER and WSI increased with severity of heat treatment. The composite of 50% sorghum and 50% cowpeas extruded at 130 °C was the most similar to a commercial instant maize–soya composite porridge in terms of composition and functional properties. A serving of 100 g would contribute 28% of the recommended dietary allowance (RDA) for protein. This represents a 110% increase in the protein RDA compared to sorghum only.

Introduction

Sorghum is a very important cereal food in Africa on account of its drought tolerance. Sorghum porridge supplies a large proportion of the protein and energy for many people living in Southern Africa (Taylor *et al.*, 1997). However, sorghum has a low protein content and quality, particularly with respect to lysine (Lásztity, 1984). Protein quality is a critically important problem in many developing countries, where human diets consist mainly of cereals (Serna-Saldivar and Rooney, 1995). The addition of cowpeas, a legume widely produced in Southern Africa, which is slightly limiting in the sulphur-containing amino acids, cysteine and methionine (Chavan *et al.*, 1989), but containing sufficient lysine to overcome the lysine deficiency of sorghum may be a solution.

In Africa, due to deforestation by utilisation of wood for fuel, there is a great need for pre-cooked foods. High-temperature, short-time (HTST) extrusion cooking could be used to produce sorghum-based foods of high nutritional quality and in a ready-to-eat form. Much important research work on the extrusion cooking of cereals has been reported (Anderson *et al.*, 1969*a, b*; Mercier & Feillet, 1975; Gomez & Aguilera, 1983, 1984; Björck *et al.*, 1984; Ilo *et al.*, 1996), and on the extrusion of cereal–legume composites (Maga & Lorenz, 1978; Almeida-Dominguez *et al.*, 1983; Colonna & Mercier, 1985; Falcone & Phillips, 1988) but nothing has been reported on extrusion cooking of sorghum–cowpea composites for production of ready-to-eat (instant) porridge. The main objectives of this study were to determine effects of feed ratio and temperature of extrusion on the chemical and functional properties of sorghum–cowpea flours for instant porridge production.

Materials and Methods

Materials

The raw materials were decorticated red sorghum meal 'super Mabela' (8.5 g protein/100 g material,

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d.b.), received gratis from Nola (Randfontein, South Africa), approximate particle size 75% >0.21 mm and <1 mm; and cowpeas of variety Seinita were sown at Umbeluzi Farm (Maputo, Mozambique) and supplied by SEMOC (Mozambique seed company). Cowpeas were coarsely de-hulled in an abrasive dehuller. To completely remove all hull materials from the cotyledons, they were then passed through a roller mill with a roller gap of 2.5 mm, to avoid crushing of the cotyledons. The hulls were then removed by aspiration. After decortication, the cotyledons were ground using a roller mill and then hammer milled (480 μm sieve). The cowpea meal had a protein content of 27.1 g protein/100 g material (d.b.). ProNutro (natural flavour), a commercial maize–soybean composite instant porridge widely consumed in Southern Africa manufactured by Bokomo Foods (Wadeville, South Africa), was used as standard.

Extrusion

A predetermined amount of distilled water was added to the meal mixture using a buret, while it was mixed at 1200 rpm for 10 min in a small double-ribbon blender equipped with a paddle attachment rotating in counter-current fashion. Water addition was calculated according to AACC Method 26-95 (AACC, 1983). Sorghum and/or cowpea meals were extruded in a Werner & Pfleiderer Continua 37/22D twin screw co-rotating extruder. Extrusion and products parameters were temperature at die end of barrel (130 °C or 165 °C), feed ratio (100, 70, 50, 30, and 0% cowpeas), feed water content (200 g/kg) and screw speed (200 rpm). Other extrusion process conditions are given in **Table 1**. After extrusion cooking, the extrudates were allowed to stand for 2 h to cool. The extrudates were roller milled with a 2.9 mm roller gap, and then hammer milled through a 250 μm screen.

Protein content

Protein content ($N \times 6.25$) was determined by the Kjeldahl method, as modified in AOAC Approved Method No. 2.057 (AOAC, 1980), using a Büchi 322 Distillation Unit and Büchi 430 Digester.

Table 1 Extrusion processing conditions for producing instant sorghum–cowpeas porridge

Processing conditions	Parameter
Throughput	430 g/min
Moisture content of feed	200 g/kg
Die diameter	5 mm
Screw speed	200 rpm
Barrel temperature	130 and 165 °C
Transporting screw	300 mm
First kneading zone (first stage)	100 mm
Second kneading zone (second stage)	100 mm
Final cooking zone (third stage)	200 mm
Specific mechanical energy (SME)	530 kJ/kg

Nitrogen solubility index (NSI)

NSI was determined according to AACC Approved Method No. 46-23 (AACC, 1983).

Colour

Colour of raw materials and extrudates was measured using a Hunter Laboratory Instrument Model CIE 1996 (Hunter Associates Laboratory, Inc., Reston, Virginia, U.S.A.) and expressed on the L, a, b scale.

Total starch (TS) and enzyme-susceptible starch (ESS)

TS was measured by gelatinisation of the starch by pressure cooking followed by hydrolysis to glucose by α-amylase and amyloglucosidase and colorimetric determination of glucose (Taylor, 1992). ESS was measured in the same way except that the gelatinisation step was omitted.

Expansion ratio (ER)

ER was determined by dividing the diameter of the extrudate (mean of 10 measurements) by the diameter of the die (Colonna et al., 1989).

Water absorption (WAI) and water solubility (WSI) indexes

WAI was determined by the method of Anderson et al. (1969) and WSI was measured by the method of Antila and Seiler (1984).

Porridge firmness

The firmness of porridges was determined using a TA-XT2 Texture Analyser (SMS-Stable Micro Systems, Goldalming, U.K.). To make the porridges, boiling water (95 °C) was added to the milled extrudate samples at a ratio of 4:1 (w/w) with mechanical stirring. Firmness was measured after the porridge (50 mL) achieved room temperature (23 °C). A perspex cylinder probe (SMS P/20p) of 20 mm diameter was used. The penetration of probe into the product was 8.0 mm and the test speed was 2.0 mm/s with the same post-test speed. The area under the peak on the recording chart was interpreted as the work (g cm) required to shear the porridge and used as a measure of firmness, as described by Kim et al. (1990).

Statistical analysis

Analysis of variance (ANOVA) with the least significant difference test (LSD-test) was applied. The level of significance used was 95%.

Results and Discussion

Protein content

As expected, the protein content of the extrudates increased proportionally with the amount of cowpeas in

the composite for both extrusion temperatures (**Fig. 1**). There was no statistically significant difference ($P > 0.05$) in protein content between the extrudates prepared at the two extrusion temperatures. A serving of 100 g (d.b.) of the 50% sorghum and 50% cowpeas porridge would provide 28% of the recommended dietary allowance (RDA) as ProNutro (commercial ready-to-eat maize, soya composite porridge).

Protein content was measured as nitrogen ($N \times 6.25$); hence, the apparent protein content was not affected by extrusion temperature, as nitrogen is not affected by heat treatment. However, the true protein content and quality may have been affected as indicated by differences in NSI.

Nitrogen solubility index
NSI increased at both extrusion temperatures as the amount of cowpeas increased (**Fig. 2**). This increase is related to the higher protein content of the extrudates of higher cowpea content and the fact that cowpea proteins are more water soluble (Chavan *et al.*, 1989) than those of sorghum (Serna-Saldivar & Rooney, 1995). Harper (1981), working with extruded maize–soybean blends, found that lower extrusion temperatures resulted in higher NSI and densities. During the HTST extrusion cooking process, the quaternary structure of proteins opens in the hot moist conditions, to produce a viscous plasticised mass (Fellows, 1990). The proteins are then polymerised, cross-linked and reoriented to form a new fibrous structure. HTST extrusion cooking reduces
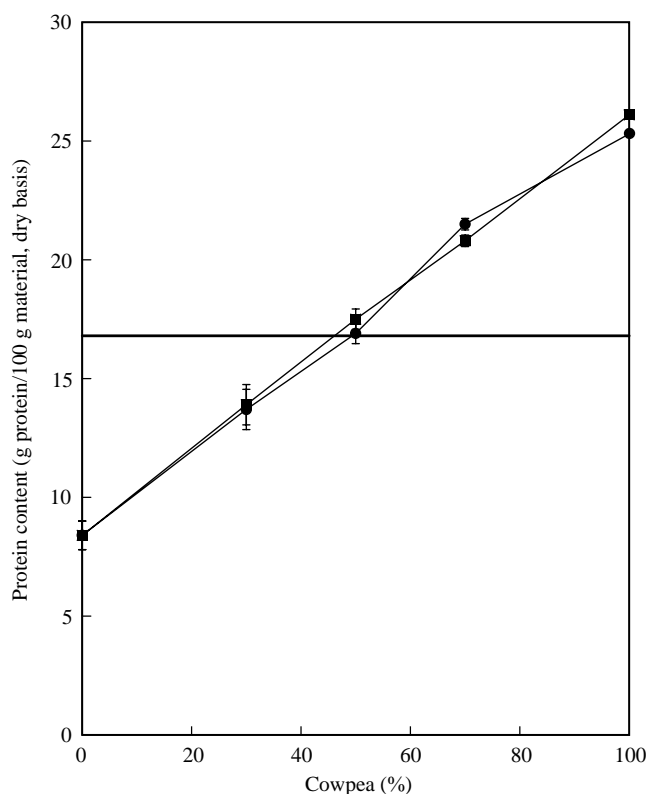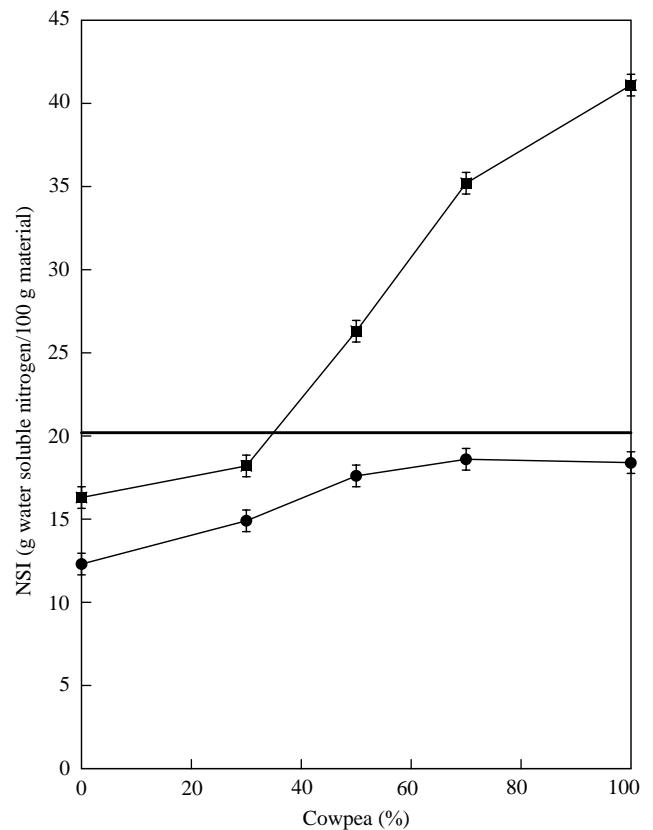

Fig. 2 Nitrogen solubility index of sorghum–cowpea composites extruded at 130 °C (■) and 165 °C (●) and that of ProNutro standard (-). Errors bars indicate ± one standard deviation

protein solubility as a function of temperature, probably as a result of thermally induced cross-links among subunits of proteins by heat (Stanley, 1989). Most of the porridges extruded at 130 °C had far higher NSI content than the ProNutro. However, the NSI of the ProNutro was higher than that of sorghum–cowpeas porridges extruded at 165 °C.

Colour
Extrudates of increasing cowpea content had higher Hunter *L* and *b* values (**Table 2**). Hunter *a* values were lower in the samples of higher cowpea content. Thus, as the amount of cowpeas increased the extrudates became lighter, less red and more yellow. This clearly agrees with the colour of the raw materials. In general, the higher extrusion temperature (165 °C) resulted in darker products, probably due to Maillard reaction (non-enzymatic browning) favoured by the high temperature and relatively low water in the extruder. Repercussions are both nutritional, by the loss of available lysine, and sensorial through formation of coloured and flavoured compounds. Lysine is the most reactive amino acid with regard to the Maillard reaction (Sgaramella & Ames, 1993). Similar results were found by Sgaramella and Ames (1993) with extruded wheat starch, glucose and lysine. With the exception of the 0 and 30% cowpea samples extruded at 165 °C, all the other extrudates were lighter than the ProNutro, implying lower loss of

Fig. 1 Protein content of sorghum–cowpea composites extruded at 130 °C (■) and 165 °C (●) and that of ProNutro standard (-). Errors bars indicate ± one standard deviation

Table 2 *L, a, b* colour of raw materials, sorghum–cowpea extrudates and ProNutro

Sample	Extrusion temperature ($^\circ$C)	*L*	*a*	*b*
Raw materials				
Sorghum		73.15	2.25	10.56
Cowpeas		83.56	−0.45	12.24
Extrudates				
0% Cowpea	130	66.51	2.91	9.67
30% Cowpea	130	71.03	1.68	10.50
50% Cowpea	130	73.80	1.13	11.29
70% Cowpea	130	80.51	1.42	11.97
100% Cowpea	130	82.98	−0.69	12.25
0% Cowpea	165	60.07	4.09	10.58
30% Cowpea	165	63.11	3.01	11.97
50% Cowpea	165	68.97	3.03	12.73
70% Cowpea	165	70.94	1.37	14.51
100% Cowpea	165	77.25	−0.06	15.46
ProNutro		63.07	5.22	24.74

available lysine. All the extrudates were less red and less yellow than the ProNutro due to the color differences of the raw materials of both instant porridges.

Total starch

Prior to extrusion, sorghum had 84.7 while cowpeas had 41.4 g starch/100 g material on d.b. As the percentage of cowpeas increased, TS decreased in the extrudates (**Fig. 3**). The material extruded at the lower temperature (130 $^\circ$C) had a higher TS content than that extruded at the higher temperature (165 $^\circ$C). Higher temperatures are known to favour the reaction between starch and protein in an irreversible reaction (Björck *et al.*, 1984). For up to 50% cowpea at the lower extrusion temperature and up to 70% at the higher temperature the decrease in the proportion of assayed starch was less than would be predicted from the calculated starch content in composites of the raw materials. Above these proportions the decrease was greater than the calculated values. The apparently lower than expected decrease in starch content could be due to reducing substances other than glucose produced during extrusion, since the assay is not specific for glucose. The apparently higher than expected decline in starch content could be due to Maillard reaction between reducing sugars produced during extrusion, by thermal and physical hydrolysis of starch, and the high level of lysine in cowpeas (Asp & Björck, 1989). The porridge of 50% sorghum and 50% cowpea extruded at 130 $^\circ$C had similar total starch content to ProNutro.

Percentage of starch which was enzyme susceptible (ESS)

For both extrusion temperatures, the percentage of starch that was enzyme-susceptible (gelatinised) decreased with the proportion of cowpeas in the composite (**Fig. 4**). One factor which may have affected ESS is the amylose/amylopectin ratio. Sorghum starch has more amylopectin than amylose (Serna-Saldivar & Rooney, 1995), while legume starch has more amylose than amylopectin (Guilbot & Mercier, 1985). Grains with a
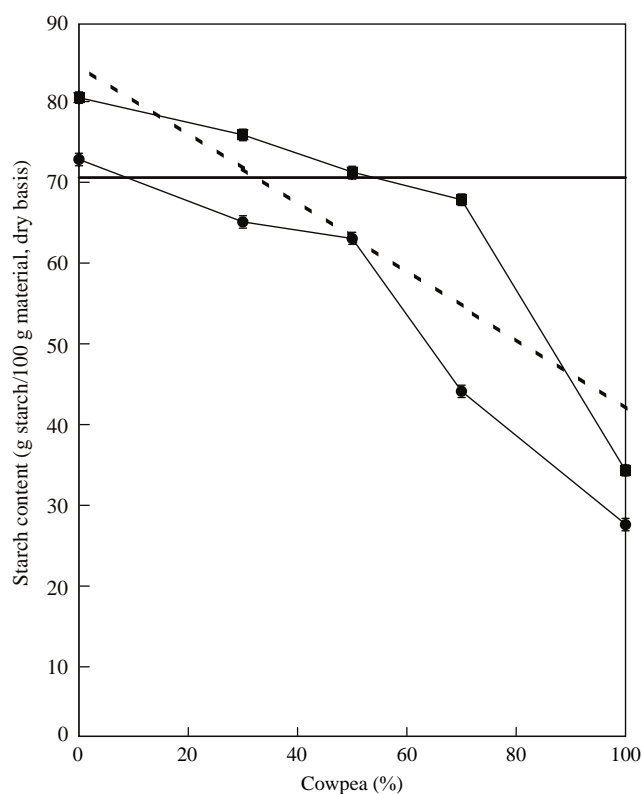
Fig. 3 Total starch content of sorghum-cowpea composites extruded at 130 $^\circ$C (■) and 165 $^\circ$C (●) and that of ProNutro standard (-). Errors bars indicate ± one standard deviation. Theoretical starch content (- - -)

high proportion of amylopectin content are more enzyme-susceptible (Harper, 1981). The fact that cowpeas had far higher protein content than sorghum could also have been responsible for the lower starch enzyme-susceptibility of the extrudates of higher cowpea content. Protein structures encapsulating starch or covering starch granules surfaces would be expected to decrease the availability of starch to amylase *in vitro* (Asp & Björck, 1989).

The proportion of ESS was higher at the higher extrusion temperature. This is because high temperature and high shear rate cause disruption of starch granule
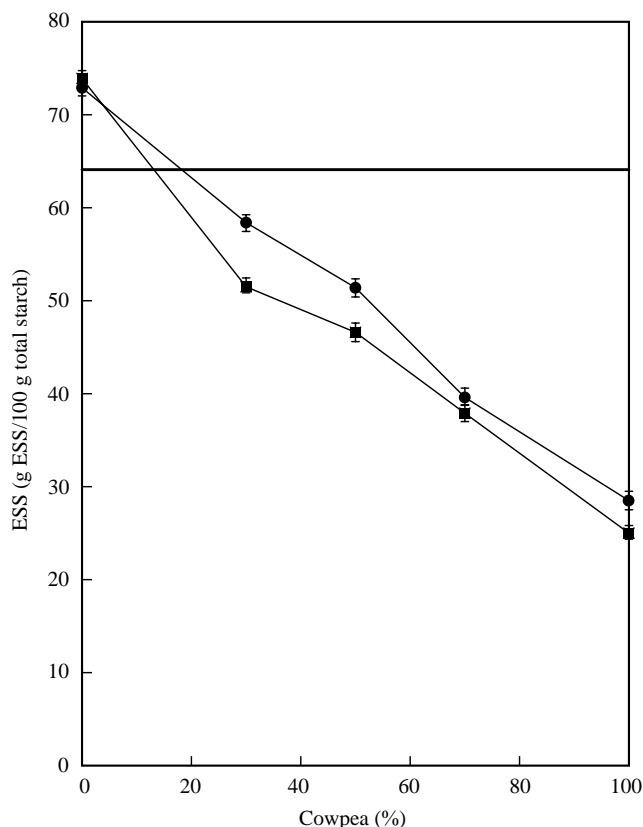
Fig. 4 Percentage of starch which was enzyme–susceptible in sorghum–cowpea composites extruded at 130 °C (■) and 165 °C (●) and that of ProNutro standard (-). Errors bars indicate ± one standard deviation

Fig. 5 Expansion ratio of sorghum-cowpea composites extruded at 130 °C (■) and 165 °C (●). Errors bars indicate ± one standard deviation

structure which leads to mechanical damage of starch molecules and/or gelatinisation in the starch fractions (Asp & Björck, 1989). All the ratios of the sorghum–cowpeas porridges at both extrusion temperatures, except that of 100% sorghum, had lower ESS than the ProNutro.

Expansion ratio
ER, measured as diameter expansion, decreased as the percentage of cowpeas increased in the composites, at both extrusion temperatures (**Fig. 5**). This might be due to the higher starch content of sorghum and/or to the far higher protein content of cowpeas. Paton and Spratt (1984) showed that increasing protein content in the mixture may decrease ER during extrusion cooking. Chinnaswamy and Hanna (1988) noted that the expanded volume of cereal flour decreases with increasing amounts of protein and lipid but increases with starch content. The lower ER in the mixtures of higher cowpea content may also be related to the lower ratio of amylose/amylopectin in sorghum. Amylopectin exerts a positive and amylose a negative influence on radial ER (Feldberg, 1969). Significantly, higher ERs occurred at the higher extrusion temperature (165 °C). Guy and Horne (1988), according to Colonna et al. (1989), stated that important granule damage occurs when specific mechanical energy (SME) inputs are higher than 500–600 kJ/kg. In this research work the calculated SME was 530 kJ/kg. Higher ER at high temperature is
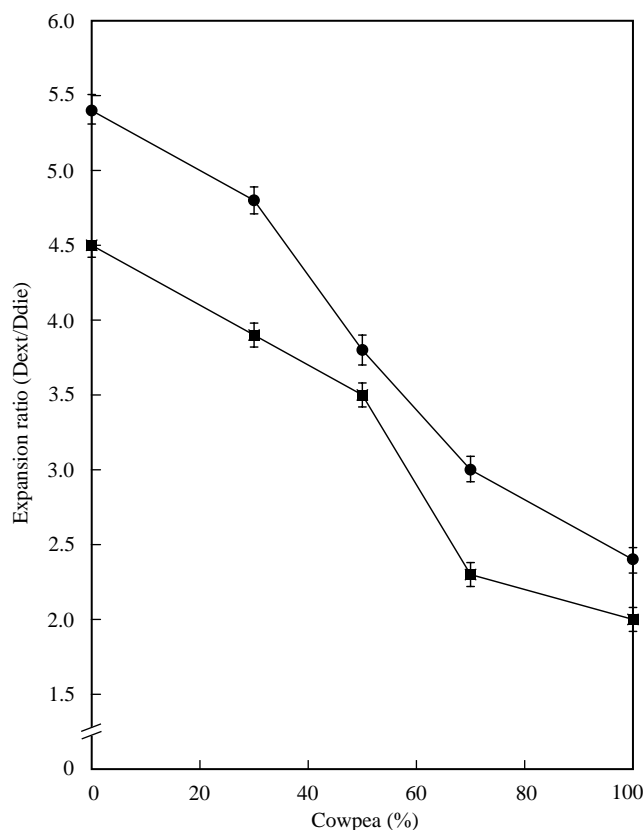
totally normal and well coherent with the physics of extrudate expansion at the die (Mercier & Feillet, 1975; Colonna et al., 1989). This indicates that the structure of extrusion-expanded products depended on starch gelatinisation. As the temperature of extrusion cooking increased, starch became more fully cooked and thus better able to expand (Balandrán-Quintana et al., 1998). A high ER is desirable in a production of ready-to-eat foods such as instant porridge.

Water absorption index
WAI increased as the proportion of cowpeas increased for both extrusion temperatures (**Fig. 6**). This can be attributed to the higher amylose/amylopectin ratio of the cowpeas. Mercier and Feillet (1975) observed that higher amylose ratio results in a higher WAI. WAI was lower at the higher extrusion temperature. This was probably due to decomposition or degradation of starch. Colonna et al. (1989) indicated that WAI decreases with the onset of dextrinisation. Gujska and Khan (1990) when extruding pinto and navy beans found that WAI increased with an increase in temperature from 110 to 132 °C. However, a further increase in temperature to 150 °C resulted in a decrease of WAI for navy beans as decomposition or degradation of starch began to take place. The porridges of 50% sorghum and 50% cowpeas at both extrusion temperatures had higher WAI than the ProNutro.
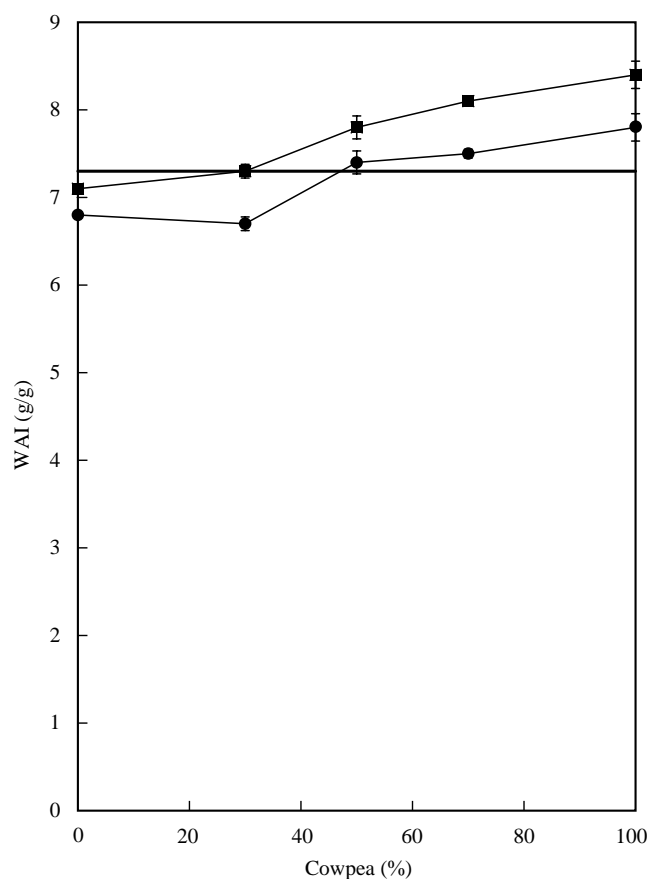
Fig. 6 Water absorption index of sorghum-cowpea composites extruded at 130 °C (■) and 165 °C (●) and that of ProNutro standard (−). Errors bars indicate ± one standard deviation
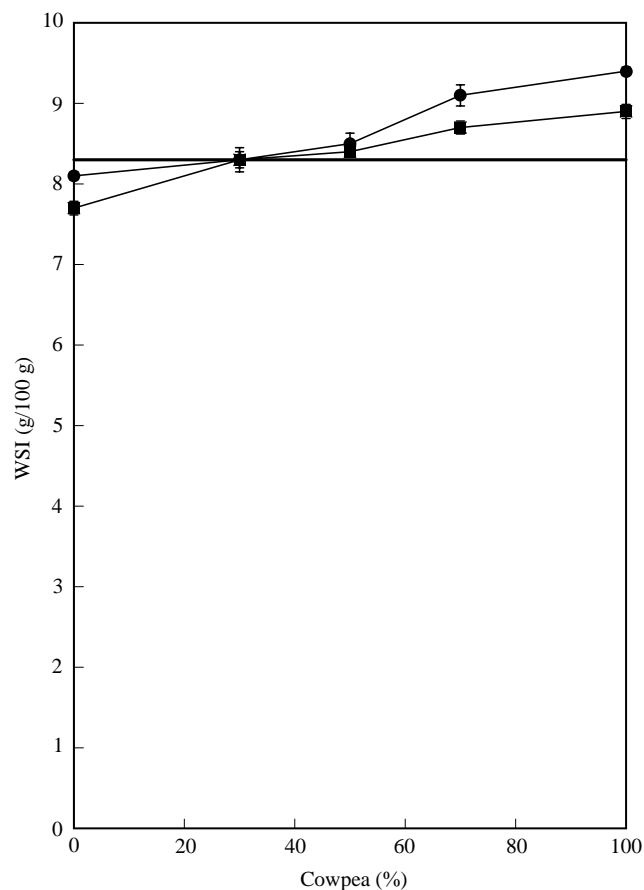

Fig. 7 Water solubility index of sorghum-cowpea composites extruded at 130 °C (■) and 165 °C (●) and that of ProNutro standard (−). Errors bars indicate ± one standard deviation

Water solubility index
WSI increased as the percentage of cowpeas increased for both extrusion temperatures (**Fig. 7**). It could be expected that WSI would decrease since extrudates of high legume content contain more starch aggregates or microgels which will be suspended in water (Gomez & Aguilera, 1983). This suggests that WSI was not only due to starch content but also due to water-soluble components, like proteins, which are present in cowpeas. Cowpea proteins have relatively higher water solubility than sorghum proteins (Serna-Saldivar & Rooney, 1995; Chavan *et al.*, 1989). The higher WSI at the higher extrusion temperature was due to the dextrinisation and depolymerisation of starch at higher temperature, reducing molecular weight of amylose and amylopectin chains. Similar results were found by other authors (Anderson *et al.*, 1969*a*, *b*; Balandrán-Quintana *et al.*, 1998; Gujska & Khan, 1990). The porridges of 50% sorghum and 50% cowpeas at both extrusion temperatures had higher WSI than the ProNutro.

Porridge firmness
The inclusion of cowpeas reduced the firmness of the porridges (**Fig. 8**). The lower firmness can be explained by the differences in amylose–amylopectin ratio in the two grains. The amylopectin molecule is more susceptible to shear forces during extrusion, its branched chains allow the water to penetrate the structure more easily and gelatinise more readily than amylose (Gujska & Khan, 1990; Rebar *et al.*, 1984). Because porridge in Africa is generally eaten with the fingers, the texture parameter firmness is particularly important (Chang *et al.*, 1989). A good, firm porridge should hold together without yielding under finger pressure when scooped from a container (Mohamed *et al.*, 1983). Thus, addition of cowpea would impact negatively on the acceptability of these products as food for adults. However, the reduced viscosity could be very beneficial for infant feeding. The high bulk (low nutrient density) of cereal weaning porridges is a major cause of infant malnutrition in Africa, since it limits nutrient intake (Da *et al.*, 1982). The addition of cowpeas not only improves the protein content and quality of the extruded porridge, but additionally the reduced viscosity would enable the porridge to be fed to infants at higher concentration, hence increasing food energy intake.
In general, severity of heat treatment did not consistently affect the firmness of the porridges.

Conclusions

Sorghum and cowpeas can be used to produce, by HTST extrusion cooking, an instant 'pre-cooked' porridge highly comparable in composition and func-
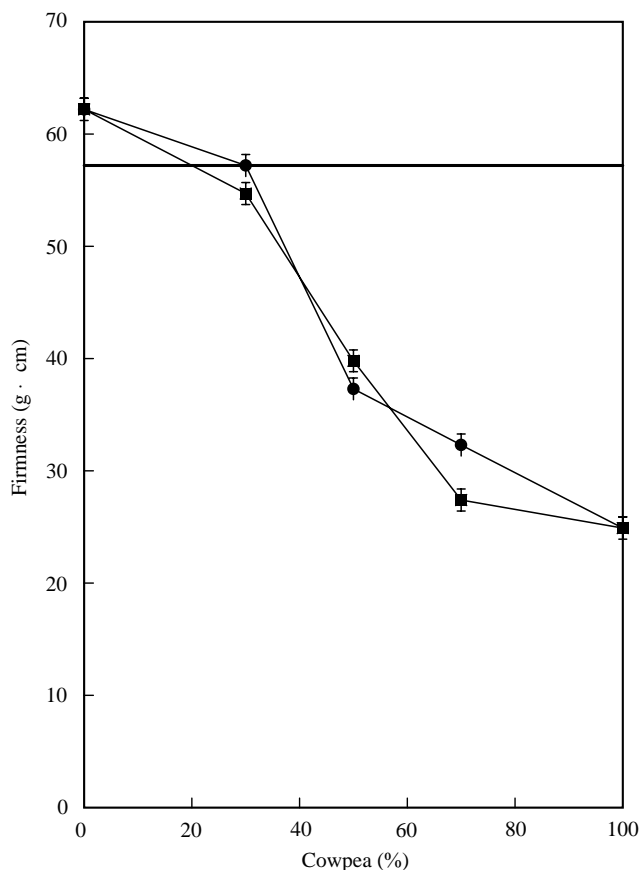
Fig. 8 Firmness of sorghum-cowpea composite porridges produced by extrusion at 130 °C (■) and 165 °C (●) and that of ProNutro standard (-). Errors bars indicate ± one standard deviation

tional properties with a commercial instant maize–soya porridge product. The use of these locally grown grains in such a product could make a great contribution to Food Security in Southern Africa. A serving of 100 g would contribute 28% of the RDA for protein, which represents a 110% increase in the RDA for protein compared to sorghum only.

Acknowledgements

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