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Production of improved infant porridges from pearl millet using a lactic acid fermentation step and addition of sorghum malt to reduce viscosity of porridges with high protein, energy and solids (30%) content

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Summary

With the aim of improving the safety and nutritional quality of traditional African weaning porridge, the reduction of the viscosity of a high solids fermented pearl millet porridge by addition of sorghum malt (amylase rich flour, ARF) was investigated. The effect of fermentation, cooking, malt addition and recooking on the microflora of, and the survival of an inoculated pathogen were determined. Addition of 5% (w/v) sorghum ARF to the gelatinized millet porridge gave an acceptable viscosity of 2500–3000 cP at a high solid content of 30%. Fermentation inhibited the growth of microorganisms in the porridge and recooking the fermented porridge after sorghum ARF addition further eliminated ($<10^2$ c.f.u./g) the moulds and coliforms that were introduced with the sorghum ARF. The recooked, fermented millet plus sorghum ARF porridge prevented the proliferation of the inoculated *Escherichia coli* and reduced it to $<10^2$ c.f.u./g within 18 h. The porridge could supply children under 3 years with the daily required protein using 1.4 feedings per day and required energy with 4 feedings a day.

Introduction

Malnutrition, mostly protein-energy malnutrition (PEM) is the cause of over 50% of childhood mortality in developing countries (Grigsby 2002). In South Africa, about 2.5 million children under the age of six are undernourished (South African Labour and Development Research Unit 1994). Stunting has been indicated among 15% of children under 12 months and higher rates (23%) were shown in weaning children of 12–23 months. According to Maclachlan & Khuzwayo (1997), the highest rate (34%) of malnutrition cases occurred in the Limpopo Province. Malnutrition results from infections/diseases (e.g. diarrhoea) caused by food-borne pathogens and/or inadequate dietary consumption due to weaning and/or feeding practices. One out of 10 children in developing countries dies due to dehydration caused by diarrhoea (Pelletier 1993). Infections are a common occurrence in rural communities often because of the lack of appropriate storage facilities (e.g. refrigerators), proper sanitation facilities and water supply.

Controlled fermentation with lactic acid bacteria (LAB) gives food a longer shelf life. It inhibits growth, survival of and toxin production by pathogenic bacteria, due to rapid growth of LAB, production of acids and the concomitant decrease in pH (Yusof *et al.* 1993; Kingamkono *et al.* 1994; Olsen *et al.* 1995). Some food fermentations also raise the protein content or improve the availability of essential amino acids (Mbugua 1984), improve *in vitro* protein digestibility (Lorri & Svanberg 1993a), enhance carbohydrate digestibility (Oyewole 1995), or provide an optimum pH condition for the degradation or reduction of phytates or tannins thus improving the bioavailability of iron (Khetarpaul & Chanhan 1989; Svanberg *et al.* 1993).

Traditional weaning foods in Eastern and Southern Africa are generally based on the local staple cereal (maize, millet, sorghum or rice) and starchy tubers (cassava, potato or plantain). Gruels or porridges made from these foods are diluted to a flour concentration of about 5–10% to attain viscosities of less than 3000 cP, the consistency suitable for feeding children younger than 3 years, and thus provide them with an energy density of only about 0.836 kJ/g, which is too low to meet their energy requirements (Mosha & Svanberg 1990; FAO/WHO 1995).

Nutrient density can be increased by thinning the prepared thick porridge with malt flour, also known as Amylase-Rich Flour (ARF), or Power Flour (PF). Small quantities of ARF (mostly wheat, maize and sorghum) when added to freshly prepared thick gruels (mostly maize and sorghum) liquefy them due to the action of α-amylase, which digests starch to dextrins and maltose (Priest & Campbell 1996). The viscosity of the gruels is then reduced without lowering their nutrient and energy density (Efiuwevwere & Akona 1995; Gimbi *et al*. 1997; Den Besten *et al*. 1998). No reports thus far have combined the use of fermented pearl millet with the addition of small quantities of sorghum ARF.

Pearl millet, an indigenous African cereal, is cultivated and available to communities in the Limpopo Province for human food and as forage. It possesses higher energy (1517 kJ/100 g), protein (11.8%) and fat (4.8%) than sorghum (1382 kJ, 10.4% protein and 3.1% fat content) and maize (1504 kJ, 9.2% protein and 4.6% fat) (FAO 1995).

The objective of this study was to examine the use of the combination of fermentation of pearl millet and the use of sorghum ARF to produce a microbiologically safe and nutritious weaning food.

Materials

Pearl millet grain was obtained from the Northern Transvaal Cooperative in Polokwane in the Limpopo Province of South Africa. To prepare the millet flour, the grains were washed, dried and milled using a coffee grinder. The flours were stored in sealed polyethylene bags at 2–4 °C. Sorghum malt flour was obtained from the Bio/Chemtek Division of the CSIR, South Africa.

Methods

Preparation of porridges

Nonfermented millet porridge with sorghum ARF (NP)
Twenty-five percent (w/v) pearl millet flour in boiling water was cooked with continuous stirring at 95 °C for about 15 min. The gruel was then put in a water bath to cool down to 35 °C. Sorghum ARF was added to a cooled porridge and was left to stand for 15 min at room temperature. At the end of 15 min, the preparation was further boiled for 5 min.

Fermented millet porridge with sorghum malt (FP)
Twenty-five percent (w/v) pearl millet flour was soaked in distilled water for 64 h at 30 °C. The slurry was then cooked with continuous stirring at 95 °C for 15 min. It was then put in a water bath to cool down to 35 °C before sorghum ARF addition. Sorghum ARF was added to a cooled porridge and was left to stand for 15 min at room temperature. At the end of 15 min, the preparation was further boiled for 5 min.

Viscosity

NP and FP were prepared as described above with the addition of different amounts of sorghum malt flour (2, 2.5, 10 and 15% (w/v)). Viscosities were measured after 15 min using the Haake Rotovisco Model RV3 viscometer with a SV1 Rotor at a shear rate of 54 rev/min.

Microbial population

Samples (10 g) were placed in sterile bags and homogenized in 90 ml sterile diluent (0.1% peptone, 0.85% NaCl), for 30 s. Tenfold serial dilutions were prepared in triplicates of appropriate dilutions and plated onto MRS (Oxoid) for LAB count, PCA (Oxoid) for total aerobic count, PDA (Oxoid) for yeast and mould count and MacConkey (Oxoid) for coliforms. MRS plates were incubated at 30 °C for 48 h, PDA plates at 25 °C for 64 h and MacConkey plates at 37 °C for 24 h before colony enumeration (Kandler & Weiss 1986).

pH and titratable acidity

The pH of the samples (10% slurry in distilled H_2O) was measured. The titratable acidity (TA), reported as % lactic acid equivalent was determined by titration of a 5 g sample mixed with 50 ml distilled H_2O against 0.1 M NaOH to an end point of pH 8.5 while stirring continuously. TA was then expressed as % lactic acid.

Inoculation with Escherichia coli

To 50 g NP and FP, 1 ml (about 10^6 c.f.u./ml) of *Escherichia coli* (ETEC, ATCC 25922) was added. The porridges were incubated with controls at 37 °C. Samples (1 g) were taken after 0, 4, 8, and 18 h for pH and TA determination (Olsen *et al*. 1995).

Nutritional profile

The feed volumes to meet the energy and protein requirements of infants and older children were calculated using Recommended Dietary Allowances tables for children, birth to age three (Food and Nutrition Board 1989).

Statistical analysis

Paired and unpaired *T*-tests were performed using MS-Excel to determine the probabilities of populations having the same or different mean values.

Results and discussion

Porridge viscosity

Addition of different amounts (2, 2.5, 5, 10 and 15% (w/v)) of sorghum ARF to NP and FP rapidly (within

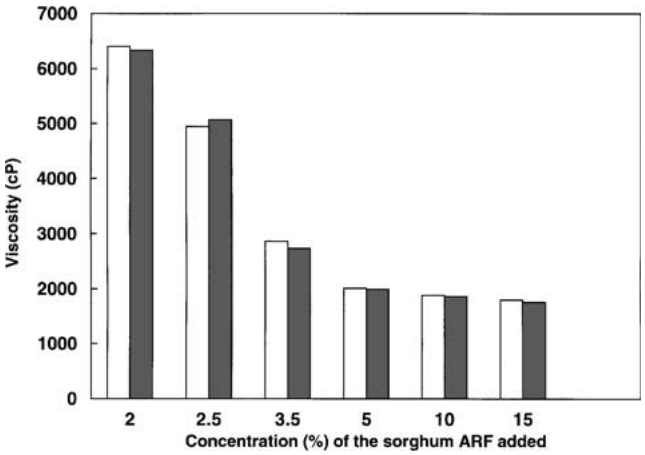

Figure 1. Effect of sorghum ARF addition on the viscosity of a 25% (w/v) pearl millet porridge. Averages of two experiments are shown. Relative standard deviation is <6%. NP (□) – non-fermented product; FP (■) – fermented product.

10 min) reduced their viscosities. The amount of reduction was related to the ARF concentration (Figure 1). The optimum reduction was obtained when 5% (w/v) sorghum ARF was added, when the viscosities of NP and FP were reduced to semi-liquid consistencies of 2864 and 2731 cP, respectively. Semi-liquid porridge consistencies of 2500–3000 cP are regarded as preferable for feeding young children (Mosha & Svanberg 1983). Mosha & Svanberg (1983) also demonstrated that addition of a small amount (5%) of germinated sorghum flour to cooked sorghum porridge decreased the viscosity to a semi-liquid consistency suitable for child feeding. Thick porridge (over 10,000 cP) can be liquefied in this way, and the energy density can be increased while an acceptable low viscosity of 2500–3000 cP is maintained. There were differences in the viscosity reduction between the fermented and unfermented sample after the addition of ARF with the viscosities of FP samples being generally slightly lower. This may have resulted from amylase production by microorganisms during fermentation or the fact that microbial amylases have been shown to work better in acidic environments (Lorri & Svanberg 1993b).

Microbial population

Table 1 shows the total count, LAB, yeast, moulds and coliforms from samples taken at different stages in the preparation of fermented pearl millet plus sorghum ARF porridge, i.e. the non-fermented and fermented pearl millet flour, fermented cooked pearl millet porridge, the porridge with added sorghum ARF and the recooked millet + sorghum ARF porridge. Raw pearl millet flour possessed a high microbial load with a total count of 2.4×10^5 c.f.u./g, LAB 1.1×10^4 c.f.u./g, yeast 6.0×10^3 c.f.u./g, moulds 1.2×10^5 c.f.u./g, and coliforms at 1.8×10^4 c.f.u./g. Fermentation of the millet flour for 64 h resulted in a higher total count of 10^8 c.f.u./g, with LAB increasing to 10^7 c.f.u./g, whereas the yeast, moulds and coliforms numbers were reduced to below detection level of $<10^2$ c.f.u./g. As would be expected, cooking substantially decreased the LAB and total count to 10^3 c.f.u./g and the yeast, moulds and coliforms remained undetectable. The addition of sorghum ARF brought about an increase in the total counts to 10^7 c.f.u./g, the LAB to 10^6 c.f.u./g, the yeast to 10^6 c.f.u./g, and moulds and coliforms both to 10^4 c.f.u./g. Subsequent recooking of the millet porridge plus sorghum ARF mixture profoundly decreased the microbial load, to a total count of 10^3 c.f.u./g, LAB of 10^2 c.f.u./g, yeast of 10^2 c.f.u./g, and moulds and coliforms to an undetectable level.

The high microbial load in the pearl millet flour probably resulted from contamination during storage and processing of the millet grains. Fermentation reduced yeast, moulds and coliforms to below the detectable level, as they did not survive the low pH (3.7) reached after 48 h fermentation (Kingamkono *et al.* 1994) and possibly because of other inhibitory substances which can be produced by LAB (De Vuyst & Vandamme 1994). Olukoya *et al.* (1994) and Kingamkono *et al.* (1994) have demonstrated the inhibition of different pathogens and other microorganisms by fermented sorghum and maize gruels. Cooking the fermented millet flour to produce porridge further reduced the microbial load, though the yeast, moulds and coliforms had already been eliminated by fermentation. The low microbial levels obtained after cooking were similar to those obtained by Mensah *et al.* (1991) when cooking a fermented maize dough. Addition of the sorghum ARF increased the microbial load of the porridge to very high, unacceptable levels (10^7 c.f.u./g). The high microbial load of the raw sorghum malt was introduced during the malting process, whereby the sorghum grains are sprouted, dried and then ground to flour without being sterilized (Rabie & Lübben 1984).

Table 1. Effect of cooking, fermentation and sorghum ARF addition on the microflora of pearl millet porridge (c.f.u./g).

Sample	Total count	LAB	Yeast	Moulds	Coliforms
Pearl millet flour	2.4×10^5	1.1×10^4	6.0×10^3	1.2×10^5	1.8×10^4
Fermented pearl millet dough	5.0×10^8	8.2×10^7	$<10^2$	$<10^2$	$<10^2$
Cooked fermented millet porridge	4.8×10^3	4.2×10^3	$<10^2$	$<10^2$	$<10^2$
Cooked fermented millet porridge + sorghum ARF	2.0×10^7	1.9×10^6	1.3×10^6	2.4×10^4	4.8×10^4
Recooked fermented millet porridge + sorghum ARF	1.1×10^3	6.3×10^2	5.0×10^2	$<10^2$	$<10^2$

Averages of two experiments are shown. Relative standard deviation is <2%.

A high level of fungi carries the risk of the presence of mycotoxins (Briggs 1998). Recooking the porridge after the malt addition eliminated fungi and coliforms, though yeast were still detectable.

Survival of pathogens

When *E. coli* (Figure 2) was inoculated into unfermented porridge (NPE) it increased from 10^7 to 10^9 c.f.u./g after 18 h, whereas the LAB increased from undetectable to about 10^5 c.f.u./g (Figure 3). When *E. coli* was inoculated into fermented porridge (FPE) it was reduced from 10^7 to undetectable levels after 18 h of incubation (Figure 2) and the LAB increased from 10^4 to 10^6 c.f.u./g (Figure 3). *E. coli* was not detected in uninoculated samples, unfermented (NP) and fermented (FP) throughout the whole experiment (Figure 2), whereas the LAB increased from being undetectable to a count of about 10^4 c.f.u./g for NP and from 10^3 to about 10^7 c.f.u./g for FP within 8–18 h (Figure 3).

The decrease in the numbers of *E. coli* in the fermented porridge (FPE) coincided with lower pH values (Figure 4) of $\leq$3.9 and higher levels of titratable acidities (1.9–2.1% lactic acid) (Figure 5), as compared to pH of $\leq$5.9 and titratable acidities of between 0.8 and 1.6% lactic acid of an unfermented porridge (NPE) over a period of 18 h. Thus a cooked fermented pearl millet plus sorghum ARF porridge is incapable of supporting growth of an enteropathogen such as *E. coli* after being contaminated at the stage of consumption. Simango & Rukure (1991) also reported that *E. coli* showed a marked decrease in numbers 24 h after inoculation in mahewu, a fermented maize gruel. Inhibition of *E. coli* added to a prefermented rice-based weaning food model has also been demonstrated by Yusof *et al.* (1993).

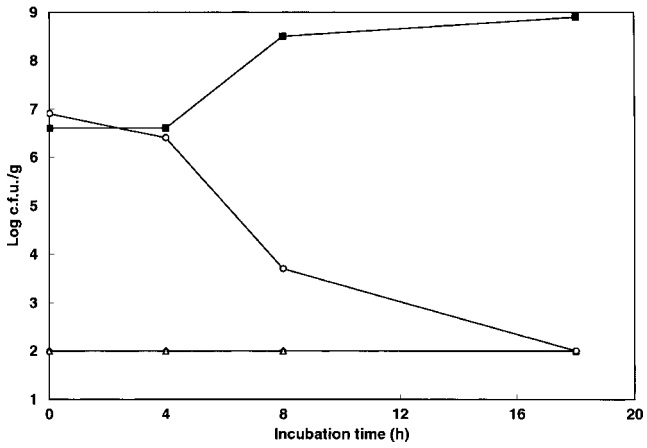

Figure 2. Growth pattern of *E. coli* in non-fermented and fermented pearl millet plus sorghum malt porridges with and without *E. coli* inoculation. Averages of two experiments are shown and the relative standard deviation is < 5%. NP (♦) – non-fermented without *E. coli* inoculation; NPE (■) – non-fermented with *E. coli* inoculation; FP (△) – fermented without *E. coli* inoculation; FPE (○) – fermented with *E. coli* inoculation.

Nutritional profile

A survey (results not shown) showed that the most common weaning foods in the three investigated areas of the Limpopo Province are the thin maize, sorghum and sometimes millet porridges containing about 10% solids. On a dry basis the protein content of 100 g of

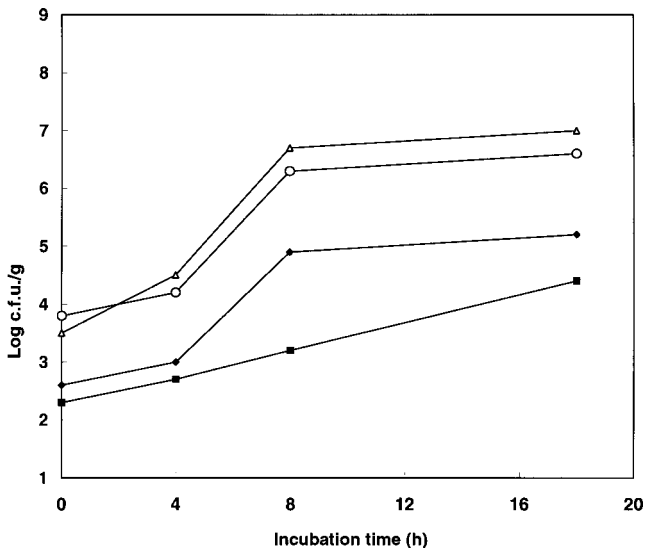

Figure 3. Growth pattern of LAB in non-fermented and fermented pearl millet plus sorghum malt porridges with and without *E. coli* inoculation. Averages of two experiments are shown and the relative standard deviation is < 5%. NP (♦) – non-fermented without *E. coli* inoculation; NPE (■) – non-fermented with *E. coli* inoculation; FP (△) – fermented without *E. coli* inoculation; FPE (○) – fermented with *E. coli* inoculation.

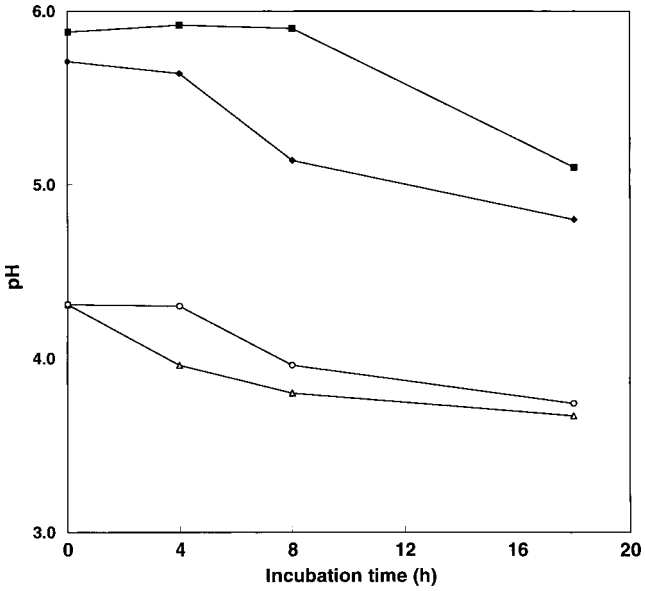

Figure 4. Changes in pH during incubation of non-fermented and fermented pearl millet plus sorghum malt porridges with and without *E. coli* inoculation. Averages of two experiments are shown and the relative standard deviation is < 3%. NP (♦) – non-fermented without *E. coli* inoculation; NPE (■) – non-fermented with *E. coli* inoculation; FP (△) – fermented without *E. coli* inoculation; FPE (○) – fermented with *E. coli* inoculation.

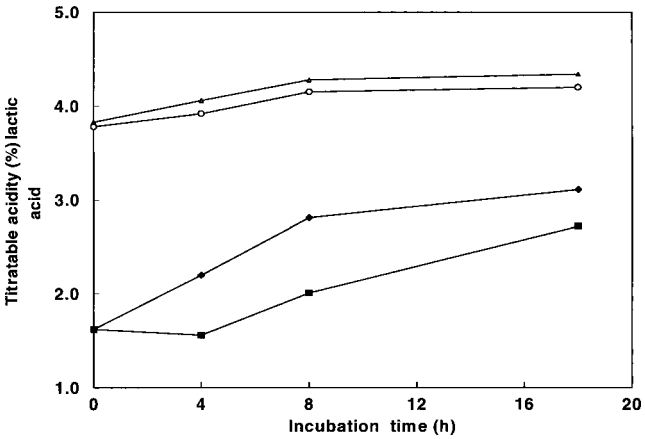

Figure 5. Changes in titratable acidity (TA) during incubation of non-fermented and fermented pearl millet plus sorghum malt porridges with and without *E. coli* inoculation. Averages of two experiments are shown and the relative standard deviation is <3%. NP (♦) – non-fermented without *E. coli* inoculation; NPE (■) – non-fermented with *E. coli* inoculation; FP (△) – fermented without *E. coli* inoculation; FPE (○) – fermented with *E. coli* inoculation.

Table 2. The RDA of protein and energy for children under 3 years and the nutritive value of the traditional porridges foods as compared with the proposed porridge (g/100 g dry weight of edible food).

	Protein (g)[a]	Energy (kJ)[a]
RDA[b]		
0–0.5 year	12	2722
0.5–1 year	13	3704
1–3 years	16	5569
Traditional porridges		
10% Maize	1.05	173
10% Sorghum	1.18	157
10% Millet	1.34	173
Proposed porridge		
(30% millet plus sorghum ARF)	3.94	512

[a] Calculated using the composition tables published by the Food and Agricultural Organization (FAO 1995).
[b] Adapted from the Food and Nutrition Board (FNB 1989).

pearl millet is 22% higher than that of maize and 12% higher than that of sorghum (Table 2). Pearl millet seems to be superior to maize and sorghum with respect to protein content. However, its protein quality has raised some concern because of low lysine content (Serna-Saldivar *et al.* 1991). The protein quality of pearl millet is superior to that of other cereals and pearl millet has greater potential to meet the lysine requirements of growing children than most cereals (FAO 1995). Its energy content is 9% higher than that of sorghum and equal to that of maize. The estimated protein and energy content of the proposed 25% (w/v) millet plus 5% (w/v) sorghum ARF porridge is higher than that of the traditional porridges made from 10% (w/v) maize, sorghum and millet porridges. It should be noted that in the absence of nutrient composition data for fermented millet and sorghum ARF, the data for unfermented millet and ungerminated sorghum flours were used to estimate the protein and energy contents. Thus the estimates do not include any changes in the protein and energy content due to fermentation of millet or germination of sorghum.

According to the RDA (recommended dietary allowances) of energy and protein for children under 3 years, volumes ranging from 970 ml (0–6 months) to 1524 ml (1–3 years) a day are required to satisfy a child's needs for protein with the traditional 10% maize, sorghum and millet porridges (Table 2). On the other hand, infants (0–6 months) can consume a maximum volume of 130 ml of porridge per feed whereas toddlers aged 6–12 months and 1–3 years can consume maximum volumes of 260 and 300 ml, respectively (Pipes & Trahms 1994). This implies that a child will have to consume 5–10 feedings a day of the traditional 10% (w/v) maize or sorghum porridges and 4–9 feedings a day of the 10% millet porridge to meet their daily protein requirements (Table 3). Mothers do not always have the time and fuel to prepare meals up to 12 times a day. With the proposed 25% (w/v) millet plus sorghum ARF (5% w/v), lower volumes of 329 ml (0–6 months), 355 ml (0.5–1 year) and 406 ml (1–3 years) will meet the daily protein requirements and volumes of 531 ml (0–6 months), 723 ml (0.5–1 year) and 1088 ml (1–3 years) will meet daily energy requirements. Therefore children would generally have to consume 3–4 feedings a day to obtain their protein and energy requirements.

Conclusions

The study resulted in a weaning porridge with a total solids content of 30% made from fermented 25% (w/v)

Table 3. Maximum stomach capacity of children under three with the estimated volumes (ml) and number of servings per day (in brackets) to meet the RDA for protein and energy of children using the traditional porridges and the proposed millet plus sorghum ARF porridge.

Age (years)	Maximum stomach capacity/meal (ml)		Porridges			
			10% (w/v) maize	10% (w/v) sorghum	10% (w/v) millet	30% millet plus sorghum ARF
0.0–0.5	130	Protein	1238 (9.5)	1102 (8.5)	970 (7.5)	329 (2.5)
		Energy	1573 (12.1)	1734 (13.3)	1573 (12.1)	531 (4)
0.5–1	260	Protein	1333 (5.1)	1186 (4.6)	1045 (4.0)	355 (1.4)
		Energy	2141 (8.2)	2359 (9.1)	2141 (8.2)	723 (2.8)
1–3	300	Protein	1524 (5.1)	1356 (4.5)	1194 (4.0)	406 (1.4)
		Energy	3258 (10.9)	3547 (11.8)	L3258 (10.9)	1088 (3.6)

pearl millet plus 5% (w/v) sorghum ARF with a semi-liquid consistency of 2500–3000 cP which is suitable for feeding young children. Recooking the porridge eliminates moulds and coliforms that are introduced with the addition of sorghum ARF. Inoculated *E. coli* could not grow in the final porridge that was ready for consumption. The porridge could supply children under 3 years with the daily required protein and energy levels at a feasible feeding regime of 3–4 feedings a day, depending on their age.

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