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Review

Complementary food blends and malnutrition among infants in Ghana: A review and a proposed solution

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Widespread malnutrition among Ghanaian infants could be attributed to unfortified plant-based complementary foods commonly used at the household level. This review summarises the publications on the development of complementary food blends and intervention trials aimed at improving the nutritional status of Ghanaian infants. The complementary food blends are cereal-based which are developed from maize (in higher proportion) together with soyabean, cowpea and/or groundnut-an effort to improve protein and energy levels. The cereal-legume blends affect growth more positively than cereal-only formulations but not micronutrient status unless fortified with micronutrients. The low level of micronutrients (including vitamin A) and the high phytate content of cereal-legume blends partly account for micronutrient deficiencies. Phytate limits the bioavailability of nutrients such as iron, calcium and zinc. We propose an alternative complementary food blend which is based on sweet potato. This proposed formulation would be relatively high in endogenous β-carotene (vitamin A precursor) and low in phytate compared to household-level cereal-based complementary foods.

Key words: Cereal-legume, complementary food, Ghana, malnutrition, phytate, sweet potato.

INTRODUCTION

The level of childhood malnutrition in Sub-Saharan Africa, an area that includes Ghana, is among the worst in the world. The proportion of children under 5 years with chronic malnutrition (<-2 SD from the reference median for height-for-age) in Sub-Saharan Africa was 38%, against a worldwide prevalence of 28% (UNICEF, 2009). Globally, an estimated 33% of children under 5 years were vitamin A deficient; in Africa, the prevalence was higher (42%) (WHO, 2009). Although the prevalence of anaemia (haemoglobin threshold of ≤110 g/L) among children under 5 years was a worldwide problem (47%), the occurrence was markedly higher (68%) in Africa (de Benoist et al., 2008). Infants are more likely to become malnourished in low-income countries when complementary foods are introduced (Dewey et al., 1992; Dewey, 1998; Gibson et al., 1998; Lutter and Rivera, 2003). The inadequacy of infant nutrition and its negative influence on attainment of full potential in life is now well established (Pan American Health Organization (PAHO) and WHO, 2003; Engle et al., 2007; Adu-Afarwuah et al., 2008; Beard, 2008). Grantham-McGregor et al. (2007) suggested that poor nutrition during infancy is likely to lead to poor academic achievement, low incomes in adulthood and inadequate care for the children of subsequent generations. This cycle has contributed to the inter-generational poverty bedevilling low-income countries in South Asia and Sub-Saharan Africa (Walker et al., 2007). Therefore, a review of the types of complementary foods available/being promoted in low-income countries, such as Ghana, demands more attention. Ghana was chosen because of the vigorous efforts by local and international researchers to improve the nutritional status of infants during the last two decades in the country.

This review is limited to publications on the formulation

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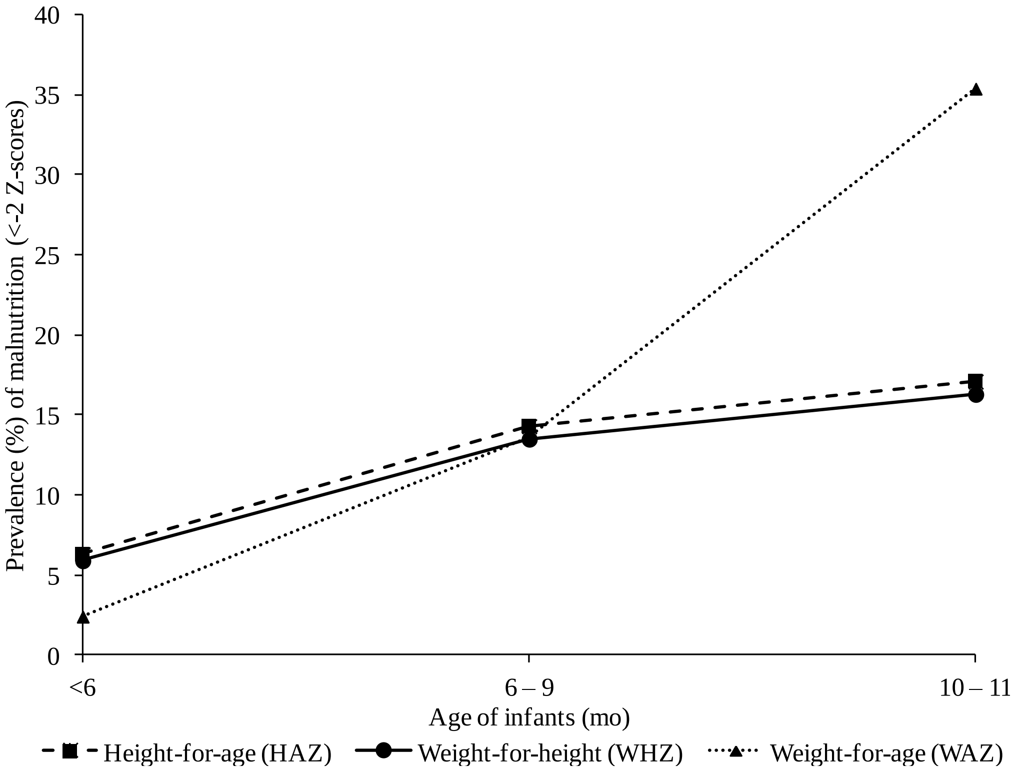

Figure 1. Percentage of infants under 12 months classified as malnourished using height-for-age (HAZ), weight-for-height (WHZ) and weight-for-age (WAZ) Z-scores* *Source: GSS (2004). Each index was expressed in standard deviation (SD) units from the median of the NCHS/CDC/WHO International Reference population.

of complementary foods based on cereal-legume blends and nutritional feeding trials conducted on complementary foods in Ghana. Reports on unfortified cereal-only formulations based on maize, millet or sorghum were not considered because such products have low energy and protein density (Lartey et al., 1997) and contribute to protein-energy malnutrition (Walker, 1990). A negative association between consumption of cereal-only (fermented maize) porridge and child nutritional status among Ghanaian infants has been established (Appoh and Krekling, 2005). Also, nutritional interventions involving the use of vitamin and/or mineral supplements only rather than added to complementary food prior to consumption, such as vitamin A supplementation, do not fall in the scope of this review. The database search for studies on the development of cereal-based complementary food blends and intervention trials involving complementary foods was done in Scopus, ISI Web of Knowledge℠ and Google scholar. Two Ghana Demographic Health Survey (GDHS) reports published in 2004 and 2009 (Ghana Statistical Service (GSS), 2004; GSS, 2009) were used to get information on feeding practices and nutritional status of Ghanaian infants. In Ghana, micronutrient deficiencies and growth faltering predicaments are worse in children under 5 years and particularly in infants after the transition from exclusive breastfeeding to complementary feeding. Figures 1 and 2 show the prevalence of growth faltering among infants <1 year using the anthropometric indices: low height-for-age (stunting), low weight-for-height (wasting) and low weight-for-age (underweight).

According to the 2004 GDHS report, the proportion of infants who were stunted (<-2 SD) was lower among infants <6 months of age (6.3%) than among infants 10 to 11 months old (17%) (Figure 1); in 2008 (Figure 2), the prevalence level followed a similar trend. It is not possible to compare the data in the two reports because different reference medians and age categorisations were used. However, both chronic and acute malnutrition indicators (stunting and underweight or wasting, respectively) had a similar trend in both reports: higher among infants 6 months old onwards. The national prevalence of anaemia (≤100.0 g/L haemoglobin) according to the GDHS 2004 report was 75% among the 6 to 9 months old infants, but in the 10 to 11 months olds, the prevalence was 86%. Similar occurrence levels and patterns are reported in the GDHS 2009 report (76% for 6 to 8 months olds and 88% for 10 to 11 months olds). The causes of anaemia were attributed to inadequate dietary intake of iron, intestinal worm infestation and malaria. There were no data on

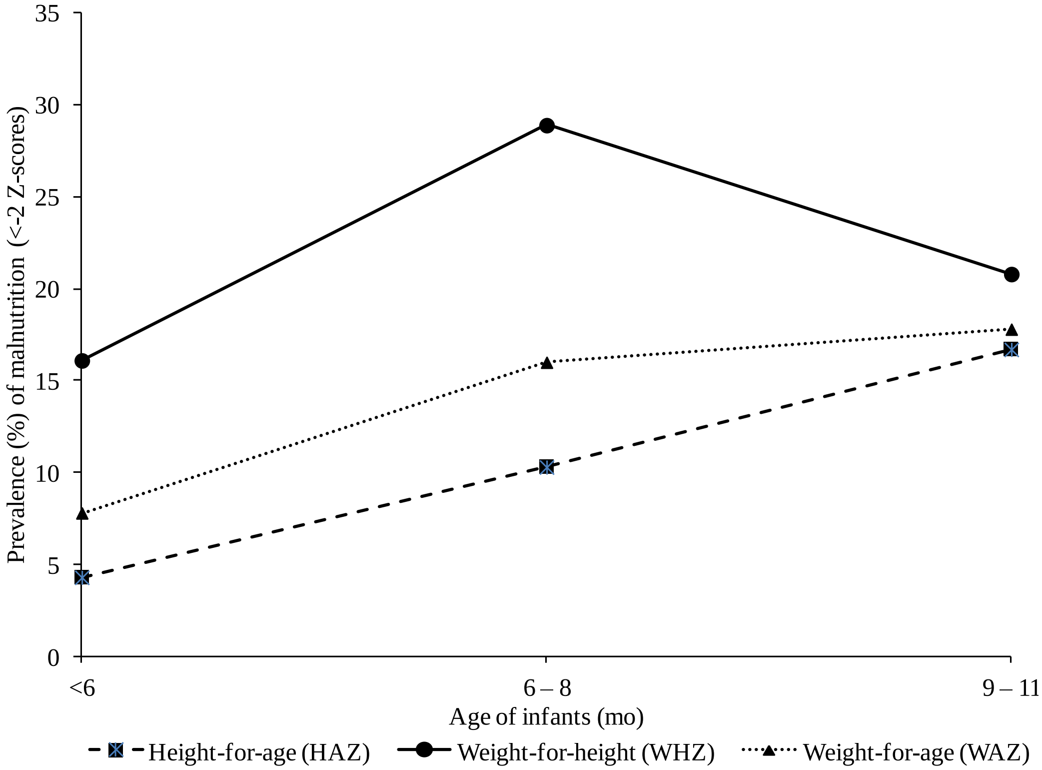

Figure 2. Percentage of infants under 12 months classified as malnourished using height-for-age (HAZ), weight-for-height (WHZ) and weight-for-age (WAZ) Z-scores* *Source: GSS (2009). Each index was expressed in standard deviation (SD) units from the median of the WHO Child Growth Reference Standards published in 2006.

vitamin A deficiency (VAD) in either the GDHS 2004 or 2009 reports. However, a prevalence of 76% VAD among Ghanaian infants and young children <5 years old using blood serum retinol of <0.70 µmol/L as cut-off has been reported elsewhere (WHO, 2009). This high VAD prevalence is despite a vitamin A supplementation programme with 95% coverage in which at least one of the required two doses offered was administered (UNICEF, 2009). This suggests that vitamin A supplementation alone will not bring the desired effect unless complemented by regular dietary intake of vitamin A.

The pattern of prevalence (lower around 6 months of age and higher 8 months of age and onwards) of anaemia and VAD among Ghanaian infants stated earlier, could undoubtedly be associated with food, specifically, complementary food as the major causal factor. The mean duration of exclusive breastfeeding and predominant breastfeeding in Ghana was 3.8 and 6.9 months, respectively from 1999 to 2002 (GSS, 2004). Predominant breastfeeding was defined as either exclusively breastfeeding or breastfeeding and consuming water only and/or non-milk liquids only. From 2004 to 2007, exclusive breastfeeding or predominant breastfeeding duration was 4.4 or 6.2 months, respectively (GSS, 2009). The percentage of infants between 12 to 15 months who were breastfeeding was about 95% in both GDHS reports. About 53% of infants from 1999 to 2002 and 63% from 2004 to 2007 were exclusively breastfed for the first 6 months of infancy. Thus, about 40% of infants in Ghana are introduced to complementary food before the recommended period of exclusive breastfeeding of 6 months (WHO, 2001); this is despite initiatives by the Ghana Health Service in establishing baby friendly centres in most health care facilities to encourage exclusive breastfeeding for the first 6 months nationwide. Comparison of the data from the GDHS reports indicates that there was a slight improvement in infant feeding practices in 2008 compared to 2003. From data in Table 1, the number of infants given complementary food from 6 months, when breast milk alone is likely to be insufficient (UNICEF, 1998; PAHO and WHO, 2003) to meet the nutrient demands of infants, was higher in 2008 than 2003 (75 versus 62%). Likewise, the proportion of infants who were exclusively breastfed for the first 6 months of infancy was higher in 2008 than 2003 as indicated earlier.

The percentage of infants who were breastfed 6 months onwards and consumed water alone was higher in 2003 (23%) than in 2008 (16%). Furthermore,

Table 1. Breastfeeding practices* (%) among Ghanaian infants.

Age of infants (months)	Exclusive breastfeeding		Breastfeeding and consuming plain water		Breastfeeding and consuming					
					Water–based liquids		Milk products (non–human)		Complementary food	
	2003	2008	2003	2008	2003	2008	2003	2008	2003	2008
<6	53.4	62.8	24.0	17.1	1.2	0.6	5.5	2.6	15.6	16.9
6–9	9.6	4.1	22.8	15.9	2.4	0.7	2.7	1.1	62.2	75.3

Source: GSS (2004, 2009); *Breastfeeding practice refers to a "24-h" period (yesterday and last night) status. For 2003, *n* = 308 for infants <6 months old and *n* = 239 for infants 6-9 months old; 2008, *n* = 308 for infants <6 months old and *n* = 188 for 6-9 months old.

Table 2. Types of complementary foods (%) given to infants using a "24-h" period (yesterday and last night) recall.

Age of infants (mo)*	Infant formula		Grains[†]		Legumes and nuts[‡]		Fruits and vegetables[§]		Root and tuber[||]		Animal source[¶]	
	2003	2008	2003	2008	2003	2008	2003	2008	2003	2008	2003	2008
6–8/9	11.2	13.7	53.1	53.2	10	9.7	28.9	54.2	12.3	16.6	20.9	28.4

Source: GSS (2004, 2009); *2003, *n* = 238 for infants 6–9 months old, 2008, *n* = 144 for infants 6–8 months old; [†]Porridge prepared from maize, millet or sorghum; [‡]Beans (including soyabean) and groundnuts; [§]Includes those rich in vitamin A: pumpkin, red or yellow yams or squash, carrots, red sweet potatoes, green leafy vegetables, mangoes, papayas, and other locally grown fruits; [||]White potatoes, white yams, cocoyam or cassava; [¶]Meat, fish, shellfish (prawn or lobster), poultry or eggs.

complementary foods given to infants contained more fruits and vegetables and included more animal derived foods in 2008 than in 2003 (Table 2). In rural settings of Ghana, porridge prepared from cereals such as maize, millet or sorghum is usually the first complementary food. The data in Table 2 show that about half of Ghanaian infants are given this cereal-only porridge as their normal complementary food, an unsuitable complementary food which has been associated with poor nutritional status in infancy (Appoh and Krekling, 2005). The average energy level is about 100 kJ/100 g and the average protein level is 0.6/100 g (Lartey et al., 1997) compared to desirable levels of at least 1670 kJ/100 g and 15/100 g, respectively (Codex Alimentarius Commission, 1991).

Efforts to improve the nutritional status of Ghanaian infants

Attempts have been made by international organisations and local researchers to improve the energy and protein content of complementary foods for infants in Ghana. In 1987, UNICEF collaborated with the Nutrition Unit of the Ministry of Health, Ghana to formulate a cereal-legume complementary food called Weanimix which can either be processed at household or industrial level (Agble, 1997; Lartey et al., 1999). It contains 75 to 80% maize, 10 to 15% soyabean/cowpea and 10% groundnut. A number of such improved complementary foods (with regards to energy and protein) have been developed using a range of ingredients, though these are generally driven by intent to incorporate a particular crop to conform to the objectives of funding agencies. Product composition and processing of complementary food blends are presented in Table 3. Key summary points of the formulations of complementary foods are:

i) Most of the formulations include maize (predominantly) together with legumes such as soyabean, cowpea or groundnut; soyabean is the most popular legume added to maize. This, coupled with the data in Table 1 (from GDHS reports), indicates that the complementary foods given to infants are mostly cereal-based.

ii) All the formulations involve the combination of flours from the grains/seeds prepared by roasting and milling.

Table 3. Complementary food formulations developed for Ghanaian infants.

Authors	Composition and focus	Major findings and conclusion
Annan and Plahar (1995)	Maize (70%), soyabean (20%), groundnut (5%) and full–fat milk powder (5%). This combination was to meet the minimum protein requirement of 15% in the Codex Alimentarius Commission standards. This formulation was referred to as FRI Weaner	The FRI Weaner had protein (17.1/100 g), fat (10.56/100 g) and carbohydrate (67.80/100 g); these were similar to the levels in Nestlé® Cerelac®–a nutritionally adequate commercial cereal-based complementary food in Africa. FRI Weaner was higher in fat and protein by a difference of 84 and 56%, respectively compared with traditional tom brown (TTB)–roasted maize only flour. FRI Weaner and Cerelac supported growth of weanling albino rats better than TTB based on anthropometric and biochemical data. The FRI Weaner could be used as an ideal weaning food to improve nutritional status of infants and help to alleviate protein–energy malnutrition.
Mensah et al. (1995)	Maize and soyabean in ratio of 4:1. The complementary food blends were either fermented (F) or non–fermented (NF). Focus was on acceptability and nutrient intake of porridge from the complementary food blends compared with traditional fermented maize–only (P) porridge among infants recovering from diarrhoea.	Mothers rated P more highly accepted than F and NF. However, using quantitative intake by infants as an index of acceptability, there were no differences among the three products. Daily protein and energy intakes for NF and F were higher by a difference of at least 78% (protein) and 65% (energy) than for P. The high nutrient density of NF and F porridges make them better suitable vehicle for macronutrients supply during the recovery diarrhoea than P.
Nti and Plahar (1995)	Maize and cowpea. To replace maize flour with cowpea flour in proportions: 0, 20, 30, 40 and 100% and assess the protein quality and chemical characteristics of such complementary food blends. Also, the effect of amino acid supplementation of the maize-cowpea blend on protein quality was assessed.	Protein level increased with increasing cowpea flour substitution at 20, 30 and 40% (13 to 15% for maize:cowpea blend versus 10% for maize only flour) but fat (3.5 to 4.1% versus 4.8% and carbohydrate (79 to 81% versus 83%) levels decreased. Calcium and iron contents of the maize:cowpea blend were higher than the maize only flour: calcium (42.6 to 53.8 mg/100 g versus 33.9 mg/100 g) and iron (5.5 to 6.3 mg/100 g versus 4.0 mg/100 g). Increasing levels of cowpea flour in maize–cowpea blend led to increase in the levels of lysine (3.9 to 4.8/16 g N compared with 2.6/16 g N for maize–only flour) and tryptophan (0.8 to 1.0/16 g N against 0.7 g/16 g N for maize), but a decrease in cysteine and methionine (4.7/16 g N for maize flour compared with 3.4 to 3.9/16 g N for the maize–cowpea blend. The protein score for the maize–cowpea blend was higher (62–78%) than for maize flour (43%).

Table 3. Contd.

		Addition of tryptophan, lysine, tryptophan and methionine to maize:cowpea (70:30) blend improve the protein quality–biological value (82% compared with 67% without supplementation) and net protein utilisation (73% against 61% without supplementation) using Wister rats as model.
Mensa-Wilmot et al. (2001a, 2001b, 2003)	Maize (43%) cowpea (42%) and groundnut (15%); maize (50%), cowpea (35%), soyabean (10%), soyabean oil (5%). These two blends were formulated to meet daily requirement for energy, two-thirds to three–quarters of daily protein requirement and at least a third of essential nutrients for 0.5 to 0.9 year old infant.	The levels of protein (17–19/100 g), fat (6 to 9/100 g) and energy (1720 to 1760 kJ/100g) of the extrudates indicated that the formulations could be used as weaning supplements. The formulated blends were sufficient to support growth because of the protein quality indices: true protein digestibility of the blends ranged from 87 to 92% compared with 96% for casein, and the protein digestibility corrected amino acid score ranged from 0.72 to 0.82 Sensory data showed that the formulation were least preferred in colour, flavour, texture and general acceptability compared with two commercial products (Nestlé® Cerelac® and Nestlé® Frisocreme®, Nestle Ghana). However, mothers found the processing of weaning food from local staples attractive.
Plahar et al. (2003a, 2003b)	Maize (75%), groundnut (10%) and soyabean (either roasted or not roasted) (15%).	The extruded non-roasted and extruded preroasted weaning formulations had higher protein (17/100 g) than roasted maize only flour (9.2/100 g). The energy content was similar for the extruded formulations and roasted maize product (1600 versus 1580 kJ/100 g, respectively). The extruded formulations had excellent rat growth response than the roasted maize formulation, indicating high protein quality of the cereal-legume blends. The extruded cereal-legume blends were more accepted and had better consistency when prepared as porridge compared to roasted maize product.
Nelson-Quartey et al. (2007)	Maize (malted), breadfruit pulp, breadnut seed and/or groundnut in varying proportions. The blends were enriched with full–fat milk powder and carrot. Sugar was added as a sweetener.	Blends were higher in nutrient compared to Traditional tom brown (roasted maize flour). The protein level was between 13.9 and 16.0/100 g and fat was from 6.6 to 12.0/100 g. Malting of cereals reduced the viscosity and increased the solubility of the complementary food formulations. One formulation containing 50% breadfruit pulp, 40% malted maize and 10% groundnuts had the most preferred sensory attributes.

Table 3. Contd.

Amankwah et al. (2009)	Maize (fermented) (43.96%), rice (31.81%), soyabean (20.09%) and fishmeal (4.14%); Maize (fermented) (51.53%), soyabean (25.97%) and rice (22.50%)	Protein contents of the formulation containing the fishmeal and without fishmeal were 19.13 and 17.18/100 g, respectively with corresponding 1690 and 1650 kJ/100 g as energy; both satisfying the Codex Standard specifications. The blends were equally accepted as complementary food based on sensory evaluation. Blends can be used as weaning foods to lessen protein-energy malnutrition.
Amankwah et al. (2010)	Maize flour (fermented) (64%), soyabean (32%) and groundnut (4%)	The blend had excellent rat growth response: weight at end of a 10 week period (190 to 230 versus 180 to 185 g, respectively, for blend and maize only diet) and haemoglobin [12.5 to 14.0 (blend) versus 10.5 to 12.0 g/dl (maize only). The blend was therefore recommended as complementary food to improve nutritional status of growing infants compared with the fermented maize only flour.

Extrusion cooking has been used to process some of the cereal–legume blends at industrial-level (Mensa-Wilmot et al., 2003; Plahar et al., 2003b).

iii) Complementary foods are formulated as dried products which need to be reconstituted with liquid to form porridge before being served to infants.

iv) Formulation involves the use of available local resources in line with the WHO (2001) recommendation of processing complementary food for infants.

iv) Most of the formulations satisfy the energy (1670 kJ/100 g) and protein (15/100 g) levels in the Codex guidelines for complementary food (Codex Alimentarius Commission, 1991).

The use of unfortified cereal-legume blends instead of unfortified cereal-only formulation as complementary food in Ghana has the potential to reduce the incidence of protein-energy malnutrition among infants. Cereal-legume blends are relatively high in protein (both quality and quantity) and energy because the legumes supply the lysine lacking in cereal and the cereals provide cysteine and methionine which are low in legumes (Annan and Plahar, 1995). Weanimix which contained 75% maize, 15% soyabean and 10% groundnut was reported to have an energy value of 1820 kJ/100 g and protein level of 15/100 g (Lartey et al., 1999) compared with 100 kJ/100 g and 0.6/100 g mentioned earlier for *koko*, a maize–only porridge prepared from fermented cereal dough (Lartey et al., 1997). There is evidence that Weanimix adequately meets the growth demands of infants using weight gain as an index (Lartey et al., 1999); but is inadequate to meet the demand for vitamin A (Lartey et al., 1998), iron or zinc (Lartey et al., 1999, 2000b) (Table 4). The poor vitamin A status of the infants may be attributed to the low levels (about 2.0 µg retinol equivalents/100 kJ) of vitamin A (Lartey et al., 1999) compared with the recommended range of 14 to 43 µg retinol equivalents/100 kJ (Codex Alimentarius Commission, 2006). Vitamin A has been identified as one of the “problem nutrients” in Weanimix (Dewey and Brown, 2003). Poor iron or zinc absorption leading to deficiency has been associated with cereal–legume based diets (Taylor et al., 1995; Hotz and Gibson, 2001; Hotz et al., 2001; Hurrell et al., 2003) because of the high phytate levels (Egli et al., 2002; Hurrell et al., 2003).

The ingredients commonly used to formulate cereal-legume blends all have relatively high levels of phytate: maize (1.15/100 g), cowpea (0.66/100 g) and soyabean (1.40/100 g) (Egli et al., 2002) and groundnut (1.76/100 g) (Lukmanji et al., 2008). The phytate level of 0.48/100 g of Weanimix (Lartey et al., 1997) could inhibit iron

Table 4. Nutritional intervention trials in Ghana using complementary food for infants and young children.

Authors	Study description	Main results and conclusion/recommendation
Lartey et al. (1998, 1999, 2000a)	Design: Longitudinal, randomized feeding trial. Group: Four groups based on food allocations: i) Weanimix (W) ii) Weanimix fortified with vitamins and minerals premix (WM) iii) Weanimix plus fish powder prepared from smoke-dried anchovies (WF) iv) *Koko* (fermented maize only) plus fish powder (KF). Subject: Breastfeeding infants (*n* = 216). Non intervention group (*n* = 464). Data on non intervention group was collected before and after the intervention trial. Approach: Infants were recruited when <1 month. Trial started when 6 months old until infants were 12 months of age. Mothers were supplied 500 g their allocated foods weekly.	Plasma retinol increased in the WM group (0.17±0.4 µmol/L) from baseline (6 months) to end of study (12 months). Plasma retinol decreased in W, WF and KF (-0.08±0.3, -0.01±0.3, -0.02±0.3 µmol/L, respectively). The group given WM had better vitamin A status than infants fed non-fortified improved complementary foods. Haemoglobin, hematocrit or zinc level was not significantly different among the intervention groups. The proportion of infants with serum ferritin level <12 µg/L (index of poor iron store) increased in the W, WF and KF groups but not in WM group from baseline to the end of the study. Fortification of locally processed complementary food with vitamin and mineral supplements led to non depletion of iron stores. The improved complementary foods formulated were associated with less growth faltering compared with the non intervention group.
Zlotkin et al. (2001)	Design: Longitudinal, randomised controlled trial. Group: Sprinkles group (*n*=245) and Ferrous sulphate drops group (*n*=247). Subjects: Infants (6 -18 months of age) with haemoglobin concentration from 70 to 99 g/L. Approach: Ferrous drops to be given 3 times a day (a total of 40 mg elemental iron) and microencapsulated ferrous fumarate plus ascorbic acid to be added to cooked complementary food before consumption (a total of 80 mg of elemental + 50 mg ascorbic acid). Treatment was for a period of 2 months. This was the first initial field testing of sprinkles	No significant difference at baseline or at the end of the study period in terms of haemoglobin and ferritin concentrations between the groups. There was significant increase in haemoglobin and ferritin concentrations from baseline to end of study. No difference in compliance on the use of the drops or the sprinkles. Microencapsulated ferrous fumarate plus ascorbic acid sprinkled once daily on complementary foods had similar rate of treatment effect on anaemia among infants as ferrous drops (administered as three drops per day).

and zinc absorption by infants. Therefore, for unfortified plant-based complementary foods, not only is the level of iron important, but the phytate content is crucial since it reduces the amount of non-haem iron that can be absorbed. The inhibitory effect of phytate on non–haem iron and

Table 4 ontd.

Christofides et al. (2006)	Design: Longitudinal, randomised, clustered (housing as clustering unit). Group: Four Sprinkles groups based on varying doses of iron and 1 iron drops group. i) Sprinkles a) 12.5 mg iron as ferrous fumarate (*n* = 26) b) 20 mg iron as ferrous fumarate (*n* = 28) c) 30 mg iron as ferrous fumarate (*n* = 27) d) 20 mg iron as ferric pyrophosphate (*n* = 27). Each sachet of the Sprinkles also contained 30 mg ascorbic acid, 300 retinol equivalents of vitamin A, 5 mg zinc, 7.5 µg vitamin D and 160 µg folic acid. ii) Ferrous sulphate (FS) a) 12.5 mg iron as ferrous sulphate drops (*n* = 25). Subjects: Anaemic infants (6 to s18 moths of age) with haemoglobin concentration from 70 to 99 g/L. Approach: Sprinkles were added to food after cooking once daily while 1 ml of FS was to be given once daily between meals for an 8 week period.	Haemoglobin and serum ferritin improved from baseline to the end of the treatment period in all groups. Haemoglobin and serum ferritin status were not different among the groups.Iron deficiency anaemia (defined as haemoglobin <100 g/L and soluble transferrin receptor >8.5 mg/L) prevalence was not different across the groups and decreased significantly from baseline to end of study, except the FS group. Sprinkles were easier to use than the drops. Also, greater teeth staining occurred in the drops group than the sprinkles. The 12.5 mg Sprinkles containing 30 mg ascorbic acid, 300 retinol equivalents of vitamin A, 5 mg zinc, 7.5 µg vitamin D and 160 µg folic acid was recommended as effective for treating anaemia by sprinkling it on complementary food before consumption.
Zlotkin et al. (2006)	Design: Longitudinal, randomised, controlled. Group: Three Sprinkles groups i) 5 mg elemental zinc as ^{67}Zn–labelled zinc gluconate combined with 50 mg ascorbic acid (LoZn group) (*n* = 21) ii) 10 mg elemental zinc as ^{67}Zn-labelled zinc gluconate combined with 50 mg ascorbic acid (HiZn group) (*n* = 21) iii) 5 mg elemental zinc as zinc gluconate, no ascorbic acid (*n* = 18). Each also contained 30 mg of elemental iron as ^{57}Fe-labelled microencapsulated ferrous fumarate. Subjects: Anaemic and non–anaemic infants (12 to 24 moths of age). Approach: Sprinkles were added to smaller portion of the cooked food to ensure that all that Sprinkles were fully ingested before feeding the entire dish.	The percentage zinc absorbed did not differ at 5 or 10 mg intakes. The zinc absorption in the form of Sprinkles was low. The amount of zinc absorbed from the HiZn group was higher and significantly different from the LoZn group (0.82 vs. 0.31 mg). Across the three groups, ascorbic acid was not associated with increased iron absorption. There was no effect of the levels of zinc or the level of ascorbic acid on iron absorption from sprinkles added to maize-based complementary food.
Adu-Afarwuah et al. (2007, 2008)	Design: Longitudinal, randomised feeding trial and cross-sectional for non intervention group.	Plasma ferritin levels were not significantly different across the interventions (SP, NT and NB), but were significantly higher than the NI.

Table 4 Contd.

	Group: Three groups based on supplement allocation as intervention group: i) Sprinkles (SP) (*n* = 105) ii) Nutritabs (NT) (*n* = 105) iii) Nutributter (NB) (*n* = 103). Non intervention (NI) group (*n* = 96).	SP, NT and NB effect on haemoglobin concentration were not significantly different. However, NT and NB but not SP effect on haemoglobin was significantly higher than NI. There was no significant effect on plasma zinc concentration among the intervention groups as well as the NI group. Head circumference and length-for-age z score were not significantly different among the four groups. NB group had significantly higher weight-for-age and weight-for-length z scores than NT but not SP or NI groups. The percentage of children at 12 months who were able to stand without support was not significantly different across the 4 groups. However, the children who were able to walk independently were significantly higher in intervention groups than the NI. NB supplement improved weight and length indices better than Sprinkles and NT. All 3 supplements had positive impact on the ability of the children to walk independently at 12 months compared to NI.
	SP met the Recommended Nutrient Intake (RNI) for 6 vitamins and minerals; NT met the RNI for 14 vitamins and minerals plus some calcium and potassium; NB met RNI for 14 vitamins and minerals plus calcium, potassium, phosphorus, magnesium, manganese as well as energy (108 kcal/day) mainly from fat (including 1.29 g linoleic acid/day and 0.29 g α-linolenic acid/day. Subject: Infants. Approach: Infants were recruited when 5 months old but longitudinal trial started when 6 months old until 12 months of age. Infants for NI were selected from the eligible subjects but who were not randomly assigned to the intervention groups at the end of study (12 months). Mothers were told to mix supplement with 1 to 2 tablespoon of the child's food to ensure that the infants took the entire dose. Each supplement was given once daily.	All supplements were well accepted.
Adom et al. (2010)	Design: Longitudinal, randomised controlled feeding trial. Group: Two groups based on food allocations:	Anaemia prevalence increased in the control group, but decreased in the test group. Haemoglobin concentration was significantly different between the groups but serum iron and total-iron binding capacity were not significantly affected.

Table 4 Contd.

	i) Test group (plus iron fortification) (n = 31)	The percentage of children who were slightly underweight decreased from baseline to the end of the study, but this difference was not significant between the groups.
	ii) Control group (without iron fortification) (n = 29) The intervention food was made from 80% maize and 20% cowpea. Subject: Infants and young children (6 to 18 months old); haemoglobin ≥9 g/dl. Approach: Dry rations of fermented blend (with or without iron fortification) were given to mothers to take home and encouraged to prepare and give thrice daily. The intervention period was 6 mo.	It was concluded that maize-cowpea blend could be a vehicle for fortification because children liked the blend and also did not present additional burden for mothers when preparing the porridge from it.

zinc bioavailability has been shown to be dose-dependent (Hallberg and Hulthen, 2000; Greiner et al., 2006); hence effort has been directed towards identifying methods for reducing phytate level in foods.

Traditional processing methods such as fermentation or germination are ineffective in reducing the amount of phytate in foods processed from either maize, cowpea or soyabean as most of these crops have low levels of endogenous phytase (Egli et al., 2002). Using natural lactic fermentation of maize flour slurry, Hotz and Gibson (2001) found that phytate content was reduced by 12% after 86 h. Songré-Ouattara et al. (2010) reported that addition of lactic acid bacteria with high phytase activity did not reduce the phytate level in pregelatinised millet and soyabean slurry after 24 h of fermentation. This is in spite of findings which suggest that damaging cell membranes by thermal processing increases phytase activity (Cheryan, 1980). The traditional soaking of maize flour in water and decanting the excess water afterwards reduces the level of phytate by only 57% (Hotz et al., 2001). However, the soaking method, which could easily be adopted at the household level, leads to leaching and loss of water-soluble micronutrients (Hotz and Gibson, 2001); it is therefore not a suitable approach particularly in preparing household-level complementary food which is seldom fortified with vitamin and mineral supplements (Gibson et al., 1998). Additionally, the soaking method has not been tested on composite flours of cereal and legume which have been shown to be superior nutritionally and more suitable as complementary food than cereal-only flour (Tables 3 and 4).

The use of phytase-containing micronutrient powder led to improved iron and zinc status in humans consuming a phytate–rich meal prepared from maize (Troesch et al., 2009, 2011). Although the phytase–containing micronutrient powder optimised iron bioavailability at low levels of iron (2.5 to 3.0 mg of per meal), Troesch et al. (2009) cautioned that the product is expensive and presents ethical issues because the phytase used was extracted from genetically modified *Aspergillus niger*. Cooking usually leads to approximately 50% phytate degradation, whereas high temperature and short time thermal processing methods such as extrusion cooking results in approximately 30% degradation (Sathe and Venkatachalam, 2002). The ineffectiveness of thermal processing on phytate reduction and enhanced iron absorption has been demonstrated by Hurrell et al. (2002). Extrusion cooking of cereal flour (polished rice, degermed maize or wheat) at about 160°C or roller drying of precooked slurry with steam injection at about 135°C had no effect on phytate degradation and consequent iron absorption compared to home-cooking of the respective cereals (Hurrell et al., 2002). The combination of fermentation for 2 h and baking at 220°C for 15 min was the only processing method which completely degraded phytate and significantly increased iron absorption in that study. Other constituents of food, either exogenous or endogenous, such as ascorbic acid (Gillooly et al., 1983; Siegenberg et al., 1991) and β–carotene (provitamin A) (Garcia-Casal et al., 2000, 2006), have been reported to promote iron absorption in the presence of phytate. However, roasting ingredients in the open-pans used in cereal-legume blends formulations (Table 3) and further cooking of the reconstituted blend as porridge would totally degrade the endogenous ascorbic acid (Teucher et al., 2004).

The effect of heat on the endogenous β–carotene

Level in orange-fleshed sweet potato is moderate (Low et al., 2009). Preparing cereal porridge with fruit juice could increase the ascorbic acid content, but this is not a common practice in Ghana because of the additional cost. Therefore, a plant-based complementary food which has appreciable amounts of endogenous β–carotene is a more feasible strategy to counteract the inhibitory effect of phytate on nutrient bioavailability. An alternative approach of reducing the inhibitory effect of phytate on nutrient absorption is to add vitamin and mineral supplements to the complementary food as carried out by Lartey et al. (1999) in a trial on Ghanaian infants (Table 4). The key summary points in the nutritional intervention studies conducted in Ghana on infants and young children presented in Table 4 are:

i) Addition of vitamin and mineral supplements to cereal-legume or cereal-only porridges had a positive effect on the micronutrient status of infants and young children.
ii) A lipid-based nutrient supplement (Nutributter) which met the recommended nutrient intake for 14 vitamins and minerals plus calcium, potassium, phosphorus, magnesium, manganese as well as energy (452 kJ/day) mainly from fat (including 1.29 g linoleic acid/day and 0.29 g α-linolenic acid/day) improved iron status as well as growth.
iii) Cereal-legume blends with/without fish powder as well as cereal-only plus fish powder complementary foods improved growth but not the iron and vitamin A status of infants. In fact, infants fed Weanimix for 6 months did not maintain their vitamin A status at the end of the study (Lartey et al., 1998).

Using micronutrient fortification/supplementation to improve infant nutriture in developing countries like Ghana is impractical, because micronutrient preparations cannot be produced at the household level from available local resources and there is a lack of commitment by policy makers to ensure their provision at a subsidised price. Hence, the availability of micronutrient supplements undesirably ends with the nutritional trials they are designed for. Vitamin and mineral supplements, if made affordable or available for resource–poor households, remain the most efficacious way of improving the nutritional status of infants in developing countries. Until vitamin and mineral supplements, lipid-based nutrient supplement or sprinkles are affordable in developing countries through government subsidies, dietary diversification (example, food–to–food fortification) holds the key to improving nutritional status of infants in low-income countries (Chakravarty, 2000; Gibson et al., 2000) as this approach can easily be replicated at the household–level. An easy-to-adopt strategy by most households in low–income countries would be to replace some of the ingredients in cereal–legume food mix with sweet potato (*Ipomoea batatas*), a locally-available food crop high in β–carotene (precursor of vitamin A) and low in phytate. The β–carotene content of the roots of coloured (red-, yellow-, cream- or orange-fleshed) sweet potato varieties ranged from 500 to 8000 µg/100 g (fresh weight basis) (Hagenimana et al., 2001; Ssebuliba et al., 2001; Ofori et al., 2009).

Flour prepared from a cultivar of orange–fleshed sweet potato [Pumpkin (CIP 420027)] with a dry matter of 89% was reported to have β–carotene as high as 13,900 µg/100 g (Hagenimana et al., 2001). The level of phytate in sweet potato is generally low ranging from non-detectable (Phillippy et al., 2003; Lung'aho and Glahn, 2009) to 6.0 mg/100 g (Gibson et al., 1998, 2010) or 10.0 mg/100 g (Lukmanji et al., 2008). Findings from two randomised control feeding trials using orange–fleshed sweet potato among children in South Africa (van Jaarsveld et al., 2005) and Mozambique (South Eastern Africa) (Low et al., 2007) showed that the coloured sweet potato had positive impact on vitamin A status of infants and young children. van Jaarsveld et al. (2005) found greater improvement of liver vitamin A stores among 5 to 10 years old school children fed boiled mashed orange-fleshed sweet potato (*n* = 90; an increase from 78 to 87% of children with normal vitamin status) compared to those consuming an equal amount of white-fleshed sweet potato [*n* = 90; a slight decrease from 86 to 82% (normal vitamin A status)] for 53 school days. About 48% (232 of 490) of children (mean age at baseline was 13 months) in the intervention group, where farmers had increased access to orange-fleshed sweet potato vines and nutritional education, had low serum retinol concentration (<0.70 µmol/L) compared to 58% (141 of 243) children in the control group (Low et al., 2007).

In another study, among 3 to 6 years old children, conducted in Indonesia, in which red-fleshed sweet potato contributed about 80% of β–carotene from test meals (children did not like spinach and swamp cabbage as the other sources of β–carotene), serum retinol level improved five times more in the group whose basic test meal was enriched with sweet potato compared with those on the basic test meal (Jalal et al., 1998). These findings suggest that β–carotene from sweet potato is bioavailable in humans. The coloured varieties of sweet potato are gaining attention in Ghana since their introduction in the mid 1990s. An extensive research programme in Ghana has resulted in the production of early maturing (3 to 3.5 months) of the coloured varieties of sweet potato, locally known as Okumkom, Sautie, Faara and Santom Pona (Otoo et al., 2001; Council for Scientific and Industrial Research (CSIR), 2006). A recent report also indicates that several varieties of the coloured sweet potato are being introduced in Ghana (Ofori et al., 2009). In the Upper East region of Ghana, it has been reported that sweet potato is exported to the neighbouring country, Burkina Faso (FAO, 2005). Sweet potato (presumably, the coloured varieties) was mentioned in the GDHS Reports as one of the food sources rich in vitamin A consumed by infants between 6 to 9 months (GSS, 2004, 2009). The leaves and/or cooked roots of these new varieties available in Ghana have been recommended as sources of minerals and vitamin A (Oduro et al., 2008; Ofori et al., 2009). These findings, coupled with the fact that sweet potato is less laborious to cultivate than cereals (Woolfe, 1991; Padmaja, 2009), presents sweet potato as a suitable choice for processing a dried complementary food. However, there is no report in the output of the database search conducted on complementary food formulation from coloured varieties of sweet potato for Ghanaian infants.

The processing of the coloured varieties of sweet potato as complementary food is likely to have a double advantage over cereal-legume blends by both improving vitamin A status and by enhancing iron absorption due to the relatively high β–carotene and low phytate content of sweet potato.

Complementary foods processed using sweet potato

The use of sweet potato in complementary foods using either household-level processing technologies (fermentation, germination, drying, milling or blending) or industrial-level methods (drum or freeze drying) have been reported in the literature: cereal (maize or sorghum) (65%)-legume (soyabean or cowpea) (30%)-sweet potato (5%) blends have been processed as complementary foods by either malting or cooking or fermenting the raw ingredients, followed by drying and milling into separate fine flours which were then blended (Nnam, 2000). Although the blends formulated satisfy the protein (15/100 g) and energy (1670 kJ/100 g) specifications of the Codex Standard for infant foods (Codex Alimentarius Commission, 1991), the sweet potato was not the main ingredient. Sweet potato flours (fermented or non-fermented) were combined with flours processed from the seeds of African breadfruit (*Treculia africana*) (with/without prior fermentation) in the ratio of 1:4 (Akubor, 2005). These formulations also meet the protein and energy specifications stated earlier. A combination of sweet potato and soyabean in proportion of 70 and 30%, respectively has been suggested by Ijarotimi and Ashipa (2006) as an ideal combination to meet the protein and energy levels desired of foods for infants. However, using soyabean at 30% in combination with sweet potato would also result in a formulation which would be high in phytate.

A sweet potato-cowpea-groundnut household-level complementary food formulated with the legume incorporated at a level between 30 to 40% (Adenuga, 2010) would likely be high in phytate also. Therefore, if the proportion of soyabean incorporated in complementary food formulations could be reduced, the phytate level in the formulation would be low; consequently increasing nutrient bioavailability. Hence, we aimed to use a lower proportion of soyabean in our proposed sweet potato-based formulations presented later in this report. Khan et al. (2011) processed complementary food formulations by drum drying composite flours of sweet potato (either 21.73 or 22.31%), rice (11.11%), wheat (12.78%), maize (5.56%) and whole milk powder (24.28%), rice bran protein isolate (either 6.16 or 6.29%), sugar (8.89%), vegetable oil (8.33%), antioxidant (0.01%) and vitamin-mineral mixture (0.10%) which met the protein, fat and energy specifications in the Codex Standard. However, these formulations would be difficult to replicate and also expensive to process because of the number of ingredients used. In all the sweet potato-based formulations mentioned earlier, the variety of sweet potato, the vitamin A level and the phytate level were not reported. It is worth stating that the focus of the research by Khan et al. (2011) was value addition to agro-industrial waste (rice bran) and not the promotion of sweet potato as an ingredient in complementary food formulation. Only the work of Nandutu and Howell (2009) described as follows stated the variety of sweet potato used in their complementary food formulations. Nandutu and Howell (2009) used freeze–dried slices of orange-fleshed sweet potato, to which fish (Tilapia skinned fillets), sunflower oil and either skim milk or soyabean flour were added to process their sweet potato-based complementary food. The ingredients were mixed and blended into a soft paste. Antioxidants (ascorbic acid and α-tocopherol) were added to the paste prior to cooking.

The soup obtained was freeze-dried and milled into flour as a complementary food. The protein (24/100g), fat (3.3/100 g) and calculated carbohydrate (62/100 g) *in vitro* starch digestibility (68% as maltose equivalent per total starch) compared well with the levels determined for a nutritionally adequate commercial cereal-based complementary food in Africa (Nestlé® Cerelac®). However, the level of fat in this orange-fleshed sweet potato-based complementary food is far below the specification (10 to 25/100 g) in the Codex Standard (Codex Alimentarius Commission, 1991). Additionally, the vitamin A and phytate levels were not reported. With reference to the information presented for sweet potato–based complementary foods mentioned earlier, we have proposed a new formulation which could meet the protein, energy and fat requirements of complementary foods using the Codex Standard (Codex Alimentarius Commission, 1991).

Proposed formulation of sweet potato-based complementary food

It is noteworthy that food-to-food fortification without addition of vitamins and minerals supplements seldom meets the nutrient recommendations for infants and young children (Lutter and Rivera, 2003). However, a careful choice of ingredients, as described earlier, is likely

Table 5. Ingredients and estimated levels of macronutrients of proposed sweet potato-based complementary food.

Ingredient (g/100 g)*	Household-level	Industrial-level
Cream-fleshed sweet potato flour	66	72
Full fat soyabean flour	10	15
Soyabean oil	6	6
Iodised salt	0.5	0.5
Sugar	0.5	0.5
Skim milk powder	-	6
Fish powder (anchovies)	17	-

Estimated nutrient composition (/100 g dry weight basis) assuming final moisture of 5%		
Nutrient	**Household-level**	**Industrial-level**
Energy (kcal)	444	427
Protein (g)	22	20
Fat (g)	24	21
Carbohydrate (g)	36	43
Vitamin A (µg RE[†])	870	780

*Nutrient composition of the ingredients was available in the GAIN Nutrition Calculator except for sweet potato and fishmeal. Nutrient composition of sweet potato FoodWorks version 6 (FoodWorks, 2009). Data on fish (*Engraulis hepsetus*) to be used was not available; therefore the data on *Engraulis encrasicholus* from USDA (http://www.nal.usda.gov/fnic/foodcomp/search/) was used. [†]Retinol equivalents.

to have some positive impact. The primary target for this formulation was to meet energy content of at least 1670 kJ/100 g, protein level of 15/100 g and fat content in the range of 10 to 25/100 g as specified in Codex Alimentarius Commission guidelines on formulated foods for older infants and young children (Codex Alimentarius Commission, 1991). The ingredients to be used in the proposed formulations are listed in Table 5, and include cream-fleshed sweet potato, soyabean flour, soyabean oil and either skim milk powder or fish powder prepared form anchovies. A computer programme (nutrition calculator) developed by Global Alliance for Improved Nutrition (GAIN) (Jonathan Siekmann, personal communication, 15/07/2010) was used to obtain the proportions of ingredients needed to get the energy, protein and fat values stated earlier. To improve the protein quality and increase the quantity of the formulations, fish powder prepared from anchovies was included as an ingredient for the household-level formulation and skim milk powder was included for possible industrial-level formulations. Anchovies are available, inexpensive and culturally acceptable additions to porridge for Ghanaian infants (Lartey et al., 1999; Akor et al., 2001). The inclusion of anchovy powder would also serve as sustainable source of calcium, iron and omega 3 fatty acids in complementary foods produced at the household-level. Skim milk powder was chosen because of the suggested positive association with linear growth (de Pee and Bloem, 2009). Further, milk is an ingredient in most industrial level powdered complementary food used worldwide, example, Nestlé® cereal-based products.

To increase fat content, and consequently the energy, soyabean oil was included in the product formulations. Two formulations (Table 5) were developed, one to be processed at household–level and the other, industrial–level. The household–level formulation containing the fish powder could be processed by toasting in an open–pan or in an oven. The industrial formulation with the skim milk powder could be processed using either roller drying or extrusion cooking as possible industrial–level methods. Roller drying is proposed because it is the oldest commercial drying technique in the food industry used to produce powdered products including complementary food (Bhandari and Hartel, 2005). On the other hand, extrusion cooking is a more recent, versatile, high temperature short time (residence time of 1 to 2 min) and widely used technique in cereal processing such as snack foods and breakfast cereals (Cheftel, 1986). The additional advantage of extruders is that several ingredients (pre-processed into grits or flour) can be combined in one run (Guy and Benjamin, 2003) into a single product (extrudates). With infant food, the extrudates are subsequently dried and milled into flour. The proposed complementary food formulations based on sweet potato will be referred to as ComFa. The data in Table 5 show that the estimated energy, protein and fat would meet the requirements in the Codex Alimentarius Commission guideline. ComFa Industrial and ComFa Home have estimated vitamin A content of 780 and 870 µg RE/100 g, respectively. Thus, both ComFa formulations are likely to contribute positively to initiatives designed to reduce VAD in Ghana compared to Weanimix which has vitamin A content of 36 µg RE/100 g.

The estimated levels of phytate in the ComFa Industrial and ComFa Home would be 154 mg and 45 mg/100 g, respectively after correcting for 30% loss due to heat processing (Sathe and Venkatachalam, 2002). The estimated phytate levels are based on the composition of the formulations and the phytate levels in sweet potato and soyabean indicated earlier. The phytate content of Weanimix is 480 mg/100 g (Lartey et al., 1997); thus sweet potato-based formulations would have about a third of the phytate content of Weanimix.

Conclusion

Complementary food processed from cereal-legume blends with/without fish powder has been shown to be positively associated with growth over cereal-only porridge. Cereal-only or cereal-legume porridge without fortification with vitamin and mineral supplements will lead to deficiency of micronutrients such as iron and vitamin A among infants because such foods are both low in the micronutrients (example, vitamin A) and high in phytate, which compromises nutrient bioavailability. Vitamins and minerals supplements are not available for use by families at households in Ghana due to cost. Sweet potato-based complementary food blends which could be processed industrially (using either extrusion cooking or roller drying) or at the household-level (using toasting in an oven or open-pan) are proposed. These formulations would satisfy the requirements for energy, protein and fat specified in the Codex Alimentarius Commission guidelines and also be a better source of β–carotene. In this regard, we suggest ComFa Home formulation should be used as household–level complementary food as it would be a better source of vitamin A (endogenous) than unfortified cereal–legume blends commonly used in Ghana.

Also, the relatively low estimated level of phytate and high level of β–carotene in the sweet potato-based complementary food would likely make iron, calcium and zinc more bioavailable than from the cereal-based products.

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