



## Conference on ‘Food and nutrition security in Africa: new challenges and opportunities for sustainability’

### Applying the food multimix concept for sustainable and nutritious diets

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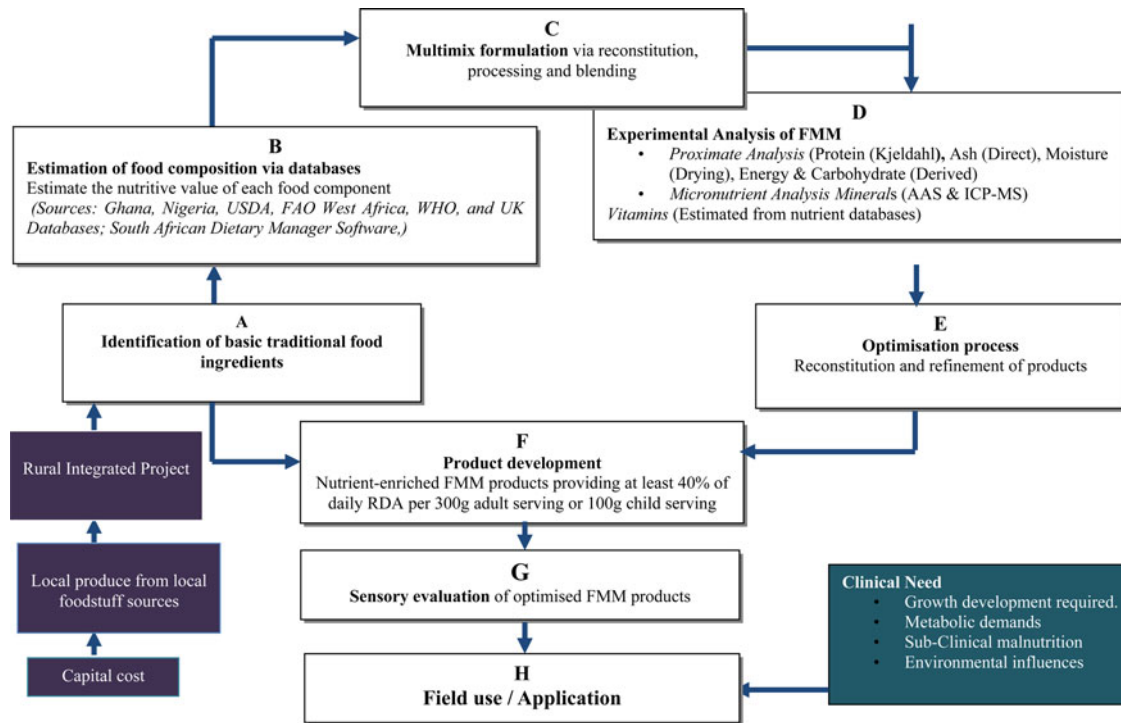
Despite a rich and diverse ecosystem, and biodiversity, worldwide, more than 2 billion people suffer from micronutrient malnutrition or hidden hunger. Of major concern are a degradation of our ecosystems and agricultural systems which are thought to be unsustainable thereby posing a challenge for the future food and nutrition security. Despite these challenges, nutrition security and ensuring well balanced diets depend on sound knowledge and appropriate food choices in a complex world of plenty and want. We have previously reported on how the food multimix (FMM) concept, a food-based and dietary diversification approach can be applied to meet energy and micronutrient needs of vulnerable groups through an empirical process. Our objective in this paper is to examine how the concept can be applied to improve nutrition in a sustainable way in otherwise poor and hard-to-reach communities. We have reviewed over 100 FMM food recipes formulated from combinations of commonly consumed traditional candidate food ingredients; on average five per recipe, and packaged as per 100 g powders from different countries including Ghana, Kenya, Botswana, Zimbabwe and Southern Africa, India, Mexico, Malaysia and the UK; and for different age groups and conditions such as older infants and young children, pregnant women, HIV patients, diabetes and for nutrition rehabilitation. Candidate foods were examined for their nutrient strengths and nutrient content and nutrient density of recipes per 100 g were compared with reference nutrient intakes for the different population groups. We report on the nutrient profiles from our analysis of the pooled and age-matched data as well as sensory analysis and conclude that locally produced FMM foods can complement local diets and contribute significantly to meet nutrient needs among vulnerable groups in food-insecure environments.

#### Food multimix: Candidate foods: Sustainable: Food security: Resource-poor: Nutrition interventions

Food-based approaches are increasingly being emphasised as more cost-effective and sustainable ways to improve food security and reduce the prevalence of micronutrient deficiencies<sup>(1–7)</sup>. Applying biofortification, improved varieties of sweet potatoes and bananas have been cultivated and used as part of feeding programmes in poverty alleviation and to tackle vitamin A deficiency

in parts of Africa<sup>(8–10)</sup>. However applying these new and improved varieties of foods singly while laudable, also attracts criticism for being similar to the single-nutrient approach adopted in the late 1970s through the early 1990s which met with limited success. A more preferred approach is the one adopted, where such improved varieties e.g. of bananas or sweet potatoes form part of a

Abbreviations: FMM, food multimix; INQ, index of nutritional quality.  
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**Fig. 1.** A schematic diagram showing the stages and processes involved in the optimisation of food multimixes (FMM)<sup>(27)</sup>.

more holistic composite recipe or diet, and in which the ingredients constituting such a diet are carefully chosen based on their ‘individual nutrient strengths’ to complement each other and provide an enriched composite product through food-to-food fortification.

Empirical evidence suggests that nutrients in food tend to naturally interact with each other and complement each other in their function<sup>(11–12)</sup>. For instance, ascorbic acid (vitamin C) from citrus fruits promotes absorption of non-haem iron in plant-based foods e.g. cereals and banana<sup>(13–18)</sup>. Similarly, protein, vitamins A, B<sub>6</sub>, B<sub>12</sub> and E; and the minerals iron, copper and zinc which play various important roles in the formation of healthy erythrocytes and preventing anaemia<sup>(19,20)</sup> can be extracted from a combination of plant and animal-based food ingredients. Thus employing a food-based approach to prevent and/or address nutritional needs of vulnerable groups is a more cost-effective and sustainable means to improve nutrition in poor communities<sup>(21–24)</sup>. Conversely, a meal which focuses on ingredients providing one or two nutrients but lacks diversity does not create a balance involving other nutrients and will not provide the full complement of nutrients required for optimum health. In this paper we examine the application of the food multimix (FMM) concept to address such nutrient gaps, and options to improve nutrition in a sustainable way are discussed.

### The food multimix concept

We define a FMM as a blend of locally available, affordable, culturally acceptable and commonly consumed foodstuffs

mixed proportionately, drawing on the ‘nutrient strengths’ of each component of the mix in order to optimise the nutritive value of the end-product without the need for external fortification<sup>(25)</sup>. Doing so by harnessing local food ingredients and employing food science, technology and food product development techniques to develop edible products to meet needs within a cultural context is desirable.

The FMM concept is built on the notion that in seeking ways to improve nutrition in resource-poor environments scant local food ingredients can be harnessed effectively for recipe development to provide composite diets for multiple uses including for optimum health and therapeutic purposes. We have argued the universal application of the concept borne out of our belief that by applying knowledge of food science, human biology and nutrition and adopting sound empirical approaches, scant food resources in resource-poor communities can be harnessed to produce nutritionally balanced recipes to help alleviate nutritional problems where chronic hunger and food-insecurity exist. The concept has previously been applied to produce nutrient-enriched recipes for clinical and population-based interventions utilising traditional food ingredients in low-income communities in Africa, the details of which are described elsewhere<sup>(25–27)</sup>. This novel scientific approach to the concept of food (and meal) diversification relies on the use of scientific methods combined with traditional food technology, and tailoring food products to the needs of specific vulnerable groups within different social and cultural contexts. In combining ingredients based on their individual ‘nutrient strengths’, the food-to-food fortification of their components can be maximised, thus enriching



**Table 1.** Nutrient compositions of original Super5<sup>®</sup> food product and food multimixes (FMM)-optimised Super5<sup>®</sup> per 300 g serving of product and Weanimix and fish-enriched Koko<sup>(25,37)</sup>

Multimixes	Original FMM*			Optimised FMM†										
	Mean (SEM)	EAR /RNI (%)	INQ	Carrot based (SEM)	EAR /RNI (%)	Tomato based (SEM)	EAR /RNI (%)	Spinach based (SEM)	EAR /RNI (%)	AVR INQ	Weanimix‡	Koko§ INQ	INQ	
Energy (MJ)	4.41 (1.16)	46.9		4.92 (0.91)	52.4	4.91 (1.08)	52.3	5.17 (0.93)	55.1	–	5.46	4.86		
Protein (g)	35.9 (0.95)	71.4	0.88	41.6 (1.09)	82.75	43.0 (1.14)	85.6	56.0 (1.48)	111.3	1.4	45	1.64	3.17	
Carbohydrate (g)	205.7 (5.43)	–		171.0 (4.51)	–	169.6 (4.48)	–	167.8 (4.43)	–		204.3			
Fat (g)	9.8 (0.26)	–		36.3 (0.96)	–	36.0 (0.95)	–	38.0 (1.00)	–		34.2			
Protein (%)	13.6 (0.62)	–		14.1 (0.64)	–	14.6 (0.67)	–	18.1 (0.83)	–		13.8			
Carbohydrate (%)	78.06 (3.57)	–		58.02 (2.68)	–	57.74 (2.64)	–	54.29 (2.48)	–		62.6			
Fat (%)	8.33 (0.38)	–		27.78 (1.25)	–	27.58 (1.26)	–	27.62 (1.26)	–		23.6			
Fibre (g)	8.76 (0.23)	36.5		22.38 (0.59)	96.6	17.28 (0.46)	72	20.52 (0.54)	85.5		–			
Minerals														
Ca (mg)	103.4 (2.73)	14.8	0.03	188.0 (4.96)	26.86	174.2 (4.60)	24.9	706.5 (18.66)	101	0.12	–	0.14	–	1.23
Fe (mg)	12.1 (0.32)	103.1	2.17	16.7 (0.44)	142.1	16.9 (0.45)	144.3	31.5 (0.83)	268.1	2.22	–	2.17	–	4.6
Mg (mg)	70.4 (1.86)	24.69	–	161.3 (4.26)	56.6	179.3 (4.73)	62.89	590.6 (15.59)	207.3	–	–	–	–	
Zn (mg)	9.2 (0.24)	111.6	0.35	12.8 (0.33)	152.4	12.6 (0.33)	153.1	13.7 (0.36)	165.8	0.85	–	0.35	–	1.55
Vitamins														
Folate (µg)	138.25 (3.65)	69.1	1.42	153.61 (4.06)	76.8	173.11 (4.57)	86.6	1280.8 (33.82)	640.3	5.6	201	1.42	84	0.87
Thiamine (mg)	1.02 (0.03)	113.3	2.55	1.19 (0.03)	132.2	1.02 (0.03)	113.3	1.47 (0.04)	163.3	3.33	1.44	2.55	0.96	2.48
Riboflavin (mg)	0.3 (0.01)	25	0.39	0.44 (0.01)	36.7	0.54 (0.01)	45	1.41 (0.04)	117.5	1.04	0.012	0.39	0.30	0.40
Niacin (mg)	5.88 (0.16)	39.2	1.02	7.01 (0.19)	46.7	7.77 (0.21)	51.8	9.3 (0.25)	62	1.39	11.7	1.02	12.3	2.12
β-Carotene (µg)	66.23 (1.75)	10.2	0.20	1687.1 (44.54)	259.6	579.93 (15.31)	89.2	4015.6 (106.02)	617	6.16	108	0.20	132	0.19
Vitamin C (mg)	7.35 (0.19)	18.4	0.15	30.03 (0.79)	75.1	39.06 (1.03)	97.7	169.36 (4.47)	423.4	1.64	0.30	0.15	0.00	0.00

AVR INQ, average index of nutritional quality; EAR, estimated average requirements; RNI, reference nutrient intake.

\* Original food multimixes.

† Carrot, spinach and tomato-based optimised products.

‡ Weanimix, a cereal-legume blend.

§ Koko, fermented maize dough (fortified with fish meal).

Applying the food multimix concept for sustainable and nutritious diets

and improving the nutritive value of the composite meal within the mix. Primarily, traditional varieties of food crops, including cereals, grains, legumes, vegetables and fruit, and where appropriate, available and affordable, animal products have been used to simulate real life community meal preparation practices. Food recipes developed are low-cost, (average, 0.20 USD per 100 g of recipe with a target to provide up to 40 % of daily energy requirements and more than 50 % of daily mineral and vitamin requirements depending on age)<sup>(27)</sup>. However in rare instances where limiting nutrients are not sufficiently represented, there may be a need to add external fortificants such as mineral and vitamin pre-mixes. The recipes thus formed with known nutrient composition, are first made in powder form (can be packaged in sachets) and subsequently developed into a variety of end products including porridge, soups, cakes, bread and muffins.

The flexibility and advantage of this approach is that the combination of traditional food ingredients can be customised within any community harnessing their own available natural, affordable, culturally acceptable and commonly consumed resources within their own economic means, and taking into account their specific physiological and clinical needs for targeted interventions e.g. in pregnancy, home or community-based nutrition rehabilitation, for normal growing infants, young children and in school feeding programmes.

#### Scope of application of the food multimix concept in meal recipes

Over the course of a decade or more, a number of recipes have been designed to meet the nutritional needs of different population groups including general adult and school-age groups, pregnant women, HIV/AIDS patients, healthy growing older infants and children, and those undergoing nutritional rehabilitation. Some of the recipes have undergone sensory evaluation to test their characteristics and acceptability, and one randomised, controlled prospective feeding intervention trial has been completed in a cohort of pregnant women in South Africa who were followed from booking enrolment to term<sup>(27)</sup>. The research and development activities employed have involved using scientific principles and methods while food processing have involved refinement of existing traditional methods. A combination of Matlab mathematical software<sup>R</sup> and Excel<sup>R</sup> have been employed to allow for the generation of a number of possible permutations and combinations of local foods from a food composition database, to form recipes and ensure desirable nutrient composition, density and energy content. Laboratory analyses are employed to determine nutrient composition following processing of recipes analyses including proximate, for energy and macronutrients; minerals; and vitamin analyses, except where methods of vitamin analysis were not available, in which cases content was estimated using standard reference food composition databases (see Process Flow Diagram in Fig. 1). These methods have been previously

**Table 2.** Summary of the criteria for food multimixes (FMM) formulations for infants aged 9–12 months

FMM criteria design	Rationale
Energy density: 2667 kJ/d	To prevent protein energy malnutrition and growth and development retardation.
Fat: provide 35–40 % of total energy intake	To enhance energy density and provide essential fatty acids for growth and development.
Protein: 12 g/d	To improve growth and development, immune function and prevent protein energy malnutrition.
Fibre: Less than 0.5 g/kg of body weight, 4 g/d (calculated by employing a reference body weight of 8 kg for infant aged 6–12 months in Malaysia)	To prevent energy reduction by increasing bulk, and prevent trapping of nutrients.
Vitamins and Minerals: provide more than 40 % of RNI	To improve energy utilisation, enhance growth and development, strengthen immune function and prevent various deficiency diseases.

RNI, reference nutrient intake.

described in detail elsewhere<sup>(25–28)</sup>. Tests of organoleptic properties including texture, taste and sensory evaluation for consumer acceptability employed standard scientific protocols.

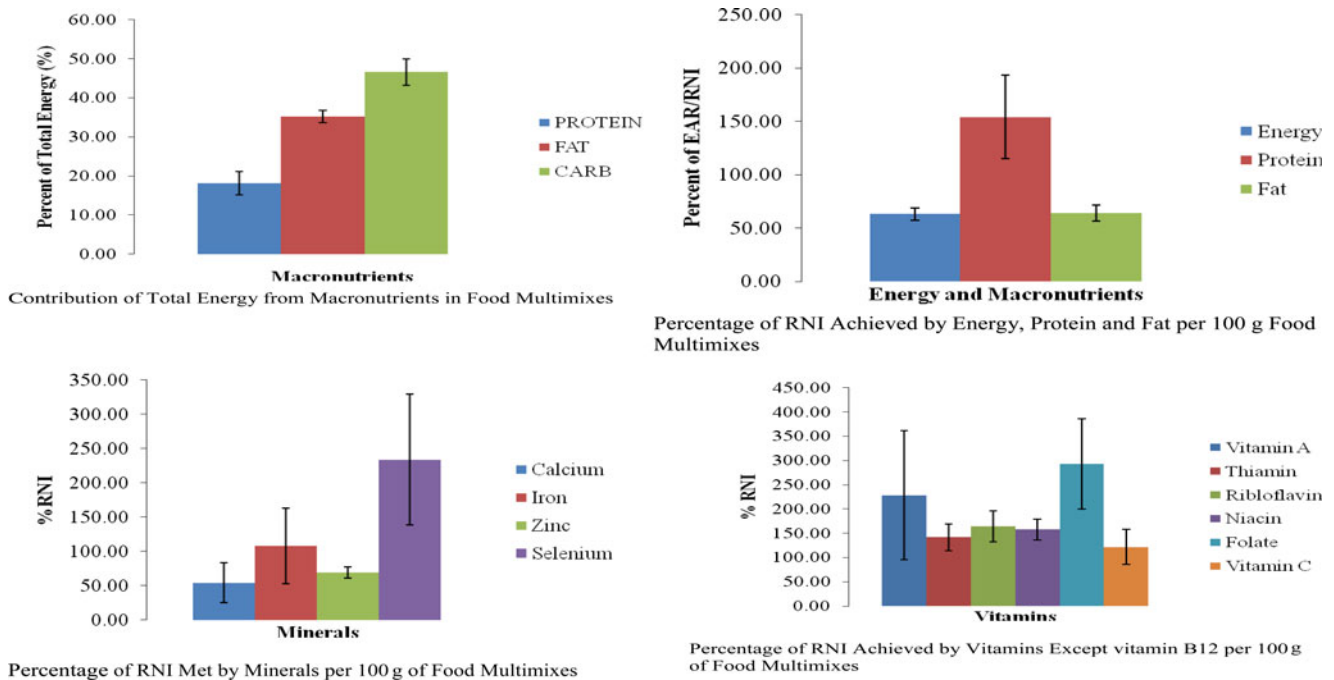
FMM products are based on locally available raw materials therefore the concept can be adapted to suit any environment globally<sup>(29–36)</sup>. For instance in most of East Africa, banana, plantain and sweet potatoes are commonly consumed, along with maize meal and a variety of legumes and green leafy vegetables. FMM products can be designed based on these local foods. The recipes can further be reviewed and then the process of optimisation can be undertaken where necessary, using Matlab<sup>R</sup> software and applying chemometrics, in order to improve the nutrient balance and nutritive value of the recipe prior to developing the end product for multiple uses.

#### Examples of food multimix design and uses

##### *Optimisation of existing commercial products*

An originally designed and already commercially marketed product Super5<sup>R</sup> supplied to certain institutions in South Africa was analysed for its nutritive value following which the product was optimised applying the FMM approach. The ingredients used included cereals, legumes, vegetables and oil. Prior to product optimisation, the carbohydrate constituted over 70 % of the energy source (mainly starch) with little protein and fat. Of the micronutrients, with the exception of vitamins B<sub>1</sub> and folate, all other vitamins in the original product were limiting, with a low index of nutritional quality (INQ; Table 1).

Following manipulation and reconstitution, the samples were prepared with three separate FMM-optimised



**Fig. 2.** Energy, macronutrient, mineral and vitamin content of food multimixes (FMM) designed for human weanlings 9–12 months old in Malaysia. EAR, estimated average requirements; RNI, reference nutrient intake.

product recipe options (carrot-based, tomato-based or spinach-based) in triplicate and analysed following initial estimation of nutrient composition from food databases. Table 1 shows the energy and nutrient content of the original Super5<sup>R</sup> commercial product, the average of the three reconstituted FMM-optimised Super5 products. These are also compared with two locally manufactured Ghanaian commercial powdered products for porridge (Weanimix and Koko) per 100 g of product. Weanimix is a cereal–legume blend introduced by the Ghana Ministry of Health, Nutrition Division and UNICEF/Ghana in 1987 to improve nutrient quality of plain maize porridge used for weanlings, and Koko is a local Ghanaian fermented maize, largely carbohydrate porridge enriched with fish meal<sup>(37)</sup> to boost its protein content.

Table 1 shows the nutrient compositions of Super5<sup>R</sup>, the FMM-optimised Super5<sup>R</sup>, Weanimix and fish-enriched Koko. Reformulation and optimisation of Super5<sup>R</sup> resulted in increases in the contribution of protein and fat to energy, and a drop in carbohydrate from 78.1 to 56.9% of total energy per 300 g. Protein (35.9 (SEM 0.95)g/300 g; an increase from 13.6 to 15.6% of energy); fat (9.8 (SEM 0.26) g/300 g; from 8.3 to 27.7% of energy). The protein content of FMM-optimised Super5<sup>R</sup> compares favourably with Weanimix and Koko. Calcium, iron, magnesium and zinc content of the product also increased following optimisation. The total number of limiting nutrients relative to the reference nutrient intake values for young infants and children (9–12 months and above) was also substantially less for FMM-optimised Super5<sup>R</sup> (three limiting) compared with Super5<sup>R</sup> (eight limiting), Weanimix (seven limiting)

and Koko (five limiting). Calcium content was low in optimised Super5<sup>R</sup> and Super5<sup>R</sup> (both plant-based) with INQ values compared with Weanimix and Koko (containing dairy and fish, respectively). This shortfall can be overcome by adding e.g. milk to porridge made from Super5. The INQ, defined as the amount of a nutrient per 4–18 MJ present in a food or meal relative to a reference standard source of that nutrient, is a measure of nutrient density and is best applied as a measure of protein and micronutrient density in composite meals. A food with overall INQ substantially greater than unity is generally considered a good source of the nutrient except for lipids which in excess may be detrimental to e.g. cardiovascular health. An INQ value less than unity implies a need to eat more to meet the requirements for that nutrient. The INQ has the potential to serve as a useful guide for meal planning for vulnerable groups, and could be used for nutrition education, food labelling and evaluation of nutrient intake<sup>(38)</sup>.

As has been shown in this example, addition of one or two other commonly consumed vegetables such as spinach, carrots, tomatoes; and oil to an existing composite product and decreasing the amounts of others e.g. the staple maize base, can improve nutritional balance and quality of the diet at minimal extra cost. Although primarily plant-based diets, these foods offer enough nutrients to meet daily requirements for targeted individuals per 300 g in the absence of animal source foods. This combination of foods using their individual nutrient strengths provides further evidence that food-based approaches even involving manipulation of largely dependent on plant based sources are beneficial. This approach can be a useful means of intervention to meet nutritional needs and a

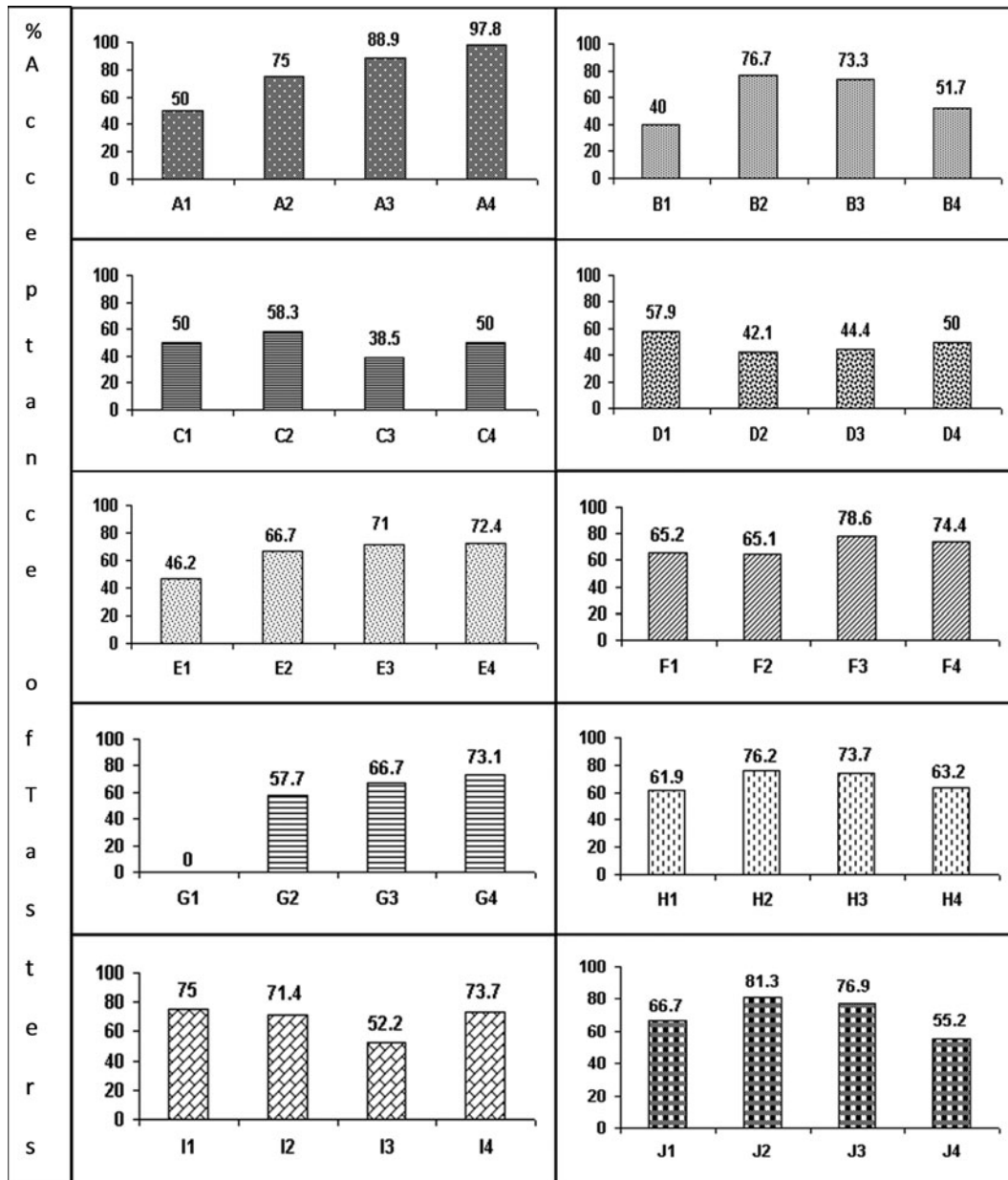


Fig. 3. Graphical representations of sensory responses to food multimix products.

useful adjunct to nutritional management of disease within hospital settings e.g. acute mental health units where patients may have limited food choices.

*Development of nutrient-dense weaning foods*

The infantile growth spurt which occurs between 6 and 9 months is associated with rapid growth, increased levels of physical activity and physiological changes. Expansion in blood volume and haemodilution may result in physiological anaemia in otherwise healthy infants, but symptomatic, clinical anaemia in high risk infants with low Hb or iron stores. Increasing demands for energy and micronutrients also occur and breast milk alone is insufficient to meet such growing demands, hence the need for the gradual introduction of

appropriate complementary foods. In many food insecure communities, breast-milk is often complemented with plain home-made porridge low in energy and nutrient density, and poor nutritional quality made from local staples such as maize and plain white rice. Early signs of protein-energy malnutrition are characteristically seen as early as the sixth month of life in such circumstances. The risk of malnutrition is made worse by poor feeding practices during this transitional or weaning period, contributing to childhood morbidity and mortality. The application of the FMM concept in meal planning for this age group is therefore an attempt to help mitigate potential shortfalls in nutritional adequacy of diets in an otherwise high risk vulnerable group.

In Table 2, we provide a rationale for developing low-cost complementary foods for use in a local context.

**Table 3.** Key nutrients in 100 g food multimixes (FMM) per child serving compared with Ghanaian commercial products

	Nutrition rehab*	Nutrition rehab†	Weanimix‡	Koko§
Proximate analyses				
Energy density (kJ (SEM)/g food product)	14.6 (0.19)	16.47 (0.32)	18.18	16.2
Energy distribution (%)				
Protein (g)	12.0 (SEM 1.85)	15.2 (SEM 0.54)	13.8	25.8
Carbohydrate (g)	58.2 (SEM 1.61)	56.6 (SEM 0.29)	62.6	66.0
Fat (g)	29.8 (SEM 0.98)	28.2 (SEM 0.58)	23.6	8.1
EAR/serving (%)	36.3	40.9	45.2	40.2
Mean mineral content				
RNI (%)	32.1	58.2	54.8	86.4
INQ	0.88	1.42	1.2	2.2
Vitamin content (%)¶				
INQ	1.65	1.89	1.1	3.29

EAR, estimated average requirements; INQ, index of nutritional quality; RNI, reference nutrient intake.

\* Lower-strength; Nutrition rehabilitation.

† Higher-strength; Weanimix.

‡ A cereal-legume blend introduced by the Ghanaian Ministry of Health Nutrition Division and UNICEF/Ghana in 1987 to improve food quality and Koko.

§ Local Ghanaian fermented maize porridge with a low-energy and nutrient density that has been fortified with fish meal<sup>(25,37)</sup>.

|| Mean content from four minerals analysed (Ca, Fe, Zn and K) nutrition rehabilitation.

¶ Mean content from seven vitamins estimated (B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>12</sub>, folate, A and C); nutrition rehabilitation: 6–36 months.

Fig. 2, also shows findings from FMM recipes developed for 9–12 months old weanlings employing local foods commonly consumed in some communities in Malaysia<sup>(39)</sup> and taking into account their energy needs per kilogram body weight. The average recipe contains at least 40 % of the total daily requirement of energy for this age group with a good balance of carbohydrate, fat and protein in the diet, which can be fed as a weaning complement to breast milk. With the exception of calcium and zinc, 100 g of the recipes are provided in excess of 90 % of reference nutrient intake values for essential vitamins and minerals. Liver which forms an integral part of the average diet, and which is a component of the recipes will also act as a rich source of animal source protein, iron and vitamin A. This rich balance of nutrients in a complementary food for weanlings was derived from commonly consumed local ingredients in relatively poor Malaysian poor communities with limited resources.

#### *Supplementary and therapeutic foods nutritional support*

Nutritional support is important for the sick child, and especially the undernourished being treated in hospital or the community. The types of foods and their nutrient composition will depend upon the type, nature and stage of malnutrition and rehabilitation, and whether supplementary or therapeutic foods are the intended target. In the design of FMM for nutritional support, metabolic challenges of malnutrition are taken into account in formulating mixes including meeting energy, protein and micronutrient needs e.g. exercising caution in the

provision of iron in the diet especially during the early phase of treatment for severe acute malnutrition. The data presented in Table 3 represent a range of low-cost micronutrient-dense local foods, selected to ensure familiarity and cultural acceptability while maintaining food diversification. FMM were formulated at different energy densities and nutrient strengths (i.e. lower-and higher-strength) based on the WHO Ten Steps rationale<sup>(40)</sup> and taking into account different nutritional needs of children at different stages of rehabilitation. The recipes were processed into edible products including cookies, biscuits, cakes, porridge and soups to allow for variety in the diet. The results of the nutrient compositions are comparable with both Weanimix and Koko, as described earlier.

#### *Complementary food products for pregnant women in a resource-poor community*

To further demonstrate the universal applicability of the FMM concept, we showcase data from recipes designed and developed into end products for pregnant women in a poor community in the Gauteng Province of South Africa with a low birth weight prevalence of 16 % (compared with the South African average of 11.5 %)<sup>(41)</sup> in a 4-month feeding trial. Optimum health and successful pregnancy outcome depend on good maternal health and adequate nutritional provision to meet fetal demands throughout pregnancy, and pregnancy weight gain is a good predictor of pregnancy outcome<sup>(42)</sup>.

In designing complementary foods for pregnant women, the factorial approach in which the extra needs imposed by pregnancy and lactation are added to 'normal' baseline requirements for the non-pregnant woman formed the basis for formulations of FMM for this target group. For instance, total maternal weight gain throughout pregnancy would range from 11 to 16 kg with an extra energy cost ranging from 78 MJ (in a typical food-insecure developing country) to 281 MJ (in a food-secure developed country)<sup>(43)</sup>. In addition to energy needs, protein, minerals and vitamin requirements are expected to increase during pregnancy, the latter two particularly being affected by increased blood volumes which produce a dilutional effect.

One hundred and twenty eligible pregnant women of similar baseline nutritional and health characteristics recruited at booking were randomly assigned in a double-blind trial to one of two groups following baseline assessment of their normal daily energy and nutrient intakes. The intervention (treatment) group received FMM complementary food (formulated high energy, high protein, micronutrient-dense food of known nutrient composition) in addition to their normal daily diet; the control (placebo) group received a commercially sold soup powder (of known nutrient composition) commonly consumed by pregnant women in the community. A 4-month feeding trial was conducted among the two groups. Outcome indicators included weight gain, haematological indices and birth weight of babies<sup>(39)</sup> born to the two groups.

**Table 4.** Daily nutrient intake of pregnant women consuming food multimixes (FMM; intervention) and placebo (control) in South Africa

Nutrient	Food intake + FMM		Food intake + placebo		P-value	DRI values
	Intervention group		Control group			
	n 60		n 60			
	Mean	SD	Mean	SD		
<b>Macronutrients</b>						
Energy (MJ)	7.6	3.24	7.1	2.94	0.36	10.09
Total proteins (g)	72.7	38.72	69.3	32.14	0.61	71.0
Total fat (g)	54.9	30.87	55.0	38.09	0.98	–
Carbohydrates (g)	242.8	109.03	213.6	97.48	0.13	175.0
<b>Minerals</b>						
Ca (mg)	497.4	337.40	286.5	200.83	0.00	1000
Fe (mg)	14.1	4.77	10.5	10.84	0.03	27
Mg (mg)	389.2	154.2	155.9	133.04	0.00	360
Zn (mg)	10.7	4.97	5.7	5.46	0.00	11
Cu (µg)	1.6	1.24	0.8	1.14	0.00	2
Selenium (µg)	31.5	31.77	28.1	36.98	0.59	60
<b>Vitamins</b>						
Vitamin A, RE (µg)	1230.3	278.02	558.6	246.34	0.17	770
Thiamin (mg)	1.35	0.53	0.87	0.89	0.00	1.4
Riboflavin (mg)	1.29	1.37	0.84	1.35	0.08	1.4
Niacin (mg)	21.9	6.00	12.76	13.66	0.00	18
Folate (µg)	323.7	149.37	143.0	174.86	0.00	600
Vitamin B12 (µg)	6.1	27.77	6.8	26.15	0.90	2.6

DRI, dietary reference intakes.

**Table 5.** Selected haematological indices among 120 healthy pregnant women from the Vaal Triangle, Gauteng Province, South Africa, following intervention using food multimixes (FMM)

	Intervention group (n 30)					Control group (n 30)					Post-intervention group (n 30)				
	Baseline		Post-intervention		P-value	Baseline		Post-intervention		P-value	Baseline		Post-intervention		P-value
	Mean	SD	Mean	SD		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
<b>Haematological indices</b>															
Erythrocyte (×10 <sup>6</sup> /µl)	3.90	0.36	4.50	0.45	0.15	4.10	0.45	4.19	0.54	0.47	4.50	0.45	4.19	0.54	0.30
Hb (g/dl)	10.42	0.65	10.89	1.63	0.03	10.36	0.65	9.44	0.90	0.00	10.89	1.63	9.44	0.90	0.00
Hematocrit (%)	31.13	3.24	32.18	5.40	0.96	32.57	2.61	30.71	4.57	0.20	32.18	5.40	30.71	4.57	0.17
Mean cell Volume (l)	79.49	3.40	83.41	15.10	0.01	81.48	6.23	80.28	6.67	0.48	83.41	15.10	80.28	6.67	0.16
Fe (µmol/l)	11.71	7.32	14.21	2.24	0.04	10.28	5.79	10.78	8.12	0.86	14.21	2.24	10.78	8.12	0.01
Transferrin (g/l)	3.56	0.51	7.21	0.94	0.03	3.32	0.72	3.84	0.81	0.23	7.21	0.94	3.84	0.81	0.04
Ferritin (µg/l)	21.21	13.54	32.65	5.67	0.08	32.28	26.57	30.18	39.18	0.35	32.65	5.67	30.18	39.18	0.27

Table 4 shows comparisons of food intake in the intervention and control group. No significant differences in energy ( $P = 0.36$ ) and protein intake ( $P = 0.61$ ) were observed between intervention (FMM) and control (placebo) groups. Significant differences were observed in mineral intake except for selenium ( $P = 0.59$ ). Higher intakes of calcium ( $P < 0.001$ ), magnesium ( $P < 0.001$ ), zinc ( $P < 0.001$ ), copper ( $P < 0.001$ ) and iron ( $P = 0.03$ ) were observed in the treatment group. Similarly higher intakes of vitamins thiamine ( $P < 0.001$ ), niacin ( $P < 0.01$ ) and folate ( $P < 0.001$ ) were observed in the treatment group. Although differences in magnitude were observed for vitamin A, riboflavin and vitamin B<sub>12</sub>, these were not statistically significant (Table 4).

We have previously reported differences in biochemical variables<sup>39</sup> which are presented in Table 5, which shows differences in Hb, iron and transferrin from baseline to post-intervention period for the intervention and control group. The control group showed no significant differences at baseline and post-intervention for most of the haematological indices<sup>(39)</sup>.

Similarly for birth outcomes, we have previously shown results of better birth size and crown–heel length of babies born to intervention compared with the control group following FMM feeding trial (Table 6) including pregnancy weight gain ( $P < 0.001$ ), birth weight ( $P < 0.001$ ), head circumference ( $P < 0.001$ ) and crown–heel length ( $P = 0.05$ ). A difference in incidence of low birth weight of 8 % compared with 16 % was also observed in the intervention group<sup>(39)</sup>.



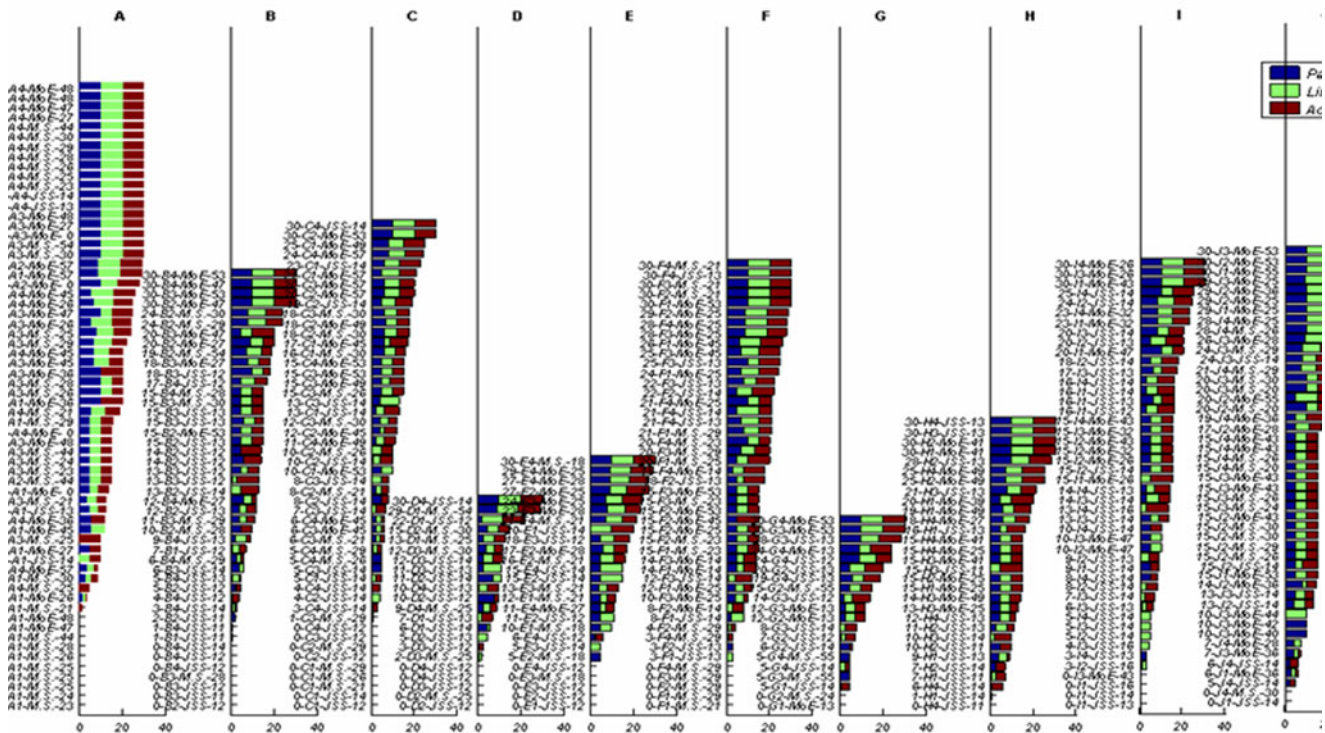
**Table 6.** Birth size and crown–heel length of babies born to intervention and control groups following food multimixes (FMM) feeding trial in South Africa

	Total weight gained Intervention	Total weight gained Control	Birth weight (kg) Intervention	Birth weight (kg) Control
Mean	11.50	10.40	3.02	2.71
SD	1.35	1.59	0.38	0.28
SEM	0.21	0.24	0.06	0.04
Median	11.30	10.20	3.20	2.80
Mode	11.10	10.40	3.20	2.80
P-values	0.00		0.00	

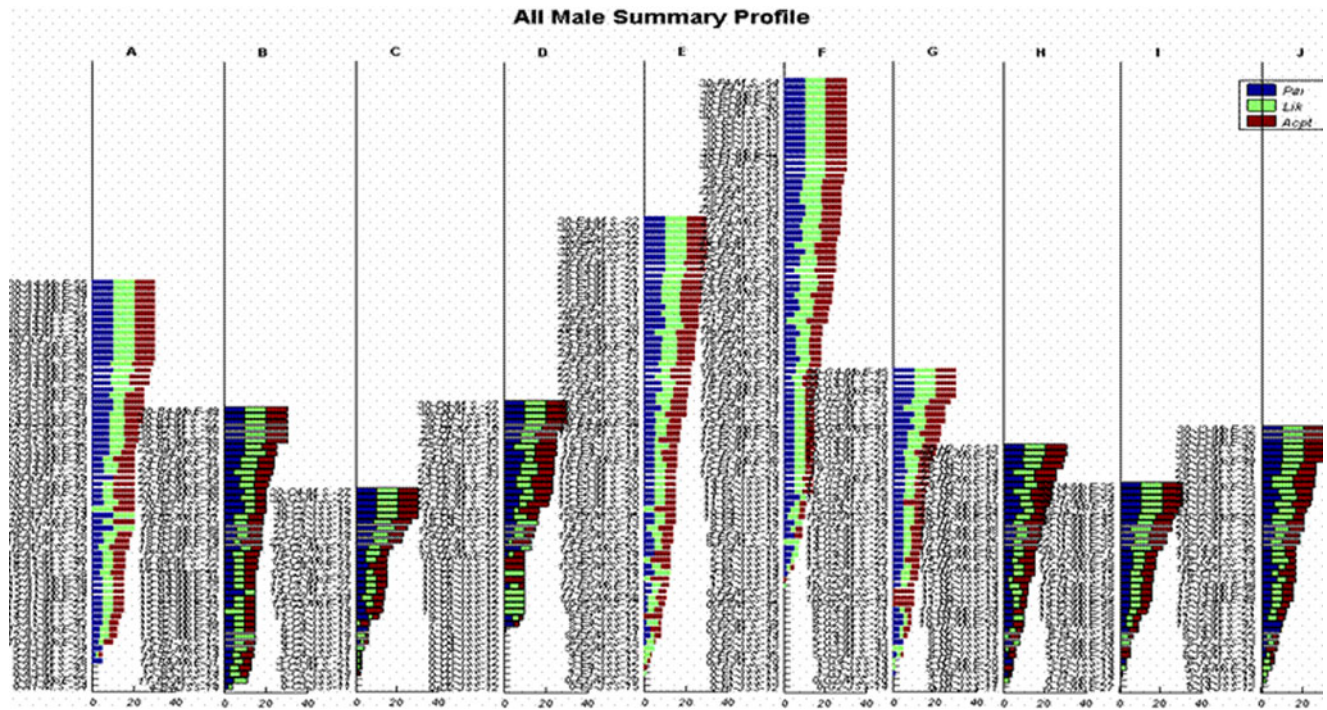
  

	Crown–heel length (cm) Intervention	Crown–heel length (cm) Control	Head circumference (cm) Intervention	Head circumference (cm) Control
Mean	49.11	47.88	34.78	33.30
SD	2.98	2.79	1.13	1.03
SEM	0.45	0.42	0.17	0.15
Median	50.10	48.90	35.10	33.50
Mode	45.60	49.90	35.80	34.10
P-values	0.05		0.00	

**All Female Summary Profile**



**Fig. 4.** This is a graphical representation showing individual responses on a Likert Scale of 0–10 with respect to palatability, likeness and acceptability shown separately (blue bar=palatability; green bar=likeness and red bar=acceptability score) of food multimix (FMM) products A to J tasted by all female subjects across the age range. The numerical values on the left hand side of the vertical axis represent individual subject codes (based on sum total score for palatability, likeability and acceptance, product ID e.g. A4, subject group e.g. Junior Secondary School and age of subjects). The size of each colour-coded bar to the right i.e. horizontal scale represents the individual score (i.e. out of a total of 10 on the Likert scale) for palatability, likeness and acceptability. The Figure shows the overall distribution of tasting attractions of female subjects for the range of products provided. The tasters had freedom to try any of the products so that the number of tasters can be taken to indicate visual attractiveness.



**Fig. 5.** This is a graphical representation showing individual responses on a Likert Scale of 0–10 with respect to palatability, likeness and acceptability shown separately (blue bar = palatability; green bar = likeness and red bar = acceptability score) of food multimix (FMM) products A to J tasted by all male subjects across the age range. The numerical values on the left hand side of the vertical axis represent individual subject codes (based on sum total score for palatability, likeability and acceptance, product ID e.g. A4, subject group e.g. Junior Secondary School and age of subjects). The size of each colour-coded bar to the right i.e. horizontal scale represents the individual score (i.e. out of a total of 10 on the Likert scale) for palatability, likeness and acceptability. The figure shows the overall distribution of tasting attractions of male subjects for the range of products provided. The tasters had freedom to try any of the products so that the number of tasters can be taken to indicate visual attractiveness.

### Testing the sensory characteristics of food multimix products

Sensory evaluation is an accepted part of the process of developing and getting new food products to market. A selection of forty FMM products developed based on Ghanaian foods were tested for their overall acceptability among different age groups within the Ghanaian population<sup>(25,26)</sup>. Volunteers varied from ages 11 to 68 years and were drawn from school pupils, students and adult from academic institutions and the Ministry of Education in Accra, Ghana. The focus of the sensory evaluation was to test their palatability, likeability and acceptance. Selected FMM were prepared in the form of soup, soft porridge, biscuits and cake.

Consumer Preference Testing was used as a method of rating classification answering the question ‘Which is liked best?’<sup>(44)</sup>. Acceptability was assessed based on appearance, flavour, taste, textural properties (feel) and smell. The testing procedures followed standard protocols used in other similar studies<sup>(45,46)</sup>.

Each sample tasted was rated on a Likert scale between 1 and 10 (where 1 = completely unacceptable, 5 = partially acceptable and 10 = completely acceptable) was used for each variable assessed and the highest average ratings score taken as a likeability score for that variable. Further data transformation and analysis combining average scores

from the different variables enabled conclusions to be drawn on the most favoured product among the target group.

Results of sensory evaluation are presented in Figs. 3; 4 and 5<sup>(25–26,47)</sup>. In Fig. 3, the graphical representation shows the overall percentage of how evaluators responded to the FMM products. Of the forty different products tested thirty-four were rated as acceptable, the most attractive was A4. Ninety-one percent ( $n = 945$ ) of subjects gave approval to the thirty-four different products with only 9% ( $n = 94$ ) registering their disapproval.

Sensory characteristics influencing acceptability between groups and within subjects is presented in a bar chart (Figs 4 and 5)<sup>(25–26,47)</sup>. Overall acceptability was plotted on the x-axis on a 10 point Likert scale. Each figure presented in the results is labelled at the top with the FMM recipes A to J. Sensory perception of each taster was ranked according to the product showing individual responses with respect to palatability, likeness and acceptability shown for males and females (blue bar = palatability; green bar = likeness and red bar = acceptability score). The graphical representation of the results appears to show that females were attracted to recipe A, whereas the males were more likely to accept recipe F (irrespective of age).

These results suggest that a number of factors influence the choice of FMM products across age and sex, even where food ingredients are familiar to individuals.

The clear sex difference in preference of FMM products present interesting findings given the fact that subjects were given a free choice and allowed to employ their own sensory preference in selecting products for tasting. The basis for these differences in attraction to products may be unclear; however, this may seem to suggest that even within the same cultural environment, food-related behaviour and choice may have a strong sex influence and this merits further investigation. It is however also worth noting that irrespective of sex, porridge made from the different FMM recipes was overwhelmingly preferred to other product ranges e.g. cakes, biscuits and soups. The possible implications of these findings are that in meal provision in clinical and public health settings and in the design of foods (including specially designed recipes) for target groups, these factors need to be given due consideration.

### Conclusion

In the present paper, we have sought to demonstrate how, employing scientific empirical evidence and our understanding of food groups, combinations of foods can be harnessed and processed to provide supplementary and complementary food recipes for multiple purposes, especially in food-insecure communities. We believe these uses merit further exploration and especially the possibility of using the FMM concept as an effective tool for developing foods for supportive purposes and therapeutic uses including in pregnancy, weaning and community-based nutrition rehabilitation.

The concept in our view offers useful perspectives on alternatives to address contemporary public health nutrition challenges and can form part of a feeding programme aimed at improving nutrition among vulnerable groups in food insecure and poor communities in developing countries. The FMM concept provides opportunities to use our understanding of food science, nutrition, human physiology, biochemistry and pathological processes to provide nutritional support including in emergencies. We are encouraged by these findings, the synopsis of which have been presented here and believe there is scope for developing prototype products to targeted markets.

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### Conflict of Interest

The authors declare no conflicts of interest.

### Authorship

F. Z. and P. A. developed the conception and design of the FMM concept. F. Z. collated results from unpublished results, re-analysed and drafted the manuscript with inputs from P. A., and B. E. F. Z. had primary responsibility for final content. All authors have critically reviewed and approved the final manuscript.

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