Orange-fleshed sweet potato-based infant food is a better source of dietary vitamin A than a maize–legume blend as complementary food

Francis Kweku Amagloh and Jane Coad

Abstract

Background. White maize, which is widely used for complementary feeding and is seldom fortified at the household level, may be associated with the high prevalence of vitamin A deficiency among infants in low-income countries.

Objective. The nutrient composition of complementary foods based on orange-fleshed sweet potato (OFSP) and cream-fleshed sweet potato (CFSP), maize–soybean–groundnut (Weanimix), and a proprietary wheat-based infant cereal (Nestlé Cerelac) were assessed using the Codex Standard (CODEX STAN 074-1981, Rev. 1–2006) specification as a reference. Additionally, the costs of OFSP complementary food, CFSP complementary food, and Weanimix production at the household level were estimated. Phytate and polyphenols, which limit the bioavailability of micronutrients, were assessed.

Methods. Energy, macronutrients, and micronutrients listed as essential composition in the Codex Standard were determined and expressed as energy or nutrient density.

Results. All the formulations met the stipulated energy and nutrient densities as specified in the Codex Standard. The β-carotene content of OFSP complementary food exceeded the vitamin A specification (60 to 180 μg retinol activity equivalents/100 kcal). All the formulations except Weanimix contained measurable amounts of ascorbic acid (≥ 32.0 mg/100 g). The level of phytate in Weanimix was highest, about twice that of OFSP complementary food. The sweet potato-based foods contained about twice as much total polyphenols as the cereal-based products. The estimated production cost of OFSP complementary food was slightly higher (1.5 times) than that of Weanimix.

Conclusions. OFSP complementary food is a good source of β-carotene and would therefore contribute to the vitamin A requirements of infants. Both OFSP complementary food and Weanimix may inhibit iron absorption because of their high levels of polyphenols and phytate, respectively, compared with those of Nestlé Cerelac.

Key words: Complementary food, orange-fleshed sweet potato, soybean, vitamin A

Introduction

The occurrence of vitamin A deficiency among infants and young children in sub-Saharan Africa is a public health concern. About 44% of preschool children are vitamin A deficient, more than twice the prevalence at which the deficiency is categorized as a "severe" public health issue [1]. In Ghana, the prevalence of vitamin A deficiency among children under 5 years of age is as high as 76% [1]. The reason could be the wide use of cereal-based complementary foods in low-income countries [2]. Culturally, white maize (*Zea mays*), which is devoid of β-carotene (provitamin A) [3], is the major cereal that is used in preparing foods for infants [4].

Without direct fortification with micronutrients, Weanimix, a blend of maize, soybean/cowpea, and groundnut, enriched with fish powder prepared from anchovy (*Engraulis hepsetus*), does not support the rapid growth requirements of infants for vitamin A [5] and iron [6]. The poor vitamin A and iron status of infants fed Weanimix as a complementary food is probably due to its low concentration of β-carotene [5, 7] and high level of phytate, an antinutrient that limits

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absorption of nonheme iron and zinc from cereals, legumes, and cereal–legume blends [8, 9]. Chang and coworkers [10] discussed the difficulties of fortifying cereal-based complementary foods with iron because of their phytate content. Also, it has been recommended that whole-grain products should be limited in, or eliminated from, complementary foods for infants and young children [11].

Despite these limitations of cereal–legume blends, no major efforts have been made to identify alternative food crops for use as complementary foods (as either household-level or industrially manufactured products). The Codex Standard and the available guidelines for complementary foods for infants and young children are limited to cereal-based foods [12, 13]. In an attempt to address the limitations of cereals and cereal–legume blends as complementary foods, sweet potato (*Ipomoea batatas*)-based foods were proposed as alternatives [14].

The complementary food formulations (oven-toasted, roller-dried, and extrusion-cooked complementary foods) that were prepared from a cream-fleshed sweet potato (CFSP) variant had phytate levels one-quarter the level of 800 mg/100 g in Weanimix [15, 16] and higher provitamin A contents than Weanimix (28 vs. 2 µg retinol activity equivalents [RAE]/100 kcal) [7]. The complementary food formulations also had better consumer preference and formed low-viscous porridge compared with Weanimix, and would avoid excessive energy and nutrient thinning resulting from excessive dilution with water during the preparation of porridge [17].

The major limitations of the studies cited above are that CFSP is lower in β-carotene than orange-fleshed sweet potato (OFSP) [18]; the flour preparation significantly increases the processing time of the complementary food products, as sweet potato has low dry matter; and there was total degradation of ascorbic acid during processing of sweet potato flour (data not reported). Ascorbic acid is an essential micronutrient that counteracts the negative effect of phytate on iron bioavailability [19] owing to its reducing properties and ability to chelate and form a soluble complex with nonheme iron [19, 20]. There are contradictory reports of the effects of polyphenols on iron absorption. Petry and coworkers [21] found that total polyphenols extracted from the hull of common bean, greater than 20 mg of gallic acid equivalents per meal, reduced iron absorption, whereas in cowpea-based flour, high phytate concentration but not total polyphenols limited iron absorption [22].

The present study investigated a household-level method of processing infant foods from an OFSP and a CFSP that eliminates the need for flour production from sweet potato. Because affordability is the limiting factor in developing countries for utilization of nutritionally adequate fortified infant cereals or micronutrient preparations, the costs of processing OFSP complementary food, CFSP complementary food, and Weanimix as household-level complementary foods were considered in this study. The basis of the proportions of the ingredients in both the sweet potato-based complementary food products and Weanimix has been extensively discussed in the literature [7, 14, 15], and is not be considered in this work.

The objectives of the present study were to estimate the cost of the ingredients for processing OFSP complementary food, CFSP complementary food, and Weanimix as household-level infant formulations for complementary feeding; compare the nutrient composition of sweet potato-based complementary foods from CFSP and OFSP, Weanimix, and a proprietary wheat-based infant cereal (Nestlé Cerelac) using the Codex Standard (CODEX STAN 074-1981, Rev. 1–2006) as a reference; and compare the levels of ascorbic acid and inhibitors of micronutrients (phytate and total polyphenols) in all the complementary foods.

Materials and methods

Ingredients for processing the blended food products

Beauregard (OFSP) and its variant, "Toka Toka gold" (CFSP), marketed as "orange and gold kumara" respectively, were sourced from three sweet potato growers based in Dargaville, New Zealand. Full-fat soybean (*Glycine max*) flour and refined white maize flour (Springbok, South Africa), soybean oil (SIMPLY Pure, Malaysia), and groundnut (*Arachis hypogaea*) paste were purchased from local supermarkets in Palmerston North, New Zealand. Fish powder prepared from smoke-dried anchovy was imported from Ghana. The anchovy powder was sifted through a 500-µm stainless steel laboratory sieve (Endecotts Laboratory Sieve) on an electromagnetic sieve shaker (EMS-8 Electropharma) set at an amplitude of 2.0 mm for 30 minutes.

Other modifications, in addition to the elimination of flour production from sweet potato, are that sucrose was not included and that different processing methods were used for the sweet potato-based complementary foods, as described below.

OFSP and CFSP complementary food

For each variety, the sweet potato roots from the different growers were mixed and further divided into three parts for processing the complementary food products in three batches. One batch of the OFSP and CFSP complementary food formulations was prepared each day for three days to obtain a total of three batches of each formulation.

Both the OFSP and the CFSP roots were washed and peeled with a potato peeler, and chipped. To prepare 2 kg of either OFSP or CFSP complementary food, 140 g of soybean oil was first measured into the saucepan and then the other ingredients in the proportions listed in **table 1** were added; the preparation was then mixed with about 5 L of water and boiled for 2 hours on a stove.

Maize-based product

Weanimix, the maize-based complementary food consisting of 75% maize, 15% dehulled soybean, and 10% dehulled groundnut (**table 1**) [6, 23], was prepared as previously described [15]. Two kilograms of Weanimix per batch were produced. The toasted composite flour was mixed with a sufficient amount of water (totaling about 10 L) and boiled for 2 hours on a stove.

The OFSP and CFSP complementary foods and the Weanimix porridges were left to cool to room temperature and freeze-dried. Freeze-drying was performed to get the household-level blended foods into a dried state for analytical purposes. The freeze-dried formulations from the three different batches of either OFSP complementary food, CSFP complementary food, or enriched Weanimix were combined and milled together to reduce sample heterogeneity.

Commercial cereal-based product (Nestlé Cerelac Infant Cereal Wheat and Ikan Bilis)

A proprietary infant dried cereal (Cerelac) prepared from wheat was sourced from Nestlé, Malaysia. The ingredients listed on the package include wheat flour, skimmed milk powder (cow's milk), sucrose, fish (anchovy), spinach, sodium chloride, calcium carbonate, vitamin C, taurine, ferrous fumarate, vitamin E, vitamin A, calcium D-pantothenate, and traces of soybean. This product was included in this study because it is the only dried infant cereal that contains anchovy, an ingredient in the complementary food and Weanimix formulations.

Blind triplicate analytical samples were prepared from the milled-freeze-dried samples of OFSP complementary food, CFSP complementary food, and Weanimix, but Cerelac was sampled "as is". The analytical samples taken were transferred into 12 separate three-letter-coded, airtight plastic containers and stored at −1.0°C until required for analysis.

TABLE 1. Composition (adjusted for moisture content), cost, and preparation of ingredients for processing 2 kg (on 100% dry matter basis) of household-level sweet potato-based and maize-based complementary foods[a]

Complementary food and ingredient	Moisture (/100 g)	Amount (kg)	Cost (Gh¢)[b]	Preparation method
OFSP complementary food				
Beauregard (OFSP)	80.38	6.63	6.63	Peeling and dicing
Full-fat soybean flour	7.60	0.17	0.29	Roasting, dehulling, and milling
Soybean oil	—	0.14	0.96	—
Anchovy powder	10.06	0.44	5.50	Breaking off heads and milling
Total cost (Gh¢)			13.38	
CFSP complementary food				
"Toka Toka gold" (CFSP)	74.22	5.04	5.04	Peeling and dicing
Full-fat soybean flour	7.60	0.17	0.29	Roasting, dehulling, and milling
Soybean oil	—	0.14	0.96	—
Anchovy powder	10.06	0.44	5.50	Breaking off heads and milling
Total cost (Gh¢)			11.79	
Weanimix				
Refined maize flour	14.20	1.75	1.75	Dehulling, milling, and roasting
Full-fat soybean flour	7.60	0.32	0.55	Roasting, dehulling, and milling
Groundnut paste	1.20	0.20	1.05	Roasting, dehulling, and milling
Anchovy powder	10.06	0.44	5.50	Breaking off heads and milling
Total cost (Gh¢)			8.85	

CFSP, cream-fleshed sweet potato; OFSP, orange-fleshed sweet potato

a. Proportions of the ingredients in the complementary food formulations, assuming a 100% dry matter basis: sweet potato root 65%, full-fat soybean flour 8.0%, soybean oil 7.0%, anchovy powder 20% [15], with slight modification for Weanimix: maize 75%, soybean flour 15%, and groundnut paste 10% [6, 23]. Anchovy was added to the base Weanimix at 20% (wt/wt). Amount to weigh, adjusted for moisture content, was calculated using the expression: (Quantity of the food to be produced × proportion of ingredient in the formulation)/(100-moisture content of ingredient).

b. Gh¢1.00 = US$0.52 (January 2013); Cost of sugar to sweeten Weanimix before consumption was not included, as it would be at the discretion of the caregiver. The costs of milling maize and groundnut, which would be about Gh¢0.47, were also not included, as unit operations were not included in the cost estimation.

Cost for production of complementary food and Weanimix blended foods at the household level

The costs of production of the sweet potato-based and maize-based household-level complementary foods were estimated by purchasing the ingredients from three markets in Accra, the capital city of Ghana. The prices of the ingredients listed in **table 1** were for whole grain or pulses, except for OFSP and CFSP, for which the cost was provided by the regional sweet potato breeder (Edward Carey, International Potato Center) for West Africa, as neither OFSP nor CFSP was available at the market centers visited.

Nutrient profiling of the complementary foods for comparison with the Codex specifications

The specifications of energy and nutrients in the Codex Standard for processed cereal-based foods for older infants and young children [13] are expressed as energy density (kcal/g) and nutrient density (/100 kcal), respectively.

Energy density

The gross energy contents of the analytical samples of OFSP complementary food, CFSP complementary food, Weanimix, and Cerelac were determined by bomb calorimetry in the Nutrition Laboratory of Massey University, Palmerston North, New Zealand, on a fee-for-service basis. The energy density was estimated by dividing the energy content of a serving size (33 g for OFSP complementary food, CFSP complementary food and Weanimix, and 50 g for Cerelac) to be reconstituted with 150 mL of water. The amount of porridge was 183 g and 200 g, respectively for the household-level products and Cerelac.

Protein, fat, and carbohydrate composition

The methods described in the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC) International [24] were used to determine the amount of moisture (AOAC 925.10, slightly modified by drying the samples at 108°C overnight for approximately 16 hours), crude protein (AOAC 960.52), and crude fat (AOAC 922.06) in all the formulations. Soluble and insoluble dietary fiber was determined by the enzymatic-gravimetric method (AOAC 991.43). The level of starch in the formulations was evaluated by the α-amylase method (AOAC 996.1), and the amount of simple sugars (glucose, fructose, maltose, sucrose, and lactose) was assessed by gas chromatography in the Massey University Nutrition Laboratory.

Calcium, sodium, vitamin A, and ascorbic acid

The calcium and sodium contents in the OFSP and CFSP complementary foods, Weanimix, and Cerelac were determined as previously described [16] using a quadrupole inductively coupled mass spectrometer (Agilent 7500ce) by the Campbell Micro-analytical Laboratory, Department of Chemistry, University of Otago, New Zealand, on a fee-for-service basis. Quality control samples (NIST Standard Reference Material 1849: Infant/Adult Nutritional formula) run with the complementary food samples had mean recoveries of about 100% for sodium and 102% for calcium.

Determination of the levels of β-carotene and vitamin A by the Carr–Price method, AOAC 974.29 (4), and of ascorbic acid by the method described by Lee and Coates [25] was carried out by the Massey University Nutrition Laboratory. The correlation coefficients for the calibration curves were 0.998 for β-carotene and 0.9997 for ascorbic acid. Quality control samples used for both analyses were recovered at 91% for β-carotene and 100% for ascorbic acid. A conversion factor of 1 RAE:12 β-carotene was used in calculating the vitamin A levels in the samples, as suggested by other researchers [26]. Retinol analysis was only performed on Cerelac, as our previous work showed that retinol levels in the complementary food and Weanimix infant products were negligible [7, 16].

Phytate

An assay kit, K-PHYT 05/07 (Megazyme Int.), was used to analyze the phytate content in the formulations by spectrophotometry, as described elsewhere [15], with slight modifications. After extraction of the phytate in samples with hydrochloric acid, the solutions obtained were filtered with CHUX Biodegradable Superwipes before the enzymatic dephosphorylation step with phytase. A quality control sample, oat flour, supplied with the kit was run alongside the complementary food samples. The phosphorus content of the internal standard was 0.57 g/100 g on an "as is" basis, compared with 0.54 g/100 g specified on the container, within the 10% difference specified in the protocol.

Total polyphenols

The total polyphenols in the samples (quantified as gallic acid equivalents) were determined by the Folin–Ciocalteu method as described elsewhere [16].

Statistical analysis

All the results of the various determinations were calculated on a dry matter basis, except for moisture content, prior to statistical analysis. The means of the complementary food samples for each response variable were compared by one-way analysis of variance (ANOVA) with the use of Minitab 16.2.2. Tukey's studentized range test was used to compare differences between means when the ANOVA result was significant ($p < .05$). Data were reported as mean ± SD.

Results and discussion

Product composition and cost analysis of the sweet potato-based complementary foods and Weanimix (maize-based) products at the household level

Briefly, the complementary food products were primarily designed to address the low levels of vitamin A in unfortified cereal-based blended foods, for example, in Weanimix [6, 23]. In the present study, dehulled flours of maize and soybean were used. The sweet potato-based and maize-based blended foods were formulated to be used for complementary feeding without the need to add any milk product before consumption by older infants. The longer cooking time of 2 hours was required because of the quantity of the products being processed. Cooking about 200 g required about 20 minutes.

The cost analysis for the complementary food products and Weanimix was calculated on a 100% dry matter basis, and it included only the costs of the ingredients and not the processing methods (**table 1**). The costs of producing OFSP and CFSP complementary foods at the household level would be about 1.5 and 1.3 times the cost of producing Weanimix, respectively. The relatively high production cost of the sweet potato-based complementary food products is due to the high moisture content of the sweet potato root, which requires at least twice as much of the fresh OFSP roots for a given amount of dried product. The costs of milling maize and groundnut, which would be about Gh¢0.47 ≈ US$0.24 (January 2013), were excluded, because the unit operations were not considered. The cost of sugar for sweetening Weanimix was also not estimated, because the amount to be added would be at the discretion of the caregiver. Thus, the addition of sugar and milling of maize and groundnut would reduce the cost difference between the sweet potato-based complementary food products and Weanimix. The unit operations listed in **table 1** are simple culinary methods that are commonly used at the household level.

Energy and macronutrient densities

Table 2 shows the data on energy and macronutrient densities, as well as other carbohydrate fractions not included in the Codex Standard. The sweet potato-based complementary food formulations, Weanimix, and Cerelac met the stipulated minimum energy density for complementary food of 0.8 kcal/g. Cerelac had the highest energy density (1.19 kcal/g), because the serving size for Cerelac used in estimating energy density is relatively high (about 1.5 times) compared with that for the nonproprietary complementary foods. Thus, these formulations would adequately meet the energy requirement for older infants during

TABLE 2. Energy and macronutrient densities and levels of other carbohydrate fractions of sweet potato-based and cereal-based complementary foods[a]

Complementary food[b]	Energy (kcal/g)	Protein	Simple sugars[c]	Fructose	Fat	Soluble dietary fiber	Insoluble dietary fiber	Maltose	Lactose	Starch
		g/100 kcal				g/100 g				
OFSP complementary food	0.89^x	4.53 ± 0.06^{wx}	4.39 ± 0.10^w	1.45 ± 0.04^w	2.36 ± 0.04^w	2.83 ± 0.45^w	9.45 ± 1.49^w	20.38 ± 0.41^x	ND	13.19 ± 0.20^z
CFSP complementary food	0.87^y	4.33 ± 0.10^x	3.02 ± 0.04^x	0.64 ± 0.01^x	2.35 ± 0.02^w	1.99 ± 0.35^w	8.06 ± 0.53^{w,x}	24.10 ± 0.54^w	ND	17.11 ± 0.22^y
Weanimix	0.88^w	4.73 ± 0.20^w	0.52 ± 0.00^z	ND	1.94 ± 0.01^y	0.03 ± 0.06^x	6.90 ± 0.64^x	2.72 ± 0.12^z	ND	48.38 ± 0.50^w
Cerelac	1.19^w	3.25 ± 0.04^y	1.69 ± 0.02^y	ND	2.23 ± 0.02^x	0.45 ± 0.31^x	1.03 ± 0.20^y	10.31 ± 0.12^y	14.67 ± 0.22	30.93 ± 0.34^x
Codex specification	≥ 0.8	2.0–5.5	≤ 5.0	≤ 2.5	≤ 4.5	—	—	—	—	—

CFSP, cream-fleshed sweet potato; ND, none detected; OFSP, orange-fleshed sweet potato

a. Mean ± SD of triplicate determinations on dry matter basis, energy density was on 33 g reconstituted with 150 mL water for complementary food and Weanimix and 50 g reconstituted with 150 mL water for Cerelac. Values within a column with unlike superscript letters are significantly different (*p* < .05). Carbohydrate fractions: soluble and insoluble dietary fibers, maltose, lactose, and starch.

b. OFSP and CFSP complementary food, orange- and cream-fleshed sweet potato-based blended infant food products; Weanimix, a maize–soybean–groundnut complementary food; Cerelac, a proprietary infant dried cereal containing wheat and skimmed milk powder and fortified with micronutrients sourced from Nestlé, Malaysia.

c. Simple sugars as sum of sucrose, fructose, and glucose.

the complementary feeding period. The quantity of 33 g stated to be reconstituted for sweet potato-based and maize-based products was based on the finding of Lartey and coworkers for Weanimix consumption by Ghanaian infants from 6 to 12 months of age [6]; the 50 g for Cerelac was the serving size stated on the package. Based on the relatively high consumer preference for the sweet potato-based complementary food products, as rated by female caregivers from sub-Saharan Africa [17], it could be suggested that, on a dry weight basis, infants will consume more sweet potato-based complementary foods than Weanimix.

Weanimix had the highest protein density, but the density was comparable to that of OFSP complementary food (4.3% difference, $p > .05$). The high protein density of the household-level products is due to the proportion of fish (about 20%) and soybean used as ingredients; and also groundnut in the case of Weanimix. Importantly, both the household-level products and the commercial dried infant cereal were in the specified protein range of 2.00 to 5.50 g/100 kcal stated in the Codex Standard. Previously, in comparisons of similar complementary foods prepared from CFSP flour and some of the other ingredients listed in **table 1** and Weanimix (same composition as in this study), their protein chemical score barely met the minimum of 80% of that of casein as a reference protein [7]. Therefore, as the proportion of anchovy powder was increased from 17% to 20% in this study, it would be expected that the chemical score would satisfy the specified value. Protein digestibility-corrected amino acid scores of these formulations are being investigated to assess their protein quality.

OFSP complementary food, CFSP complementary food, and Cerelac contained significant amounts of carbohydrate as simple sugars (expressed as the sum of glucose, fructose, and sucrose, and fructose only in Codex Standard) compared with the levels in Weanimix. Only the sweet potato-based products contained fructose, and as would be expected, lactose was available only in Cerelac, which contained skimmed milk. The simple sugars in the sweet potato-based complementary food products were from sweet potato, but in Cerelac the simple sugars were added as ingredients. The data on simple sugars indicate that the sweet potato-based complementary food products would be naturally sweet and may not require addition of sucrose before feeding them to babies, but not so for Weanimix. Needless to say, the cost of sugar to sweeten Weanimix may offset the differences in the production cost between the sweet potato-based complementary food products and Weanimix, as stated earlier. OFSP complementary food had the highest simple sugar density, 4.39 g/100 kcal, but this was below the maximum stipulated value of 5.0 g/100 kcal. As the levels of simple sugars are within the limits specified in the Codex

Standard, the quantity of these simple carbohydrates in the sweet potato-based complementary food products will not be deemed detrimental to health.

Almost half of the carbohydrate in Weanimix was starch, but in OFSP and CFSP complementary foods, the starch content was 13% and 17%, respectively. The relatively low starch contents of the sweet potato-based complementary foods are directly related to the level of endogenous β-amylase [27], which converts most of the starch to maltose when the roots are heated at 65°C or above [27–29]. Because it has been suggested that infants only efficiently digest starch when it is present in food in small quantities [30, 31], it is likely that the sweet potato-based complementary food products would be easier for infants to digest. CFSP complementary food had a 17% higher maltose content than OFSP complementary food, indicating a varietal difference that may be due to differences in starch and/or β-amylase concentrations. Cerelac had about half the maltose content of the sweet potato-based complementary food products, but its maltose content was relatively high, more than twice that of Weanimix. The maltose content is higher in Cerelac than in Weanimix because the cereals used in the production of dry infant cereals by Nestlé are subjected to enzymatic hydrolysis to reduce part of the starch into simple carbohydrates such as maltodextrins and maltose [32].

The lipid contents of all the products evaluated in this study were about half the maximum level of 4.5 g/100 kcal in the Codex Standard. Because fat enhances β-carotene absorption [33], the fat content of 3.0 g/100 g reported for an OFSP-based complementary food by other researchers [34] may not promote bioavailability of β-carotene as well as the OFSP complementary food, with a fat content of approximately 12.0 g/100 g. It has been reported that only a minimal amount of oil (about 3 to 5 g per meal) is required for optimal absorption of β-carotene [35]; the higher fat content of our OFSP complementary food, but not the fat content of the OFSP-based complementary food of the other researchers[34], will meet this requirement.

The total dietary fiber contents of OFSP and CFSP complementary foods were significantly higher than that of Cerelac (157% and 149% differences, respectively). The dietary fiber content of Weanimix was 56% lower than that of OFSP complementary food and 37% lower than that of CFSP complementary food. This may raise a concern about using the sweet potato-based products for complementary feeding based on the recommendation of a dietary fiber content of less than 5 g/100 g on a dry matter basis in the proposed draft Codex guideline for infant food [36]. However, this study showed that about 20% of the total dietary fiber of the sweet potato-based products was soluble fiber, compared with 30% for Cerelac; conversely, the total dietary fiber in Weanimix is predominantly insoluble

fiber. Therefore, the complementary food formulations might support the growth of health-promoting bacteria, such as lactobacilli and bifidobacteria [37, 38], better than Weanimix.

Phytate and total polyphenols

The phytate content of Weanimix was about twice that of OFSP complementary food, and both were significantly higher than that of CFSP complementary food and Cerelac (**table 3**). The levels of phytate in CFSP complementary food and Weanimix were far lower than the values of 230 and 800 mg/100 g reported earlier [15], indicating that the processing method (boiling the blends for 2 hours) described in this study resulted in further degradation of phytate.

As previously highlighted [16], the phytate assay may slightly overestimate the phytate level, as it included inositol diphosphate. However, the method quantified inositol tri- and tetraphosphates (a common occurrence in thermal-processed foods), which have been shown to inhibit iron absorption [39], but ignored if only inositol penta- and hexaphosphates are reported.

The sweet potato-based foods contained about twice the concentration of total polyphenols as the cereal-based products. However, when the serving size stated earlier is used, the concentration of total polyphenols per meal is greater than 20 g, and thus all the complementary foods in this study may limit iron absorption [21]. OFSP complementary food, CFSP complementary food, and Cerelac, but not Weanimix, contained ascorbic acid (discussed below), which is likely to offset the inhibitory effects of phytate [19] and polyphenols [40] on nonheme iron absorption.

Micronutrient density

Table 3 shows that the sodium content of the complementary food products and Weanimix was about half the maximum stipulated value of 100 mg/100 kcal, but the sodium content of Cerelac was about this value.

The calcium content of the sweet potato-based and maize-based complementary foods (**table 3**) supports the trend previously reported, and the finding that sweet potato is higher in calcium than is maize [7, 16]. All the formulations met the stipulated value of at least 80 mg/100 kcal.

As expected, OFSP complementary food had the highest provitamin A (as β-carotene) content of all the products and even exceeded the recommended level of between 60 and 180 μg RE/100 kcal (**table 3**). There is no tolerable upper limit for β-carotene, as there are no data on adverse effects of excessive intake [41]. Therefore, if OFSP is promoted as a dietary source of provitamin A (example, OFSP complementary food as processed in this study), it could reduce vitamin A deficiency among infants and young children in low-income countries where sweet potato is available or could be cultivated. There is convincing evidence that consumption of boiled OFSP by young children improves their vitamin A status [33, 42, 43].

Measurable amounts of ascorbic acid were contained in OFSP complementary food, CFSP complementary food, and Cerelac formulations but not in Weanimix (**table 3**). Ascorbic acid was added to Cerelac and is endogenous in the sweet potato-based complementary food products. Cooking the sweet potato chips and the other ingredients abrogated the total degradation of ascorbic acid, which was seen with the other processing method of flour production from the roots before using

TABLE 3. Micronutrient density and levels of ascorbic acid and phytate in sweet potato-based and cereal-based complementary foods[a]

Complementary food[b]	Sodium (mg/100 kcal)	Calcium (mg/100 kcal)	Vitamin A (μg RAE/100 kcal)	Ascorbic acid (mg/100 g)[c]	Phytate (mg/100 g)	Total polyphenols (mg gallic acid equivalents/100 g)
OFSP complementary food	$54.50 \pm 0.41^{x,y}$	$128.30 \pm 12.95^{w,x}$	226.24 ± 30.70^{w}	32.48 ± 0.48^{x}	229.85 ± 20.36^{x}	466.27 ± 9.36^{w}
CFSP complementary food	59.05 ± 1.27^{x}	135.08 ± 14.23^{w}	$21.79 \pm 0.35^{x,y}$	$37.40 \pm 0.61^{w,x}$	78.62 ± 3.50^{y}	466.42 ± 34.97^{w}
Weanimix	36.19 ± 0.66^{y}	100.90 ± 12.84^{x}	0.58 ± 0.20^{y}	ND	438.10 ± 8.58^{w}	263.68 ± 17.82^{x}
Cerelac	94.16 ± 17.23^{w}	$107.64 \pm 1.68^{w,x}$	47.72 ± 5.84^{x}	53.11 ± 12.07^{w}	66.92 ± 4.00^{y}	213.45 ± 29.93^{x}
Codex specification	≤ 100	≥ 80	60 – 180	≤ 50	—	—

CFSP, cream-fleshed sweet potato; ND, none detected; OFSP, orange-fleshed sweet potato; RAE, retinol activity equivalent

a. Mean ± SD of triplicate determinations. Values within a column with unlike superscript letters are significantly different ($p < .05$).

b. OFSP and CFSP complementary food, orange- and cream-fleshed sweet potato-based blended infant food products; Weanimix, a maize–soybean–groundnut complementary food; Cerelac, a proprietary infant dried cereal containing wheat and skimmed milk powder and fortified with micronutrients sourced from Nestlé, Malaysia.

c. Added as a food additive or carry-over from ingredients.

as an ingredient [15]. This is of nutritional significance, as the low phytate coupled with the level of ascorbic acid of the sweet potato-based complementary food products could promote the bioavailability of nonheme iron. All the formulations have similar ($p = .10$) levels of iron: OFSP complementary food, 7.76 ± 1.22 mg/100 g; CFSP complementary food, 7.26 ± 0.08 mg/100 g; Weanimix, 6.53 ± 1.55 mg/100 g; and Cerelac, 8.85 ± 0.17 mg/100 g. Iron uptake from these formulations will be investigated using an *in vitro* digestion/Caco-2 model.

Conclusions

The findings suggest that OFSP complementary food is a good source of β-carotene and could improve the vitamin A status of infants more than unfortified cereal–legume blends. OFSP complementary food, CFSP complementary food, and Weanimix, as well as Cerelac (a proprietary wheat-based infant cereal), meet almost all the stipulated energy and macronutrient densities in the Codex Standard. Both OFSP complementary food and Weanimix may inhibit nonheme iron absorption because of their high levels of polyphenols and phytate, respectively, compared with that of Cerelac.

Conflict of interest

The authors declare they have no conflicts of interest.

Authors' contributions

Both authors were involved in the development of the sweet potato-based complementary foods and data collection and analysis, and approved the final version of the manuscript.

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