A randomized, community-based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6 to 12 mo of age[1–3]

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ABSTRACT

Background: *Koko*, a fermented maize porridge used as the primary complementary food in Ghana, has been implicated in the high prevalence of child malnutrition. Weanimix, a cereal-legume blend developed by the United Nations Children's Fund and the Ghanaian government, has been promoted as an alternative.

Objective: We evaluated the effect of feeding Weanimix and 3 other locally formulated, centrally processed complementary foods on the nutritional status of 208 breast-fed infants.

Design: Infants were randomly assigned to receive 1 of 4 foods from 6 to 12 mo of age: Weanimix (W), Weanimix plus vitamins and minerals (WM), Weanimix plus fish powder (WF), and koko plus fish powder (KF). Dietary and anthropometric data were collected regularly. Blood was collected at 6 and 12 mo of age to assess iron, zinc, vitamin A, and riboflavin status. Before and after the intervention, cross-sectional data on the anthropometric status of infants not included in the intervention (NI; $n = 464$) were collected.

Results: There were no significant differences between intervention groups in weight or length gain or in hemoglobin, hematocrit, transferrin saturation, plasma zinc, or erythrocyte riboflavin values between 6 and 12 mo of age. From 9 to 12 mo of age, z scores were lower in NI infants than in the combined intervention groups [at 12 mo: -1.71 ± 0.90 compared with -1.19 ± 0.93 for weight and -1.27 ± 1.02 compared with -0.63 ± 0.84 for length ($P < 0.001$ for both), respectively]. The percentage of infants with low ferritin values increased significantly between 6 and 12 mo of age in groups W, WF, and KF but not in group WM. Change in plasma retinol between 6 and 12 mo of age was significantly greater in group WM than in the other 3 groups combined (0.14 ± 0.3 compared with -0.04 ± 0.3 μmol/L, $P = 0.003$).

Conclusions: All 4 foods improved growth relative to the NI group. Infants fed WM had better iron stores and vitamin A status than those fed nonfortified foods. *Am J Clin Nutr* 1999;70:391–404.

KEY WORDS Complementary feeding, breast-feeding, infant growth, micronutrient status, iron, zinc, vitamin A, riboflavin, Ghana, energy density, Weanimix, *koko*, fermented maize porridge

INTRODUCTION

The growth rate of fully breast-fed infants in developing countries is comparable with that of infants in developed countries during the first 4–6 mo of life (1–4). However, infants in developing countries commonly deviate from this satisfactory pattern of growth after this period. Lack of nutrient-dense complementary foods (5) and frequent infections (6) are the main factors accounting for this decline. In Ghana, in West Africa, the traditional complementary food fed to infants is a fermented maize porridge called *koko*. Koko is generally perceived by mothers as easy to digest and is often the first food introduced to infants and the food of choice during illness. Although it takes 4–5 d to prepare the fermented dough used to make koko (7), once prepared the dough requires no refrigeration and can be kept for ≈1 wk for daily use by the household. The dough can also be purchased in a ready-to-use form from local markets. The availability, minimal cost, and ease of preparation make koko the preferred complementary food for the majority of Ghanaian infants. However, koko, like many traditional weaning foods in developing countries, has low energy and nutrient density (8), and has been implicated in the development of protein-energy malnutrition in infants (9).

In an effort to improve the quality of weaning food, the Ghanaian Ministry of Health Nutrition Division and the United Nations Children's Fund (UNICEF/Ghana) in 1987 introduced Weanimix, a cereal-legume blend, as an alternative. Weanimix is composed of 10–15% soybeans or cowpeas, 10% groundnuts (peanuts) and 75–80% maize (corn). Although Weanimix is an improvement over koko with respect to its energy and protein density, it has high phytate and fiber contents (estimated phytate-iron and phytate-zinc molar ratios of 7.3 and 17, respectively), which may impair iron and zinc absorption (10, 11). In addition, it is low in vitamin A (0.36 mg retinol equivalent/kg) and riboflavin (0.4 mg/kg).

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Before its promotion, no intervention trial had been undertaken to assess its effect on growth and micronutrient status of infants. Furthermore, results of a study with weanling rats (21 d old) raised questions about its ability to support adequate growth (12). The weight gain (30 ± 2 g) of rats fed Weanimix for 28 d was similar to that of rats fed an iron-deficient 20%-casein diet (23 ± 10 g) and lower than that of rats fed a casein diet with 12 mg Fe/kg (82 ± 10 g). Rats fed fermented maize dough gained only 10 ± 2 g, whereas those fed fermented maize dough plus 20% fish powder gained 113 ± 13 g ($P < 0.05$).

The present study was designed to compare the growth and micronutrient (iron, zinc, riboflavin, and vitamin A) status of Ghanaian infants 6–12 mo of age fed Weanimix (W) or 1 of 3 other improved complementary foods, namely: Weanimix with vitamins and minerals added (WM), Weanimix with fish powder (WF), or koko with fish powder (KF). Fish powder (from anchovies), a relatively cheap and available ingredient in most households, was added to Weanimix and koko to study whether it could be used as a fortificant to improve the nutrient quality of these complementary foods. The main hypothesis was that children fed WM, WF, or KF would have significantly better growth and iron, zinc, and riboflavin status than infants fed unmodified Weanimix.

SUBJECTS AND METHODS

Study site

The study was conducted in Techiman in the Brong Ahafo region of Ghana, located ≈400 km north of Accra. Techiman is a district capital with a population of ≈45 000 and has the largest market in Ghana. The main occupations are farming and trading. The Brong Ahafo region is one of the major food-growing regions of the country. Foods grown include yam, cassava, plantain, maize, beans, and other vegetables. Most households keep domestic animals such as chickens, goats, and sheep. The so-called hungry season (December–April) is relatively short in the Brong Ahafo region compared with the northern regions of the country where dry climatic conditions and a short rainy period result in longer periods of drought. Although malaria is endemic year-round in Ghana, the incidence is highest in the wet season (June–August) with the peak incidence in July (13). A pilot study we conducted in 1993 on infant-feeding practices in Techiman showed that breast-feeding was almost universal and >90% of infants were fed koko by 3 mo of age. The median duration of breast-feeding in the region is 23 mo (14). The source of water for most households is dug-hole well water.

Study design

The study had 2 parts: the main longitudinal trial (a randomized intervention) and a cross-sectional study of the nutritional status of nonintervention infants. For the longitudinal study, infants <1 mo of age were recruited between November 1994 and April 1995; all of them had reached 12 mo of age by March 1996. Cross-sectional data on infants 6–12 mo of age were collected both before (July–August 1993) and after (April–Sept 1996) the longitudinal study.

Longitudinal trial

Preparation of diets

The Weanimix used in this study consisted of 75% maize (corn), 15% soybeans, and 10% groundnuts (peanuts). The whole ingredients were roasted separately, mixed, and milled. WM was formulated to meet or exceed the vitamin and mineral requirements of infants when consumed with typical volumes of breast milk. Nutrients were added directly to the W flour; we used a vitamin-mineral premix (TSD #10781) from Roche Vitamins and Fine Chemicals (Nutley, NJ) plus additional iron (electrolytic iron), potassium (as potassium citrate), calcium, and phosphorus (as dicalcium phosphate) to meet the target amounts. To avoid potential toxicity problems, 2 levels of fortification were used, the higher one for infants consuming ≤60 g W/d and the lower one for infants consuming >60 g/d (**Table 1**). The fish powder was prepared from smoked anchovies purchased in bulk from the local market in Techiman. The head, scales, and intestines were discarded. The remaining parts were dried in a solar dryer and milled into powder by using a plate mill. For the WF, the fish powder was added to W at 20% by weight. In the preparation of KF, the fermented maize dough was prepared from dry maize by using traditional methods (7). The resulting dough was dehydrated in a drum dryer and ground into fine flour. To this flour, fish powder was added at 20% by weight. All the diets were centrally processed and were packaged into 500-g packets by the Techiman Weaning Food Project; which is privately owned, operates under the Sunyani Catholic diocese, and produces W for sale within the region.

The compositions of the 4 intervention foods (W, WM, WF, and KF) are shown in Table 1. The energy content of KF was slightly lower than that of the other 3 foods because of the soybeans and peanuts in W, WF, and WM. Fish powder added to WF and KF increased their protein, calcium, iron, zinc, phosphorus, and vitamin B-12 contents relative to W. By design, the micronutrient content of WM was considerably higher than that of the other 3 foods.

Before these foods were used in the intervention study, acceptability trials were conducted with 34 infants 6–12 mo of age. In these trials, each mother was given one of the project foods to prepare a porridge suitable for feeding her infant (n = 10 for W, 5 for WM, 7 for WF, and 12 for KF). The trials were conducted at a central facility in the presence of project assistants. The food was considered acceptable to the infant if at least some of the food was consumed; each of the 34 infants consumed some of their assigned project food. The average amount consumed was one-half to three-fourths of the amount offered (250 g) for all 4 foods. Feedback from mothers after the feeding trials indicated their willingness to feed the project foods to their infants.

Intervention

Infants ≤1 mo (n = 216) were recruited from Maternal and Child Health centers run by the Techiman Ministry of Health. Selection criteria were as follows: birth weight ≥2.5 kg, breast-fed, no congenital abnormalities, assigned a Maternal and Child Health card, and the child's mother was not planning to travel or move out of study area during the study period. Informed consent was given by both parents or the mother alone in the case of single mothers. The study was approved by the Human Subjects Review Committee of the University of California, Davis, and the Ministry of Health, Ghana.

At the time of recruitment, baseline data on the study households were collected and mothers were given advice on infant-feeding practices and encouraged to breast-feed exclusively for the first 6 mo. Between the ages of 1 and 6 mo, monthly anthropometric measurements were taken (weight, length, triceps and subscapular skinfold thicknesses, and midupper arm and head

TABLE 1
Nutrient content of complementary foods per kg dry weight[1]

	Weanimix	Weanimix plus vitamins and minerals[2]		Weanimix plus fish powder	*Koko* plus fish powder
		High	Low		
Energy					
(kJ)	18 200	18 200	18 200	18 240	16 190
(kcal)	4350	4350	4350	4360	3870
Protein (g)[3]	150 (14)	150 (14)	150 (14)	280 (26)	250 (26)
Fat (g)[4]	114 (24)	114 (24)	114 (24)	116 (24)	35 (8)
Calcium (mg)	530	17 360	8950	4560	4160
Iron (mg)[4]	56	366	183	101	89
Zinc (mg)[4]	28	171	86	34	40
Copper (mg)[4]	4	25	13	4	3
Magnesium (mg)[4]	1400	1400	1400	1570	490
Potassium (mg)	5660	18 960	12 310	6730	4240
Sodium (mg)[5]	30	30	30	780	770
Phosphorus (mg)	2920	17 900	9400	5540	5300
Ascorbic acid (mg)	1	781	391	1	0
Niacin (mg)	39	259	149	55	41
Pyridoxine (mg)	3.5	31.3	17.4	3.7	2.4
Riboflavin (mg)[4]	0.4	19.5	9.8	1.2	1.0
Thiamine (mg)	4.8	22.1	13.5	4.3	3.2
Vitamin B-12 (μg)	0	70	35	29	29
Folic acid (μg)	670	5470	3070	620	280
Vitamin A (RE)	360	18 360	9360	370	440

[1] Weanimix, a cereal-legume blend; *koko*, fermented maize dough; RE, retinol equivalents.

[2] High and low refer to 2 formulations of Weanimix with vitamins and minerals added: "high" for infants consuming ≤ 60 g/d and "low" for infants consuming >60 g/d of the food. Iron was in the electrolytic form; zinc was added as zinc oxide; copper was added as copper gluconate; vitamin A was in the form of retinyl palmitate; calcium and phosphorus were provided as di-calcium phosphate.

[3] Percentage of energy intake in parentheses.

[4] Determined by analysis.

[5] Mothers generally added salt to the project foods during preparation.

circumferences). Information on infant-feeding practices and morbidity data were collected monthly.

Eight infants dropped out before 6 mo of age, 7 because the parents moved out of the study area, and 1 because the father refused participation. At 6 mo of age, infants who remained eligible ($n = 208$) were randomly assigned to receive 1 of the 4 foods to be fed from 6 to 12 mo of age. Random assignment to treatment groups was done as follows: 35 blocks of varying sizes (4, 8, or 12 subjects) were created and randomly shuffled. Within each block, subjects were assigned to the 4 treatment groups in equal numbers. At 6 mo of age, subjects were assigned to the next value on the list as they entered the study. The result of this randomization scheme was that the subjects were equally assigned among groups over time, but the investigators could not predict to what treatment the next subject would be assigned.

The prepackaged complementary foods were supplied to mothers weekly (500 g/wk) without charge. Mothers were encouraged to feed the project foods ≥ 3 times/d but they were free to feed other foods. To reduce problems of contamination through unhygienic handling and storage of the porridge, all mothers were given a vacuum flask in which to store the prepared porridge and were educated on how to maintain the flask.

Food intake. Intake of project and nonproject foods was monitored by monthly 24-h recalls for 3 d (2 weekdays and 1 weekend day) at 6, 7, 8, 10, and 12 mo. In addition, 12-h weighed food records were completed for $\approx 50\%$ of subjects randomly selected at each of the same ages. For the latter method, an observer weighed all foods and beverages consumed by the infant during a 12-h period. Energy and nutrient intakes from foods were calculated by using FOOD PROCESSOR PLUS software (ESHA Research, Salem, OR), local food-composition tables, values published elsewhere (8, 15), and, for project foods, analyzed values for fat, iron, zinc, and riboflavin.

Anthropometry. Birth weights were recorded mostly from birth certificates. Because birth length is not routinely measured in hospitals in Ghana, 2 trained assistants recorded birth weights and birth lengths of infants born in the 2 major maternity facilities in Techiman (Holy Family Hospital and Armstrong Maternity Home) during the 5-mo recruitment period. Of these infants, those who were eligible by 1 mo of age were recruited for the study ($n = 70$). Other infants, born at these facilities or elsewhere who were eligible by 1 mo of age but for whom birth length was not measured, were also recruited. In these cases, birth weight was recorded from birth records, and birth length was missing. We examined the validity of the birth weights obtained from records by checking the correlation with weight at 1 mo ($r = 0.61$). Birth weight measured by project assistants also correlated with weight at 1 mo ($r = 0.69$).

Anthropometric measurements (weight, length, triceps and subscapular skinfold thicknesses, and midupper arm and head circumferences) were taken monthly until 12 mo of age. Infants were weighed naked (to the nearest 100 g) on a digital infant scale (Perspective Enterprises, Portage, MI). Recumbent length was measured to the nearest 0.1 cm on a portable infant measuring board

(Perspective Enterprises). Triceps and subscapular skinfold-thickness measurements were taken on the left side to the nearest 0.1 mm by using Holtain skinfold calipers (Crymych, United Kingdom), and midupper arm and head circumferences were measured to the nearest 0.1 cm by using an insertion tape. Maternal weight was measured monthly (to the nearest 0.2 kg) and height (to the nearest 0.1 cm) was also measured at baseline. Anthropometric measurements were taken by 2 trained assistants whose techniques were standardized according to World Health Organization procedures (16). Measurements were completed at Maternal and Child Health centers when mothers reported with their infants for the regular monthly growth monitoring. Absentees were measured in their homes within 1 d. Weight and length measurements of infants were converted to *z* scores by using National Center for Health Statistics (NCHS) reference values (17). Midupper arm fat area (MAFA) and midupper arm muscle area (MAMA) were calculated by using the following equations (18, 19):

$$\text{MAFA} = (\text{TSF} \times \text{C})/2 - [\pi \times (\text{TSF})^2]/4 \qquad (1)$$

$$\text{MAMA} = [\text{C} - (\pi \times \text{TSF})]^2/4\pi \qquad (2)$$

where TSF is triceps skinfold thickness (mm) and C is midupper arm circumference (mm).

Clinical chemistry measurements. At baseline (6 mo) and at 12 mo of age, 5 mL blood was collected by venipuncture from all infants. Hemoglobin concentration and hematocrit were determined within 15 min of blood collection. Infants with hemoglobin concentrations <90 g/L ($n = 28$ at 12 mo) were given medicinal iron drops (12 mg Fe in 5 mL daily for 2 mo). Plasma was separated and was kept frozen at −20°C until analyzed. The red blood cells were washed 3 times in saline solution (0.9% NaCl), centrifuged at 1380 × *g* at room temperature for 15 min, and the supernate was discarded. The cells were kept frozen at −20°C. Samples were transported to the Clinical Nutrition Research Unit at the University of California, Davis, for analysis of plasma iron and zinc (by atomic absorption spectrophotometry; 20, 21), ferritin (by immunoradiometric assay; Diagnostic Products Co, Los Angeles), C-reactive protein (by rate nephelometry; Beckman Instruments Inc, Galway, Ireland), retinol (by HPLC; 22), transferrin (by rate nephelometry; Beckman Instruments Inc), and erythrocyte riboflavin (by HPLC; 23). Total iron-binding capacity (TIBC) was determined as transferrin concentration divided by 0.7 (24). Percentage transferrin saturation was calculated by dividing the plasma iron concentration by TIBC. All analyses (except plasma retinol and erythrocyte riboflavin) were performed in duplicate.

Morbidity data. Infant morbidity data were collected by maternal recall monthly before 6 mo and weekly during the intervention phase (between 6 and 12 mo). To assist this process during the intervention phase, mothers were given a daily grid on which to record stool numbers, vomiting, and specific symptoms of fever and respiratory illness between visits. For data analysis, diarrhea was defined as ≥3 liquid or semiliquid stools in 24 h. Respiratory illness was defined as the presence of a purulent nasal discharge or cough. Morbidity prevalence, for example, diarrhea prevalence, was calculated as the ratio of the number of days diarrhea was present to the number of days information was collected on diarrhea for each child. Morbidity incidence, for example diarrhea incidence, was the ratio of the number of new episodes of diarrhea to the number of days at risk for an episode of diarrhea (excluding days with missing data or diarrhea already present). An episode was considered new when it was preceded by ≥2 symptom-free days.

Cross-sectional study

After completing the longitudinal study, preliminary data analysis indicated no significant differences in growth between the 4 intervention groups and less growth-faltering than had been observed in the 79 infants 6–12 mo of age in the cross-sectional study done earlier to estimate the required sample size. To confirm the latter observation, we decided to collect additional cross-sectional data ($n = 385$) on infants who received no intervention at all. The selection criteria for the longitudinal and cross-sectional study infants (both before and after the longitudinal study) were the same except that the age of infants at recruitment was 6–12 mo in the cross-sectional study compared with 1 mo in the longitudinal study. Information collected on the infants in the cross-sectional study included baseline data on their households, infant-feeding practices, and one-time measurement of weight, length, triceps skinfold thickness, and midupper arm and head circumferences with use of the same methods as described for the longitudinal study.

Statistical analysis

Data were entered by using EPI-INFO (version 6.03; Centers for Disease Control and Prevention, World Health Organization, 1996), and analyses were done by using PC-SAS (release 6.04; SAS Institute Inc, Cary, NC). Analysis of variance was used to examine differences in baseline characteristics between the 4 intervention groups. Analysis of covariance was used to determine whether there were significant differences between the intervention groups in weight gain, length gain, or changes in hemoglobin concentration, hematocrit, percentage transferrin saturation, or plasma ferritin, zinc, or retinol concentration, or erythrocyte riboflavin from 6 to12 mo of age, with the independent variables being intervention group and values at 6 mo of age of the respective dependent variable. Baseline characteristics between the pooled intervention groups and the pooled cross-sectional study infants were compared by using *t* tests and chi-square tests. Growth status (weight-for-age and length-for-age) of the pooled intervention and pooled cross-sectional study infants was compared at each age (6–12 mo) by using Student's *t* tests. Differences in baseline characteristics and the potential influence of seasonality were controlled for by using multiple regression analysis.

RESULTS

Subjects

There were no significant differences between the intervention groups with respect to weight or length at birth or at 6 mo of age, nor in household characteristics such as parental age and education, household income, and household size (**Table 2**). During the intervention study, there were 18 dropouts, resulting in a final sample size of 190 (50 fed W, 47 fed WM, 48 fed WF, and 45 fed KF). The dropout rate did not differ significantly between groups. The reasons for dropping out were that the child's mother left the area ($n = 8$), the father refused the child's participation ($n = 1$), the infant rejected the project food (2 for WM, 1 for WF, and 1 for KF), the mother did not feed the project food (2 for WF and 2

TABLE 2
Baseline measures and characteristics of the households of infants in the 4 intervention groups[1]

	W (n = 28 F, 25 M)	WM (n = 27 F, 24 M)	WF (n = 26 F, 26 M)	KF (n = 29 F, 23 M)
Birth weight (kg)	3.16 ± 0.38	3.22 ± 0.50	3.17 ± 0.48	3.02 ± 0.38
Birth length (cm)[2]	48.6 ± 2.3	48.3 ± 2.1	49.4 ± 3.4	48.7 ± 2.2
Weight at age 6 mo (kg)	7.54 ± 1.09	7.09 ± 0.84	7.29 ± 0.93	7.37 ± 0.73
Length at age 6 mo (cm)	66.4 ± 2.5	65.9 ± 2.1	66.3 ± 2.4	66.3 ± 1.9
Mother's age (y)	27.0 ± 5.9	27.8 ± 5.9	28.5 ± 6.2	27.4 ± 5.5
Father's age (y)	33.6 ± 6.9	35.2 ± 10.1	36.0 ± 8.5	35.8 ± 9.3
Mother's education (y)	5.3 ± 5.1	6.5 ± 5.2	6.4 ± 5.2	7.0 ± 4.9
Father's education (y)	6.6 ± 5.8	8.5 ± 6.1	7.2 ± 6.5	7.8 ± 5.7
Household income spent on food (%)	37.0 ± 20.7	37.9 ± 20.8	36.7 ± 19.9	37.3 ± 16.7
Household size	7.3 ± 3.7	7.3 ± 3.9	7.1 ± 2.8	7.4 ± 3.7

[1] $\bar{x}$ ± SD. There were no significant differences between groups. W, Weanimix (cereal-legume blend); WM, W plus vitamins and minerals; WF, W plus fish powder; KF, *koko* (fermented maize dough) plus fish powder.

[2] n = 70.

for KF), and the death of infant (n = 1). Data were available to 12 mo of age for only 4 of the 8 infants who did not receive the project foods; analyses were done both with and without these 4 subjects and the results remained the same. Except for birth weight (2.9 ± 0.3 and 3.2 ± 0.4 kg for dropouts compared with nondropouts, respectively; $P < 0.002$), dropouts did not differ from nondropouts in any of the other characteristics compared.

Baseline characteristics and infant-feeding practices of the pooled intervention-study infants were compared with those of the cross-sectional study infants (**Table 3**). Birth weight and maternal education were lower in the cross-sectional group (P = 0.001 and 0.06, respectively), but birth weight data were available for only 64 infants in the cross-sectional study group. The baseline characteristics, infant-feeding practices, and anthropometric z scores at ages 6–12 mo of the cross-sectional study infants for whom birth weights were known were compared with those of infants without birth weight information, and no significant differences were observed. At 6 mo of age, there were no significant differences in weight, length, infant sex, or maternal age between the intervention and cross-sectional study infants, but infant feeding practices were significantly different between the 2 groups. Compared with the intervention group mothers, who were advised to exclusively breast-feed for the first 6 mo, the cross-sectional study infants were breast-fed less frequently and were given koko earlier, and more of them were given koko as the first food (Table 3).

Dietary intake

Although energy intake from the repeated 24-h recalls correlated with energy intake from the 12-h weighed food records (r = 0.42, $P < 0.0001$), the results indicated that mothers underestimated their infants' food intake when using the former method, possibly because of difficulties recalling exact quantities consumed (data not shown). Therefore, the dietary data presented here are based on the weighed food records (available for a sample of 50% of the subjects chosen randomly at each age).

Breast-feeding frequency and the contribution of project complementary food to the mean daily energy intake from non-breast-milk foods are shown in **Table 4**. Breast-feeding frequency was not significantly different between the 4 groups. At 12 mo of age, all but 2 infants were still being breast-fed. From age 7 to 12 mo, the project foods provided 500–1096 kJ/d, ≈40–78% of the total non-breast-milk food intake. At 7 mo, intake of energy from complementary foods was significantly higher in the WM group than in the WF group. No significant differences were observed between intervention groups at 8 and 12 mo of age. At 10 mo, the percent-

TABLE 3
Baseline characteristics and feeding practices of infants in the intervention and cross-sectional studies

	Intervention (n = 110 F, 98 M)	Cross-sectional (n = 235 F, 229 M)	P
Birth weight (kg)	3.18 ± 0.44[1,2]	2.93 ± 0.36[3]	<0.001
Weight at age 6 mo (kg)	7.31 ± 0.90	7.34 ± 1.19[4]	0.88
Length at age 6 mo (cm)	66.2 ± 2.4	65.9 ± 2.9[4]	0.38
Mother's age (y)	27.7 ± 5.9	27.3 ± 5.8	0.48
Mother's education (y)	6.3 ± 5.1	5.5 ± 4.1	0.06
Number of daytime breast feeds at 6–12 mo of age	11.1 ± 2.7	10.0 ± 3.6	<0.001
Number of nighttime breast feeds at 6–12 mo of age	4.1 ± 1.3	3.6 ± 1.8	<0.001
Age other foods started (mo)	3.8 ± 1.9	3.6 ± 1.5	0.1
Age *koko* introduced (mo)	5.1 ± 2.3	4.0 ± 1.6	<0.001
Infants given *koko* as first food (%)	32.4	68.9	<0.001

[1] $\bar{x}$ ± SD. *Koko*, fermented maize dough.

[2] n = 173.

[3] n = 64 (all in 1996).

[4] n = 64 (15 in 1993, 49 in 1996).

TABLE 4
Breast-feeding frequency and contribution of project complementary food to daily energy intake from non-breast-milk foods estimated by a 12-h weighed food record[1]

Intake and age	W	WM	WF	KF
Breast milk				
Breast-feeding frequency 6–12 mo	14.4 ± 3.2	15.1 ± 4.0	14.9 ± 3.0	14.5 ± 3.0
Complementary food				
6-mo total intake (kJ)[2]	774 ± 439	636 ± 506	531 ± 243	908 ± 548
7-mo total intake				
(kJ)	720 ± 418^{a,b}	1142 ± 565^{a}	782 ± 498^{b}	778 ± 406^{a,b}
(% from project food)[3]	68 ± 29	78 ± 13	70 ± 26	73 ± 14
8-mo total intake				
(kJ)	1050 ± 661	1105 ± 866	979 ± 477	1130 ± 548
(% from project food)[3]	70 ± 21	78 ± 13	71 ± 23	64 ± 20
10-mo total intake				
(kJ)	954 ± 653	1385 ± 724	1192 ± 573	1167 ± 757
(% from project food)[3]	64 ± 30^{a,b}	75 ± 16^{a}	49 ± 28^{a,b}	46 ± 31^{b}
12-mo total intake				
(kJ)	1602 ± 958	1431 ± 615	1360 ± 841	1598 ± 933
(% from project food)[3]	52 ± 29	53 ± 33	48 ± 29	39 ± 34

[1] $\bar{x}$ ± SD. Based on data from 50% of the sample. W, Weanimix (cereal-legume blend); WM, W plus vitamins and minerals; WF, W plus fish powder; KF, *koko* (fermented maize dough) plus fish powder. Means in the same row with different superscript letters are significantly different, $P < 0.05$ (Tukey test).

[2] Preintervention.

[3] Contribution of project foods to daily energy intake from non-breast-milk foods.

age of energy from complementary foods contributed by the project food was significantly higher in the WM group than in the KF group, but no differences were observed between the 4 groups in total energy intake from non-breast-milk foods. The contribution of project foods to iron, zinc, vitamin A, and riboflavin intake is shown in **Table 5**. As expected, the intake of these micronutrients was significantly higher in the group fed the fortified product (WM). There were no significant differences in intake between the other 3 groups (W, WF, and KF) except at 7 mo, when intake of iron and zinc was higher in the KF group than in the W group, and intake of riboflavin was higher in the WF than in the W group. Generally, by 12 mo of age, when the intake of nonproject foods increased, the percentage contribution of project food to the total intake of these micronutrients decreased. However, for the WM group, even at 12 mo of age, the fortified food still contributed >75% of the total micronutrient intake from foods.

Growth

Weight-for-age *z* scores were not significantly different between the 4 intervention groups at any age between 6 and 12 mo (**Figure 1**). Average weight-for-age *z* score was slightly below the NCHS reference median at 6 mo and ≈−1.2 at 12 mo of age (17). Similarly, length-for-age *z* scores did not differ significantly between the 4 intervention groups (**Figure 2**). The overall mean for all the intervention infants combined was ≈−0.2 at 6 mo and −0.6 at 12 mo of age. These results were not altered when infant sex, energy intake from project foods, or the total energy intake from complementary foods were controlled for. Weight gain and length gain between 6 and 12 mo, and other anthropometric indexes (midupper arm and head circumferences, triceps and subscapular skinfold thicknesses, MAFA, and MAMA) also did not differ significantly between the 4 intervention groups (**Table 6**). Further analyses were done to determine whether the effect of the intervention on infant growth was more evident in infants of taller mothers, but the interaction between maternal height and intervention group was not significant. Similarly, there was no interaction between intervention group and either infant sex or the amount of project food consumed.

When the weight-for-age *z* scores of the pooled intervention infants (n = 190) were compared with those of the cross-sectional study infants (n = 465), the average *z* score between 9 and 12 mo (though not between 6 and 9 mo of age) was lower in the latter group (**Figure 3**). A similar difference was observed for length-for-age *z* scores (**Figure 4**). After the observed differences in baseline characteristics (ie, maternal education and infant feeding practices) and the potential influence of seasonality were controlled for, the differences in weight-for-age and length-for-age at 9–12 mo between the combined intervention group and the cross-sectional study group remained significant. We could not control for birth weight because this information was missing for most of the cross-sectional study infants. However, the fact that the *z* scores at 6–7 mo of age were similar for the cross-sectional study and intervention study infants suggests that birth weight is unlikely to have been a confounding variable after 6 mo of age. Head circumference, midupper arm circumference, and triceps skinfold thickness were significantly different between the intervention (n = 183) and cross-sectional (n = 74) groups only at 12 mo of age [44.9 ± 1.4 compared with 44.4 ± 1.3 cm; 14.0 ± 1.0 compared with 13.7 ± 0.9 cm; and 7.3 ± 1.3 compared with 6.8 ± 0.9 mm, respectively; $P < 0.05$].

Clinical chemistry measures

The changes in hemoglobin, hematocrit, plasma transferrin saturation, ferritin, zinc, vitamin A, and erythrocyte riboflavin values between 6 and 12 mo of age are shown in **Table 7**. Plasma ferritin at 6 and 12 mo of age correlated significantly with C-reactive protein concentration (r = 0.33, $P < 0.0001$ at 6 mo; r = 0.56, $P < 0.0001$ at 12 mo of age) and therefore subjects with high C-reactive protein values (>8 mg/L; n = 18 at 6 mo of age and n = 21 at 12 mo of age), indicative of infection, were not included in the ferritin analyses. The biochemical data reported here are for subjects with values at both 6 and 12 mo of age.

TABLE 5
Contribution of project complementary foods to daily iron, zinc, vitamin A, and riboflavin intakes from non-breast-milk foods estimated by a 12-h weighed food record[1]

Age and nutrient	W	WM	WF	KF
Iron intake				
6 mo (mg)	1.8 ± 1.0[2]	2.4 ± 3.0	1.6 ± 1.1	2.3 ± 1.9
7 mo				
(mg)	2.1 ± 2.0^{b}	18.3 ± 10.6^{a}	3.4 ± 1.9^{b}	3.2 ± 1.7^{b}
(% from project food)	80 ± 34	96 ± 12	86 ± 4	97 ± 8
8 mo				
(mg)	3.0 ± 2.0^{b}	15.8 ± 15.1^{a}	4.4 ± 2.4^{b}	4.4 ± 2.6^{b}
(% from project food)	80 ± 30	95 ± 9	87 ± 25	90 ± 11
10 mo				
(mg)	2.7 ± 2.2^{c}	20.9 ± 13.0^{a}	4.4 ± 2.2^{b}	4.9 ± 3.8^{b}
(% from project food)	78 ± 34^{a,b}	98 ± 4^{a}	69 ± 30^{a,b}	62 ± 42^{b}
12 mo				
(mg)	4.6 ± 3.5^{b}	16.6 ± 11.0^{a}	5.6 ± 3.7^{b}	5.9 ± 4.4^{b}
(% from project food)	61 ± 38	78 ± 35	66 ± 36	54 ± 43
Zinc intake				
6 mo (mg)	1.1 ± 0.7[2]	0.8 ± 0.6	0.7 ± 0.4	1.2 ± 0.8
7 mo				
(mg)	1.0 ± 0.6^{b}	8.4 ± 5.0^{a}	1.1 ± 0.6^{b}	1.5 ± 0.8^{b}
(% from project food)	79 ± 32	98 ± 6	85 ± 28	94 ± 12
8 mo				
(mg)	1.4 ± 0.9^{b}	7.4 ± 7.1^{a}	1.5 ± 0.8^{b}	2.1 ± 1.2^{b}
(% from project food)	82 ± 25	96 ± 7	88 ± 25	87 ± 14
10 mo				
(mg)	1.1 ± 0.7^{b}	9.8 ± 6.0^{a}	1.5 ± 0.8^{b}	1.9 ± 1.4^{b}
(% from project food)	79 ± 33^{a,b}	98 ± 4^{a}	69 ± 28^{a,b}	64 ± 41^{b}
12 mo				
(mg)	2.0 ± 1.2^{b}	7.8 ± 5.1^{a}	1.7 ± 1.1^{b}	2.5 ± 2.0^{b}
(% from project food)	65 ± 36	79 ± 35	68 ± 34	55 ± 42
Vitamin A intake				
6 mo (μg RE)	0.14[3]	0.10	0.82	0.09
7 mo				
(μg RE)	10.2^{b}	695.8^{a}	13.7^{b}	17.2^{b}
(% from project food)	80 ± 34^{a,b}	99 ± 4^{a}	77 ± 37^{b}	91 ± 25^{a,b}
8 mo				
(μg RE)	24.3^{b}	564.6^{a}	17.9^{b}	29.7^{b}
(% from project food)	65 ± 42^{b}	99 ± 2^{a}	81 ± 37^{a,b}	75 ± 35^{a,b}
10 mo				
(μg RE)	16.2^{b}	882.6^{a}	26.6^{b}	22.1^{b}
(% from project food)	69 ± 42^{a,b}	96 ± 13^{a}	47 ± 43^{b}	59 ± 45^{b}
12 mo				
(μg RE)	33.0^{b}	865.7^{a}	35.6^{b}	37.8^{b}
(% from project food)	53 ± 44^{a,b}	76 ± 36^{a}	46 ± 47^{b}	47 ± 46^{b}
Riboflavin intake				
6 mo (mg)	0.08 ± 0.08[2]	0.04 ± 0.17	0.05 ± 0.04	0.07 ± 0.06
7 mo				
(mg)	0.02 ± 0.02^{b}	1.0 ± 0.6^{a}	0.06 ± 0.04^{b}	0.07 ± 0.06^{a}
(% from project food)	59.2 ± 36.9^{b}	98.1 ± 4.4^{a}	74.8 ± 30.7^{a,b}	75.8 ± 32.2^{a,b}
8 mo				
(mg)	0.05 ± 0.06^{b}	0.8 ± 0.8^{a}	0.07 ± 0.05^{b}	0.08 ± 0.06^{b}
(% from project food)	56.3 ± 36.5^{b}	95.5 ± 6.8^{a}	81.9 ± 25.8^{a,b}	66.6 ± 26.1^{a,b}
10 mo				
(mg)	0.03 ± 0.03^{c}	1.09 ± 0.7^{a}	0.08 ± 0.07^{b}	0.08 ± 0.06^{b,c}
(% from project food)	60.2 ± 37.3^{a,b}	98.6 ± 2.3^{a}	62.2 ± 30.4^{a,b}	48.9 ± 39.0^{b}
12 mo				
(mg)	0.13 ± 0.30^{b}	0.87 ± 0.59^{a}	0.09 ± 0.05^{b}	0.11 ± 0.11^{b}
(% from project food)	42.9 ± 34.2^{b}	80.5 ± 33.7^{a}	63.5 ± 33.8^{b}	41.8 ± 38.8^{b}

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[1] Based on data from 50% of the sample. 6-mo values are preintervention. RE, retinol equivalents. W, Weanimix (cereal-legume blend); WM, W plus vitamins and minerals; WF, W plus fish powder; KF, *koko* (fermented maize dough) plus fish powder. Means in the same row with different superscript letters are significantly different, $P < 0.05$ (Tukey test).

[2] $\bar{x}$ ± SD.

[3] Median; statistical comparisons based on ranks.

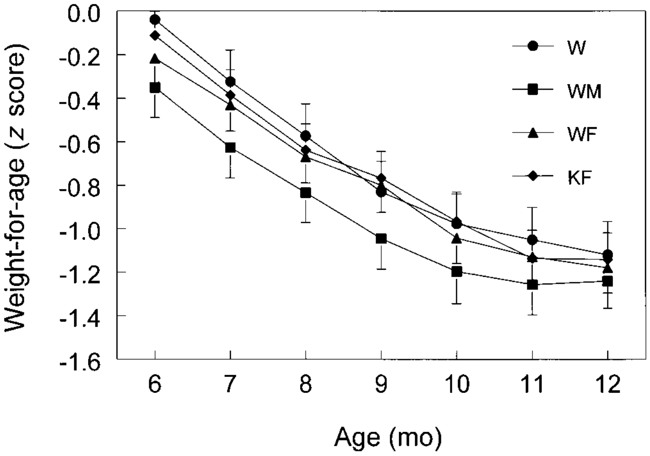

FIGURE 1. Mean weight-for-age *z* scores of infants in the 4 intervention groups: W, Weanimix, a cereal-legume blend; WM, W plus vitamins and minerals; WF, W plus fish powder; KF, koko (fermented maize dough) plus fish powder. There were no significant differences between groups.

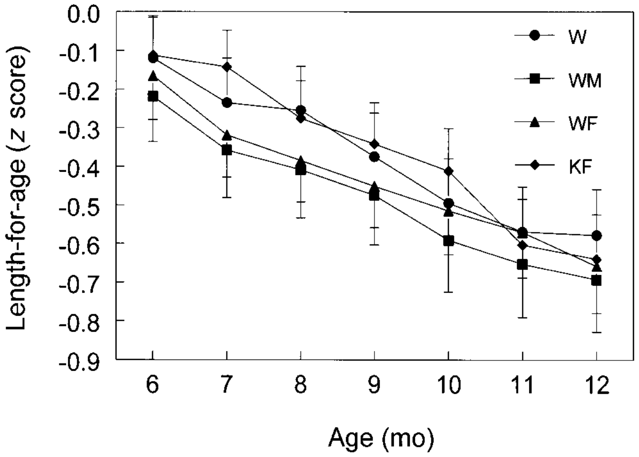

FIGURE 2. Mean length-for-age *z* scores for infants in the 4 intervention groups: W, Weanimix, a cereal-legume blend; WM, W plus vitamins and minerals; WF, W plus fish powder; KF, *koko* (fermented maize dough) plus fish powder. There were no significant differences between groups.

There was a general decline in mean hemoglobin and hematocrit between 6 and 12 mo of age. No significant differences were observed between groups in the mean change in hemoglobin, hematocrit, percentage transferrin saturation, plasma ferritin or zinc, or erythrocyte riboflavin between 6 and 12 mo of age. The change in plasma retinol concentration between 6 and 12 mo of age was significantly different in group WM compared with the other 3 groups. After infections were controlled for, that is, high C-reactive protein values at 6 and 12 mo of age, the change in plasma retinol in group WM was still significantly different from that in group WF but not in the other 2 groups ($P < 0.05$), although the magnitude of the difference between group WM and the other

TABLE 6

Weight and length gains from 6 to 12 mo of age, and circumferences, skinfold-thickness measurements and midupper arm fat and muscle areas of infants in the 4 intervention groups[1]

	W	WM	WF	KF
Weight gain (kg)	1.2 ± 0.6	1.3 ± 0.5	1.3 ± 0.5	1.2 ± 0.4
Length gain (cm)	7.0 ± 1.2	7.0 ± 1.4	6.9 ± 1.2	6.9 ± 1.2
Midupper arm circumference (cm)				
6 mo	14.1 ± 1.1	13.7 ± 1.0	13.8 ± 1.1	14.0 ± 0.9
12 mo	14.1 ± 1.2	13.9 ± 0.9	14.0 ± 0.9	14.0 ± 0.9
Difference	0.0 ± 0.7	0.2 ± 0.7	0.2 ± 0.8	0.0 ± 0.6
Head circumference (cm)				
6 mo	42.8 ± 1.3	42.6 ± 1.2	42.4 ± 1.3	42.9 ± 1.3
12 mo	45.0 ± 1.3	44.9 ± 1.2	44.7 ± 1.3	45.1 ± 1.3
Difference	2.2 ± 0.7	2.3 ± 0.7	2.3 ± 0.5	2.2 ± 0.7
Triceps skinfold thickness (mm)				
6 mo	8.1 ± 1.4	7.4 ± 1.1	7.6 ± 1.3	8.0 ± 1.3
12 mo	7.5 ± 1.6	7.2 ± 1.2	7.3 ± 1.2	7.2 ± 1.3
Difference	−0.6 ± 1.2	−0.2 ± 1.2	−0.3 ± 1.0	−0.8 ± 1.1
Subscapular skinfold thickness (mm)				
6 mo	7.3 ± 1.4	7.1 ± 1.2	7.3 ± 1.5	7.2 ± 1.2
12 mo	6.7 ± 1.5	6.5 ± 1.2	6.9 ± 1.5	6.5 ± 1.1
Difference	−0.6 ± 1.0	−0.6 ± 0.7	−0.4 ± 09	−0.7 ± 0.8
Midupper arm fat area (mm^2)				
6 mo	524 ± 117	470 ± 94	486 ± 102	513 ± 101
12 mo	487 ± 134	465 ± 96	472 ± 93	464 ± 98
Difference	−37 ± 93	−7 ± 81	−14 ± 74	−49 ± 76
Midupper arm muscle area (mm^2)				
6 mo	1078 ± 153	1036 ± 154	1048 ± 168	1052 ± 130
12 mo	1107 ± 176	1081 ± 140	1093 ± 133	1100 ± 141
Difference	29 ± 117	40 ± 115	44 ± 126	48 ± 89

[1] $\bar{x}$ ± SD. There were no significant differences between groups. W, Weanimix (cereal-legume blend); WM, W plus vitamins and minerals; WF, W plus fish powder; KF, koko (fermented maize dough) plus fish powder.

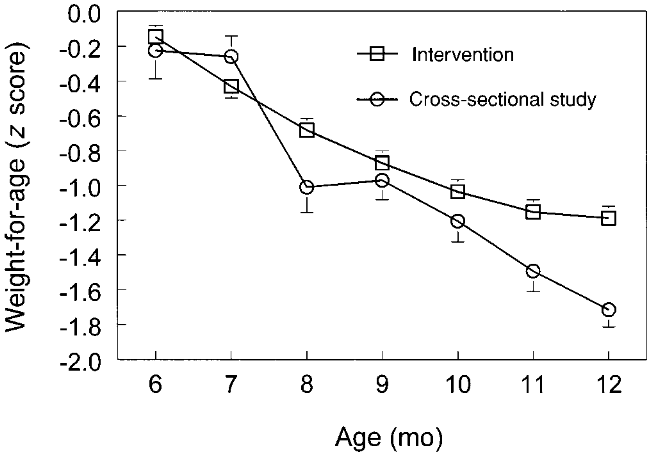

FIGURE 3. Mean (±SEM) weight-for-age *z* scores of the combined intervention groups and the cross-sectional study infants; *z* scores were significantly different between groups at 8, 11, and 12 mo of age, $P < 0.05$.

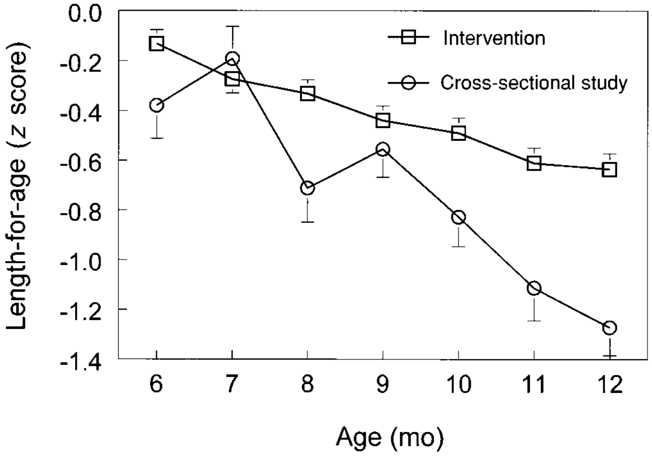

FIGURE 4. Mean (±SEM) length-for-age *z* scores of the combined intervention groups and the cross-sectional study infants; *z* scores were significantly different between groups at 8, 10, 11, and 12 mo of age, $P < 0.05$.

2 groups was very similar to the unadjusted results. Further analyses comparing plasma retinol concentration in group WM with that in the other 3 groups (W, WF, and KF) combined, while controlling for initial retinol concentrations and infection, showed significant differences (0.14 ± 0.3 μmol/L in WM compared with −0.04 ± 0.3 μmol/L in the combined groups; $P = 0.003$).

The percentage of infants with values below the cutoffs for hemoglobin (<100 g/L), hematocrit (<0.33), percentage transferrin saturation (<16%), ferritin (<12 μg/L), zinc (<10.7 μmol/L), and retinol (<0.7 μmol/L) are given in **Table 8**. The percentage of infants with low ferritin increased significantly ($P < 0.05$) between 6 and 12 mo of age (reaching 48–57% at 12 mo) in groups W, WF, and KF, but not in group WM (10.7% at 12 mo). Similarly, the prevalence of low plasma retinol concentrations decreased significantly between 6 and 12 mo in group WM ($P < 0.05$) but not in the other 3 groups.

Morbidity

The prevalence and incidence of diarrhea, fever, and respiratory illness in the intervention infants are shown in **Table 9**. No significant differences were observed between the intervention groups in any of the morbidity outcomes. The overall prevalence of diarrhea, fever, and respiratory infections was 15%, 8% and 17%, respectively. However, when respiratory infection was redefined as the presence of cough plus runny nose, the prevalence decreased to ≈2% and was still not significantly different between the 4 groups.

DISCUSSION

The results of this study showed no significant difference in growth between infants fed 4 different improved Ghanaian complementary foods for 6 mo. However, compared with the growth status of infants who were not in the intervention, weight and length *z* scores of the intervention groups were higher between 9 and 12 mo of age, which has been found to be the most vulnerable period for growth faltering in other studies of breast-fed infants (25). Our study hypothesis predicted differences between the 4 intervention groups. The original sample size was based on the cross-sectional data we collected on Techiman infants in 1993, which suggested that between 6 and 12 mo of age, infants gained only 260 g in weight and 4.2 cm in length. These values are very low compared with the NCHS reference values. We predicted that the modified Weanimix or koko foods would narrow the growth deficit between infants in Techiman and the NCHS reference by about one-third. This is approximately the magnitude of the difference between the nonintervention group and the pooled intervention groups (Figure 3). In the 4 intervention groups, the sample size of ≈50 per group is sufficient to detect a difference ≥0.5 kg in weight gain or 1.0 cm in length gain over the 6-mo period with a power of 0.9. As it turned out, the weight gain from 6 to 12 mo of age of the "control" group in the intervention (those fed unmodified Weanimix) was not as low as initially anticipated, and the maximum difference observed between this group and any of the other intervention groups was only 0.15 kg. A sample size of 539 per group would have been necessary to show statistical significance for a difference of that magnitude with a power of 0.9.

There are several possible explanations for the growth results. First, all subjects in the intervention were given the project foods free of charge, which may have improved overall food availability for the infants. Second, all 4 intervention foods had a relatively high macronutrient content compared with traditional complementary foods typically fed to infants in West Africa (5, 7, 26). It would have been desirable for study purposes to include a group assigned to koko alone, but this was not considered acceptable because of the known nutritional limitations of koko. Third, the attention received by all intervention infants through regular weekly visits may have influenced the mothers' child-care and infant-feeding practices, and the regular morbidity surveillance may have prompted them to seek treatment earlier for their sick infants (27). Fourth, seasonal differences in the timing of data collection for the longitudinal compared with the cross-sectional studies could have confounded the results, even though this was controlled for during data analysis. However, this would most likely have worked against finding greater growth in the intervention infants because the proportion of infants who were 9–12 mo of age during the hungry season was greater in the intervention groups than in the cross-sectional group. Finally, the precautions taken to reduce contamination of project foods by

TABLE 7

Clinical chemistry measures of infants at 6 and 12 mo of age in the 4 intervention groups[1]

	W	WM	WF	KF
Hemoglobin (g/L)				
6 mo	105 ± 10[2]	104 ± 13	106 ± 11	108 ± 10
12 mo	100 ± 17 [48]	104 ± 15 [47]	103 ± 13 [48]	105 ± 12 [44]
Difference	−5 ± 19	0 ± 14	−3 ± 14	−3 ± 14
Hematocrit				
6 mo	0.339 ± 0.033	0.338 ± 0.040	0.344 ± 0.035	0.346 ± 0.031
12 mo	0.330 ± 0.057 [47]	0.336 ± 0.041 [47]	0.340 ± 0.036 [48]	0.343 ± 0.035 [44]
Difference	−0.009 ± 0.060	−0.002 ± 0.041	−0.004 ± 0.042	−0.004 ± 0.041
Plasma transferrin saturation (%)				
6 mo	37 ± 18	42 ± 30	36 ± 15	38 ± 19
12 mo	39 ± 21 [31]	33 ± 16 [30]	38 ± 18 [30]	39 ± 19 [28]
Difference	2 ± 26	−9 ± 38	2 ± 23	−1 ± 22
Plasma ferritin (μg/L)[3]				
6 mo	26.2[4] (17.1, 36.3)	32.0 (22.0, 46.3)	29.9 (21.4, 42.7)	28.5 (18.9, 36.8)
12 mo	14.6 [31] (9.4, 19.9)	22.1 [28] (17.0, 28.7)	14.9 [30] (10.3, 22.6)	12.1 [28] (9.2, 15.1)
Change (%)	−45	−31	−49	−55
Plasma zinc (μmol/L)				
6 mo	15.5 ± 3.2	15.6 ± 4.3	14.7 ± 3.2	15.6 ± 2.8
12 mo	15.5 ± 4.3 [31]	14.4 ± 3.4 [30]	15.9 ± 2.8 [31]	15.6 ± 3.4 [29]
Difference	0.2 ± 6.1	−1.1 ± 4.6	0.8 ± 4.6	0.2 ± 4.6
Plasma retinol (umol/L)				
6 mo	1.01 ± 0.5	0.81 ± 0.3	0.85 ± 0.3	0.94 ± 0.4
12 mo	0.93 ± 0.4 [37]	0.98 ± 0.3 [29]	0.84 ± 0.4 [34]	0.92 ± 0.3 [32]
Difference	−0.08 ± 0.3^{a}	0.17 ± 0.4^{b}	−0.01 ± 0.3^{a}	−0.03 ± 0.3^{a}
Difference[5]	−0.08 ± 0.3^{a,b}	0.14 ± 0.3^{b}	−0.01 ± 0.3^{a}	−0.03 ± 0.3^{a,b}
Erythrocyte riboflavin (nmol/L)				
6 mo	283.4[4] (261.8, 306.9)	285.3 (259.5, 313.7)	268.2 (246.3, 292.0)	266.7 (244.1, 291.3)
12 mo	283.3 [41] (262.7, 305.5)	278.1 [43] (258.2, 299.4)	262.1 [43] (243.4, 282.3)	251.0 [39] (235.3, 267.8)
Change (%)	−0.05	−2.5	−2.2	−5.9

[1] W, Weanimix (cereal-legume blend); WM, W plus vitamins and minerals; WF, W plus fish powder; KF, *koko* (fermented maize dough) plus fish powder. Values in the same row with different superscript letters are significantly different, $P \leq 0.05$. Values in brackets at 12 mo are the final *n*.

[2] $\bar{x}$ ± SD.

[3] Excluding subjects with high C-reactive protein values.

[4] Geometric mean; 95% CI in parentheses.

[5] Values adjusted for C-reactive protein concentration.

providing vacuum flasks to all mothers in the intervention study may have reduced infant infection, which has been negatively associated with growth in other studies (28–30). We showed, in a concurrent study carried out in this same community, that vacuum flask storage reduced microbial contamination of Weanimix (31). It is unknown whether this effect is large enough to reduce infant morbidity. In hindsight, the study design would have been stronger had we included in the randomized longitudinal study a fifth group that was not provided with any of the project foods, but for budgetary and practical reasons this was not considered feasible or acceptable to the community.

All of the above explanations may account for the improvement in growth of the intervention groups compared with the nonintervention group and the lack of significant differences in growth between intervention groups. Nonetheless, given that some (though not all) studies have reported positive growth effects of supplementation with micronutrients such as zinc (32–35), iron (36–38), and vitamin A (39, 40), it is surprising that there was no significant difference in growth between the group fed the micronutrient-fortified food and the other 3 groups. It is possible that the micronutrient needs of infants at this age have been overestimated and that the control food (unmodified Weanimix), along with frequent breast-feeding, was nutritionally adequate. However, the biochemical results from this study indicate otherwise, because the infants fed diets W, WF, and KF had lower iron and vitamin A status at 12 mo than the WM group. Therefore, the results suggest that either the micronutrient deficiencies in this population were not severe enough to impair growth, or the growth response to micronutrient supplementation was constrained by other factors such as frequent infections (28, 29) or prenatal programming (25).

Of the 3 alternatives to Weanimix examined (WM, WF, and KF), only the micronutrient-fortified food resulted in improved micronutrient status. In all groups except the WM group, hemoglobin concentration declined between 6 and 12 mo of age (although the mean values at 12 mo of age did not differ significantly between groups). Fortification with vitamins and minerals clearly prevented the depletion of iron stores in group WM. About

50% of infants in each of the other 3 groups (W, WF, and KF) had plasma ferritin concentrations <12 μg/L by 12 mo of age, whereas only 11% of infants in the WM group had concentrations below this cutoff. Despite the high iron content of fish powder, its addition to Weanimix and koko did not improve infant iron status.

There are several possible reasons for this. Diets with phytate-iron molar ratios ≥6 have poor iron bioavailability (41). However, only the unmodified Weanimix had a phytate-iron molar ratio greater than this (7.3 compared with 2.2, 4.0, and 4.7 for WM, WF, and KF, respectively). It is therefore unlikely that interference from phytate is the reason for the lack of benefit from fish powder. Alternatively, high rates of malaria in this population could be an important factor. Malaria parasitemia has been reported to be a common cause of anemia in this age group (42–44). Besides the increased destruction of red blood cells, reduced iron absorption and disturbed iron metabolism during acute episodes (45–47) may increase the requirement for iron above normal physiologic needs. Although the addition of fish powder almost doubled the iron content of the food compared with unmodified Weanimix, the amount of iron in WF and KF was still considerably lower than that in WM. The mean daily intake of 33 g WF, which had an iron content of 0.1 mg/g, provided only 3.3 mg Fe/d, which is lower than the estimated 10.8 mg/d required from complementary foods with medium iron bioavailability (4).

The change in plasma zinc concentration between 6 and 12 mo of age did not differ significantly between groups. The average zinc concentration at 6 mo was lower than values reported in some studies (48), but comparable with 6- and 12-mo values in several other studies (33, 49, 50). Some studies have reported improved linear growth in zinc-supplemented infants (32, 33, 51), especially in those who were stunted or had low plasma zinc concentrations at baseline (51). No such effects were observed in these study infants. The project foods contributed a large proportion of average daily zinc intake, but the total zinc intake from all complementary foods in the W, WF, and KF groups combined was still only ≈81% of the recommended amount (2.8 mg/d; 4), whereas the WM group consumed an average of 281% of the recommended intake. Despite this, at 6 and 12 mo of age only 5 and 8 infants, respectively, had low plasma zinc concentrations (<10.7 μmol/L). Therefore, it is likely that zinc status was generally satisfactory and that this accounts for the lack of response (in both plasma zinc and growth) to increased zinc intake by the WM group. However, we cannot rule out the possibility that the zinc added to the WM food was poorly absorbed.

Infants fed the vitamin and mineral fortified diet had a significant increase in plasma retinol between baseline and 12 mo, whereas no improvement was observed in the other 3 groups. At 6 mo of age, 29% of the study infants had plasma concentrations <0.7 μmol/L. By 12 mo of age, this declined significantly in the WM group but increased in the other 3 groups. Vitamin A deficiency in the Brong Ahafo region as a whole is common; a recent survey indicated that 42% of children from 6 mo to 5 y of age had serum retinol values <0.35 μmol/L and 11% of infants 6–11 mo of age had a modified relative dose response >0.06 (R Agble, Ministry of Health, unpublished data, 1998). In our study, the improvement in plasma retinol concentration in group WM could be attributed to the significantly higher intake of the vitamin by this group. Typically, complementary foods fed to infants in this population contain little vitamin A. Provitamin A carotenoids in foods such as palm soup, palm oil, pawpaw, mangoes, and dark-green leafy vegetables are the main sources of vitamin A in the adult diet, but are not usually fed to infants and young children. Breast milk is therefore an important source of vitamin A for infants. However, breast milk vitamin A concentrations could be low due to inadequate maternal dietary intake and poor nutritional status (52). In rural mothers in southern Ghana, the average breast milk retinol concentration was only 1.0 μmol/L (53), which is much lower than the value for well-nourished mothers (2.3 μmol/L; 54). Using the former value, we estimated that the total vitamin A intake (from breast milk and other foods) between 6 and 10 mo of age by infants in groups W, WF, and KF was only 50–70% of the recommended 350 μg/d (55). By contrast, the WM group consumed 2–3 times the recommended intake as a result of fortification of the Weanimix. These results indicate that feeding W or WF to breast-fed infants in this population, in which maternal breast milk vitamin A concentration is likely to be low and other sources of vitamin A are infrequently offered before 12 mo of age, does not provide sufficient vitamin A. Fortification of complementary foods with vitamin A should be seriously considered in Ghana, especially given the reported beneficial effects of vitamin A supplementation on childhood mortality and severity of infections in children in the northern part of the country (56, 57).

It was surprising that there was no significant difference in erythrocyte riboflavin concentration between the 4 groups, given that infants fed WM had a significantly higher dietary intake of the vitamin than did the other 3 groups. During the 6-mo intervention period, the total daily intake of riboflavin from non-breast-milk foods in groups W, WF, and KF was much lower than the estimated 0.2 mg/d required from complementary foods for breast-fed infants (4). The results of our study differ from those of other studies in which riboflavin supplementation resulted in improved status in weaning-age infants in China and Gambia (58, 59). In our

TABLE 8

Percentage of infants in the 4 intervention groups with low clinical chemistry test values at 6 and 12 mo of age

Test cutoff and age	W	WM	WF	KF
		%		
Hemoglobin < 100 g/L				
6 mo	31.3	40.4	27.1	20.5
12 mo	37.5	34.0	35.4	22.3
Hematocrit < 0.33				
6 mo	36.2	36.2	31.3	25.0
12 mo	40.4	34.0	33.3	29.6
Transferrin saturation < 16%				
6 mo	6.5	3.3	3.3	10.7
12 mo	19.4	10.0	6.7	7.4
Ferritin < 12 μg/L				
6 mo	19.4^{a}	17.9^{a}	19.4^{a}	14.3^{a}
12 mo	54.8^{b}	10.7^{a}	48.4^{b}	57.1^{b}
Zinc < 10.7 μmol/L				
6 mo	6.5	3.3	6.5	0
12 mo	3.2	10.0	6.5	6.9
Retinol < 0.7 μmol/L				
6 mo	21.6^{a}	34.5^{a}	25.7^{a}	21.9^{a}
12 mo	27.0^{a}	10.4^{b}	34.3^{a}	28.1^{a}

[1] W, Weanimix (cereal-legume blend); WM, W plus vitamins and minerals; WF, W plus fish powder; KF, *koko* (fermented maize dough) plus fish powder. Values in the same column with different superscript letters are significantly different between 6 and 12 mo of age, $P < 0.05$.

TABLE 9

Morbidity incidence and prevalence in infants between 6 and 12 mo of age in the 4 intervention groups[1]

	W	WM	WF	KF
Diarrhea				
Incidence	7.2 ± 6.0	7.8 ± 7.7	6.7 ± 6.6	7.7 ± 7.1
Prevalence (%)	15.3 ± 12.9	17.9 ± 17.7	13.6 ± 11.2	15.2 ± 15.7
Fever				
Incidence	2.2 ± 1.5	2.5 ± 1.9	2.7 ± 2.1	2.4 ± 1.8
Prevalence (%)	8.4 ± 7.8	9.0 ± 7.3	8.4 ± 7.0	7.4 ± 6.0
Respiratory illness				
Incidence of C or R (%)	3.0 ± 3.8	3.1 ± 2.7	3.4 ± 3.0	2.6 ± 2.2
Prevalence				
C+R (%)	2.1 ± 3.9	2.0 ± 3.1	2.4 ± 4.0	2.0 ± 3.6
C or R (%)	17.8 ± 17.0	17.4 ± 14.1	17.5 ± 13.7	14.9 ± 13.1

[1] $\bar{x}$ ± SD; incidence, number of new episodes/100 d at risk; prevalence, percentage of days ill, 6–12 mo; W, Weanimix (cereal-legume blend); WM, W plus vitamins and minerals; WF, W plus fish powder; KF, *koko* (fermented maize dough) plus fish powder; C, cough; R, runny nose. There were no significant differences between groups.

study, riboflavin status was determined by direct measurement of erythrocyte flavin adenine dinucleotide (FAD), the coenzyme, using HPLC. Erythrocyte FAD is a good indicator of tissue stores and a measure of long-term riboflavin status (60). Measurement of erythrocyte FAD by HPLC has been used in other studies to assess riboflavin status of very-low-birth-weight infants (61) and healthy male adults (23). In healthy adult males, a mean FAD concentration of 280 ± 21 nmol/L was reported (23), which is similar to the average concentration in infants in our study. As far as we know, a cutoff indicating low tissue stores for infants has not been established. The lack of effect on riboflavin status in our study may be attributable to the relatively higher riboflavin stores at 6 mo in the Ghanaian infants compared with Gambian infants (59), which may reflect differences in breast-milk riboflavin concentrations. In the Gambian infants, riboflavin status was assessed by erythrocyte glutathione reductase activity coefficient (EGRAC). At 6 mo of age, EGRAC was ≈1.27 in the unsupplemented infants, which is considered equivalent to an erythrocyte FAD concentration of 196 nmol/L [calculated by using the equation of Becker and Wilkinson (62): erythrocyte FAD = 53 nmol/L ÷ (EGRAC − 1)]. The latter value is lower than the median erythrocyte FAD concentration in the infants in our study at 6 mo of age. It should be noted, however, that predicting red blood cell riboflavin concentration from EGRAC values may be problematic because different versions of the assays may have different normal ranges.

Morbidity was not significantly different between the 4 intervention groups. The incidence rates of diarrhea, fever, and respiratory illness were similar to rates reported for rural Guatemalan infants (51), whereas the prevalence of fever was higher in infants in our study, probably due to the prevalence of malaria in the region. The prevalence rates of all 3 types of illness were similar to rates typically observed in infants 6–11 mo of age in our study region (14). The lack of effect of micronutrient fortification on morbidity differs from the results of some studies in which supplementation with iron, zinc, or vitamin A did reduce morbidity (63–65). Inadequate statistical power may account for this. For example, to detect a 30% decrease in diarrheal morbidity with a power of 0.8, we would have needed a sample size of 200 per group. On the other hand, not all studies have shown an effect of micronutrient supplementation on morbidity (66–68), and it is possible that micronutrient malnutrition in these Ghanaian infants was not severe enough to affect those outcomes.

We conclude that feeding improved complementary foods to Ghanaian infants between 6 and 12 mo of age most likely improved growth compared with the usual growth pattern of infants in the community. The addition of fish powder to dehydrated koko supported growth just as well as did Weanimix. Efforts to improve complementary feeding in developing countries have often focused on the use of cheap, locally available ingredients as a way to make these foods affordable to poor families. Although these measures may improve the macronutrient content of the diet, the micronutrient quality is often neglected. Our results indicate that fortification of Weanimix with vitamins and minerals improves iron stores and vitamin A status. Whether local foods can achieve the same results is not clear. Fortification with some nutrients such as iron and vitamin A may be the most effective strategy.

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