

Nutrient composition of premixed, packaged complementary foods for sale in low- and middle-income countries: Lack of standards threatens infant growth

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This is the author's preprint (pre-peer review) of:

Masters, W.A., Nene, M.D. and Bell, W., 2016. Nutrient composition of premixed and packaged complementary foods for sale in low-and middle-income countries: Lack of standards threatens infant growth. *Maternal & Child Nutrition*, e12421.

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Financial support and acknowledgements:

This work was made possible by USAID funding to Tufts University through the International Food Policy Research Institute (Linkage Grant No. 3047-001-56-01) and Feed the Future Nutrition Innovation Lab (grant number AID-OAA-L-1-00005). Many thanks are due to Patrick Webb and Jenny Aker at Tufts, Laurian Unnevehr at IFPRI, and numerous other colleagues for comments and advice on this project. Samples were collected with the help of Ambroise Agbota, Jean-Paul Anoh, Mahaman Bamba, Aaron Cheng, Gnanbo Christian, Amelia Darrouzet-Nardi, Issa Fadiga, Matt Hazel, Dorothy Nzembi Kimanthi, Yolande Kouame, Emmanuel Kouame, Rachid Laajaj, Perrine Looock, Janeen Madan, Menno Mulder-Sibanda, Fatouman Ouattara, Galase Ramolefhe, Claude Emile Rwagacondo, Marianne Santoso and Robin Shrestha.

Manuscript MCN-07-16-OA-2155, submitted to *Maternal & Child Nutrition* on 26 July 2016, revised 22 October 2016, accepted 18 November 2016, published 22 December 2016.

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Abstract

Premixed flours for infant porridge are increasingly produced and sold in developing countries to complement continued breastfeeding. Such complementary food (CF) products have known efficacy against malnutrition in children from 6 to 24 months of age, but ingredient ratios and production processes may vary. This study provides the first systematic measurement of their actual nutrient composition. We purchased samples of 108 premixed CF products in 22 low- and middle-income countries, and commissioned blind laboratory measurement of each product's macro- and micronutrients. We compared measured contents to nutrient claims on their packaging, and to CF standards from the Codex Alimentarius, the SuperCereal *Plus* product used in nutrition assistance programs, and the Lutter and Dewey (2003) recommendations, as well as our own modeled nutrient requirements for a healthy breastfed child. Actual densities are significantly different from nutrient claims for protein ($p=0.013$) and fat ($p=0.000$). Only 15% of samples met two of the three benchmarks for fat, 32% met the most stringent protein standard, while only 22% met them for iron and 21% for zinc. The median healthy child consuming breastmilk plus enough of these solid foods to meet energy needs would experience deficits of zinc at 6 months, iron at 6 and 9 months, and dietary fat from 12 months of age. In summary, premixed CF products can provide adequate nutrient density but usually do not, revealing the need and opportunity for independent monitoring and quality assurance to help grain millers making premixed foods maintain uniform ingredient ratios and production practices.

Keywords

Complementary foods, nutrient composition, infant nutrition, malnutrition, IYCF, quality assurance

Key messages

- Premixed complementary foods sold by local millers in developing countries can meet infants' nutritional needs at low cost, but products are rarely tested so actual nutrient composition is unknown.
- Sampling 108 different products from 22 countries reveals their contents to be highly variable relative to nutrient claims on each product's own label, and often inadequate relative to three published standards and the nutrient needs of infants at 6, 9, 12 and 24 months of age.
- Independent quality assurance services could inspect mills and test samples, offering a trademarked certification symbol assuring potential buyers that various products all meet a common standard.
- Nutritional certification of premixed complementary foods would increase access to local products of uniformly high quality, meeting infant needs more reliably at lower cost than with existing practices.

Introduction

Stunting and linear growth faltering affects approximately 165 million children under the age of five worldwide (Black *et al.* 2013), primarily in low- and middle-income countries (LMICs) where its adverse effects on child survival and cognitive development have wide-ranging consequences for social and economic life (Dewey & Begum 2011). Linear growth faltering occurs primarily from 6 to 24 months after birth (Victora *et al.* 2010) and is associated, among other things, with inadequate caloric and nutrient intake (Black *et al.* 2013). Nutrient inadequacy is particularly widespread at this age because the infant's small size and limited gastric capacity calls for food of higher nutrient density and digestibility than their family's normal diet (Brown *et al.* 1998, Chiocca 2015). Meeting nutrient needs requires solid complementary foods (CF) to accompany continued breastfeeding, but preparing such foods from raw ingredients at home is sufficiently difficult that foods actually fed to infants often lack sufficient nutrient density (Dop & Benbouzid 1999, Gibson *et al.* 2010, Solomons & Vossenaar 2013, Ferguson *et al.* 2015).

Premixed complementary foods (CF) offer a way to prepare uniform, high-density CFs frequently throughout the day, in the gradually increasing quantities needed by a growing infant. The flour is mixed with water and boiled to produce a solid cereal-based food. In contrast to liquid infant formulas that substitute for breastmilk (Zehner 2016), eating porridge generally complements continued breastfeeding. And unlike lipid-based compounds or nutrient powders that supplement family foods (de Pee 2015), premixed cereals can potentially meet all nutrient needs other than breastmilk, with less vulnerability to the potential bacterial contamination and nutritional variation of family foods. Premixed cereals can readily be produced by local grain millers alongside other flour products, unlike either infant formulas or nutrient supplements that are typically manufactured by specialized multinational food and pharmaceutical companies. The oldest and best-known premixed cereal developed for LMICs is Incaparina, launched in Guatemala in 1961 (Wise 1980, Scrimshaw 1980). Incaparina was launched initially as a beverage, but since then it and a wide variety of similar CF products have been distributed for use as complete CF products by donor agencies and local grain millers, typically using a cereal such

as rice, maize or wheat fortified with a roasted legumes and other ingredients (Porter & Shafritz 1999, Lutter 2003).

With increased female labor force participation and schooling there has been rapid growth in the marketing and consumption of both liquid and solid infant foods in developing countries, even among low-income populations (Zehner 2016, Nielsen 2015, Ferguson & Darmon 2007). Despite growing demand for solid premixed CF in LMICs, the few studies to have assessed their nutritional quality have focused on micronutrients such as Gibson *et al.* (2010), Gibbs *et al.* (2011) and Roos *et al.* (2013). But quality can vary for macronutrients as well, with protein and fat density that depends on ingredient ratios and production processes which are rarely subject to independent inspection and testing. This study provides the first systematic, large-scale collection and measurement of such products, to compare their measured nutrient content against the information on their labels, relative to various international standards for CF products, and relative to the nutrient needs of an otherwise healthy child who might be fed these foods to complement continued breastfeeding. All measurements and comparisons are made in terms of macronutrients (protein, fat and total energy) plus two sentinel micronutrients (iron and zinc) which have been identified as common constraints on infant nutrition in LMICs (Santika *et al.* 2009, Skau *et al.* 2014).

Materials and methods

This study concerns the nutritional adequacy of premixed, packaged complementary foods produced and sold in LMICs around the world. Products included in the study were explicitly marketed as composite flours made with more than one ingredient, to be boiled with water and served as porridge to infants after 6 months of age. We excluded any products manufactured in high-income countries, and also excluded any infant formulas to be served in liquid form. Almost all of the sampled products were locally made by small- and medium-scale millers who also sold other packaged cereal products; a few of the products were made in other LMICs and brought by wholesalers to the country where we purchased them.

Design and execution of sample collection

To identify products for this study we assembled a global catalogue of eligible complementary foods between June and October of 2014 and then purchased a purposeful sample of one package for each product from local markets. To identify the products available for purchase, we contacted by email a wide range of potential collaborators across LMICs as classified by the World Bank (2013). We invited these collaborators to send us photographs of the locally produced packaged CF for sale at local retailers, and then to purchase one sample of up to five different products from a typical vendor. Each participating collaborator was offered a Western Union cash transfer equivalent of 20 USD per sample to cover the costs of purchase and shipping. Samples to be tested were sent by collaborators to the study authors through their country's national postal service using Express Mail Service, or in some cases were hand-carried into the United States. The target sample size was at least 100 different infant foods from at least 20 different countries, and we stopped data collection in November 2014 when we reached 108 samples from 22 countries.

Nutrient testing and statistical analyses

Each product was blind-tested within a month of purchase by Midwest Laboratories in Omaha, Nebraska, a commercial laboratory whose selection was based on a competitive bidding and past performance (citation omitted for anonymity). On receipt of the purchased foods, each product was removed from its packaging, repacked as a numbered sample in a sealed plastic bag, and shipped to the lab facility for measurement of total energy, total fat, total protein, total carbohydrates (by subtraction), total iron, and total zinc, as well as moisture and ash content.

The analytical methods carried out by Midwest Laboratories for testing the macronutrient and micronutrient contents of samples follows standards set by the Association of Official Analytical Chemists, with protein analysis by combustion; fat analysis by alkaline hydrolysis; carbohydrates by

subtraction after calorimetry; and iron and zinc analysis by microwave digestion and spectrometry.

Specific procedures are available on request from Midwest Laboratories.

Statistical analyses compared each product's measured nutrient composition to the nutrient claims on its packaging. The nutrient composition of each product was also compared to three published benchmarks for CF products: the Codex Alimentarius (FAO/WHO 2013), the nutrient profile used for Super Cereal *Plus* (WFP 2014, USDA 2014), and the nutrient composition of CF proposed by Lutter & Dewey (2003). Codex standards are widely used to compare food products and have served as the basis for various benchmarks (Lutter *et al.* 2008, Mahmoud & Anany 2014). Super Cereal *Plus* (SCP) is a product standard used by UN agencies and donor organizations for nutrition assistance and complementary feeding in institutional settings since 2010. The nutrient composition framework proposed by Lutter and Dewey (L&D) was developed as part of a consultative process convened by the Pan American Health Organization in 2001. The three standards are presented in **Table 1**. The benchmark proposed by L&D is generally more stringent than the SCP and the Codex standards; Codex is the least demanding standard, and SCP generally falls between the other two with the exception of protein for which the SCP is the more restrictive standard.

[Insert Table 1 about here]

Modeling infants and young children's intake relative to nutrient needs

In addition to the three fixed standards, we also compare each product to a child's changing needs as they develop from 6 to 24 months (Lutter & Rivera 2003, Dewey 2003). For this study we use estimated requirements for healthy growth in a child at each age along the median of the WHO reference population (de Onis *et al.* 2006), given consumption of sufficient quantities of each product to meet energy needs while continuing to breastfeed. This modeling approach is designed to provide a lower bound on the fraction of children who, despite exclusive breastfeeding for the first 6 months and continued breastfeeding and sufficient additional energy from the CF product until 24 months, would experience

inadequate intake of specific nutrients due to insufficient density of that nutrient in each food. Actual diets include gradual introduction of family foods in addition to both breastmilk and whatever premixed CF product might be used. Our model reveals which nutrients would be needed at each age, and whether it is even possible for a caregiver to fill those gaps during the infant's transition from breastmilk to the family diet.

To estimate the quantity of each CF product consumed at each age, we use the total energy needs of a median male child in the WHO reference population at 6, 9, 12, and 24 months, and subtract the energy available from continued breastfeeding. The resulting quantity of each CF product allows us to calculate total intake of protein, fat, iron, and zinc, based on the measured nutrient composition of each food in addition to the nutrients obtained from breastmilk. We then subtract estimated nutrient needs, revealing the nutrient profile of other foods that would be needed to sustain healthy development of a child.

Recommended total energy and nutrient intakes

Total energy intake is modeled using age and sex-specific requirements of 77 to 79 kcal/kg/d from 6 to 12 months of age, and then 82 kcal/kg/d with moderate physical activity at 24 months of age, all obtained from FAO/WHO/UNU (2004). The corresponding recommended nutrient intake (RNI) for protein is 1.31 g/kg/d at 6 and 9 months, 1.14 g/kg/d at 12 months and 0.97 g/kg/d at 24 months obtained from FAO/WHO/UNU (2007). Total daily fat requirement was calculated based on an Acceptable Macronutrient Distribution Range (AMDR) of 35% for infants and young children aged 6 to 24 months from FAO (2010), using the Atwater conversion factor of 9 kcal/g of fat. The RNIs for iron and zinc were based on age-specific nutrient requirements and assumed bioavailability of 10% and 30% for iron and zinc, respectively, from FAO/WHO (2004). Recommended intake for iron is 9.3 mg/d from 6 to 11 months and 5.8 mg/d from 12 to 24 months, and for zinc it is 4.1 mg/d at each of these ages. These benchmarks designed to meet nutrient needs for 97-98% of healthy infants at each age, and some would need more or less than this depending on their nutritional status and disease conditions.

Energy and nutrient intakes from continued breastfeeding

The energy and nutrients available from breastmilk (BM) are calculated using the estimated average volume consumed at each age in LMICs, and the estimated energy density and nutrient concentration of mature human BM from Brown *et al.* (1998). BM intake was assumed to be 674g/d for infants aged 6-8 mo, 616g/d for infants aged 9-11 mo, and 549g/d for young children aged 12-24 mo. We used an average BM energy density of 0.67 kcal/g from Butte & King (2005), and a protein concentration of 10.5g/L, a fat concentration of 39g/L, an iron concentration of 0.3 mg/L, and a zinc concentration of 1.2 mg/L from Brown *et al.* (1998). As reported in Vossenaar & Solomons (2012), the nutrients delivered by BM exceed the child's RNI at 6 months of age for only one nutrient, dietary fat. For all other nutrients, complementing BM with a high-density solid food would be needed to achieve adequacy.

Modeled and desired nutrient intakes from CF

Given adequate quantity of each CF to meet a breastfed infant's energy needs, we use its measured protein, fat, iron and zinc density to calculate nutrient intake and the resulting nutrient gaps at each age. To maintain energy adequacy, modeled intake of each food rises from an average of 40 g/day at 6 months to about 150 g/day at 24 months. This is within the range of 25 – 250 g/day suggested by Dewey (2003), and is designed to produce a conservative lower bound on the frequency of inadequate nutrient intake.

All statistical analyses for this research were carried out using Stata/SE 14 with preliminary data collected and tabulated in Excel. Statistical tests were considered significant at P-values below 0.05.

Results

Our final sample consisted of 108 packaged CF products from 22 countries. Most of these products were purchased in Sub-Saharan Africa (88 products from 17 countries), while the remainder was purchased in China, Haiti, Indonesia, Morocco, and Nepal. On average we obtained five different products from each

country, but only one variety was available at the time of purchase in China and the Democratic Republic of Congo, while we obtained 10 and 12 from Ghana and Ethiopia, respectively.

Nutrient content relative to published standards

Testing revealed that the nutritional content of these products was highly variable, with some varieties meeting each of the three published benchmarks but many falling short (**Table 2**). The nutrient that is most often inadequate is total fat, as only 15% of sampled products meet the Codex and SCP standards, and only 1% meet the higher L&D standard. Only 9% of products meet the L&D standard for total dietary energy, and 22% and 21% meet the L&D standard for iron and zinc respectively. The full distribution of measured macro- and micronutrient content relative to each benchmark can be seen using box plots (**Figure 1**). For energy density the mean and median of our sample are above the benchmarks set by Codex and SCP, but well below the more stringent requirement of L&D. For total protein, the mean and median of our sample contained more than twice the benchmarks set by Codex and L&D, and just below the more stringent requirement of SCP. Total fat is the most often limiting nutrient, with the 25th percentile well below all three standards. Iron is the most widely varying nutrient, with mean and median below all three standards. For zinc, the mean and median are below two of the three benchmarks. Looking across all five nutrients it is clear that some products had levels well above the three standards while some others were far below.

[Insert Table 2 about here]

[Insert Figure 1 about here]

Nutrient content relative to products' own labels

Many of the purchased products include nutrient claims on their packaging. The nutrient claim most often provided is total protein, which is listed on 83 of the 108 products. Total energy is listed for 80 of them, while 77 list fat content, 58 list iron content, and 43 list zinc content. We compared our measured contents to those nutrient claims (**Figure 2**), and found little correlation between them. A Wilcoxon

matched-pairs test rejects equality between measured and labeled values for protein ($p=.013$) and fats ($p=0.000$), and nearly rejects equality for zinc ($p=0.076$) but not for iron ($p=0.130$). The closest correlation between the measured and labeled value is for total energy, which was equal to, or above, the labeled value for 47.5% (38 of the 80 labeled products). For protein and fat, most products have less than their labeled content, 54% and 66% respectively, whereas products with labeled iron or zinc exceed the labeled values about as often as they fell short.

[Insert Figure 2 about here]

Nutrient content relative to modeled needs of a healthy child

Based on our model of a healthy breastfed child at the median of WHO growth standards, **Table 3** shows means for each age of the RNI, the estimated nutrient intake from BM, the desired nutrient intake from CF, the modeled intake of nutrient from CF, and the resulting difference between desired and modeled intake. In this model, the quantity of each CF consumed each day is exactly sufficient to meet estimated energy requirements. As shown in the rightmost column the resulting mean intake of protein is sufficient to meet modeled protein needs at every age from 6 to 24 months, but mean intake of both iron and zinc is insufficient at 6 months, and zinc remains insufficient at 9 months. At 12 and 24 months the mean intake of these micronutrients becomes adequate, but mean intake of dietary fat becomes insufficient.

[Insert Table 3 about here]

The distribution of intake among children fed each of these foods is also presented in **Table 3**. For protein, over 90% of products in our sample had sufficient density to meet recommended intake levels at every age. About 91% of products have adequate protein density to meet modeled needs at 6 months, and that fraction rises to 98% at 24 months. For fat, breastmilk alone is adequate at 6 months of age so all products are adequate, but the proportion of products with adequate density to meet modeled needs falls rapidly to 67% at 9 months, 14% at 12 months and under 1% at 24 months. At 24 months of age more than half (51.85%) of products would be providing less than half of the recommended RNI for dietary fat.

Among the micronutrients, adequacy increases with age. For iron, only 7% of products have adequate density at 6 months, and 22% are adequate at 9 months while for zinc, 20% are adequate at 6 months, and 40% are adequate at 9 months. That proportion rises to over 80% by 24 months of age for both minerals. As shown in the last column of **Table 3**, the magnitude of micronutrient deficiency at younger ages is very large. The proportion of products providing less than half of the recommended intake for iron is over two-thirds (69.4%) at 6 months and over half (53.7%) at 9 months. For zinc, the corresponding share is over half (55.6%) at 6 months and more than one-fifth (21.3%) at 9 months.

Discussion

This study is, to the best of our knowledge, the first systematic sampling and testing for nutrient composition of locally premixed complementary foods being sold throughout the developing world. We extend previous work by measuring both macronutrients and micronutrients in a large sample of 108 products from 22 countries, testing them against three international standards for CF as well as each product's own packaging claims. In addition we use modeled intake relative to recommendations for healthy growth at 6, 9, 12 and 24 months to determine whether a product's nutrient density is sufficient to meet infants' changing needs over the entire period of complementary feeding.

Our main finding is that some premixed CF products can have adequate nutrient density, by any standard, but many products do not. This is consistent with the closest precedent to our study, Roos *et al.* (2013), who tested micronutrients in 12 CF products from Africa and Asia. In our larger sample we find wide variation in both macronutrients and micronutrients, and frequent inconsistency between these products' actual composition and the information printed on their labels. Many products fall short of published standards and would lead to inadequate intake, with large differences among nutrients relative to children's needs at different ages. The first nutrient shortfalls appear at 6 and 9 months for iron and zinc, while for older children (12 and 24 months) the most widespread shortfall is for dietary fat. Levels of protein are generally adequate relative to international benchmarks and modeled requirements, which is

consistent with previous studies such as Lutter & Rivera (2003), although further analysis of the CF would be needed to assess protein quality (Suri *et al.* 2014). The clearest deficits are in dietary fat, which is consistent with previous work by Prentice & Paul (2000) and Michaelsen *et al.* (2011). In our sample, only 14% of tested products have sufficient fat to meet infants' needs by 12 months of age; by 24 months more than 50% of them provide less than half of the fat required for healthy child development. Adding some family foods cannot fill the gap, since caregivers cannot know what combination of foods (plus continued breastfeeding) would achieve desired nutrient ratios.

Our results imply that the potential for premixed CF products to meet infants' nutrient needs cannot be fulfilled until potential users can trust them to have high and uniform content of macro- and micronutrients. Under current conditions, the actual nutrient content of premixed products differs significantly from labeled nutrients, and is often far below infants' requirements for healthy growth. However, some products do have adequate nutrient density, which confirms that local millers have the capacity to produce and sell sufficiently nutrient-dense products. The WHO/UNICEF (2003) strategy for infant and young child feeding states that after six months of exclusive breastfeeding, "...low-cost complementary foods, prepared with locally available ingredients using suitable small-scale production technologies in community settings, can help to meet the nutritional needs of older infants and young children". We find that fulfillment of this potential is severely impeded by the variability and unpredictability of these products' actual nutrient content. Similar products sold in high-income countries are much more uniform, as shown for example in the UK and Norway by Zand *et al.* (2012) and Melø *et al.* (2008), where a variety of voluntary and government standards are routinely enforced through inspection and testing.

Research on many other foods reveals how food standards arise and spread, resulting in increased sales of high-quality products at competitive prices (Swinnen *et al.* 2015). Quality assurance for premixed complementary foods could have similar effects by giving local millers sufficient incentives to maintain

uniform levels of attributes that consumers want to buy. The introduction of new inspection and testing services begins with agreement on what those attributes should be. For premixed complementary foods, research has generally focused on marketing regulations rather than production standards (e.g. Sweet *et al.* 2013), and policy documents typically treat premixed flour for complementary foods as similar to premixed formulas for breastmilk substitutes (WHO 2013, 2015). The recently revised Codex Alimentarius guidelines (FAO/WHO 2015) do not mention macronutrient density at all, focusing instead on smaller recommended serving sizes to protect BM intake, guidance on essential fatty acids and their optimal ratio, and processing techniques to reduce anti-nutrients (Siekmann *et al.* 2015).

If one or more organizations were to propose appropriate standards for the nutrient composition of complementary foods, local inspection and testing services to determine which products meet those standards could be provided by a wide range of private- and public-sector organizations. To be widely used a quality assurance service must be trusted by both potential producers and also potential consumers. Such services actively inspect production facilities, collect samples and conduct laboratory tests, before authorizing use of a licensed trademark. The cost of testing and inspection is typically shared between producers and consumers, in the form of a licensing fee paid by sellers and included in product prices, and may also be supported by philanthropic or donor funds.

The need for independent testing and product certification to create markets for high-quality products was first demonstrated by George Akerlof (1970), for which he was awarded the 2001 Nobel Prize in economics. Sustaining a certification program depends on the tester's ability to measure an attribute that consumers need but cannot see for themselves, which is often the case for high-quality food products (Caswell & Padberg 1992). With premixed CF products, buyers can readily detect odors, colors and textures but cannot observe nutrient density itself. Once mixed, the product's ingredient ratios can be detected only through testing, even after purchase and use. Products with inadequate nutrients will cause ill-health and stunted growth, but for any given child those effects could also have been caused by many

intervening confounders and cannot be attributed to nutrient density without controlled trials. To be cost-effective, certification programs must focus on the most important quality attributes that are otherwise unobservable. Other traits such as taste and convenience may be equally important, but need not be certified since they are directly observable by consumers. In effect, third-party certification introduces a separate market for information about product quality, allowing consumers to see it directly and inducing suppliers to maintain quality at competitive prices.

When testing actually provides valuable information, certification programs can operate on a voluntary fee-for-service basis to which sellers subscribe (Crespi & Marette 2001). For CF in Africa, a market experiment in Bamako, Mali, found that even very poor and illiterate mothers were aware of the risk that premixed products could have inadequate nutrient levels and were willing to pay more than enough to cover the estimated costs of inspection and testing (Sanogo & Masters 2002), and a survey of small-scale millers producing CF products in Ghana found them to be keenly interested in using certification to signal their quality (Masters *et al.* 2011).

A close precursor to what would be needed for infant foods is the seal of nutritional excellence that has been promoted by INCAP, the Institute of Nutrition in Central America and Panama (Tartanac 2000). A major challenge is the size of market demand, which helps spread the fixed cost of certification over a larger volume of sales (Auriol & Schilizzi 2015): infant foods are a niche product, and even within that market only lower-income consumers would need certification, since higher-income consumers can buy enough of the name-brand products to meet their children's needs. Furthermore, certification programs are typically introduced to detect toxins and adulterants in response to fears of contamination. Quality assurance about nutritional composition would expand a small food category, rather than protect a large one, so there is no popular clamor to introduce infant food certification. End-users who would benefit from such a program are infants and their caregivers, while the producers who would benefit are small-

scale local entrepreneurs for whom the lack of quality assurance is most constraining (Unnevehr & Hirschhorn 2000).

In summary, premixed CF products can have adequate nutrient density, by any standard, but many products do not. To remedy this problem third-party quality assurance for the nutrient density of solid CF products would help local millers meet caregivers' increasing demand for nutrient-dense porridge at low cost, using local ingredients and packaging. Third party certification programs can emerge from either the public, private or philanthropic sectors, but require a high degree of coordination and responsiveness to earn the trust of both buyers and sellers. The data presented in this paper demonstrate the importance of that effort.

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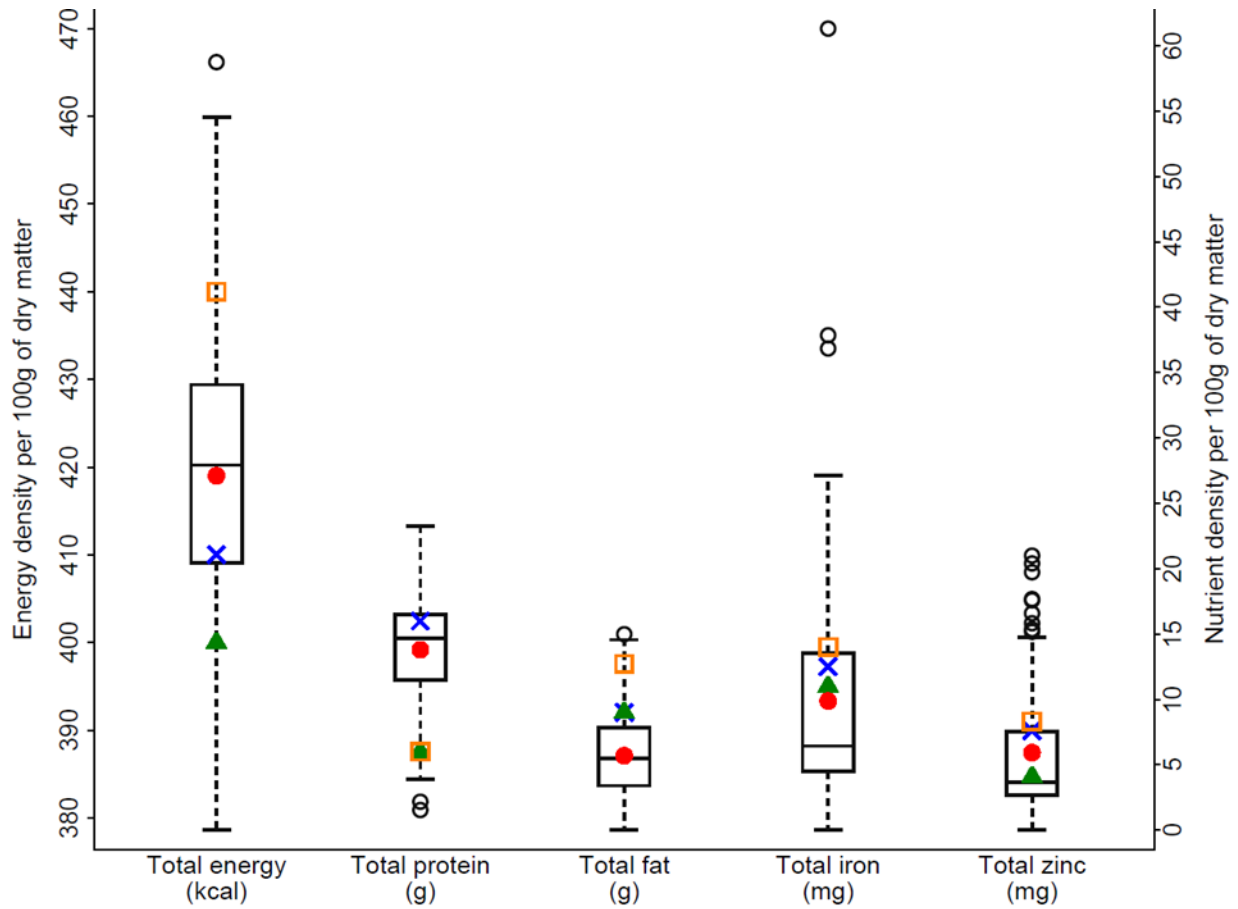
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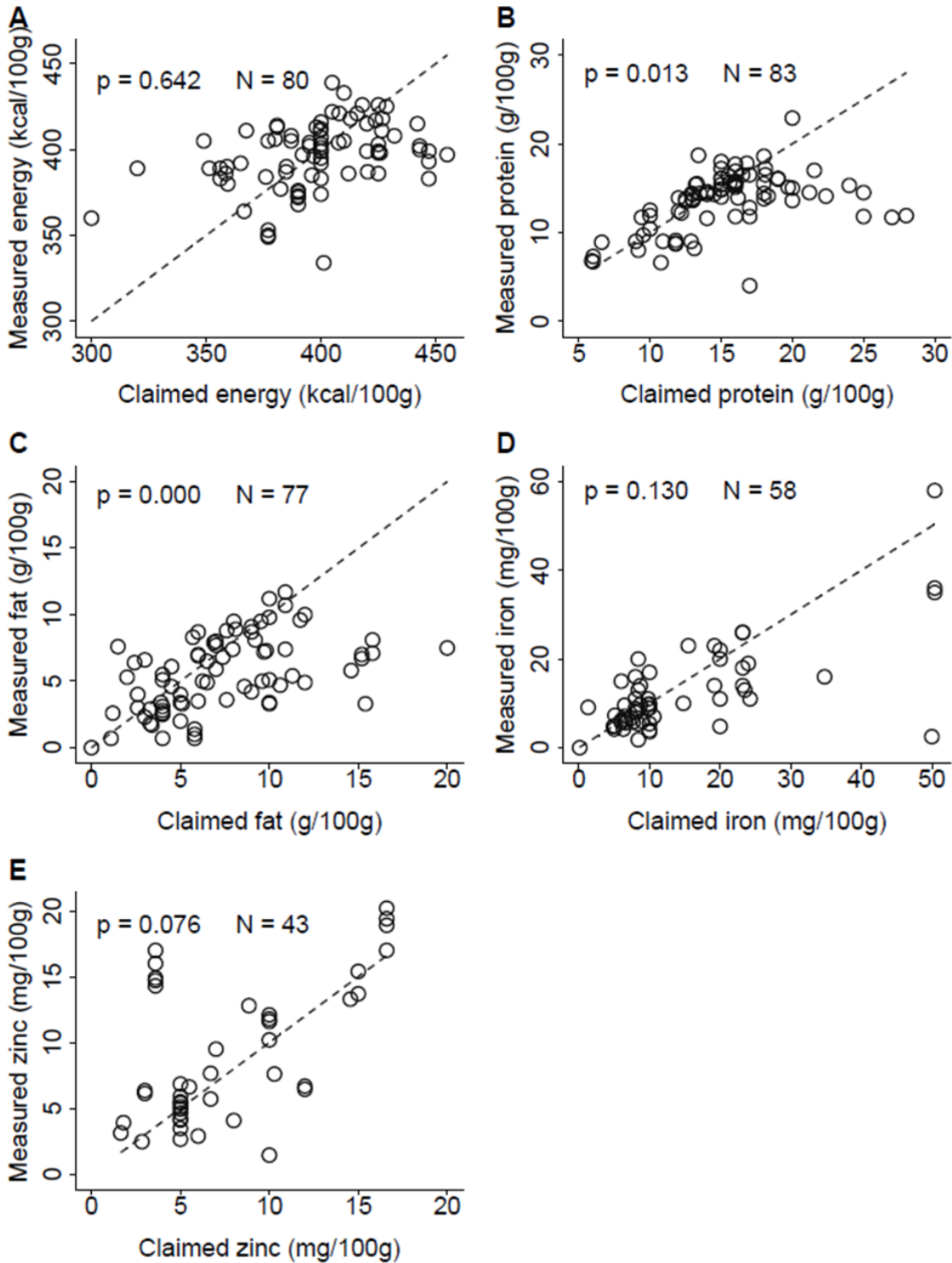
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Figure 1. Variation in macro- and micronutrient content relative to desirable benchmarks



Note: Authors' calculations, from all 108 samples relative to the three benchmarks. Energy density on the left axis and nutrient content on the right are shown here per 100g of dry matter. Boxes indicate the 25th, 50th and 75th percentile; whiskers extend to 25th percentile minus 1.5 IQR and from 75th percentile plus 1.5 IQR. The open circles and the filled circles show the outliers and the means, respectively. The filled triangle, the cross, and the open square indicate the benchmarks from Codex Alimentarius, SuperCereal Plus and Lutter & Dewey (2003), respectively.

Figure 2. Variation in macro- and micronutrient content relative to claims on product labels



Note: Authors' calculations, with number of comparisons between claimed and measured values shown on each panel for energy (A), protein (B), fat (C), iron (D), and zinc (E). The dotted line in each panel shows equality; p is derived from a Wilcoxon matched-pairs signed-ranks test that the paired differences between measured and labeled values for each nutrient are symmetrically distributed around zero.

Table 1. Benchmarks used to assess the nutritional quality of CF

Nutrient content (per 100g)	Codex	SCP	L&D
Energy (kcal)	400	410	440
Macronutrients			
Protein (g)	6.0	16.0	6.0
Fat (g)	9.0	9.0	12.7
Micronutrients			
Iron (mg)	11.0	12.5	14.0
Zinc (mg)	4.1	7.6	8.3

Proteins and fats contents are given per 100g of dry matter. Iron and zinc contents are given per 100g of finished product. Fat and protein for Codex and L&D are implied from their respective recommended AMDR and converted using the Atwater conversion factors of 9 kcal/g of fat and 4 kcal/g of protein. Iron and zinc for the SCP are from Webb *et al.* (2011). L&D recommendations for total fat are from Lutter and Dewey 2003 (Table 5) for children from 6 to 23 months, with more specific recommendations of 11.9 and 13.7 for children aged 6-11 and 12-23 months respectively.

Table 2. Summary Statistics for 108 complementary foods from 22 countries

	Mean \pm SD ¹ (min - max)	Fraction that meets standard (%) ²		
		Codex	SCP	L&D
Energy (kcal)	419.0 \pm 16.0 (378.6 - 466.2)	94 (87.0)	76 (70.4)	10 (9.3)
Macronutrients				
Protein (g)	13.8 \pm 3.9 (1.5 - 23.3)	104 (96.3)	35 (32.4)	104 (96.3)
Fat (g)	5.7 \pm 3.1 (0.0 - 15.0)	16 (14.8)	16 (14.8)	1 (0.9)
Micronutrients				
Iron (mg)	9.9 \pm 8.8 (0.0 - 61.3)	35 (32.4)	29 (26.8)	24 (22.2)
Zinc (mg)	5.9 \pm 4.9 (0.0 - 21.0)	49 (45.4)	26 (24.1)	23 (21.3)

¹All values are nutrient content per 100g of dry matter.

²Values are number of products that meet or exceed benchmark and in parentheses are the percentage of products that meet or exceed benchmark.

Table 3. Estimates of differences between desired and modeled nutrient intakes from 108 CF

Energy, nutrient, and age	RNI	Intake from BM	Desired intake from CF ¹	Modeled intake from CF (Mean ± SD) ²	Nutrient intakes gap (Mean ± SEM)	p-value ³	Proportion of RNI from CF (%)			
							-100	99-75	74-50	49-0
Energy (kcal)										
6	618.8	451.6	167.3							
9	685.4	412.7	272.7							
12	762.2	367.8	394.4							
24	1,001.3	367.8	633.4							
Protein (g)										
6	10.4	7.1	3.3	5.5 ± 1.5	2.2 ± 0.1	1.00	90.7	5.6	1.8	1.8
9	11.7	6.5	5.2	9.0 ± 2.5	3.8 ± 0.2	1.00	91.7	4.6	1.8	1.8
12	11.0	5.8	5.2	13.0 ± 3.6	7.7 ± 0.3	1.00	96.3	1.8	0.0	1.8
24	11.8	5.8	6.0	20.8 ± 5.9	14.8 ± 0.6	1.00	98.1	0.0	0.9	0.9
Fat (g)										
6 ⁴	24.1	26.3	0.0	2.2 ± 1.1	2.2 ± 0.1	1.00	100.0	0.0	0.0	0.0
9	26.6	24.0	2.6	3.6 ± 1.8	1.0 ± 0.2	1.00	66.7	14.8	6.5	12.0
12	29.6	21.4	8.2	5.3 ± 2.7	-3.0 ± 0.3	0.00	13.9	25.0	24.1	37.0
24	38.9	21.4	17.5	8.4 ± 4.3	-9.1 ± 0.4	0.00	0.9	13.0	34.3	51.8
Iron (mg)										
6	9.3	0.2	9.1	4.0 ± 3.6	-5.1 ± 0.3	0.00	7.4	7.4	15.7	69.4
9	9.3	0.2	9.1	6.5 ± 5.9	-2.6 ± 0.6	0.00	22.2	12.0	12.0	53.7
12	5.8	0.2	5.6	9.4 ± 8.6	3.7 ± 0.8	1.00	56.5	18.5	12.0	13.0
24	5.8	0.2	5.6	15.0 ± 13.8	9.4 ± 1.3	1.00	83.3	5.6	4.6	6.5
Zinc (mg)										
6	4.1	0.8	3.3	2.4 ± 2.0	-0.9 ± 0.2	0.00	20.4	13.0	11.1	55.6
9	4.1	0.7	3.4	3.9 ± 3.3	0.5 ± 0.3	0.95	39.8	5.6	33.3	21.3
12	4.1	0.6	3.4	5.6 ± 4.7	2.2 ± 0.5	1.00	48.1	23.1	19.4	9.3
24	4.1	0.7	3.4	9.0 ± 7.6	5.6 ± 0.7	1.00	84.3	9.3	1.8	4.6

¹Values are derived by subtracting energy and nutrients intakes provided by mature human breastmilk from RNI.

²Estimates are based on the quantity of product necessary to meet the energy requirement and the nutrient density of products. Estimated average quantity (minimum – maximum) of products necessary to satisfy energy requirements were 40.0g (35.9 – 44.2) at 6 mo, 65.2g (58.5 – 72.0) at 9 mo, 94.3g (84.6 – 104.2) at 12 mo, and 151.4g (135.9 – 167.3) at 24 mo.

³p-value is derived from a one-sided t-test of the negative difference between the desired and the average modeled intake.

⁴All products were assumed to provide at least 100% of RNI from CF for fat regardless of their fat content because at 6 mo BM provides ample fat to cover the RNI.