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ENHANCING THE NUTRIENT BIOAVAILABILITY OF FOOD AID PRODUCTS

A Report from the Food Aid Quality Review

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JANUARY 2019

This report was produced for the United States Agency for International Development (USAID). It was prepared under the terms of contract AID-OAA-C-16-00020 awarded to the Friedman School of Nutrition Science and Policy at Tufts University.



This report is made possible by the generous support of the American people through the support of the Office of Food for Peace (FFP) of the Bureau for Democracy, Conflict and Humanitarian Assistance (DCHA), under terms of Contract No. AID-OAA-C-16-00020, managed by Tufts University. The contents are the responsibility of Tufts University and its partners in the Food Aid Quality Review Phase III (FAQR Phase III) and do not necessarily reflect the views of the United States Agency for International Development (USAID) or the United States Government.

Recommended citation:

Joseph, Michael; Alavi, Sajid; Johnson, Quentin; Walton, Shelley; and Webb, Patrick. 2019. Enhancing the Nutrient Bioavailability of Food Aid Products, Report to USAID, Boston, MA: Tufts University.

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ACRONYMS

ACF	Action Against Hunger
ARA	Arachidonic acid
ARF	Amylase-rich flour
BHA	Butylated hydroxyanisole
BHT	Butylated hydroxytoluene
Ca	Calcium
cP	centi Poise
CSB	Corn-soy blend
CSB+	Corn-soy blend Plus (also, CSB++)
CSWB	Corn-soy-whey blend
DCHA	Bureau of Democracy, Conflict and Humanitarian Assistance
DHA	Docosahexaenoic acid
DP	Diastatic power
DWG	Defatted and toasted wheat germ
E	Energy
EAA	Essential amino acid
EPA	Eicosapentaenoic acid
FAO	Food and Agriculture Organization (of the United Nations)
FAQR	Food Aid Quality Review
FBF	Fortified blended food
FFP	Office of Food for Peace (USAID)
FOS	Fructo-oligosaccharide
GI	Gastrointestinal
g/L	Gram per liter
GOS	Galacto-oligosaccharides
HCl	Hydrochloride
HEBs	High-energy biscuits
HMO	Human milk oligosaccharide
HSCAS	Hydrated sodium calcium aluminosilicate
IVPD	In vitro protein digestibility
K	Potassium
lc	Long-chain
LNS	Lipid-based nutrient supplement
LOS	Lactulose
MAM	Moderate-acute malnutrition
Mg	Magnesium
MUAC	Mid-upper arm circumference
NDO	Non-digestible oligosaccharide
NPU	Net protein utilization
P	Phosphorous
PDX	Polydextrose
PG	Propyl gallate
PUFA	Polyunsaturated fatty acid
RUSF	Ready-to-use supplementary food

RUTF	Ready-to-use therapeutic food
RVA	Rapid visco analyzer
SAM	Severe-acute malnutrition
sc	Short-chain
SCFA	Short-chain fatty acid
SC Plus	Super Cereal Plus
SNFP	Specialized nutritious food product
SPI	Soy-protein isolate
TBHQ	Tert-Butylhydroxyquinone
USAID	United States Agency for International Development
USD	United States dollar
USDA	United States Department of Agriculture
WHO	World Health Organization
WPC	Whey-protein concentrate
w.r.t.	With respect to
w/v	Weight/volume

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I. EXECUTIVE SUMMARY

Food aid products designed to achieve nutrition goals remained largely unchanged over many years until the publication of a 2011 report called *Improving the Nutritional Quality of U.S. Food Aid: Recommendations for Changes to Products and Programs*. That report made numerous recommendations relating to specialized food aid products, most of which have been put into use. In a second phase of work, it was decided that a new focus on nutrient bioavailability was needed. This report presents findings and recommendations in the nutrient bioavailability domain. It includes a literature review to understand current thinking on nutrient bioavailability through a food matrix lens. In addition, it includes feedback from consultations with experts and meetings with stakeholders on practical aspects of improving the food aid products' nutrient bioavailability.

Food aid products are formulated with the objective of treating or preventing different forms of undernutrition but studies which examine foods' nutrient bioavailability as a contributing factor to the overall health outcome have rarely been investigated. This report, which is part of work under the Food Aid Quality Review (FAQR) project funded by USAID's Office of Food for Peace (FFP), is to review the role science plays in food matrices by impacting the nutrient bioavailability. This report explores the different components of the food matrix's specialized nutritious food aid products and considers its effects on the nutrients consumed. The goal is to identify areas of improvements. A snapshot of challenges and recommendations is provided below.

Challenges

- Energy Density
- Protein Digestibility
- Antinutritional Factors

- Protein Quality

- Essential Fatty Acids

- Gut Health

- Mycotoxin Contamination

- Optimum Processing

Recommendations

1. Diastatic Malt

2. Defatted & toasted wheat germ; synthetic amino acids

3. Oils rich in ω -3 fatty acid, e.g. canola oil

4. Oligosaccharides/Prebiotics

5. Yeast cell components

6. Compaction of FBFs

II. INTRODUCTION

The major types of U.S. food aid products used in programs that address specific forms of undernutrition are: i) dry grain flour-based; ii) lipid-based smooth paste; and iii) baked products. The dry flour products are categorized as fortified blended food (FBF), and the lipid-based smooth pastes are termed as ready-to-use therapeutic food (RUTF), ready-to-use supplementary food (RUSF) or lipid-based nutrient supplements (LNS), and high-energy biscuits (HEBs) constitute the baked products.

These different foods are used in the treatment of moderate-acute malnutrition (MAM) and uncomplicated severe-acute malnutrition (SAM). FBF, RUSF and LNSs are used for treating MAM, and RUTF is used for treating SAM. Another category of product, independent of the categories listed above and used in the food aid basket, is vitamin-mineral powder which does not provide energy and macronutrients but is used as a solution for tackling micronutrient deficiencies like anemia (DFID HDRC, 2011). **Table 1**, presents a list of different products and their uses in combating malnutrition, adapted from a report of ACF International (2011).

Depending on their composition and processing, different products have different food matrices. The food matrix can be defined as “the nutrient and non-nutrient components of foods and their molecular relations to each other” (USDA NAL Glossary, 2015). Ingredients included and processed initiate changes in the end product at physical and molecular levels. Due to these changes, they create a newer and different product with characteristics unlike the product at the beginning of the process.

Nutrient bioavailability has been defined as “the proportion of nutrient that is released, digested, absorbed and metabolized through normal pathways” (Srinivasan, 2001) or as “the proportion of intake that is capable of being absorbed through/by the intestine and made available either for metabolic use or storage” (Lowe and Wiseman, 1998). In other words, bioavailability of nutrients is a function of the food consumed (food matrix) and the response of the consumer to effectively utilize the ingested food (dependent on parameters like age, health, gut health, diseases, etc.).

The level of nutrients is not the most critical factor; it is the ability of the nutrient to be released from the food matrix and utilized by the body that ultimately determines benefits to the consumer.

Food aid products are formulated with the objective of treating or preventing different forms of undernutrition, however studies that look at their nutrient bioavailability as a contributing factor to the overall health outcome have not often been investigated. The purpose of this report, which is a part of work conducted under the Food Aid Quality Review (FAQR) project funded by USAID’s Office of Food for Peace, is to review the state of science on the role of food matrices in impacting the nutrient bioavailability. It examines the effects of different food aid products in addressing undernutrition by

understanding the gaps in food matrices and suggests ways to improve the nutritional efficiency of these foods.

Table 1. Food Aid Products, Food Matrices and Their Main Uses

Intent	Treatment of SAM	Treatment of MAM		Prevention of Undernutrition				Other
Product Category	RUTF	LNS-HQ	FBF	LNS-MQ	FBF	LNS-LQ	Vitamin & mineral powder	HEB
Macronutrients per 100g	500 kcal 12.5g protein 32.9g fat	500 kcal 12.5g protein 32.9g fat	840 kcal 32g protein 18g fat	247 kcal 5.9g protein 16g fat	840 kcal 32g protein 18g fat	108 kcal 2.5g protein 7g fat	---	1800 kcal per 400g biscuits
Shelf life	24 months	24 months	12 months	24 months	12 months	18 months	24 months	5 years
Dose	According to weight: 6-59m: 200kcal/kg/day	One sachet/day 92g/day (75kcal/kg/day)	200g/day	47-50g/day	200g/day	20g/day	One sachet/day 1g/day or 5g/day	Adults: 400g/day (HEB), 500g/day (NRG-5, BP-5)
Cost/dose /day (USD)	\$50-\$70 0.36/sachet	0.29/day	Super Cereal*: 0.15 / day Super Cereal Plus 0.26/day	0.18/day	Super Cereal*: 0.15 / day Super Cereal Plus 0.26/day	---	0.028/day	2.84/day

Adapted from ACF, 2011. SAM-Severe-acute malnutrition; MAM-Moderate-acute malnutrition; RUTF-Ready-to-use therapeutic food; LNS-HQ-Lipid nutrient supplement-High quantity; FBF-Fortified blended food; LNS-MQ-Lipid nutrient supplement-Medium quantity; LNS-LQ-Lipid nutrient supplement-Low quantity; HEB-High-energy biscuit; kcal-kilocalorie; USD-United States dollar

*Note that Super Cereal is programmed with vegetable oil; Super Cereal Plus is not programmed with vegetable oil. The cost/dose/day of Super Cereal includes the cost of oil.

Multiple micronutrients are present in food aid products and they can have synergistic or antagonist effects on others. Some interactions that can be seen between the nutrients within the food matrix are: i) High levels of zinc affects iron and copper absorption (Pressman et al., 2017); ii) presence of vitamin C and vitamin A enhances iron uptake (Dias et al., 2015); iii) presence of fat in the foods help in bioavailability of fat-soluble vitamins (Roodenburg et al, 2000); and iv) the metals present in the mineral premix may promote lipid oxidation (Bookwalter, 1977) and affect the shelf life.

These types of interactions are well-known, and the micronutrients are added with

certain overages keeping the interactions and the losses during storage in mind. Utilization of the processing in the correct way may lead to less use of some micronutrients or may also help in reducing the addition of expensive forms of compounds. As well as correct amounts of micronutrients being added, the effect of food matrices or the interactions with the various components of food seem to impact the levels of micronutrients (Schlossman et al., 2017). At the end of a 26-week accelerated shelf-life study on foods being programmed by USAID–Super Cereal Plus (SC Plus), Corn-Soy Blend Plus (CSBP), RUSF, and fortified vegetable oil along with a newly-developed food based on FAQR Phase I recommendations–Corn-Soy-Whey Blend (CSWB), they found that vitamin A levels degraded substantially in all FBF but remained stable in RUSF and oil. Vitamin C was found to be uniformly low—below the normal range. In addition to packaging, lipid-based matrices like RUSF provide additional protection to vitamin C from degradation due to moisture and oxygen. Correspondingly, it can be inferred that low levels of vitamin C would impact iron absorption. **The food matrix plays a critical role in determining the fate of micronutrients through the productive life of a product.**

III. METHODS

A detailed review of literature (n = 300) was conducted to understand the nutrient bioavailability from foods in general and in food aid products in particular. This report includes studies relating specifically to food aid products from 2000 to mid-2018. The three main search engines used were: Web of Science, Scopus and Google Scholar. The main keywords used were: food, nutrient bioavailability, fortified foods, food aid, nutrient interactions, processing and nutrition, food matrix(ices), and antinutritional factors. Expert interviews and a one-day roundtable meeting with experts and stakeholders—academia, industry, government agencies and non-profit organizations—added to the information collected from the literature review. The roundtable meeting focused on assessing the current understanding of nutrient bioavailability and future pathways for improving the nutritional effectiveness of specialized food aid products.

IV. CHALLENGES IN IMPROVING BIOAVAILABILITY OF NUTRIENTS IN FOOD AID PRODUCTS

Food aid products are key interventions in the effort to treat and prevent all forms of malnutrition. The foods are energy dense, with high-quality protein and micronutrients that help consumers get adequate nutrition to overcome the debilitating conditions. The general outcome of health and the effectiveness of foods is measured by changes in stunting (due to chronic malnutrition) and underweight, and to a lesser extent with wasting (due to acute malnutrition) (Lenters et al., 2016). The focus should be on approaches that can lead to overall healthy growth and can also help in addressing the

issues related to wasting. Because several factors greatly affect the bioavailability of foods' nutrients, addressing those issues would make these products more nutritionally efficient. The challenges explored include: 1. Optimum Processing, 2. Energy Density, 3. Protein Quality, 4. Antinutritional Factors, 5. Essential Fatty Acids, 6. Gut Health, and 7. Mycotoxin Contamination.

I. Optimum Processing

Food aid products are divided into two groups based on processing: i) unprocessed products; and ii) processed products. The unprocessed products consist of whole grains (wheat, rice, corn, peas, lentils, etc.). The processed products are: wheat flour, corn-soy blend (CSB), fortified vegetable oils, wheat-soy blend, high-energy biscuits (HEBs), etc. (Marchione, 2002). While unprocessed products have a long shelf life, they are not nutritious enough to provide the requisite energy and nutrients to populations suffering from acute malnutrition.

On the other hand, processed products are specially formulated to address specific forms of undernutrition. They are more energy dense with high-quality protein and fortified with micronutrients to address both chronic and acute forms of undernutrition. The type of processing used to make a product affects the food matrix, and because of this, affects the digestibility and nutrient absorption. Extrusion processing of cereals and legumes to make products like CSB have more digestibility as compared to the same product made by using roasting. Therefore, the porridges made from extruded products are much thinner and thus easily consumable by children as compared to those made from roasting. However, the initial cost of accessing the extrusion technology is much higher than the cost for roasting. Milling helps refine the grain or legume by removing the germ and seed coat, thereby increasing the shelf life of the flour as well as helping lower the antinutritional factors present in whole grains.

Another process, baking, is used to produce HEBs, which is a different food matrix as compared to extruded products. Generally, baking needs a higher temperature (220°C or approximately 425°F) and a longer preparation time as compared to extrusion (approximately up to 160°C or 320°F) for a very short period of time. Ultimately, the process used is selected based upon the end product characteristics needed. Similarly, compaction of FBF is a potential technique for addressing shelf life and transportation concerns. The main objective of processing is to provide a safe, nutritious food with a shelf life to match the product movement and consumption pattern by the beneficiaries.

Therefore, ways to improve processing to make food aid products more nutritious, shelf-stable and cost-effective should be constantly explored. This report recommends compaction as a potential technology to improve shelf life and can be found in Recommendation 6.

2. Energy Density

FBF is the mainstay of supplementary feeding programs because they are relatively low-cost products with a relatively high protein content and a reasonably comprehensive micronutrient profile. Corn-soy blend (CSB) has been the most commonly programmed FBF since the 1960s. It has a minimum energy density of 380 kcal/100 (USDA, 2014) and is the primary source of micronutrients in the target population. However, FBF must be consumed as a porridge after cooking it in boiling water. Often, the cooking dilutes the product, which decreases the actual intake of macro- and micronutrients. Due to the restricted gastric capacity of young children who consume the porridge, the intake (consumption) of solid food is limited. Since FBFs are typically used for treating or preventing MAM, any deviation from the standard preparation practices could lead to the product failing in achieving its intended use.

Alternately, if less water were used for cooking, then the porridge would become too thick and the children could not consume it easily. This too results in incomplete consumption of FBF, leading to subpar output by those who consume the product. Therefore, changes in the matrix (too thick or too thin) lead to poor utilization of the nutrients from the FBF. The use of enzymes has been explored to address the challenges of viscosity and energy density (Kampstra et al., 2017).

Conversely, lipid-based pastes are ready-to-eat and require no preparation. These products could have a better chance of achieving the intended outcomes as they are not dependent on individual preparation practices.

For example, a study by Matilsky et al. (2009) in Malawi showed that lipid-based fortified spreads had more effective recovery rates than CSB in moderately-wasted children. One of the reasons attributed was that ready-to-use spreads were more energy dense and smaller volumes of it were needed as compared to CSB, in which 20 percent more was needed. In a systematic review of randomized-controlled trials and controlled before-after studies, Gera et al. (2017) found that LNS may be slightly more effective in recovering individuals from MAM as compared to FBF. However, in a Malawian study with children between 6 to 50 months old with isocaloric products, novel CSB recipe (CSB++) with higher protein but lower fat than soy-based RUSF and soy-whey RUSF was not inferior in facilitating recovery from MAM (LaGrone et al., 2012). It was found that the addition of lipids in iron-based meals more than doubled (2.55-fold) the iron absorption from ferric pyrophosphate (Monnard et al., 2017).

Energy density plays a critical role in catalyzing positive health benefits for food aid recipients. Diastatic malt has been recommended (Recommendation 3) in this report as a way to address the issue of energy density in FBF.

3. Protein Quality

Proteins are an important component of food aid products. Insufficient protein intake has been called the possible cause of child growth stunting in many low-income countries (Arsenault and Brown, 2017). The utilization of protein by the body depends on protein digestibility and the amino-acid profile of the ingested protein source. Due to the poorer amino acid profile in plant proteins, plant-based proteins such as those from cereals and legumes are considered “lower quality” than animal-source proteins such as meat and dairy. Additionally, sufficient energy must be provided in the food so that the proteins can be used by the body for supporting growth rather than channelizing it for maintenance energy needs.

One study that compared isocaloric and non-isonitrogenous proteins from animal and plant sources (Matilsky et al., 2009) found that both soy-peanut fortified spread (18.9g) and dry skim milk-peanut-fortified spread (18.9g) had significantly increased weight and MUAC better than CSB (34.4g non-animal source protein) and had better recovery rates for MAM. However, between the fortified spreads, no additional benefits were found by the use of dry skim milk. LaGrone et al. (2012) conducted a trial which compared near-isonitrogenous soy-whey RUSF (15g protein), soy-RUSF (17g protein) and CSB++ (21g protein). The CSB++ contained dry skim milk powder but its level as animal source protein was four times less than that of soy-whey RUSF. The whey supplementation led to a significantly greater MUAC increase compared with soy RUSF and CSB++, which did not differ from each other. Both RUSF groups gained significantly more weight than CSB++ participants, recovered from MAM wasting significantly earlier and developed significantly less SAM. An efficacy study in Malawi by Sato et al. (2018) measured plasma EAA (essential amino acid) in two groups of children aged 6 to 23 months and 24 to 59 months being treated for SAM with amino-acid-enriched milk-free RUTF or amino acid-enriched low-milk RUTF and compared the outcomes with standard peanut-milk RUTF. They concluded that amino acid-enriched cereal was as effective as milk-based RUTF in recovering EAA and support nutritional recovery from SAM in 6 to 59-month-old children.

Delimont et al. (2017) compared the protein efficiency between FBF produced from sorghum and cowpea but containing either whey-protein concentrate (WPC) or soy-protein isolate (SPI) in a rat study. They found that the SPI-based FBF had lower energy efficiency, protein efficiency and weight gain. Various studies have been done on developing complementary foods using non-traditional protein sources like amaranth (Okoth et al., 2017), chickpeas (Malunga et al., 2014; Christian et al., 2015), pigeon peas (Okafor et al., 2018), and other legumes. Using defatted and toasted wheat germ (DWG) can provide an alternate source of quality protein at a lower cost than soy.

It can be concluded that sources of protein other than soy have the potential to be used in food aid products—provided that they are cost-effective and

bring about measurable changes in the nutritional status of consumers. Recommendation 1 in the latter part of this report details the incorporation of DWG in FBF formulations as an effective solution to have good quality protein at relatively lower cost. Recommendation 3 on diastatic malt being effective in improving protein digestibility would further add to the quality of protein. Recommendation 4 presents an alternate way of improving the protein quality by addition/supplementation of synthetic amino acids.

4. Antinutritional Factors

The major ingredients in food aid products are cereals, legumes and dairy-based products. The plant-based ingredients have antinutritional factors like phytic acid, tannins, trypsin inhibitors, etc. and their presence can affect the digestibility and bioavailability of nutrients from these food matrices. Phytic acid binds with multivalent metal ions especially calcium, iron and zinc to form phytates (Lonnerdal 2002; Abebe et al. 2007) and make them unavailable for absorption and utilization by the body. Even small amounts of phytate can affect iron absorption (Hurrell, 2004). Processes like degerming of corn, removing the hull of beans, exogenous phytase addition are some ways to reduce the phytic acid content in these blends.

Complementary foods made from unrefined cereals and legumes have been found to have the highest phytate concentration. In order to successfully overcome the effect of phytates and molar ratios of phytate, metal ions should be assessed when formulating the mineral premix for addition to food aid products. Roos et al. (2013) conducted a study to screen antinutritional compounds in complementary foods and food aid products for children and infants. They analyzed the products for phytates, polyphenols, and trypsin and chymotrypsin inhibitors. The study found that only two out of the eleven FBFs had adequately low molar ratios for phytate. This screening study points out the high phytate levels in cereal legume blends. They also observed a high variation in phytates from peanut-based products and low or no measured antinutrients in rice-based products. Similar observations were found by Gibson et al. (2010) which concluded that foods with rice and no legumes had low phytate content.

High phytate content in FBF, due to non-removal of fiber and use of whole corn and soybeans substantially limits mineral bioavailability (Sight and Life, 2008) and has direct impact on iron and zinc absorption. Degerming and dehulling of corn and dehulling of soybeans would contribute to the decrease in phytate content and lead to better mineral bioavailability. Phytase enzyme-rich fractions from cereals, like diastatic malt can be used to reduce phytic acid in FBF. Monnard et al. (2017) found that addition of phytase to calorie-rich RUTF and iron-containing micronutrient powder increased the iron absorption by a factor of 1.8.

The literature presents ample evidence that the presence of antinutritional factors in food aid products represents a challenge to achieving nutrition goals. FBF and peanut-based products both contain factors that can impair the uptake of minerals like iron and zinc from the food matrix. Rice-based products have low or no measured antinutritional factors as compared to other cereals. In this report, Recommendation 3 looks at the use of diastatic malt as a solution to address antinutritional factors in FBF.

5. Essential Fatty Acids

The commodity specifications for oil to be used in international food aid programs have been classified as “salad oil” by USDA (USDA, 2015). It further specifies that the oil can be obtained from canola, corn, cottonseed, safflower, olive, soybean, sesame, sunflower or any other vegetable oil or blends of these oils after the refining process. Other than being an intensive source of dietary calories from the foods consumed by the beneficiaries of food aid, oils are carriers of vitamin A and D.

Oils are also a source of essential fatty acids—especially long-chain omega-3 (ω -3 or n-3) and omega-6 (ω -6 or n-6). Essential fatty acids are polyunsaturated fats and remain as liquid at ambient temperatures. The oils rich in polyunsaturated fatty acids (PUFAs) are unstable and are susceptible to autoxidation or enzymatic oxidation. The causes of rancidity are exposure to oxygen, elevated temperatures, exposure to light, and the presence of pro-oxidants such as iron and copper ions (Feiner, 2016). Experimental studies have shown that lipid peroxidation may increase with high (> 11%E) PUFA consumption, particularly with low tocopherol consumption (FAO/WHO, 2008).

Essential fatty acids are critical for brain function, cognitive abilities, proper functioning of the body cells and cardiovascular health (Glick and Fischer, 2013). These are important attributes that play a defining role in the overall effect the beneficiaries get from fortified foods. Providing fortified foods that are nutritious and energy dense may serve as a major part of the strategy to reduce undernutrition. Looking beyond these nutritive deficiencies would help in better lasting effects on the consumers.

However, it is important that a proper balance of ω -6 and ω -3 be maintained as ω -6 competes with ω -3 for use in the body (Lands et al., 1990). The ratio of ω -6 to ω -3 in 6 to 36-month-old children has been recommended between 5:1 and 10:1, which is similar to the profile in breast milk (Lutter and Rivera, 2003). The ideal ratio of ω -6 to ω -3 should be between 1:1 and 4:1 (Simopoulous, 1999) in normal healthy people. It has been recommended that an intake of 2.5 percent and 3.5 percent PUFA prevents deficiencies related to it.

Recommendation 2 presents the use of oils like canola oil as a better source of oil with better balance of essential fatty acids.

6. Gut Health

The array of microbes present in the human gut are an important component of overall human health and contribute to increasing the effectiveness of nutrients absorbed from the ingested food. The gut microbiome is characterized by plasticity during infancy and the responses to diets, illness, etc. can cause a change in the microflora of the gut (Krajmalnik-Brown et al., 2012).

“Dysbiosis” or an altered microbiota composition has been associated with a number of disease states (Kane et al., 2015). They further added that even in the event of adequate food intake, a decrease in abundance or absence of the species that efficiently process foods or produce vitamins can lead to malnutrition. The microbiome was found to be a causal factor of kwashiorkor (protein malnutrition) in a study on Malawian twins (Smith et al., 2013).

A rat study focused on transferring the gut microbiota of kwashiorkor children to mice and assessing the gut changes in the microbiome after the consumption of RUTF. However, the microbiome recovery was not complete as the mice lost weight when they were fed a normal diet. It was discovered that RUTF alone was not sufficient as a treatment plan for SAM plus kwashiorkor cases. Subramaniam et al. (2014) found that Bangladeshi children suffering from SAM had gut microbiota significantly “younger” than their chronological age. They too reported that the administration of RUTF could only partially and transiently rescue the microbiota and raised the question of whether the immaturity of gut microbiome is a cause or effect of childhood malnutrition. The use of the correct levels and types of oligosaccharides in food aid products as prebiotics can be an effective strategy to improve gut health.

It may be possible to modify the food matrix and its overall properties in such a way that it can influence gut microbiota—but much more applied research in this area is needed. Recommendation 5 suggests the specific addition of oligosaccharides in food aid formulations such as prebiotics to improve gut health.

7. Mycotoxin Contamination

Feeding of cereal-legume blends fortified with micronutrients and other growth promoting ingredients like dairy proteins is a common strategy for tackling the problem of undernutrition. However, cereals and legumes are susceptible to aflatoxin contamination (Temba et al., 2016) in areas that do not have adequate post-harvest practices to protect the stored crops’ high temperature and relative humidity, and insect

and pest damage (Gong et al., 2016). Depending on the exposure to aflatoxin contamination, it can lead to low birth weight (Lombard, 2014), growth impairment like stunting, wasting, and low body weight (Wagacha and Muthomi, 2008; Gong et al. 2004), and immune suppression as well as mental retardation by instigating changes in the insulin-like protein growth factor and impeding mineral bioavailability (Shephard 2008). Complementary foods produced from such infected grains and legumes would directly affect the well-being of beneficiaries, mainly children and young children,

This problem may not be widespread in complementary foods originating from the United States but is a problem in many developing economies where food aid is distributed. Consumption of foods infected with mycotoxins in a regular diet would indirectly hinder the positive effects on health outcomes from consuming energy and nutrient-dense food aid products. Therefore, it would be prudent to attend to this issue through food aid products.

Addressing the issue of mycotoxin contamination would help in mitigating the negative effects of mycotoxin consumption from other food sources. Recommendation 6 suggests strategies that can be adopted to reduce mycotoxin contamination.

V. RECOMMENDATIONS

The recommendations below are aimed at improving the nutrient bioavailability of food aid products. These recommendations are based on the literature review, expert interviews and input from stakeholders during the one-day roundtable meeting held in June 2017. The recommendation identifies ingredients that can be added to food aid products to improve their nutritional bioavailability, thus being “cost-effective” on the basis of improved health outcomes. The recommendations can be categorized as: A) Macro-ingredients (that are constituents of the food matrix); B) Food Additives; and C) Processing.

A. Macro-ingredients

I. Toasted and Defatted Wheat Germ

Literature on the formulation of food aid products or similar products show that there have been studies using alternate sources of protein as a substitute to the most common source of protein: soy. These alternate protein sources like cowpea, chickpea, amaranth, etc. have been found to provide a similar quality of protein. However, it is important that the protein source be at least similar in the quality and cost of soy to have the potential of being adopted in large-scale food aid programs. Presently, soy has been the major ingredient of plant-based protein source in food aid products. It has

been used in food aid products like corn-soy blend, soy-fortified corn meal and soy-fortified sorghum (Marchione, 2002). An alternate and cost-effective additive to boost the protein profile of these products could be the use of defatted and toasted wheat germ (DWG). Wheat germ is the by-product of the wheat milling industry and is widely available. Due to the high oil content (7 to 14 percent) in the germ (Mahmoud et al., 2015; Srivastava et al., 2007), it's very unstable. Therefore, the use of DWG, which is already defatted (which makes it shelf-stable), can be used in products that require longer shelf life. The well-balanced protein profile of wheat germ has been compared to that of egg proteins (Zhu et al., 2006a). Wheat germ protein has been classified with effectively superior animal proteins and is a rich source of amino acids, especially the essential amino acids, lysine, methionine, and threonine, which are deficient in many cereals (Yiqiang, Aidong, & Tongyi, 1999; Abbas et al., 2015). Therefore, it is suitable to be utilized in the enrichment of cereal-based foods and can be a valuable ingredient for nutritional enhancement (Arshad et al. 2007).

The amino acid digestibility of wheat germ is comparable to that of soybean meal as found in a study on pigs (Brestensky et al., 2013). Tsadik and Emire (2015) found that substitution of DWG flour by 15 percent in the wheat flour helped maintain the cookie-dough characteristics along with an increase in protein, fiber, ash and mineral (Ca, K, P, and Mg) contents and favorable sensory characteristics. Arshad et al. (2007) found that substitution of wheat flour by 15 percent of DWG flour resulted in cookies that were similar to the one made with 100 percent wheat flour. In addition, they found that the protein efficiency ratio, net protein utilization, biological value and true digestibility of this substituted cookie was similar to that of cookies containing 10 percent casein when fed to rats. A study by Ge et al. (2001) showed that a 15 percent addition of DWG flour to 85 percent wheat flour produced noodles of acceptable and nutritious quality.

Heat-treated wheat protein concentrate, obtained from total millrun middlings (the product of the milling process that is not flour) during normal flour mill operations have been recommended at an inclusion level of 20 percent in wheat-soy blend specifications (USDA, 2005). Similarly, DWG can be incorporated in fortified blended food (FBF). Furthermore, the DWG is shelf-stable and has a shelf life of one year.

DWG flour stands to be a suitable ingredient to be used in making protein-enriched food aid products. It can be added at 1 to 100 percent levels in food aid products, particularly in corn-soy blends as a substitute/replacement of soy. The addition rate would depend on how much of the soy is substituted. Its effectiveness in field trials based on protein quality and shelf life of the product should be tested before incorporating it into suitable food aid product formulations. Cost effectiveness of adding DWG is presented in **Appendix I**.

2. Oils and Essential Fatty Acids

The use of oils in food aid products is primarily to add energy density to these foods. Additionally, it plays a role in reducing the viscosity of porridges by replacing a part of the cereal (or the starch component), is a source of essential fatty acids, enhances the absorption of fat-soluble vitamins, supports neurodevelopment and visual acuity, and improves the texture, flavor and aroma of foods (Fleige et al., 2010). It is important that oils be considered as a source of essential fatty acids as they would add to the improvements in the children's health outcomes in addition to being a source to increase the energy density.

The major oils used in food aid programming are: soybean oil or other oils (for use with fortified blended foods and in lipid-based nutrition supplements) which have higher levels of ω -6 content relative to essential fatty acids requirements and negligible amounts of ω -3 (Brenna et al., 2015). They were similarly concerned about therapeutic foods being able to correct fatty acid status of children recovering from SAM. They further stated that in many studies related to animals fed with ω -3 deficient diets using peanut and other similar oils, it was found that the animals grew normally but had functional deficits like poor maze navigation performance, aggression, poor impulse control, poor balance, etc. Corn-soy blend has been reported to have a high ω -6 to ω -3 ratio which is calculated to be approximately 14-15:1 (Fleige et al., 2010). The expert recommendation for the addition of DHA (docosahexaenoic acid, ω -3) and ARA (arachidonic acid, ω -6) in infant formula for term infants is 0.2-0.4 percent of total fatty acids and 0.35-0.7 percent, respectively (Kuratko et al., 2013).

During rehabilitation of children with severe-acute malnutrition (SAM), emphasis is put on adequate intake of energy and protein along with micronutrients, whereas PUFA intake is given less attention (Babirekere-Iriso et al., 2016). A recent study comprised of 120 children with SAM and 29 healthy control children by the authors found that the ω -6 to ω -3 ratio was lower in children admitted with SAM but the ratio increased in healthy controls following treatment and follow-up. This was a reflection on the overall lack of ω -3 PUFA in the therapeutic diets. Hsieh et al. (2015) found that RUTF formulated with high oleic oil supported growth in the same way as traditional RUTF but improved the levels of DHA and EPA (eicosapentaenoic acid) in SAM-affected Malawian children between 6 and 59 months in a four-week study.

Oils rich in unsaturated fats are less shelf-stable and prone to rancidity. Hydrogenation of these oils would make them stable but they are considered less healthy. The use of antioxidants, synthetic or natural, would prolong the shelf life of these oils. Synthetic antioxidants commonly used are butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), tert-Butylhydroquinone (TBHQ) and propyl gallate (PG). Natural antioxidants are extracts from plants which are mainly phenolic compounds and

essential oils like green tea extract, rosemary extract, olive extract, etc. (Taghvaei and Jafari, 2015). Encapsulation of essential fatty acids and adding them to oils can also slow down the oxidation process.

Care should be taken that while processing soy, as in CSB, lipoxygenase, peroxidase and lipase enzymes are deactivated to prevent lipid peroxidation. In fact, the aim should be to identify oils and/or oil blends that can be a source of ω -3 in addition to being shelf-stable and not cost-prohibitive. Watters et al. (2012) conducted a cost analysis for the supply of 500 mg EPA plus DHA which are long-chain ω -3 fatty acids from different food sources and found that fish, especially salmon and pelagic marine fish was among the least expensive source of EPA and DHA compared to eggs, milk and soymilk because they are produced and sold solely as a source of long-chain ω -3s. Algal oil is also a good source of DHA and EPA but it is more expensive than fish oil on a weight-for-weight basis. It is currently used in infant formulas (Winwood, 2013).

It is important for food aid suppliers to explore the potential for, and estimated value-to-cost ratio of, including essential fatty acids in SNFPs.

Trials need to be conducted to understand the overall “cost-effectiveness” of this strategy of providing more essential fatty acids through food aid and dietary diversification on the overall health gains for individuals.

B. Food Additives

These ingredients are used in small amounts to achieve specific purposes within the particular food.

3. Diastatic Malt

Complementary foods can have lower nutritional value than their potential for reasons such as the presence of antinutritional factors in cereal-legume blends and high viscosity of porridges. To support growth, these foods should have adequate nutrient density and be of low viscosity (for ease of ingestion). The use of sustainable technologies like malting, dry roasting, popping, steaming and boiling (Malleshi et al., 1989) in food aid products would help increase the nutritional efficiency of these products. It could also be proposed to continue use of these products at the local level after the end of the food aid program. External addition of phytase and amylase would be a solution to address the issues of antinutritional factors, particularly phytates and high viscosity, respectively. However, it could be rather expensive as compared to the natural source of these enzymes. Therefore, the incorporation of diastatic malt into food aid formulations should be explored. Diastatic malt is produced by sprouting and controlled drying of grains (often barley and wheat). These germinated, dried and milled grains are natural and inexpensive sources of enzymes like amylase, phytase and protease.

Many research studies have explored the use of various malts from grains like barley, wheat, sorghum, oats, etc. However, barley malt is the most easily available and

therefore preferred to be incorporated in cereal-legume blends. Barley malt has been used in the beer industry for many years. When properly germinated, it produces the highest diastatic activity among all cereal grains (Serna-Saldivar, 2010). Depending on the type of beer produced, the manufacturers seek different levels of diastatic power in barley malts (Brewers Association, 2016). It has also been used in the baking and confectionery industries. The major use of diastatic malt is for the activation of amylase enzymes during germination. This enzyme breaks down starch into simple sugars which are used in fermentation (beers) or providing yeast food and higher loaf volume (breads). Malt used for viscosity reduction applications of porridges is also known as “power flour” or “amylase-rich flour” (ARF) (Alnwick et al., 1988). It is acknowledged that public health efforts have been directed toward the caregivers to prepare thicker porridges, whereas the viscosity of porridges made with added diastatic malt is thin. Adjusting messaging to this new formula would be necessary, as in this case, the thin porridge is still capable of providing full nutrition to the recipient, which is in contrast to when the current formulas of FBF are prepared too thin.

The amount of solids present in porridges accounts for the nutritional density of the product. Because of this, higher solids would lead to higher nutritional density but it also leads to the porridge becoming thick and difficult to ingest by infants and children. Thaoge et al. (2003) reported that the addition of 5 percent of sorghum malt to 25 percent solids of pearl millet porridge to make 30 percent solids concentration, reduced the viscosity from more than 6000cP to an acceptable level of 2500 to 3000 cP (Mosha and Svanberg, 1983). They further noted that porridges may become more palatable by the action of malt beta-amylase to produce added sweetness due to the generation of maltose. This could also help in reducing the amount of added sugar in the porridge formula. Singhavanich et al. (1999) observed that viscosity reduction of 90 percent was more effective (drop batter consistency) with cereal based ARFs as compared to legume based (0 percent reduction in viscosity) ARFs (doughlike consistency) when used for viscosity reduction of 25 percent cereal legume gruel. Devi et al. (2014) observed that the addition of 15 percent of ragi malt to different combinations of extruded cereals and cereal legume blends reduced the viscosity of the gruel.

In addition to the amylase activity in diastatic malt, protease and phytase enzymes are also triggered and can be utilized in cereal-legume blend-based food aid products. Phytase content which breaks down phytate increases 7.9 fold in malts like barley malt (Herlache, 2007). Two types of phytase enzymes are found in barley—one that has peak activity at 55°C (131°F) and a pH of 6.0, and the other that has peak activity at 50°C (122°F) and a pH of 5.0 (Sung et al., 2005). In addition, phytase remains stable up to 100°C (212°F) during the heat treatment period of drying (Rimsten et al., 2002) and in the pH range of 4.8 to 7.0. The protease aids in the digestion of proteins and is relatively active at temperatures up to 80°C (185°F). The addition of 10 percent of

three-day-old sorghum malt to sorghum flour and incubated for 120 minutes at $28\pm 2^{\circ}\text{C}$ significantly reduced the phytate content by 83 percent (Elkhalil et al., 2001). They also observed that the in-vitro protein digestibility (IVPD) of the malt-included blend was significantly higher, and that both the phytic acid decrease and the IVPD were dependent on the amount of sorghum malt, the age of malt and the incubation period.

Similarly, Fageer et al. (2004) found a significant reduction in the phytate content of corn flour when added with six-day-old corn malt at 12 percent. The reduction reported by them was 71 percent and 42 percent for the uncooked and cooked mixtures, respectively. IVPD was significantly improved due to the addition of malt. The rate of phytate reduction was lower in cooked and malt-treated corn flour due to the inactivation of the indigenous phytase in the germinated corn flour when cooked for 30 minutes at 100°C .

Herlache (2007) built upon this by discovering that diastase levels in brewer's malt are at levels of 100 to 140 diastatic power (DP) but power flour has more than 200 DP. Higher DP level helps the breakdown of carbohydrates at a much faster rate than brewer's yeast. Diastase or amylase enzyme can remain active/potent up to 72°C (160°F) and its rate of action is linear until that temperature is reached (University of North Dakota). The use of ARF could be beneficial in enhancing the energy density of porridges which would allow the proteins not to be used for energy but for other necessary bodily functions like muscle growth, maintenance and the repair of muscles. Malt addition would therefore enhance the overall cost-effectiveness of foods. In the feed industry, inclusion of microbial phytase in feeds has resulted in cost savings of 3 percent and improved animal performance (Maller and Peixoto-Nogueira, 2014). **Based on laboratory experiments on the viscosity of FBF, it is recommended to add 0.25 percent diastatic barley malt to cereal-legume blends to improve the mineral bioavailability, energy density and protein digestibility of these blends.** The estimated cost effectiveness of different scenarios based on the addition of diastatic malt can be found in **Appendix 2**.

4. Synthetic/Supplemental Amino Acids

Along with meeting other metabolic demands, proteins are a critical component in the food that helps in the growth and repair of body tissues. Proteins are broken down into amino acids (the building blocks of proteins) by digestive enzymes like pepsin. These amino acids are then absorbed by the body. Plant proteins are considered to be less digestible than animal proteins due to the presence of cell wall components, the presence of antinutritional factors and the need for food processing or heat treatment (Tome, 2013). Processed food aid products recommend the use of animal-based proteins, particularly dairy proteins in the food matrix to help beneficiaries gain the maximum benefits from those foods. Although the addition of animal-based proteins improve the protein value of foods, it also increases the cost of these foods. Most often,

the animal protein component is the most expensive ingredient in the food matrix. Depending on the “effective cost of treatment,” in the management and prevention of moderate acute malnutrition (MAM) and during pregnancy, the optimal levels of animal-sourced proteins in food aid products can be included (DiRienzo, 2016).

In cases where long-term treatments are needed to reverse the effects of MAM or other malnourishment conditions, alternate but effective protein sources should be looked into. One such option is the use of synthetic amino acids. This could help significantly improve the foods’ protein efficiency.

Supplemental amino acids have been an integral part of animal feed for more than 60 years (FEFANA, 2014) but it has rarely been used in human foods. The animal feed industry claims that the use of supplemental amino acids helps animal feeds to be produced using smaller quantities of protein-rich raw materials, allowing these limited, scarce resources to be used more sparingly. These synthetic or supplemental amino acids are utilized to provide the exact amino acid requirements for the animals. It also provides for improved digestibility and better absorption of amino acids, which helps in cost reduction due to lowering the amount of crude protein in the feed formula. With the increasing cost of feed ingredients and competition with the biofuel industry, plant-based ingredients will see a cost hike in the future (Vieira et al., 2016).

The “ideal protein” can be defined as one that provides the exact balance of amino acids needed for optimum performance and maximum growth. Lysine is used as the reference amino acid to calculate the amount of the rest of the amino acids in diets (Mello et al., 2012). Broiler diets have been formulated with the “ideal protein” concept by lowering the crude protein levels and maintaining the ratio of amino acids to lysine to prevent an excess amount of amino acid absorbed relative to lysine. This approach avoids excess oxidation, decreases metabolic costs and improves amino acid balance (Lemme, 2003; Vierira and Angel, 2012). The main, commercially-available supplemental amino acid sources used in poultry diets are L-Lysine, DL-Methionine or Methionine analogues and L-Threonine. These are usually included in diets as digestible amino acids maintaining ratios to digestible lysine to satisfy the ideal protein concept (Baker and Han, 1994).

Similarly, swine feeds have been using supplemental amino acids for several years. Han and Lee (2000) reported that supplementation with limited amounts of synthetic amino acids (0.1 to 0.3 percent) for swine and poultry feeds could reduce two to three percentage units of dietary protein. Toledo et al. (2014) reduced the crude protein in swine feed (for piglets between 15 to 30 kg) by 1.5 percentage points to create low protein diets. These diets were created for amino acids using L-lysine, DL-methionine, L-threonine, L-tryptophan, L-valine and L-isoleucine. They found that the plasma urea concentration decreased linearly, indicating that there was a better use for amino acids with the crude protein reduction. Bassily et al. (1982) reported that the net protein

utilization (NPU) values for broad beans and casein indicated that protein utilization was greatest at low dietary protein levels and it decreased by increasing the protein content of the diet. The serum urea concentration showed an inverse proportion with the NPU values. This was demonstrated by correlations of -0.67 and -0.75 for broad beans and casein, respectively. The most common source of synthetic lysine is L-lysine monohydrochloride, which is 78 percent lysine. In diets for pigs over 50 pounds in body weight, 100 pounds of soybean meal can be replaced by the addition of three pounds of L-lysine HCl and 97 pounds of grain per ton. If the three pounds of L-lysine HCl and 97 of pounds grain (corn) are cheaper than 100 pounds of soybean meal, the diet costs would be reduced by using supplemental lysine. In sow diets, 50 pounds of soybean meal can be replaced by 48.5 pounds of grain and 1.5 pounds of L-lysine HCl (Hansen, n.d).

Very early-on, Ottenheim and Jenneskens (1970) reported that fortification with pure amino acids was instrumental in raising the poor nutritional quality of cereal proteins. They further reported that supplementation with synthetic lysine was more preferable in cereals than fortification with other native protein sources. Recently, Bahwere et al. (2017) published a study which demonstrated that a milk-free RUTF based on soya, maize and sorghum and enriched with synthetic amino acids could be effectively used to treat severe acute malnutrition in 6 to 59-month-old children. The product was found not to be inferior than the regular peanut and milk-based RUTF in achieving recovery and length of stay in treatments. Also, this milk-free RUTF was found to be superior in treating anemia and restoring body iron stores.

Reducing crude protein levels and including supplemental amino acids holds a great potential for raising the digestibility and bioavailability of amino acids, thereby increasing the nutritional efficiency of food aid products. The incorporation of synthetic amino acids should be based on first limiting the amino acid, lysine, and then following the “ideal protein concept.” Measurement of health outcomes and plasma urea concentration should be undertaken to further verify and improve the formulations with supplemental amino acids. A cost impact on CSB+ due to the addition of synthetic amino acids has been provided in **Appendix 3**.

5. Prebiotics/Oligosaccharides

To obtain the maximum benefits of nutritional absorption in the body, gut health is a very important criterion toward accomplishing this goal. Blanton et al. (2016) conducted studies on germ-free mice to understand the role of gut microbiome on childhood malnutrition and found that underdeveloped gut microbiome is a cause of childhood malnutrition, rather than an effect. A related study by Charbonneau et al. (2016) found that human breast milk had a component, sialylated human milk oligosaccharides (HMOs), that helped promote healthy growth and metabolism in malnourished children. According to the Charbonneau study, the relapse of children treated for malnourishment after the end of the feeding program was due to the failure of current

treatment regimens to restore the proper functions mediated by gut microbes, such as synthesizing vitamins and minerals. HMOs, present as the third largest component in breast milk, provides breastfed infants with protection from potential pathogens (bacterial-eg. *e. coli*, fungal-eg. *Candida spp.* and viral-e.g. noroviruses) and also plays an active role in developing healthy gut microbiota like bifidobacteria and reduces the levels of pathogenic bacteria (Harmsen et al., 2000; Morrow et al., 2005).

A food with adequate levels of macro- and micronutrients may not be enough to create a milieu of microbiota in the gut. This becomes more important in bodies that are undernourished. The addition of prebiotic food ingredients like oligosaccharides would beneficially affect the host by selectively stimulating growth and/or activity of one or a limited number of bacteria (*Bifidobacteria* or *Lactobacilli*) in the colon to improve host health (Gibson and Roberfroid, 1995). In addition to having positive impact on gut health restoration of the host, some oligosaccharides like chitosan have been reported to have antibacterial and antifungal properties (Elsabee and Abdou, 2013).

Non-digestible oligosaccharides (NDO) like fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS) and inulin have been the most clinically-tested prebiotic sources with regard to mineral absorption and retention to be included in infant foods (Schloz-Ahrens et al., 2007; Boehm and Moro, 2008). Several other carbohydrates are being investigated for their prebiotic properties like pectins, resistant starch, soybean oligosaccharides (or isomaltulose) (Topping and Clifton, 2001; Roberfroid and Slavin, 2000). Carbohydrate utilization patterns and the production of short-chain fatty acids and gas by infant fecal bacteria have been studied in vitro and have shown that larger, more complex carbohydrates, such as polydextrose (PDX) and inulin, are fermented more slowly and less completely than short-chain materials such as lactulose (LOS), FOS and GOS.

In other words, a combination of specific long-chain and short-chain carbohydrates may allow for slower fermentation by fecal bacteria. Furthermore, in vitro data suggest that blends of prebiotic carbohydrates would be more likely to stimulate fermentation by a broader array of gastrointestinal bacteria, resulting in greater SCFA (short-chain fatty acid) production and reduced pH—both conditions that are considered unfavorable for pathogens (Mead Johnson, 2009). The increase in mineral absorption (magnesium, iron and calcium) due to the production of SCFAs is due to their influence on decreasing the intestinal pH and improving the epithelial health which leads to increased mineral solubility and uptake. A blend of short-chain GOS (scGOS) and long-chain FOS (lcFOS) has been reported to produce a similar SCFA profile as that of human milk oligosaccharides during in-vitro and in-term infants (Knol et al., 2005).

Boehm and Moro (2008) reviewed different research studies done on the use of prebiotics singly or in mixtures in infant milk formula. The prebiotic ingredients used in

these studies were scGOS, scFOS, inulin, lactulose and the mixtures were of scGOS (90% percent w/v)/lcFOS (10 percent w/v). The studies involved infants up to 12 months of age. The dose of the mixtures of scGOS/lcFOS in the infant formula was 4, 6 or 8 g/L. Based on the research objectives, the studies showed increased counts of bifidobacterial and lactobacilli, a decreased rate of recurrent upper tract respiratory infection, a reduction of gastrointestinal (GI) problems, etc. The effects were more pronounced with the use of mixtures and in some studies, inulin was used interchangeably as FOS because inulin is a long-chain FOS. Decreased levels of potentially pathogenic bacteria were observed in some studies with prebiotic supplementation (Donovan et al., 2009).

A clinical trial involving 90 term infants investigated the effects of a mixture of 90 percent (w/v) GOS and 10 percent (w/v) FOS on bacterial growth (Moro et al., 2002; Moro et al., 2003). Infants were randomized to receive control formula or formula supplemented with either 4 g/L or 8 g/L of the GOS:FOS blend for four weeks. The study showed a significant increase in bifidobacteria in both supplemented groups compared to the control group at the end of the treatment period. However, this effect was dose-dependent and significantly different between the supplemented groups. Lactobacilli were also significantly increased in the supplemented infants compared to the control group, but there was no statistically significant difference between the two supplemented groups.

The beneficial effects of prebiotics on gut health was not found in some clinical trials. In a study of 72 infants supplemented with FOS at 1.5 g/L or 3.0 g/L for seven days, only mild prebiotic effects were reported (Euler et al., 2005). In another study with 76 infants, supplementation with FOS at 2 g/L for 13 weeks did not result in significant increases in fecal levels of bifidobacteria and lactobacilli compared to control formula (Brunser et al., 2006). Supplemented infant formulas usually contain 6.0 to 7.2 g/L GOS together with 0.6 to 0.8 g/L FOS (Rastall 2006; Playne and Crittenden 2009). Currently, GOS and FOS are added in a ratio of 9:1. This ratio was chosen to mimic the molecular size distribution of HMOs (Knol et al., 2005)

Michaelsen et al. (2009) reported that the use of oligosaccharides and/or resistant starch may have prebiotic properties in moderately-malnourished children. They added that the fiber content, especially insoluble fibers, should be kept as low as possible in moderately malnourished children up to two years of age and in children with GI problems. While the clinical data are promising, more studies including data from randomized controlled trials are needed to understand the conditions under which prebiotic formula ingredients can positively influence malnourished infant growth and development. Such research could optimize feeding regimens to take into account the beneficial effects of the microbiota.

However, studies on the effect of pre-and probiotics on micronutrient undernutrition are limited (Fluitman et al., 2017). Thus, the utilization of SCFA, which also affects the glucose and lipid metabolism (Fluitman et al., 2017), can be used as an additional pathway to improve the nutritional efficiency of food aid products. **The inclusion of prebiotics, especially a blend of scGOS and lcFOS should be tested in food aid products to understand its effect on the gut health of undernourished children as well as any adverse effects like dysentery, etc.**

6. Mycotoxin Mitigation Strategies

Besides its excellent nutritional value, yeast or yeast cell walls show potential as mycotoxin binders. Using only yeast cell walls instead of whole cells, the adsorption of mycotoxins can be enhanced. The cell walls harboring polysaccharides (glucan, mannan), proteins and lipids exhibit numerous different and easily accessible adsorption centers as well as different binding mechanisms, e.g. hydrogen bonds, ionic or hydrophobic interactions (Jouany, 2007). Yeast components like fibrous material from the yeast cell wall was shown to have a potential to bind several mycotoxins (Devegowda et al. 1998). Esterified glucomannan polymer extracted from the yeast cell wall was shown to bind with aflatoxin, ochratoxin and T-2 toxin, individually and combined (Raju and Devegowda, 2000).

The recommended dose for the extracted active yeast compounds is in the range of 1 to 2 kg/ton of feed (Kolossova et al., 2009). Organic binders are efficient against a larger range of mycotoxins than inorganic binders, which makes them more adapted to the most frequent cases of multi-contaminated feeds. Apart from that, they are biodegradable and do not accumulate in the environment after being excreted by animals. On the contrary, clays which are incorporated at a higher rate than organic binders, accumulate in manure and then in the field during spreading and can harm soils and pastures (Jouany, 2007).

It is recommended that different yeast components (0.1 to 0.25 percent) like cell wall, modified cell wall, mannoproteins, and especially purified β -glucans alone and in combination with HSCAS (hydrated sodium calcium aluminosilicate), and clay should be tested as an additive in food aid products to mitigate different groups of mycotoxins. Additionally, extrusion processing should be utilized to further help in lowering mycotoxin levels (Doyungan et al., n.d. unpublished). However, future trials should be designed to find the correct levels of these additives and the overall benefits it can provide in reducing mycotoxin contamination in populations affected by undernutrition.

C. Processing

Methods to improve the nutritional quality and shelf-stability of foods.

7. Compaction of Fortified Blended Food (FBF)

The literature has limited information on whether the compaction of foods can improve their digestibility. Food aid products in dry, powdery forms or fortified blended foods form the major part of processed food aid products (Marchione, 2002). These products are generally packed in 50-pound multilayered paper bags. Due to extra headspace in the bags, products are prone to moisture and oxygen migration which may affect their shelf life. The rate of transfer can be reduced in a product like flour if it is mechanically treated to create as small a pore size and pore size distribution as possible (Labuza and Hyman, 1998). Reduction of flour volume by mechanical compression or compaction of flour could offer advantages for long-term storage.

Compaction (reduction in pore space or porosity) would reduce storage volume, slow down the diffusion of oxygen into the flour during storage and because of this, reduce oxidative processes and improve storage stability. Additionally, compacted flour would have more resistance to possible infestation by mites or other microorganisms (Cenkowski et al., 2000). They reported that compaction to 55 percent volume caused a moderate decrease in oxidation during storage for compacted wheat flours between 20 and 30°C as evident from P (resistance of dough to extension)/L (extensibility of dough) values of alveograph for compacted and loose flours. Ramanathan and Cenkowski (1995) stated that the compaction of flour to 60 percent of its original volume could lead to a significant decrease in storage volume and transportation costs. They also pointed out that compaction may prevent diffusion of oxygen into the flour and thereby reduce enzymatic activity and infestations by mites and micro-organisms.

The process of agglomeration can be conducted in several ways, including pressure agglomeration (e.g. tableting), growth agglomeration (e.g. pelleting) and agglomeration by drying (e.g. spray drying) (Pietsch, 2002). However, these processes are not similar to vacuum packaging which also compacts the contents but with very little force, leading to low compaction. A complete/full vacuum measures 760 mmHG or 0.1MPa, whereas for a compaction study by Cenkowski et al 2000, they used 7 to 8 MPa for achieving 55 percent compaction. In addition, vacuum packaging cannot lower the volume to the extent of compaction by mechanical means. Once vacuum packing is opened, the contents will not be in compacted state, as found with a sugar cube or a bouillon cube.

A suitable way to compact dry powders, which, in a food aid scenario would be corn-soy blends (CSBs) and other fortified blended food (FBF), is through pressure agglomeration. This may or may not require other liquids or binders and subsequent drying. This process has less operating cost and requires simpler equipment (Augsburger and Vuppala, 1997). It involves a compaction procedure where small particles are subjected to compressive forces in a confined space to densify and shape them. The overall effect of geometry of the confined space, nature of applied force, physical properties of the particulate material and of the confining walls control the ability of the

material to form and maintain interparticle bond during compaction (Snow et al., 1999). The type and amount of binders that need to be added (if any) can be determined after calculating the compressibility percent or Hausner Ratio (WHO, 2012; LFA Tablet Press, n.d.).

Compaction agglomeration is carried out by using equipment like the piston and molding presses, tableting presses and roll presses. Some of the commonly-seen agglomerated powders are tablets, bouillon cubes and sugar cubes. Agglomeration improves the instantaneous properties of the compacted powder like instant dissolution in water. Compacted FBF with this property would be of great advantage since it would reduce the overall volume of the food but can easily expand in water to make the porridge as usual. No change in preparation or cooking habits would be needed, though there would be programmatic changes if compaction of FBF were adopted.

Based on the above information **it seems feasible that the compaction of FBF using molding or tablet press can be an additional processing step to lower the volume and possibly improve its shelf life.** [Appendix 4](#) depicts the benefits while shipping compacted FBF. However, the following must be explored further to finalize the recommendation:

- 1) Incremental cost of compaction;
- 2) Effect of compaction on shelf life;
- 3) Actual study of compaction of FBF; and
- 4) Changes in shipping cost due to compaction.

VI. CONCLUSIONS

Nutrient bioavailability is in large part determined by food matrices. The common factors affecting the matrices in food aid products are energy density, protein quality, antinutritional factors, nutrient interactions and processing. The effect of antinutritional factors on mineral absorption has been frequently observed and reported in literature. Energy density and protein quality have also been observed as a factor that influences the health outcomes from food aid products. Other factors like gut health also influence absorption of nutrients.

Recommendations and cost implications (see Tables 2 and 3 below) based on ingredients and processing addresses the issues relating to improving energy density and protein digestibility and lowering antinutritional content in these foods. Other issues can be tackled by improving essential fatty acid levels, lowering mycotoxin levels and improving gut health by the addition of prebiotics have been recommended. The incorporation of these suggestions in part or completely would result in food aid products with higher nutritional bioavailability. Additional costs could be incurred implementing some recommendations, whereas processing-related recommendation

would incur increased capital expenditure. The increase in cost may be justified by improved health outcomes which would make these recommendations more “cost-effective,” justifiable and sustainable.

The list of recommendations must be field tested to finally understand appropriate dosage, feasibility of use in the field and changes in measurable health outcomes in order to make it truly “cost-effective.”

Table 2: Summary of Recommendations, Their Uses and Role in the Food Aid Products

Recommendations	Potential Uptake*	Potential Uses	Use/Role
Inclusion of Diastatic Malt	Certain	FBF	Improve energy density of FBF Improve protein digestibility Reduce phytates
Use of Defatted Wheat Germ	Certain	FBF, Plant-based RUTF and RUSF, HEBs	Source of high-quality protein with branched chain amino acids higher than corn
Include oils rich in ω -3 like canola oil	Probably	FBF, RUTF, HEBs	Provide ω 6: ω 3 ratio as close to 1 Neurocognitive and immune development
Add oligosaccharides for gut health	Likely	FBF, RUTF and RUSF, HEBs	Need more information on use of fibers for undernourished population
Add synthetic amino acids	Likely	FBF, Plant-based RUTF and RUSF, HEBs	Provide highly bioavailable form of lacking/limiting amino acids
Incorporate yeast cell components like cell wall	Likely	FBF, RUTF and RUSF, HEBs	Mycotoxin binding
Compaction of FBF	Exploratory	FBF	Improve shelf life

* Potential uptake is based on ease of including the recommendation in food aid products

Table 3: Estimated Cost of Implementing Recommendations

Recommendations	Cost Changes	Cost implications
Diastatic Malt (@0.25%)	+ \$4.66/MT	Scenario 1: 0.43% increase in feeding cost/child/day Scenario 2: 24% increase in feeding cost/child/day
Use of Defatted Wheat Germ (@ 0-18%)	- \$14-36/MT	Cost savings of 2-5% depending on 0-100% replacement of soy
Canola oil (@25.7g/day)	+ \$124/MT	20% increase in feeding cost/child/month w.r.t. using vegetable oil
Oligosaccharides–Prebiotics (@ 0.4-0.8%)	+ \$31-62/MT	8.6% increase in product cost
Synthetic amino acids (@ <1.5%)	+ \$1.5-33/MT	0.2-4.6% increase in product cost
Yeast cell wall (@ 0.1-0.25%)*	----	----
Compaction (@ ≥70%)	- \$102/MT in freight cost	32.4% decrease in freight cost and 25% decrease in loading cost/container

More details on costs can be found in the Appendices 1-5.

* Costs for implementing yeast recommendation are not available.

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VIII. ACKNOWLEDGEMENTS

This study would not be possible without the support of the USAID Office of Food for Peace (FFP) and their ongoing commitment to improving Title II programming in order to address food insecurity in vulnerable populations. The time and support offered to the Food Aid Quality Review by Title III awardees, both headquarters and field staff, as well as Food for Peace Officers abroad and in Washington, D.C. and the Policy and Technical Division of FFP headquarters were also invaluable to informing this study.

IX. APPENDIX I

Cost of Adding Defatted and Toasted Wheat Germ (DWG) as Protein Source in FBF

	Corn (%)	Full fat Soy (%)	Other (vitamin, mineral) (%)	Protein (%)	Fat (%)	Fiber (%)	Energy (kcal)
CSB+ Specifications	78.47	20	1.53	14	6	5	380

Cost* of substituting soy from 0 to 100 percent with toasted wheat germ with added oil

	Formulation of Raw Ingredients				Raw Material Cost		Cost Saving (%)
	Corn (%)	Full Fat Soy (%)	Toasted Wheat Germ (%)	Oil (%)	Cost/kg U.S.\$	Cost/ton U.S.\$	
CSB+	78.47	20	0	0	0.72	718.11	---
Modified FBF	78.09	0	18.03	2.35	0.68	681.67	5.07
Modified FBF	76.17	2.3	17.5	2.1	0.69	693.06	3.49
Modified FBF	76.47	5	15	2	0.70	702.91	2.12
Modified FBF	77.47	10	10	1	0.70	703.19	2.08
Modified FBF	78.47	15	5	0	0.70	703.48	2.04

All the formulations meet the CSB+ specifications for protein, fat and energy. The remaining 1.53 percent of the formulation will be used for addition of vitamins and minerals. From the above table it is observed that cost savings can be introduced in the FBF formulation by incorporating toasted wheat germ to partly or completely replace full fat soy and making up for its low oil content by adding oil. The cost savings range is between 2 to 5 percent, depending on the level of soy replaced. Apart from the cost savings, wheat germ is a good source of vitamins and minerals and does not have to be processed to decrease/deactivate antinutritional factors like trypsin inhibitor found in soy. This could further save on the laboratory analysis expenditure for the urease test for soy as well, however the test needs to be done if soy is used even sparingly.

* Selective proximate content and costs of raw materials are provided in **Appendix 5**.

X. APPENDIX 2

Cost of Adding Diastatic Malt (DM) to FBF

Cost of diastatic malt—U.S.\$0.85/lb.

Addition rate in FBF—0.25 percent (based on actual experiments, shown in **Appendix 6**)

Amount of diastatic malt to be added in 1 ton of FBF = 5.5 lbs (2.5 kg)

Additional cost for incorporating 5.5 lbs in 1 ton of FBF = $5.5 \times 0.85 = \$4.67/\text{ton} \dots (\text{A})$

The addition of diastatic malt will liquefy the porridge to a drinkable consistency and this fact can be used in two scenarios to improve the absorption of nutrients from the porridge matrix. Additionally, the presence of protease and phytase enzymes in diastatic malt would help in improving protein digestibility and reducing phytic acid respectively.

Scenario I

Adding diastatic malt as it is to the existing FBF like CSB+.

CSB+ Cost

Current, CSB+ specifications have solids in 100 gm porridge = 13.76 gm

Raw material (corn and soy) cost for blend per MT = U.S.\$718.11

Assume 50 percent processing cost over the cost of raw materials

Therefore, cost of CSB+ per MT = U.S.\$1,077.16... (B)

The cost of CSB + with added DM per MT = (A)+(B) = U.S.\$1,081.83... (C)

CSB+ Consumption and related costs

Amount of CSB+ consumed/child/day = 85.7gm... (D)

Number of feeding days/year = 300... (E)

Amount of CSB+ consumed/child/year = (D) x (E) = 25710gm = 25.71kg... (F)

Therefore, cost of feeding CSB+ per child/year = U.S.\$27.69... (G)

And, cost of feeding CSB+ per child/day = (G)/(D) = U.S.\$0.09

Change in cost of CSB+ after adding DM

New cost of feeding CSB+ with added DM/year = ((C)/1000) x (F) = U.S.\$27.81... (H)

So, new cost of feeding CSB+ with added DM/day = (H)/(E) = US\$0.09... (I)

Increase in cost of CSB+ with added DM as compared to regular CSB+ = (H) – (G) = US\$0.12... (J)

Percent increase in cost of CSB+ per child/year or per day = ((J)/(G)) x 100 = 0.43 percent

Therefore, at a very small incremental cost, the porridge matrix characteristics can be modified to make its constituents more bioavailable and thus have a better cost efficacy. The improved nutritional outcome cannot be quantified at this time but based on the literature available, the new matrix would provide better health outcomes, though actual in vivo or human trials may be needed for evaluating the real effect.

Scenario 2

Due to lowering of viscosity of CSB+ porridge, it presents an opportunity to increase the solids in the porridge to provide higher levels of protein and energy in addition to the possibility of lowering the micronutrient content. Lowering of micronutrient content may be needed because the current levels may be sufficient and can be provided with higher solids (macronutrients).

Current level of CSB+ solids in 100gm porridge = 13.76gm...(K)

Current level of solids in 100 gm porridge with Super Cereal Plus with amylase = 17.0 gm...(L)

Proposed increase in solids of CB+ in 100 gm porridge = (L)-(K) = 3.24 gm...(M)

Percent increase in solids of CSB+ in 100 gm porridge = (M)/(K) = 23.55 percent...(N)

New serving size of CSB+ per child/day = (D)+(100+N)/100 = 105.88 gm...(O)

New amount of CSB+ needed to feed a child/year = (O) × (E) = 31763.81 gm...(P)

Increase in CSB+ consumption per child per year = (P)-(F) = 6053.81 gm...(Q)

Percent increase in CSB+ consumption per child per year = (Q)/(F) = 23.55 percent...(R)

Thus, increase in feeding cost per child per year = (Q)×(C/10⁶) = U.S.\$6.55...(S)

And, increase in feeding cost per child per day = (S)/(E) = U.S.\$0.02...(T)

Percent increment in feeding cost per child per day or per year = [(S)/(G)]x100 = 23.64 percent

Thus, at an additional cost increase of 23.64 percent, the ration size can be increased from the current 85.7 gm to 105.88 gm per day. This additional increase in solids will provide higher protein and energy to the beneficiaries with a higher possibility of better health outcomes than that with the provision of 85.7gm per day serving. Again, field trials need to be conducted to gauge the actual improvements in health. The incremental cost also has a possibility of some reduction due to keeping the micronutrient levels the same as being currently provided.

XI. APPENDIX 3

Impact of Adding Synthetic Amino Acids to Food Aid Products

This uses CSB+ as an example to show impact of synthetic amino acid addition to CSB+

	Lysine	Threonine	Methionine	Isoleucine	Leucine	Valine	Phenylalanine	Tryptophan
Select amino acid profile of CSB+	0.67	0.58	0.11	0.60	1.47	0.72	0.73	0.15
Digestibility of AA	0.58	0.50	0.09	0.52	1.26	0.62	0.62	0.13
Additional Synthetic AA added	0.10	0.08	0.02	0.09	0.21	0.10	0.10	0.02

Based on the need, some or most of the amino acids can be supplemented with synthetic amino acids

* The increase in cost would range from U.S.\$1.53 per MT for supplementing only lysine in CSB+ to U.S.\$37.04 per MT for supplementing lysine, threonine, methionine, isoleucine, valine and tryptophan. The percent increase cost per MT would thus range from 0.21 percent to 5.16 percent respectively. If all of the soy is replaced by toasted wheat germ then the cost increment for all the amino acids would be approximately 4.65 percent.

* The costs of some synthetic amino acids are provided in **Appendix 5**.

XII. APPENDIX 4

Use of Compaction to Lower the Volume of FBF

This example uses a 20-foot container as the preferred shipment mode.

Maximum net weight carried in 20-foot container = 28200 kg...(A)
(Please see **Appendix 5**)

20-foot container volume

Volume of empty 20-foot container = 38.51 m³ (1360 cu. ft.)
Head space left while loading the container = 6 inches
Net effective volume that can be used for loading = 36.22 m³ (1280 cu. ft)...(B)

Increase in loading capacity of 20-foot container

Net weight of each bag of FBF (CSB+) = 25 kg...(C)
Average number of CSB+ bags filled in a container = 762 bags...(D)
Net weight of these bags = (D)X(C) = 19058 kg...(E)
Loss in additional weight capacity of loading = (A)-(E) = 9142 kg...(F)

Compaction can reduce the volume of FBFs by at least = 70 percent (by lab experiments)...(G)

Volume of 1 bag of CSB+ = 1.7 cu. ft...(H)
Volume taken up 762 bags = (B) = 36.22 m³ = 1280 cu. ft
Compaction would reduce the volume of 762 bags = (B)X(G) = 384 cu. ft....(I)
Remaining space left in 20-foot container = (B)-(I) = 896 cu. ft....(J)
Additional uncompacted bags that can be filled in the container = (J)/(H) = 534 bags...(K)
Due to weight limitations/container, the actual additional bags that can be filled = 366 bags...(L)
Increase in loading capacity/20-foot container = [(L)/(D)]X100 = 48.0%...(M)
Containers need to load 100 MT of uncompacted FBF = (100MT/E) = 5.2...(N)
Containers needed to load 100 MT of compacted FBF = 100MT/[(E)+(L)X(C)] = 3.5...(O)

Savings in loading of 100 MT FBF

Cost of loading one 20-foot container = \$ 600 (internal communication)...(P)
Therefore, the cost of loading 100 MT of uncompacted FBF = (P)X(N) = \$3,148.23...(Q)
Increase in loading cost/container for loading extra bags = 10 percent (internal communication)...(R)
Therefore, the increase loading cost/container = (P)+(P)*(R) = \$660...(S)
Therefore, the cost of loading 100 MT of compacted FBF = (S)X(O) = \$2340.43...(T)
Cost saving in loading 100 MT of compacted FBF = {[(Q)-(T)] / (Q) } X 100 = 25.7 percent

Savings in freight cost per 100 MT FBF

Freight cost will vary based on the port of loading and the destination. The following calculation is based on approximate freight rates from Port, NY to Port Ouagadougou, Burkina Faso.

Approximate freight cost/20-foot container for shipping to Burkina Faso = \$6,000...(U)

Freight to ship 100 MT of uncompacted FBF = (U)X(N) = \$31,200...(V)

Freight to ship 100 MT of compacted FBF = (U)X(O) = \$21,000...(W)

Percent cost savings in freight/100 MT of compacted FBF = $\{[(V)-(W)]/(V)\} \times 100 = 32.4$ percent

XIII. APPENDIX 5

Necessary Information to Arrive at Different Values in the Above Appendices

Selective Proximate Composition and Cost of Different Raw Materials

	Proximate composition per 100 gm			Costs	
	Protein (%)	Fat (%)	Energy (kcal)	Cost/lb (US\$)	Cost/kg (US\$)
Whole Corn*	10.4	4.5	400	0.25	0.55
Full Fat Soy**	30	16.93	415	0.65	1.43
Toasted Wheat Germ***	32.6	0.8	300	0.52	1.14
Oil			884	0.9	1.98

*<https://www.researchgate.net/publication/313369209> Proximate composition and mineral content of maize grains influenced by mulching

** <https://www.soya.be/soybean-oil-nutritional-values.php>

***Viobin@USA

Cost of Synthetic Amino Acids

Synthetic Amino Acids	Costs (U.S.\$/MT)
Lysine	1,600
Methionine	3,000
Threonine	2,300
Isoleucine	14,000
Valine	14,000
Tryptophan	30,000

Source: Personal communication with people working on animal feeds at Kansas State University

Amino Acid Profile of Yellow Corn Grain

<https://ndb.nal.usda.gov/ndb/foods/show/20014?n1=%7BQv%3D1%7D&fgcd=&man=&lfacet=&count=&max=25&sort=default&qlookup=corn&offset=&format=Full&new=&measureby=&Qv=1&ds=&qt=&qp=&qa=&qn=&q=&ing=>

Amino Acid Profile of Roasted Full Fat Soy Flour

<https://ndb.nal.usda.gov/ndb/foods/show/16116?n1=%7BQv%3D1%7D&fgcd=&man=&lfacet=&count=&max=25&sort=default&qlookup=full+fat+soy&offset=&format=Full&new=&measureby=&Qv=1&ds=&qt=&qp=&qa=&qn=&q=&ing=>

Amino Acid Profile of Toasted Wheat germ

Viobin@USA

20-foot Container Dimensions and Volume

<https://boxhub.co/guides/container-dimensions/something-about-container-dimensions>

XIV. APPENDIX 6

Improving the Viscosity Profiles of FBF by Using Diastatic Malt (DM) and Thereby Enhancing the Potential of Increasing the Energy Density

Figure I. Rapid Visco Analyser (RVA) analysis of corn-soy blend plus (CSB+) with and without diastatic malt (DM)

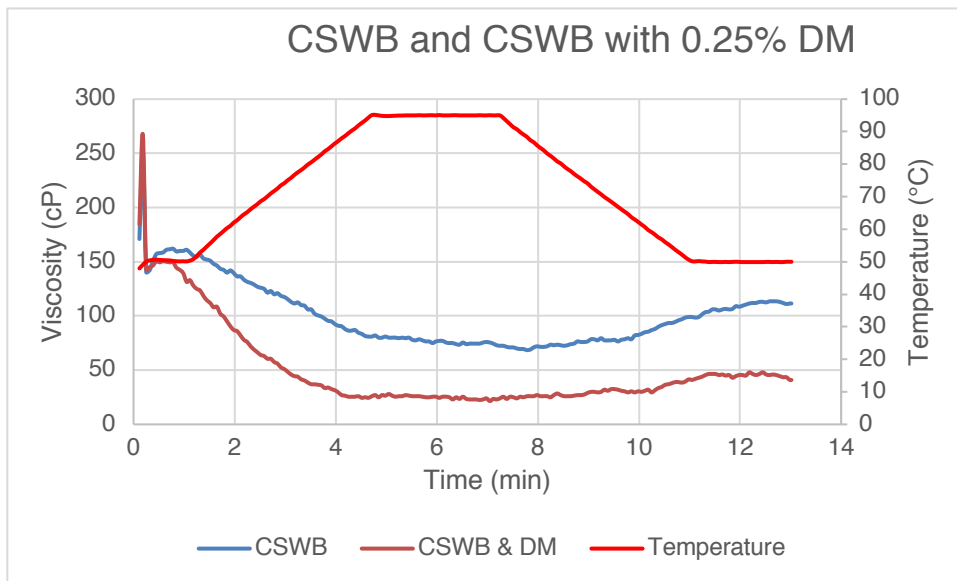
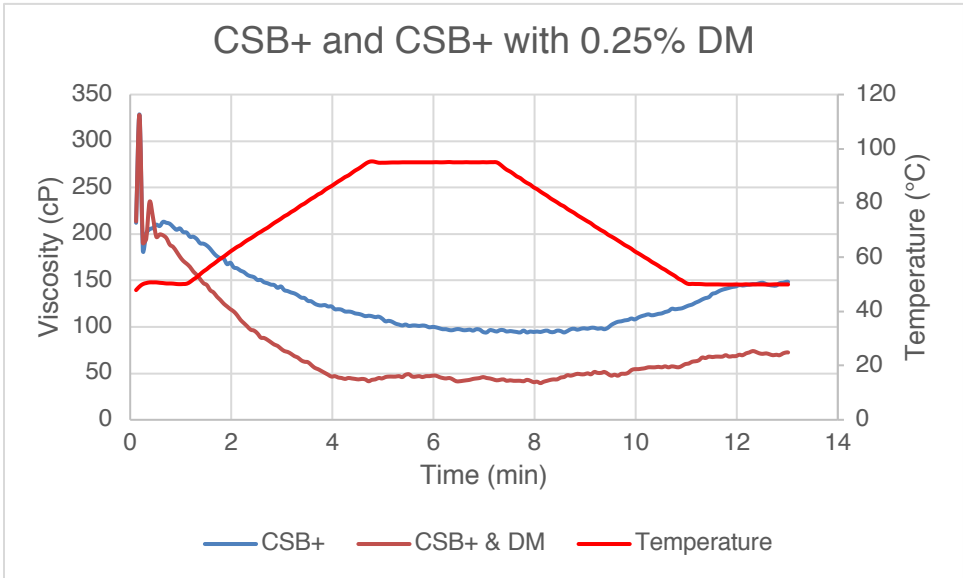


Figure 3. RVA analysis of Super Cereal Plus with amylase (SC+)

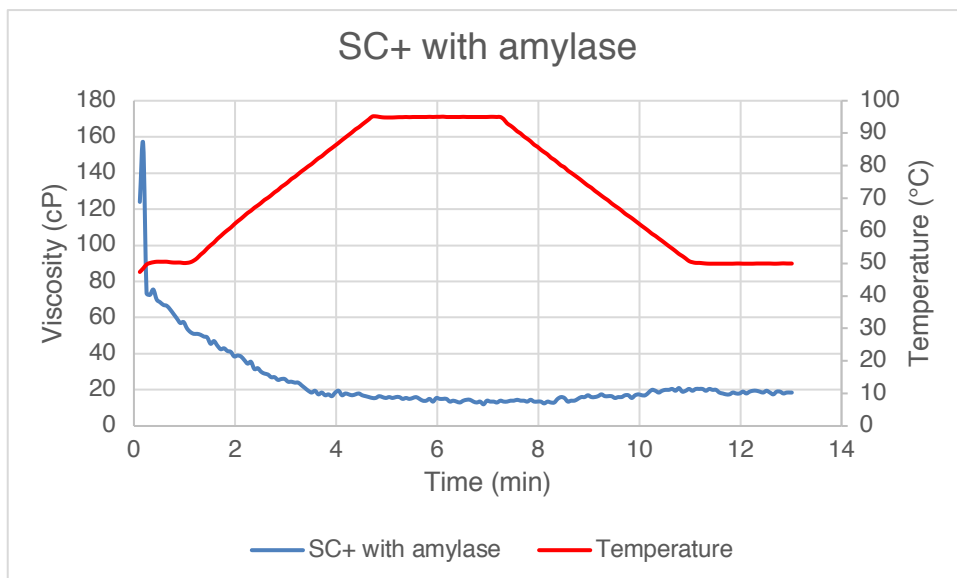


Table 3. Increase in Bostwick flow value of FBF due to addition of diastatic malt

Product	Bostwick Flow (mm) (without DM) at 45°C	Bostwick Flow (mm) (with DM) at 45°C
CSB+	45	110
CSWB	65	185
SC+	>240	---

The **Table 3** shows that the Bostwick flow rate has increased after the addition of diastatic malt. These results have been corroborated with the RVA analysis in **Figures 1, 2** and **3**. The RVA analysis shows that in CSB+ and CSWB, the addition of DM has lowered the viscosity of the FBF (red curves have lower viscosity values than corresponding blue curves in respective graphs). The reduction in viscosity is important as it presents the porridge in drinkable consistency to the beneficiaries and also provides the opportunity to increase the solids content (addition of more FBF in per serving) in the porridge. Both methods would enhance the nutritional value of the porridge.