IMPROVING THE NUTRITIONAL VALUE OF FOODS IN THE USAID FOOD AID BASKET: OPTIMIZATION OF MACRO AND MICRONUTRIENTS, FOOD MATRICES, NOVEL INGREDIENTS AND FOOD PROCESSING TECHNOLOGIES

A Report from the Food Aid Quality Review

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MAY 2018

This report was produced for the United States Agency for International Development. It was prepared under the terms of contract AID-OAA-C-10020 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; Mohamedshah, Farida; Walton, Shelley; and Webb, Patrick. 2018. Improving the nutritional value of foods in the USAID food aid basket: Optimization of macro and micronutrients, food matrices, novel ingredients and food processing technologies. Report to USAID: Tufts University, Boston, MA

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ACKNOWLEDGEMENTS

This report would not have been possible without the collaborative efforts between food matrices team of Food Aid Quality Review (FAQR) project and the participants of the Roundtable. The authors would like to thank all participants for agreeing to be a part of this effort.

Great acknowledgement for strong support provided by Rufino Perez-USAID/FFP, in planning and conducting this event.

Special acknowledgement goes to Farida Mohamedshah, Director, Food, Health and Nutrition, at the Institute of Food Technologists (IFT) for guiding us in planning this Roundtable, which was held prior to IFT17 (IFT's annual event). Many thanks to all participants for actively collaborating in the events leading to the Roundtable and later providing their input on multiple occasions while working on this report.

ACRONYMS

AFRI	Agriculture and Food Research Initiative
ALA	Alpha-Linoleic Acid
API	Active Pharmaceutical Ingredient
CSB	Corn-Soy Blend
DHA	Docosahexaenoic Acid
EDTA	Ethylenediaminetetraacetic acid
EED	Enteric Enteropathy Disease
FAQR	Food Aid Quality Review
FBF	Fortified Blended Food
FDA	Food and Drug Administration
GAIN	Global Alliance for Improved Nutrition
GIT	Gastrointestinal Tract
GMO	Genetically Modified Organism
IFT	Institute of Food Technologists
Ig	Immunoglobulin
LCT	Long-chain Triglycerides
LNS	Lipid-based Nutrient Supplements
MAM	Moderate Acute Malnutrition
MCT	Medium-chain Triglycerides
MMP	Multiple Micronutrient Powder
MNP	Micronutrient Powder
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
NIFA	National Institute of Food and Agriculture
NIH	National Institutes of Health
nM	Nanometer
PDCAAS	Protein Digestibility-Corrected Amino Acid Score
R&D	Research and Development
RCT	Randomized Control Trial
ROI	Return on Investment
RUSF	Ready-to-Use Supplementary Food
RUTF	Ready-to-Use Therapeutic Food
SAM	Severe Acute Malnutrition
STH	Soil-transmitted helminths
TAG	Technical Advisory Group
UHT	Ultra-high Temperature
USAID	United States Agency for International Development
USAID/FFP	United States Agency for International Development/Food for Peace
USDA	United States Department of Agriculture
USDA/FAS	United States Department of Agriculture/Foreign Agricultural Service
WFP	World Food Programme
WHO	World Health Organization

Table of Contents

I. EXECUTIVE SUMMARY

The need to optimize the nutritional quality of food aid products has gained considerable support in recent years. The Food Aid Quality Review (FAQR), a project supported by United States Agency for International Development/Office of Food for Peace and implemented by Tufts University and partners, has been on the (USAID/FFP) forefront of exploring and recommending ways to improve the quality of food aid. As a part of this effort, a roundtable was held on 25th June, 2017 in Las Vegas, prior to IFT's annual event to discuss potential ways to improve the bioavailability of nutrients in food aid products. The daylong event was designed to gain input from the scientists and researchers, industry stakeholders and government agencies (such as USAID and USDA) to enhance our understanding of the science and practicalities that affect the bioavailability of nutrients in food aid.

The bioavailability of nutrients is often overlooked in the process of reformulating foods. The Roundtable was organized to find ways to make food aid products more cost-effective, not only in terms of price and delivery methods but in terms of health outcomes per unit of food consumed.

The Roundtable was attended by 38 experts from academia, industry, nonprofit groups and government agencies. The inclusion of various stakeholders allowed for concrete insights into the various aspects of food matrices (the physical and molecular interactions between different nutritional and non-nutritional constituents in a food) and generated implementable, practical ideas which could help improve the bioavailability of nutrients in food aid products. Deliberations included topics such as food safety and its impact on nutrition and the need for interagency and interdisciplinary collaborations.

To achieve its objective of identifying areas where the bioavailability of nutrients within food matrices, in food aid products, could be improved, the discussion was divided into subtopics. These subtopics were chosen to cover all of the influencing parameters in a food matrix and its subsequent effect on bioavailability of nutrients. The subtopics included: a) processing; b) macronutrients; c) micronutrients; d) nutrient delivery techniques; e) bioavailability of nutrients and bioactive components; and f) functional compounds. For each subtopic, the state of current knowledge and practices were discussed. During the brainstorming session, recommendations to be implemented were identified based on the needs and research gaps discussed.

This report aims to capture the outputs from the Roundtable and serves as a springboard for new hypotheses and research to advance knowledge on this subject. The resulting recommendations provide realistic ways to apply science in the food aid sector, such as: increase the portfolio of processed foods in the food aid basket; improve the stability of vitamin C; investigate new sources of macronutrients; explore multifunctional food aid products; learn from the food industry; and choose optimal functional compounds. The report charts a direction for future public-private partnerships, funding priorities and efforts by the U.S. government and other entities that have a stake in addressing macro and micronutrient deficiencies and hunger around the world and designing more cost-effective food aid products.

II. INTRODUCTION

The importance of food aid products in combating hunger and undernutrition is well documented[1]. Different types of food aid products like fortified blended foods (FBFs), micronutrient powders (MNPs) and lipid-based pastes such as ready-to-use therapeutic food (RUTF), ready-to-use supplementary food (RUSF) and lipid-based nutrient supplements (LNS), have been used to treat different manifestations of undernutrition. Several studies have shown the beneficial effect of these products in helping undernourished populations recover from their poor health status. The overall effect of these foods is primarily dependent on the type of product, nutritional profile of the product and overall health of the beneficiary. The form, or matrix, of food as consumed is one of the most important factors that can influence the overall pathway for nutrients to be absorbed by a body.

The food matrix consists of the different components (nutrients and non-nutrients) in a food and their molecular interactions. A nutrient can be more bioavailable and present itself for absorption in the body if that nutrient is easily released from the consumed food matrix. Some examples include easier absorption of vitamin A from an oil-rich matrix (vegetable oil) as compared to non-oil rich matrix (flour), and animal-based proteins which are complete sources of proteins because they contain all of the essential amino acids as compared to plant-based proteins.

This report identifies opportunities and constraints in improving the bioavailability of nutrients.

III. PRESENTATION SUMMARIES

Below is a summary of presentations on a variety of key sub-topics related to the food matrix and bioavailability.

III-a Keynote Address

Presented by: Dr. Rufino Perez, USAID/Food for Peace (FFP)

By the time the Roundtable took place, 2017 had already seen four food emergencies in Nigeria, South Sudan, Somalia and Yemen which exposed more than 20 million people to famine like conditions. In response to this grave situation, humanitarian assistance organizations sought to respond with effective food aid interventions. One element of effective response involves the use of specially-formulated food products designed to address certain forms of moderate and severe undernutrition among children.

As part of its ongoing mandate, the USAID-supported Food Aid Quality Review (FAQR) has continued to facilitate scientific and operational dialogues aimed at promoting innovative, cost-effective solutions to the world's unacceptably high burden of malnutrition. One such dialogue was organized in June 2017 as a roundtable of experts focused on identifying potential innovations aimed at enhancing the bioavailability of nutrients within food aid products.

Some of the overarching issues which were addressed included: i) what industry research and development (R&D) can do to help inform U.S. government decisions on food aid optimization for nutrition; ii) innovations in packaging and food processing which can help improve the shelf life and quality of food aid products; iii) what new ingredients or additives can be added to foods; and iv) what the best way is to determine projected costs for proposed/new ingredients, products or processes.

III-b Food Aid Scenario: Scope for Improvement

Presented by: Dr. Patrick Webb, Tufts University

Food aid products are moving into a phase where formulated foods are processed in particular ways to deliver improved nutrition through maximizing the bioavailability of its nutrients. These particular foods take the major share of food aid product costs. The effort and goal of food aid quality is to ensure that all foods are fit-for-purpose and are cost-effective not only in dollars/ton but also the cost of food being delivered in relation to its intended effect. In this context, the role of industry (mainly the food industry) becomes much more important. The 2011 Food Aid Quality Review Report was a major undertaking to systematically examine different dimensions of food aid from formulation to logistics and to recommend important changes to enhance the nutritional quality and efficiency of food aid products. The FAQR III project moves forward its agenda of improving food quality by improving cost-effectiveness and helping programmers choose wisely from the food aid basket of products.

The inclusion of animal-based protein sources based on 2011 FAQR recommendations has led to the development of many new, innovative products and subsequently, testing these products in field trials. These studies/trials examine the dose response and whether or not these animal proteins help recovery from moderate acute wasting and stunting in children less than 18 months of age. A different study looked into food matrices and packaging through an accelerated shelf life study of vitamin A retention in the grain-based products Super Cereal Plus and Corn-Soy Blend Plus over a two-year period. It showed that by the end of the study there was a significant reduction in vitamin A levels from the target range. By contrast, a similar study with lipid-based RUSF, which is processed and packaged differently than grain-based products, showed that vitamin A levels were within the acceptable range throughout the two-year life of the product.

This demonstrates that there is a critical effect of the type of processing, form of micronutrient and packaging type in determining the nutritional quality of a food product. The results indicate the potential role of industry (food product manufacturers, equipment manufacturers, packaging material producers and premix producers) to create products which are designed by science, and which also can be cost-effectively used to improve the nutritional quality of food aid products to provide the best quality of formulated foods to the undernourished through U.S. government programs.

III-c Iron bioavailability issues in food matrices

Presented by: Dr. Diego Moretti, ETH Zurich

Iron absorption is dependent on the solubility of iron and its redox potential. Though iron is the fourth most abundant element on earth, iron deficiency in humans is the most common mineral deficiency worldwide. Iron is present in ferrous ($Fe2^+$) or ferric ($Fe3^+$) and both are soluble at pH 1. However, as pH rises, iron's ferric form becomes virtually insoluble while its ferrous form has very little solubility. Iron is absorbed in the duodenum (the first section of the small intestine) and if the iron is not released from the food matrix, then iron cannot be utilized by the body. The iron available naturally in foods is water soluble and during the process of digestion, this iron joins the common non-heme pool of iron. Because of this, a small part of it is absorbed and the rest is excreted. Water-insoluble compounds like contamination iron and iron used for fortification also follows the same pathway but an additional step of use of ligands helps in the absorption process.A large increase in iron absorption is observed from 18 to 82 percent when the phytic acid: iron molar ratio is decreased to around 0.2 from 22.4[2].

Another strategy to improve iron absorption would be by considering the fact that higher lipid content in food increases gut transit time and delays digestion and thereby providing more time for iron to solubilize and be more bioavailable. RUTFs which are lipid-based high energy foods used in treating SAM areone such product that effectively uses the lipid matrix to improve iron absorption. In a study of LNS/RUTFs with and without phytase and compared to MNPs, it was found that the addition of phytase at the point of consumption helped increase iron absorption from MNPs as well as LNS[3]. However, the hypothesis that a lipid base would help improve iron absorption with phytase was not observed.

Some fortified products would not allow incorporation of more bioavailable forms of iron in the formulation due to sensory considerations. For example, the challenge with rice fortification is to maintain the white color and therefore, the fortificants must also be white in color to make it visually appealing. Due to their light color, low solubility iron forms, ferric pyrophosphate or ferric orthophosphate can only be used.

The low bioavailability of these iron forms is compensated by adding higher levels of iron (twice as that of ferrous sulphate) leading to an increase in product cost. To improve the solubility of ferric pyrophosphate, a study was conducted where citric acid and trisodium citrate were added to ferric pyrophosphate prior to extrusion. It was discovered that this helped improve the fractional iron absorption from 1.7 percent to 3.2 percent in nonanemic women in Switzerland[4]. The same study showed that iron absorption was higher from fortified rice made using cold extrusion than hot extrusion, probably due to the fact that iron in hot extruded rice might be less accessible. They attributed this phenomena to the starch polymorphism which showed V type polymorphism in hot extruded rice, which is less water soluble as compared to A type polymorphism found in cold extruded rice.

In another study with fortified rice in Ghana, it was found that coated rice was comparable to extruded rice as a fortification technique. The use of chelating agents like CA/TSC or EDTA also improves iron absorption and can be similar in bioavailability as ferrous sulphate.

III-d Challenges to improve nutritional value of food aid products–using animal proteins

Presented by: Dr. Sajid Alavi, Kansas State University

New sorghum-based fortified blended foods (FBFs) for infants and young children were developed and field trials were done in Tanzania. These blended foods were created after extensive R&D in the areas of processing, in vivo and in vitro nutritional studies, and sensory and acceptability tests, as well as shelf-life studies before being used in nutritional aid programs in Tanzania. The highlights of these products were the use of grain sorghum in combination with cowpea or soy along with extrusion as a viable processing method, the use of whey protein concentrate (WPC80) as a protein source and new levels of vitamins and minerals based on 2011 FAQR recommendations.

In addition to whey protein, it is important to understand the characteristics of sorghum proteins. Proteins in sorghum are very tightly bound and are not as easily digestible as other cereal proteins. These interact with starch bodies as well as lower starch digestibility. Not only are sorghum proteins low in digestibility but after wet cooking, the protein digestibility decreases further. This challenge can be remedied to a great extent by extrusion processing because it is primarily a dry cooking process and has shown to increase protein digestibility of sorghums.

Another advantage of sorghum compared to other traditional ingredients for FBFs is that the starch retrogrades at a lower rate than corn starch. This feature is extremely useful in fortified blended foods since cooling of the porridge after cooking will make corn-based FBF much thicker than sorghum-based FBF. This leads to better acceptability of sorghum-based porridge as it is easier to consume (more viscous) than corn-based FBF at same solid levels. This eventually would lead to more FBF being consumed with sorghum-based FBF and therefore more nutrients being provided to the beneficiary. Sensory studies also showed a higher preference to sorghum-based FBFs as compared to corn-soy blend.

The key outcomes from the Tanzania-based field trials showed that most sorghum-based FBFs were able to reduce anemia risk and vitamin A deficiency more than a similarly-formulated corn-soy blend 14. However, the anthropometric outcomes were similar between sorghum and corn FBFs. Additionally, some of the challenges faced by the industry are incorporation of animal source protein, added allergen to their processing system, coextrusion or separate processing of corn and soy in manufacture of CSB and product shelf life.

III-e Food Structures: Processing, digestibility and bioavailability

Presented by: Dr. Harjinder Singh, Massey University

A food matrix is defined as the physical and molecular interactions occurring in a food. Some naturally-occurring food matrices are fibrous structures in muscles, fleshy materials in fruits and vegetables, encapsulated embryos in grains and legumes, and complex fluids like milk. The fleshy structure of fruits and vegetables consist of hydrated cells surrounded by cell wall and components within the cell. However, in cereals and legumes, the major components of starch, proteins and lipids are assembled into discrete pockets. During processing these structures undergo many changes—for example, size reduction, disruption of cells, starch gelatinization, protein denaturation and the release of nutrients. All of these changes in the food matrix influence how the food is digested in the body and specifically, the release of nutrients in the gastrointestinal tract (GIT). The food matrix and its ability to release nutrients that can be readily absorbed and utilized by the body impacts physiological processes and subsequently, human health. In light of this, the processing of food can affect the kinetics of release of nutrients (bioaccessibility or bioavailability) which can then be absorbed and utilized by the body.

One of the macronutrients, lipids, are the key energy nutrient in our foods. Lipids occur in several forms but mainly as triglycerides coated with a stabilizing layer or multilayer of membrane phospholipids. In processed foods, lipids can be designed in different ways such as oil-in-water (milk) or water-in-oil (butter) emulsions. For example, lipids exist in milk where triglycerides are covered by multilayered phospholipids. In formulated foods, lipids can be stabilized by the use of various kinds of surfactants and protein molecules.

In a study to understand the uptake of oil from different food matrices, 50g of test fat was provided either through almond seed macroparticles, almond flour and oil, and was compared with control sunflower oil. The macroparticles had the least oil absorption due to the type of matrix which embedded the fat. Cell walls, for example, impacted the release of fat from the macroparticle matrix. An important point to note is that the food structure can be utilized to control the rate of stomach emptying with slower emptying leading to slower absorption and vice versa.

Another key macronutrient is proteins. Protein quality is generally defined based on the presence of essential amino acids. Generally, the digestibility of animal proteins is higher than that of plant proteins. In addition to the lower amino acid profile of plant proteins, the lower quality of plant-based proteins is also influenced by the presence of antinutritional factors, fibers and different structures.

Overall, the food matrix should be considered as a part of the nutrition study design. A move from simple compositional nutrition to study the effect of matrix in defining the real nutritional value of foods is highly recommended. It is also recommended that validation of in vitro models using in vivo models should be undertaken.

III-f Maximization of Vitamin A, folic acid and other essential micronutrient utilization in the body

Presented by: Dr. Michael McBurney, DSM Nutritional Products

The pathway for micronutrient utilization in the body depends on previous intake and a person’s nutrient status as well as the properties of the ingested food matrix such as its concentration, the presence of other products in the food matrix, including antinutritional factors, fat, type, and level of processing and storage. Depending on the person’s nutritional status, different results can be seen from ingesting the same food. An important point to consider is that if the load of nutrient is high then the absorption is low and vice versa. Bioavailability must be considered through the following aspects: 1) Acute studies where product A versus B or ingredient A versus B is compared; and 2) long-term studies on health outcomes along with nutritional status outcomes where structure/function measures and disease incidence can be more coherently understood.

Existing literature reveals that added vitamins are at least equivalent to vitamins in indigenous foods, and in some cases, they exceed bioavailability of vitamins found within cell walls or other complexes. Loss of bioavailability from vitamins can be avoided in foods, beverages or condiments by using high-quality materials and correct formulations. In a study on bioavailability of food folate in comparison to synthetic folic acid it was found that food folates were relatively less bioavailable (around 80 percent) as that of folic acid. Factors like moisture, heat, light, pH, processing conditions, affect the stability of vitamins. A study found that 31percent of Americans were clinically deficient in one to three vitamins using biochemical measures which was not due to bioavailability issues but instead, because of lower levels of vitamins in the foods that are consumed.

Processing parameters like temperature and shear inside extruder affects the retention of vitamins in the food matrix being processed. In order to overcome the shortfall, overages are added which can go as high as 80 percent in order to be compliant with the labeling requirements until the end of shelf life. The bioavailability of vitamins does not change over time; it is the amount of vitamin in the food that changes over a period of time at the point of consumption. For example, in a study it was found that temperature affected the stability of vitamin A in fortified soybean oil stored at household conditions. After 56 days of storage the concentration of retinyl palmitate (vitamin A) decreased by approximately 80 percent.

A different study looked at the effect of light and oxidation on stability of vitamins A, D, and E in fortified soybean oil. This study found that there was twice the amount of vitamin A and D that was lost when exposed to natural light and temperature. The drivers of this loss were storage time, light exposure and oxidative status of oil. Therefore, some of the considerations to improve vitamin stability are to protect the vitamins against humidity, oxygen, radicals and metal ions. Actions such as the coating of vitamins and the addition of stabilizers would help achieve this purpose. Optimization of manufacturing and packaging conditions would further enhance vitamin retention in the food matrix at the point of consumption.

III-g Delivery of nutrients through delivery systems

Presented by: Dr. David McClements, University of Massachusetts

The human body's nutrient delivery systems are designed to protect and carry nutrients like vitamins and minerals, probiotics, nutraceuticals to their site of absorption in the body, thereby making nutrients more bioavailable. Several structural design approaches can be used to condense the nutrients. Some of the designs are nanoemulsions, multilayer droplets, filled lipid droplets and hydrodgel beads. The criteria for choosing the delivery system is multifactorial: 1) it should be made of food grade ingredients in an economical manner; 2) it should have functionality over a wide range of conditions in food products and the human body; and 3) it should have sensory acceptance.

The major factors that limit the bioavailability of nutrients are bioaccesibility (liberation from the encapsulation and subsequent solubilization), absorption (transport of nutrients across mucus layer and epithelium cells) and transformation (chemical or biochemical changes). However, there is a difference between nutrient delivery systems (encapsulated nutrients are dispersed within the food matrix) and excipient food (nutrient-rich food is consumed with normal food). There are many types of delivery systems but the emulsion-based delivery system is probably the most economical. Although it can be made by different methods, the most suitable would be to encapsulate hydrophobic nutrients. The size of these particles can be controlled to form nanoemulsions (100 nanometer) in keeping with regulations, especially in Europe, or as conventional emulsions. The manipulation of these emulsions can be on the particle size of these emulsions with lower particle size having more bioavailability. This changes the composition of the oil phase but it does not have much effect on bioavailability. Additionally, interfacial properties can be changed or aggregation state may be modified.

All of these factors impact the behavior of the encapsulated material in the emulsion in the GIT. These can then be delivered in liquid form or in spray dried (powder) form. The powder form would have higher shelf life. In an animal study to understand the effect of particle size and particle composition on bioavailability, it was found that smaller particle size had higher bioavailability. The composition of the oil base also affected the bioavailability, long-chain triglycerides (LCT)had higher bioavailability as compared to medium-chain triglycerides (MCT). This occurs because different nutrients have different dimensions and if the nutrient has hydrophobic molecule, then a hydrophobic environment has to be formed in the GIT to accommodate those molecules. If MCT is used (such as in coconut oil), the micelles formed may not be big enough to solubilize the coconut oil and would get a very low bioavailability. Conversely, in corn oil, which has LCT, the micelles can accommodate the oil molecules and thus have higher bioavailability. Overall, these systems can be designed to improve food performance like digestibility, controlled and targeted release, increased bioavailability and to modulate satiety.

III-h Role of processing in altering food matrices and influencing bioavailability of nutrients

Presented by: Dr. Yi Wu, The Wright Group

Food is processed commercially for a variety of reasons such as creating acceptable sensory characteristics, inactivating spoilage and pathogenic microorganisms, increasing shelf life, and inactivating antinutritional factors. However, the most important concern associated with processing is food safety. As a first step towards using micronutrients to fortify foods, their physical and chemical properties and stability must be understood.

Traditional food processing technology involves milling (for grains and legumes) where the grinding and fractionation removes the intrinsic vitamins and minerals along with dense bran and embryo. It also involves cutting/shredding (for fruits and vegetables) where mechanical disruption of cell structure occurs. This leads to the leaching out of intrinsic vitamins and minerals during wash or maceration along with degradation by exposure to oxygen and enzymes.

Other processing methods like thermal (blanching, baking, frying, etc.) or thermomechanical (extrusion) processing also causes loss of vitamins and minerals. To prevent or reduce nutrient degradation, innovative processing methods like high-pressure processing (non-thermal) or pulse electric field (non-thermal) can be useful. These methods are useful for high-moisture products like meats, juices, fruits and baby foods. However, the operating costs are high and there are still some barriers for commercialization of these methods. Infrared heating and ohmic heating are also new methods which are generally integrated with traditional processes.

Fortification is an innovative method to produce nutritionally-enhanced food. This nutrient delivery system, which can be tailored to meet specific requirements, has proven to be cost-effective. Fortification can be undertaken using different methods like micronutrient premixes, grain fortification, micro-encapsulation, and nanocapsules. An example of fortification is the highly-successful corn-soy blend (CSB). The blend is a dry powder which is fortified with 17 vitamins and minerals and three macro minerals (potassium, calcium and phosphorous) and is consumed as porridge after boiling it in water. Rice fortification has also gained much interest in recent years because of the significant consumption of rice globally. However, rice fortification is very different from other fortification systems because in many cultures, the practice of washing rice before cooking is common. This is a challenge because washing removes most of the micronutrients. Rice fortification can be done either by coating technology or by extrusion (rice like kernels are produced from fortified rice flour). Fortified rice kernels with concentrated nutrients must be blended with normal rice, usually in ratios from 1:99 to 1:199. The specification for fortified rice specify nutrient retention after washing to be >90% and that after cooking to be >80%. Studies have shown that both rice fortification technologies are viable. However, the challenge is the variation in quality of rice based on the technologies and maintaining quality of the supply chain from the factory to storage and then to consumer.

III-i Promoting evidence-based research

Presented by: Dr. Melvin Carter, USDA-NIFA

National Institute of Food and Agriculture (NIFA) is a Federal agency within the United States Department of Agriculture (USDA). NIFA's mission is to invest in and advance agricultural research, education and extension to solve societal challenges. Even though NIFA funds domestic research, some opportunities do exist for global engagement with the overall goal of advancing the domestic mission. NIFA funds research by issuing requests for applications every year where university stakeholders can write proposals to address issues on improving food safety, improving food quality, food manufacturing technologies and function and efficacy of nutrients. Some of NIFA's currently-funded projects are: One Health (to understand the complex issues at animal, human and ecosystem interface through mitigation and science), Sensor Technology (use of biosensors by attaching antibodies and phages to sensors to detect pathogens in bulk shipments of food), and Allergens (achieving 98-100 percent reduction in peanut allergen by using protein-breaking enzymes).

NIFA collaborates with the FDA to run the food safety outreach program to address the needs of owners and operators of small to mid-sized farms, beginning farmers, socially-disadvantaged farmers, small processors or small fresh fruit and vegetable wholesalers. Bioactive and functional foods are other areas of interest for NIFA. Within NIFA, the Agriculture and Food Research Initiative (AFRI) is the flagship grant program. International partnerships or engagements are encouraged if they support AFRI's domestic goals. NIFA has also developed partnerships with foreign governments and international organizations that invest in agricultural research on common issues of interest. Therefore, engaging with NIFA is crucial to undertake research to help find solutions for domestic problems that can have a global impact. Further, in an increasingly interconnected world, information and cooperation from beyond the borders is critical.

IV. THEMATIC CHAPTERS

The following thematic chapters cover the topic of food matrices and nutrient bioavailability through six subtopic chapters, a) processing; b) macronutrients; c) micronutrients; d) nutrient delivery techniques; e) bioavailability of nutrients; and f) bioactive compounds and functional compounds. Each chapter summarizes the state of current knowledge and practices, then considers recommendations and areas of further research.

IV-a Processing

Foods and processing

Currently, the major constituent of food aid products are staples like wheat, corn and oil as compared with processed products like CSB and RUTFs[5]. Staples are excellent sources of energy but are often relatively low in protein and micronutrients. Staples also have several antinutritional factors, such as phytic acid, tannins and trypsin inhibitors which negatively impact the bioavailability of nutrients from the consumed foods. The role of processing is to improve the quality, palatability and shelf life of foods as well as the bioavailability of nutrients. Processing technologies should also aim at efficiently delivering "problem" nutrients like vitamin A in the food matrices. The mapping of current technologies used in food aid products would be a good starting point to assess the technological input into these products. The design of foods for humanitarian aid trails the food industry by several decades due to the nature of this program.

The adoption of technologies depends on the sustainability of the technology. Variables such as access to quality raw materials, trained manpower and ease of logistics also determine the adaptation of technology. Most of the food aid products are produced in the U.S. and in European countries[6]. Whether or not the target countries can match that quality with the available resources is not a difficult question to raise. Many times, these countries fall short on different aspects of processing which leads to poor quality of food products. For example, the idea of a UHT technology with Tetra Pak for a milk plant was considered by WFP in Burundi. But the management system/capabilities were found to be bottlenecks in moving the idea forward.

Other than the technology used, consumer preferences would likely affect the adoption/use of a product. While designing foods, the nutritional efficiency of it would be enhanced if foods are targeted for specific needs. For example, foods specifically for diabetics, for children or for adults.

Practicalities and future pathways of processing

Typically, manufacturers of fortified-blended food products such as CSB desire a lengthy shelf life for their finished products in order to meet the demand, however inconsistent the product may be. A shelf life of at least a one-year is often needed. The problem of CSB's shorter shelf life arises when the raw blend is extruded. Based on the study by Meance et al. (1999)[7], WFP recommends extrusion as the preferred processing method for making FBFs. Some manufacturers of CSB experience difficulties maintaining a one-year shelf life of these FBFs when they extrude the raw blend due to differences in ideal extrusion cooking procedures on the individual blend components. This difference is largely attributed to the proximate composition of corn and soy.

Corn (maize) is very high in starch and low in protein and oil as compared to soy, which is rich in protein and oil. Heat treatment of soy is needed to deactivate the anti-nutritional factors present in soy which partially-inhibit digestion in the intestine. Therefore, these manufacturers recommend a two-step extrusion: 1) extrude soy by itself to thoroughly deactivate antinutritional factors and then blend with corn after cooling; and 2) extrude again under different conditions (lower temperature, lower pressure) than that of soy alone. These extrusion conditions allow for a greater production capacity and could be used to produce corn starch with reduced gelatinization. This means that a CSB could be made with a reduced glycemic index, which would result in a slower and steadier release of glucose into the circulation, while still providing ample available amino acids from soy protein and fatty acids from oil.

Additionally, properly processed soy could be sold locally as an ingredient for livestock feed, thereby providing processors with another market opportunity when they encounter inconsistent demand for FBFs. However, some manufacturers have reported direct extrusion of the raw blend and have achieved long shelf life for FBFs. This example very clearly shows the changes that may be required in processing parameters and in the type of equipment to make these products. Expertise and manpower to understand and manage these processing challenges would certainly help in making products with better quality.

Investigation of processing technologies with increased energy and water use efficiency is recommended. The relationships between water, energy and food supply systems are complex and play a key role in plans for sustainable development in resource-constrained countries[8]. Assessment of renewable energy sources, which may increase energy efficiency while decreasing water input needs, integrates some of these concepts[9]. Scalability of technologies represents another component of these relationships. The size of processing units in developing countries varies from small scale units in local communities to a few large scale state-of-the-art facilities[10].

Most food aid products are physically solid in form due to ease-of-handling and improved shelf life. However, the option of liquid-based nutritious food must be considered. The inclusion of liquid-based foods such as milk or nutritious beverages would provide additional options to the providers and beneficiaries to impart nutrients which are suited to these matrices more effectively. In this context, improving milk production and distribution capabilities is of interest to many African countries. Several small projects in these countries have been producing traditional dairy-based products. It's timely to widen that horizon to produce cheese and yogurt as a part of dairy operations. In another facility, there is an extruder with a theoretical production capacity of 8t/h. The current demands of production on this extruder is met within five to six days of running. The challenge is to keep the system/equipment running for at least most of the month to justify such investments along with the problem of sourcing quality raw material to make the endeavor sustainable.

Way forward
An effective approach would be to consider each country of intervention as a case study. This would help to understand the realistic status of the food processing industry in that country. Then, based upon the needs and equipped with the understanding of the exiting scenario, a future roadmap can be carved. For example, extrusion is a common type of processing equipment used in the production of food aid products. The other technologies common in processing food aid products are: roasting, milling and grinding. Single screw extruders are cheaper whereas twin screw extruders are more versatile. Another important feature needed to choose a technology is the assessment of capabilities to optimize the technology to local requirements–capabilities for regular maintenance and to access spare parts, current food safety practices, overall facility design and the management systems. Therefore, it would be of great importance to identify a country for case study.

This should be followed with identifying the current challenges and demands (product-wise and nutrition-wise). Next, all possible solutions should be examined (public-private partnerships, investment opportunities in technologies, training of manpower, etc.). For example, Rwanda could be chosen as a target country for such a case study because it is politically stable, it has a desirable geographic location, the willingness of foreign investors to invest there compared to other countries in the continent, productivity and capability. Most importantly, the community buy-in must be there to successfully implement any planned activity. However, the challenges foreseen for such an activity include, access to quality raw ingredients, capital investment, sustaining such a facility, the availability of trained manpower (and keeping them on the payrolls), traditional markets, regulatory affairs and no large incentive for keeping the food aid products to be produced on regular scale.

Processing Recommendations

A roadmap of at least 5 to10 years would be an adequate timeline to plan on processing trends, raw materials and the like. Identification of processing trends in the current food aid basket include 80 percent staples as compared to 20 percent. The recommendations include:

- **Increase the processed food portfolio in food aid basket.** Based on the nutritive value of processed foods over staple foods, plans should be in place to transform the portfolio of products in the food aid basket to 50 to 60 percent staples and 40 to 50 percent processed foods. However, to achieve such a transformation, there should be a general model in place to identify needs or demands of food aid and processing which is sustainable. An example of this would be identifying malnourished children in a certain area and their needs which can be supported by food aid. The existing processing technologies in the target country should be identified. Based on the input collected, solutions must be proposed based on various approaches, including public-private partnership with investment in new technologies, new interventions, new processing facilities or upgrading the existing capabilities and facilities in the target countries. Upgrading existing facilities would require a lower level of investment, though food safety must be top of mind and a bottoms-up approach (progressing incrementally from small units to larger units) would be helpful.

- **Identify efficient technologies which can be adapted to local requirements.** Meeting the water and energy needs for food processing practices in developing countries across the spectrum will involve identification of opportunities to reduce the strain on limited resources. To fully understand the constraints within different communities, stakeholder input should represent an integral part of the entire investigative process.

- **Involvement of the country/community in project implementation.** This is a crucial element in the overall scheme of things and would ensure local buy-in for the project before any planned improvements or investments are made towards technology. To be specific, it should be examined if components from the general model could be applied to target countries like Rwanda, Ethiopia and others, and then carry on that model to additional countries with the scope of variations needed to adhere and adjust to local requirements.

IV-b Macronutrients

The feedstock

A food's macronutrients are the key source of energy to the body. Macronutrients consist of carbohydrates, proteins and fats. The sources for these macronutrients can be either from plants or from animals. Major plant-based sources are grains (wheat, corn, rice, sorghum), tubers/roots (cassava, yellow sweet potato). Major animal sources are dairy (milk, cheese, yogurt), meats and poultry. The plant-based sources can be classified as genetically modified organism (GMO) or non-GMO. The notion of "clean label" has been gathering momentum as well. The clean label movement promotes the use of simple, natural ingredients and avoids adding chemicals to food formulas and recipes.

The quality of raw ingredients as a source of macronutrients is a very important factor. The attributes of digestibility, bioavailability and fatty acid profile must be considered while choosing these ingredients. In the current environmental scenario, sustainability of the sources is a crucial aspect and should not be overlooked. In addition, opportunities for alternate resources as partial replacers/boosters for the current macronutrients (including spent grains, rice bran, distiller's grains) should be considered to fill the existing gaps and to enhance the nutritional profile of the foods. Insects should also be considered as a source of quality protein which can fully or partially replace existing plant and animal proteins from the food recipes. However, while looking to incorporate these changes in the macronutrient mix, the cultural sensitivities and preferences of the consumer should also be considered.

The most common complete protein source used in food aid products are milk-based proteins like skim milk and whey protein. Several studies have shown that dairy is effective in treating moderate acute malnutrition (MAM) and also promotes linear growth. In addition to physical growth, these milk proteins have been shown to help reduce morbidity, stimulate cognitive development and reduce chronic diseases. However, there are outstanding questions about the level of dairy nutrients during the critical first 1,000 days in the life of a child, most specifically, the effect of dairy supplements given to the breastfeeding mother on the child.

Due to the high cost of dairy and animal-based proteins, their use can limit the reach of food aid products. Therefore, alternate protein sources from plants should be considered since they are less expensive and are more sustainable. For example, 43 gallons of water is needed to produce one pound of pulses as compared to 1,857 pounds of water needed to produce 1 pound of beef[11]. Many plant-based proteins like canola protein, defatted soy flour and pea concentrate have a protein digestibility-corrected amino acid score (PDCAAS) value of more than 0.80. However, there are some challenges in using plant-based proteins, including its impact on sensory qualities, the high price of new protein sources and limited sourcing. Because of this, the opportunity exists to study the effects from combining different plant-based proteins (to meet the essential amino acid requirements) with respect to animal-based protein formulations in food aid products.

Exploring new avenues

Some of the gaps and opportunities in this field are: i) alternate sources of protein; ii) combining different proteins; iii) sensory attributes of modified proteins; iv) exploring the concept of blending plant and animal proteins (algal oil with fish oil, and others); v) the use of omega-3 fatty acids (long-chain polyunsaturated fatty acid); vi) moving from a "one shoe fits all" concept to "designer foods" (normal foods fortified with health-promoting ingredients). Incorporating designer foods would have the potential to be designated as "fit for purpose." In this way, food aid products could be developed or modified to suit different needs.

Another area would be to focus on antinutritional factors like phytates and tannins as well as allergens like mycotoxins. Potential use of so-called "fancy diets" alternates like quinoa and wild or brown rice could be explored as sources of macronutrients. The availability of these new or alternate grains in U.S. should be assessed before diverting to these sources. Packaging is an important part of the overall food aid program as it is the primary component to keep the food matrix safe and nutritious.

Macronutrients Recommendations

- **Identify potential new sources of macronutrients.** Future research should be directed to identify new and alternate sources of protein, fat and carbohydrate ingredients, and identify advances in processing technology to make all nutrients more bioavailable.

IV-c Micronutrients

Bioavailability overview

For the most part, food aid commodities have been formulated as "one-size-fits-all" without looking at the other food aid basket/diet components and total diet in terms of micronutrient composition and components which affect their bioavailability. The composition of the food aid basket is important since dependence on one product alone for energy and micronutrient requirements may not be a viable option. The need for fortification may be higher (or lower) depending upon the nutrient composition of the other foods in the food basket. The presence of antinutrients or dietary components that either increase or decrease the absorption of nutrients will also determine the extent of fortification.

Current studies on nutrient bioavailability from food aid products are only focused on a particular food or on a particular nutrient being tested and not necessarily on other foods consumed by the children/beneficiaries. These "other foods" interact with other nutrient-rich foods within the body and could affect the outcome of nutrient absorption from consuming the fortified food being studied. Therefore, the bioavailability studies conducted in controlled settings may produce alternate results in various realistic field contexts. Because of this, exploration of synergies between different foods consumed and how the foods interact with other foods is relevant to understand the bioavailability of micronutrients. Another area of concern while measuring the bioavailability of nutrients is that many times populations are simultaneously exposed to doses of multiple micronutrient powders (MMPs) along with fortified foods. However, enteric enteropathy disease (EED) and gut pH of the population may have a greater impact on the bioavailability of nutrients than interactions among the ingredients.

The World Health Organization (WHO) has developed guidelines for corn and wheat fortification which are being followed in many geographical regions. However, it is anticipated that the rice fortification guidelines developed by the WHO have some practical difficulties due to the blending of extruded fortified rice kernels with raw rice in a specific ratio.

Iron has been one of the most important micronutrients which has been studied in public health. Iron deficiency is considered to be the leading micronutrient deficiency worldwide and is responsible for a large proportion of worldwide anemia burden[12,13]. In a recent study by Hackl et al. (2016)[14] on fortified rice, the team discovered that combining citric acid with trisodium citrate instead of ethylenediaminetetraacetic acid (EDTA) improved the bioavailability of iron.

Proteins from animal sources are more bioavailable and provide all of the essential amino acids but whether their inclusion in food aid products would be cost-effective or feasible is still unclear. Protein digestibility has always been an important topic in the food aid arena due to its impact on child growth and recovery from malnutrition. Techniques to improve digestibility of plant proteins can be effective and economical and should be explored further.

Enhancing micronutrient uptake

New ideas to enhance gut health and absorption must also be examined. The exogenous addition of enzymes like phytase could help gut microbiota in its action on phytates, which is an antinutritional factor[15,16]. This breaks down phytates in food to release phosphorous and makes minerals such as iron, calcium and zinc more bioavailable and has a positive impact upon gut health. Since phytase is heat labile (susceptible to alteration or destruction at high temperatures), the only way to safely incorporate it into the diet is to add it to MMPs or to RUTFs and energy bars (i.e. formulations that need no cooking). It is also being added at the point of manufacturing in LNS (micronutrient spread) products[17].

The possibility of incorporating prebiotics or probiotics into food aid products as a facilitator of gut health should be investigated. Substances like pea proteins, cowpea and oligosaccharides are being used as probiotic ingredients in infant formulas to promote bifidobacterial in western countries[18]. The use of chicory powder as a source of fiber as well as a prebiotic in food aid products should be examined. Another factor that influences bioavailability outcomes is inflammation and has not been adequately considered in bioavailability studies for food aid products. For example, zinc absorption is affected by inflammation. Other ingredients which could be studied include the possibility of replacing sugar in the formula with noncaloric sweeteners, used in many commercial products. Promoting the inclusion of MNPs in food aid baskets, rather than fortifying all types of foods may be a way to proceed.

Micronutrients and food matrices

The addition of micronutrients through the process of fortification to all fortified foods warrants a reexamination. For example, vitamin A is added to all fortified food products but its addition to a fatty matrix alone may be more rational (e.g,. oil and not flour). In contrast to vitamin A, folic acid has not yet been investigated in detail. Folic acid is relatively stable and its testing is not mandatory for USDA products while tests are needed for vitamin A and iron fortificants. Folic acid is tested in domestic products, however, its quantification becomes difficult due to the low amount of folic acid used. Efficacy studies from rice fortification have shown that low levels of iron fortificants with chelates are just as effective as fortification with high levels of iron without chelates.

The possibility of adding higher amounts of micronutrients to compensate for lower bioavailability should be investigated. It is of great importance to know if higher amounts of one micronutrient will impact the bioavailability (increase or decrease) of other nutrients. In other words, will the addition of higher amounts of micronutrients best compensate for lower bioavailability? Alternatively, is it more effective to use a more bioavailable form, add enhancing agents or add components that improve gut health to enhance bioavailability? The above suggested examples to improve bioavailability cannot be studied or examined in isolation. Theoretically, there seems to be great potential but the practicalities of modifying existing recipes must consider the industry viewpoint as well. For ease of stocking, handling and processing, the industry would prefer to have/handle a minimum amount of ingredients. They already face enough challenges, including GMO, gluten-free, organic criteria, which require frequent flush-outs. Therefore, the idea of introducing new ingredients/allergens could be a big concern.

Furthermore, the use of different chemical forms of a nutrient to suit the matrix in which it is being added also calls for stocking all forms of that nutrient. For example, different types of iron need to be added in foods to suit the matrix, so all of iron’s forms must be stocked as well.

Ferrous sulfate is the most popular form of iron source being used to fortify domestic food products, including wheat flour in the U.S. Encapsulated ferrous sulfate is also used to fortifying corn-based products. This adds to the complexity of sourcing and storage, and also affects product pricing. Encapsulation of micronutrients causes them to be used in higher doses than unencapsulated forms, which adds to the cost. For example, one-quarter ounce of ferrous sulfate is needed to fortify one hundredweight of corn meal, but due to rancidity issues, the encapsulated form must be used at the rate of one-half ounce. This raises questions on whether we have enough scientific knowledge and evidence to suggest what forms of iron are better suited for food aid products.

Also, we must consider which forms of other micronutrients are not influenced by food components or processing. How could ingredient addition be made more efficient and cost-effective? Would it be possible to cut down on micronutrient forms/types for ease in stocking and use by manufacturers? Would overexposure to certain micronutrients during feeding programs self-correct after feeding is stopped? How can it be ensured that the micronutrient status is maintained after feeding is stopped? Is there enough information on the rate of time needed for absorption of nutrients or the effects of overcompensation of certain nutrients long and short term? The sustainability of nutritional status after the end of food aid products/programs is also a lingering concern.

Micronutrients Recommendations

The priorities and focus for future direction can be categorized as High (five to10 years) and Medium (three to five years). High priority items are needed in the short range and medium priority activities are on the long range horizon. Additionally, funding would be an integral part for achieving any of the priority areas. Recommendations include:

- **Improve the stability of vitamin C (ascorbic acid).** The high-priority area would be vitamin C (ascorbic acid) which is added to improve iron absorption. But since it is heat labile, the addition of vitamin C will be useful in products which are consumed without heating. Since vitamin C is added in all food aid products whether or not they are heated before consumption, it’s unclear if the recipients are getting enough vitamin C. Because of this uncertainty, the stability of vitamin C is a high-priority topic. This could include heat stability, impact on iron absorption, the effects of the food preparation process and technology to evaluate quality at point of use/consumption.

- **Water fortification at point-of-use.** This would use the higher bioavailability of nutrients from water[19]. Micronutrients in water soluble forms can be added to water just as zinc sulfate and iron (FeSO4) are added to water tanks in refugee camps. This water is then used for cooking sticky rice and having sachets instead of jerry cans, which would make it easier to use this water efficiently.

- **Better knowledge on bioavailability related to iron, calcium, vitamin D with a key focus on iron.** This is another essential topic. A systematic review of all micronutrients in all vectors is needed to assess the current knowledge and plan toward what could be done to move the science and technology forward. A step in this direction has been currently undertaken in food fortification by Technical Advisory Group (TAG), led by Global Alliance for Improved Nutrition (GAIN). Efficacy trials of fortified rice have shown that formulations are effective but the scale of study is very small. Long-term studies should be carried out to further validate the results of the rice fortification studies and funding would play a decisive role in carrying this forward.

The medium priority areas to focus on are:

- **Study the role of micronutrient stability, gut function and interactions within the entire diet.** The use of affordable food sources (legumes, pea flour) as prebiotics without using expensive ingredients could be an interesting innovation both targeting gut health and examining it as a protein source. Investigation into the limitations, if any, of what can be added to food aid products and examining if there was a scope for addition of other ingredients and bioactive compounds would be a suitable step in improving bioavailability issues. For example, can oligosaccharides that mimic human milk oligosaccharides in breast milk be added to these products? More bioactive compounds should be used in lesser quantities as much as possible.

- **Explore opportunities for inclusion of bioactive compounds in food aid products.** Studies on how diets affect the efficacy of a product and how difference in absorption in individuals with varying gut health and inflammation levels would provide us with better insight into bioavailability and nutrient utilization within the body.

- **Cost-effectiveness of the identified propositions**. This would explore if it would be more effective to add small amounts of high cost, more bioavailable product or vice versa. A case in point being that the price of ferric sodium EDTA is higher than the advantages that it gives in terms of bioavailability but is useful in products which contain phytic acid. If phytic acid is high then it would be useful to have more of EDTA-based compounds as an iron fortificant than iron in any other form which will be less absorbed. It would be worthwhile to focus on the food aid basket diet rather than just a single fortification vehicle. The role of local foods in providing nutrition is another area which should be explored to improve overall bioavailability of nutrients from foods.

IV-d Nutrient delivery techniques

Encapsulation

Encapsulation is a process which functionally entraps useful agents (e.g. chemicals or living organisms) within a carrier material or delivery vehicle. Encapsulation technologies have been known for many decades and were initially applied in the pharmaceutical sector, especially for drug and vaccine delivery. Since their introduction, encapsulation technologies have gained relevance for the food industry for a myriad of applications. For example, encapsulation is needed to: a) protect bioactive but labile molecules like antioxidants, minerals, vitamins, phytosterols, lutein, fatty acids, lycopene and living cells (e.g. probiotics) from heat, oxygen and moisture; b) protect labile compounds or organisms from digestion and release at the place of absorption or action; c) enhance or control flavor release, color, texture or preservation properties; d) prevent undesirable interactions of the cargo with the food matrix; e) allow easier handling of foods; and, f) provide an adequate quota and distribution of the active compound. Functional wall materials should be food-grade, biodegradable and able to create a barrier between the cargo and its surroundings.

Current encapsulation technologies that employ plant (e.g. soybeans) or animal (e.g. dairy) carbohydrates (e.g. chitosan, gums), proteins (e.g. casein, glycinin) and lipids (e.g. solid fat, emulsifiers) can be used in food aid applications. These are more preferred over synthetic micro or nanoparticles due to their historical use and regulatory status, which is generally recognized as safe. The vast majority of encapsulation technologies use spray-drying. Other encapsulation technologies include spray-chilling, freeze-drying, melt extrusion, melt injection and emulsification. Current technologies employ spray-drying to create functional and wettable powders. Other drying technologies are vacuum and freeze-drying, though these methods are more expensive. After these technologies are employed, powders can then easily be included in food applications. Nonetheless, even when caution is taken, these encapsulated materials could also suffer from poor particle size control and distribution, and degradation.

Spray-drying is the most extensively-applied encapsulation technique in the food industry because it is flexible, continuous and offers significant scale after the initial capital investment. The molecular inclusion of fat-soluble agents in cyclodextrins and liposomal vesicles are more expensive technologies, but offer significant advantages to spray-dried encapsulates, including higher resilience during digestion and ease of encapsulation (i.e. no major capital investment on a spray-dryer).

Encapsulation of macronutrients and other bioactive agents (*e.g.*, vitamins, minerals, nutraceuticals and probiotics) can be used to improve their handling, food matrix compatibility, shelf life, and bioavailability. From the wide variety of different encapsulation technologies that have been developed, an appropriate one must be identified and customized for each particular application. This depends on the nature of the bioactive component to be encapsulated, as well as the nature of the food matrix into which it will be delivered. Characteristically, encapsulation of hydrophilic nutrients is much more challenging than hydrophobic ones. It is also possible to encapsulate different nutrients together, using single or mixed delivery systems. However, the effectiveness of encapsulation depends on the nature of the food matrix and processing operations used. Therefore, the stability and performance of the encapsulation system selected must be investigated and optimized for each product. The food matrix must be studied and the changes which occur during processing as well as within the GI tract must be taken into consideration. Heat, moisture, oxygen and light stability are challenges for many types of nutrients.

Technology which has been developed for the encapsulation of drugs can sometimes be adopted for use in the food industry, however, the components used to assemble the encapsulation system must be food grade and the processing operations must be commercially viable. The profit margins in the food industry are generally much lower than those in the pharmaceutical industry, which reduces the number of technologies which are commercially feasible. Currently, overages are added to compensate for losses during processing and storage. There are technologies like antioxidant packages which can protect the vitamin A losses in processing and storage. Encapsulation can also be used to retard oxidation and other forms of chemical degradation during storage. The release rate of the nutrients in the delivery systems must be controlled to ensure good stability in the gastrointestinal tract and absorption by the body.

Nanotechnologies

The use of nanomaterials to encapsulate vitamins and minerals and the use of these nanocarriers holds great potential. However, global regulation on the use of nanotechnologies in foods is inconsistent, with some countries and regions having much more developed legislation than others. The National Nanotechnology Initiative defines nanotechnology as "the science, engineering and technology conducted at the nanoscale, which is about 1 to 100 nanometers. It does not include, however, those materials which start with the prefix "micro" and end with the suffix "nano," such as most of the nutrients which are not purposely designed. It does, however, include materials that start with "nano" by design, but end with "micro," both in our foods and in our guts.

Typically, the upper cutoff size (diameter) for a nanoparticle in foods is approximately100 nanometers (but this varies depending on the organization). The belief that reducing the size of the particles in delivery systems increases the bioavailability of nutrients is strongly supported by in vitro and in vivo studies. These studies have shown that nanosizing can increase the absorption of minerals (like ferric pyrophosphate), oil-soluble vitamins (β-carotene, vitamin A, vitamin D, vitamin E) and proteins (such as gluten). Due to the differences in regulatory issues for nano and non-nanosized materials, and the potential negative implications like concerns about food safety and toxicology associated with using products involving nanotechnology, it would be worthwhile to work around these limitations. Rather than focusing on the "nano" portion of the word, it is suggested that a description like "size reduction" should be used as an option instead of the word "nanotechnology." As an example, a compound that is 101 nanometers shouldn't be absorbed much differently than one that is 99 nanometers and would avoid using the label "nano."

At this early juncture, it is necessary to evaluate the benefits versus the risks of those "controversial" technologies (i.e. GMOs, nanotechnologies). It will also be important to develop a strong educational/outreach component to highlight the risks and benefits of using structural design principles to enhance bioavailability for this application. It is well known that food aid products are made using decade-old technology but in order to improve the nutritional quality of these foods, we must look toward future pathways. This new technology should be tested in food aid products because it would help improve shelf life and hopefully, the cost won't prove to be too high. The regulatory practice will examine benefits and risks, which can be discussed by the recommended country. The belief is that it's better to create options and work on fine-tuning them than to give no options at all. In addition, GMO product acceptability is also a challenge.

NASA and the U.S. army also have interest in nanotechnologies for making their foods last longer and with better bioavailability. The same concept applies in emergency relief solutions—the need to keep products for a long period of time (more than two years shelf life)—then the term "nano" definitely has a role to play. It presents a great scope to bring together NIFA, USAID, NASA and the U.S. army to conduct research on nano. Acceptability has been the major issue with nano-based products for the military and NASA as people don't typically want to consume these products. The biggest challenge is to make it economically viable. The industry needs to be involved in taking this research/pathway forward. The more manipulation, processing and technology required in the process, the higher the costs. Food aid applications alone would most likely not justify investments, but if the technologies could be widely used in other commercial products, then it could be worth the industry investing in research and development. In order for this initiative to be successful, it is necessary to highlight how the companies could benefit from helping the food aid world and developing new technologies.

It is surprising that nanosized applications are so little favored in the food sector. This makes the funding agencies curious as to whether the potential benefits of nano are so small that there may be no need for nano. Are there any ways in which we can look for changes in the dynamics of food structure by examining the food particles occurring in the gut to have a better understanding of the changes that occur to food inside the body? Are we looking for short-term solutions as well as long-term solutions?

Public-Private Partnership

Food aid is currently measured by the number of beneficiaries reached. This mindset encourages the use of the cheapest options—the cheaper a food is produced, the more people it has a potential to reach for the same amount of monetary investment. However, a better alternative would be to consider food aid from a cost-effectiveness perspective. Acceptability is a big challenge (i.e. peanut-based products in Asia are less accepted than in African countries). It is also key at the governmental level (i.e. the ban of products containing GMOs) since regulation is always a challenge when introducing new technologies. Transparency is necessary. Regarding product formulation, the main issue is stability, particularly of active ingredients which are typically quite labile. Because of sensitivity to heat, there sometimes is not much nutrients left to use by the time the food reaches the absorption site. A range of products with different taste profiles, tailored to the particular region, could be used to increase compliance.

The role of industry in contributing toward food aid technologically as well as in foods cannot be overlooked. Industry also donates some of the products used in emergency situations. Several private companies are interested in participating in some form of aid when emergencies arise, but due to the lack of proper mechanisms in place it is not always possible to engage them in a sustainable way. An option could be that the purchasers of food aid products (i.e. governments, NGOs) lay down product type and specifications for the type of products they wish to procure and then contract them to companies so they can make the product and donate or sell it at cost. This process would most closely resemble the process of vaccine development where there are no returns to the drug company for its research efforts though it has a huge social health impact. RUTFs, for example, are in the market more to do good than to turn a profit. Two major advantages included these products' long shelf life due to their lower content of unsaturated fats and its flexibility to consumption without preparation. Also, the opportunity exists for modifying the product by improving flavor and diversity. More importantly, animal-source proteins such as milk, sugars and micronutrients complement the nutrient profile, making the product a complete meal replacement. Yet, research on these products lag behind in terms of design and modification as our understanding of food science, nutrition and health continues.

Generally, there has been a lack of forward thinking and this has led to slow changes to the desired outputs in food aid products. FAQR's 2011 report is a case in point and illustrates that the field is far behind in terms of formulating products which are more nutritious and better absorbed by the body. There is adequate knowledge on individual nutrients but perhaps not in terms of matrices and which matrices would be the best to carry these nutrients.

Enteric Status

In low-resource settings, children under five years of age are vulnerable to enteric parasitic infections due to their undeveloped immune system and the inadequate sanitation, hygiene, and healthcare systems, which are not the exception, but the norm in places such as Southeast Asia and Sub-Saharan Africa[20]. Parasitic infections alter the epithelial integrity and weaken the immune system in children, resulting in reduced nutrient digestion and absorption, gut inflammation, anemia, protein-energy malnutrition, and reduced growth and cognitive development[21]. This infectious and proinflammatory state is further worsened by the overconsumption of diets rich in omega-6 and low in omega-3 fatty acids (30:1 to 70:1)[22]. A lower ω6:ω3 ratio is recommended not only for normal growth, cell functioning and immune function but also for adequate anti-inflammatory response[23,24]. If our intent is to provide adequate nutrition, our efforts will be soon diluted by the continuous burden of opportunistic diseases. Therefore, interventions focused on providing both adequate nutrition and addressing parasitic infections and gut inflammation in children are needed to effectively address the multietiological problem of undernutrition[25].

In low resources settings, most of the parasitic infections are due to cryptosporidiosis from contaminated soil, food and water, and from soil-transmitted helminths (STH). Cryptosporidiosis is caused by the protozoan *Cryptosporidium* spp. and it is the second leading cause of diarrheal disease and death in infants after rotavirus[26]. Cryptosporidiosis follows the fecal-oral route. It is excreted in the feces of an infected host in the form of an oocyst and is mainly transmitted from person to person, animals and indirectly through the environment (water and food)[27]. Cryptosporidiosis's resilience against most environmental factors and even chlorination is due to its thick-walled oocyst[28]. *Cryptosporidium parvum* is a monoxenous apicomplexan mucosal parasite which has gained wide recognition due to its association with a severe diarrheal disease that affects mostly infants and children who are immunocompromised and undernourished. In the gut, oocysts excyst releases four infective sporozoites. These motile sporozoites attach to the enterocyte and evade detection as they create a membrane around the cell but outside the cytoplasm[29]. The parasite relies solely on the host for nutrient acquisition as it lacks enzymes for energy metabolism[30].

Soil-transmitted helminths (STH) are among the most widespread and diverse infectious agents burdening all population groups[31,32]. It is estimated that more than one billion people in developing regions of sub-Saharan Africa, Asia and the Americas are infected with one or more species of helminths. This places a significant burden on populations enabling a vicious circle of infection, poverty, decreased productivity and inadequate socioeconomic development[33,34]. Infections with STHs such as roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*) and hookworm (*Necator Americana, Ancylostoma duodenale*) result in growth impairment and undernutrition[35,36]. Hookworm infection, for example, damages the intestinal mucosa leading to bleeding, loss of iron and anemia. Similarly, *Trichuris trichiura* infection results in a chronic reduction of food intake, which, during pregnancy, can cause anemia to the mother and damage to the fetus, leading to low birth weight. Unfortunately, there is not a simple, single or short-term approach to tackle the stalemate of parasitical infections and all the associated burdens. Therefore, a more comprehensive and sustainable model is critical.

Parasitic Infections

Both current and new concepts in food science and engineering applied to food aid could be transformative since new food concepts can both address undernutrition and inflammation as well as prevent and/or treat parasitic infections. Presently, food aid products only address nutritional gaps. There are some developments in the research for new formulations to add more omega-3 fatty acids. Nonetheless, the addition of this oxidative-labile lipids poses significant hurdles to developers. Because of this, encapsulation technologies using micro or nanodelivery vehicles are a sound approach to both enhance the stability of fatty acids and reduce the organoleptic effects often associated with the addition of these substances from diverse origins such as plant oils (e.g. flaxseed, camelina oils) and animal (e.g. algae, fish oils). Indeed, significant advances in colloidal sciences have led to several concepts which use various approaches to create functional wall materials such as from carbohydrate or protein useful to disperse not just oils, but other fat-soluble nutrients and bioactives into food applications[37].

The addition of encapsulated drugs to address parasitic infection is not a new concept. These, however, would inevitably have the same fate of most antibiotics, i.e., promote resistance. The addition of essential oils, containing not one but several active ingredients, especially from spices and herbs already consumed by target populations could result in a more holistic approach to fend off parasites. Current evidence shows that essential oils are bioactive at concentrations well tolerated by humans. Essential oils contain a diverse set of several small phenolic molecules (e.g. carvacrol, thymol, estragol, linalool and p-cymene) with distinct functionality in vivo. These have been studied for their effect against virus and bacteria but to a lesser extent on parasites. Essential oils from basil, oregano, hops, thyme, and other herbs have been used in both the Ayurveda and Chinese medicine for centuries. They are limited, however, due to their instability and pungent aroma after extraction.

Regardless of the encapsulation technology, more research is critically needed, especially in the addition of bioactive agents into food aid products. Additional research is also indicated in the evaluation of their physical-chemical effects to and interaction with the food matrix, consumer consumption compliance, efficacy against infection and effectiveness of current nutrition programs.

Lack of nutrition is another important aspect to consider. Infection in the body of the host is an additional factor which affects absorption. If food can help resolve both lack of nutrition and infection, an immune-enhancing component added to the food (or the component which promotes the growth of beneficial bacteria in the gut) would be an excellent method to stave off infections. A new version of LNS product (i.e. LNS 2.0) can add a functional quota of essential oils (e.g. from hops or oregano) or even drugs encapsulated with beta-cyclodextrin. If this version is designed to treat a health condition, it now becomes a therapeutic food and is then governed by a different set of regulations. If it is designed to complement meals and potentially address nutritional gaps, it is still considered a supplementary food. For example in India, the former version of LNS would be difficult to set up due to cost. The second version, however, is more feasible to add to say, 1,000 children in an Anganwadi center in places such as Gujarat (India).

Fortification

Fortification of alternative products could be a complementary technology to address nutrition gaps in large populations at an even lesser cost. Dairy fortification of fermented products, such as chaas (a yogurt-based drink which is often called "buttermilk"), can bring both helpful lactic acid bacteria and nutrition through the food supply. The addition of nutrients is not without its hurdles, however. Encapsulation and chelation technologies could be implemented in order to reduce the effect of fortification on the products' flavor, consistency and shelf life. Companies usually use purified products, which also adds to the cost. If, in some way, non-purified products can be used then the cost will be lower to produce the same effect.

This type of work is generally done by drug companies' (APIs) nutrition divisions. Feeding through food matrices would be more cost-effective rather than refining the product and putting it back in food. Encapsulation works in the case of essential oils because these tend to get absorbed in the mouth and stomach rather than in the gut. By the time the bioactive molecule reaches the gut, there isn't much of its effect left to fend off opportunistic parasites. Nonetheless, the more manipulation of the matrix, the more the cost. Using local sources and available food technologies would be key to keeping expenses low as well as effective.

A limiting factor of local sourcing is the lack of ingredients in the inventory to supply and meet the needs of the demand. To remedy this, increasing the productivity of crops in target countries would be a step in the right direction. Several USAID-funded Innovation Labs look into these aspects. For example, Nutriset made the peanut butter paste (Plumpy'Nut) and transferred the technology to African countries to stimulate their economy as well as to keep the product local. The problem was that there were not enough manufacturers to keep up the demand so Edesia (a nonprofit organization that manufactures specialized RTUFs) was set up to fill in the gaps.

In addition, local flavors should be added to food aid products to increase their acceptability. However, there are often pitfalls due to high cost associated with this. In many countries, when other cooking oils are scarce, shea butter oil is used for frying. But because shea butter is also used in cosmetics, it is in high demand in the beauty industry and therefore expensive. Due to its lipid profile as being high in saturated fat, shea butter oil is an extremely stable oil. Other ingredients such as whey protein gels are very good in food applications and can supply high-quality protein to promote linear growth in children. These are limited, however, for transportation overseas due to their high water content. The other challenge associated with the main ingredient in Plumpy'Nut is peanut storage. Making the paste is relatively easy, but aflatoxin contamination due to poor postharvest practices can lead to the necessity of disposing entire lots of contaminated peanut butter. This situation is better controlled with RUF manufacturers in the U.S. The producers have strict specifications for levels of aflatoxin in peanuts which the suppliers must adhere to.

The use of advanced technologies like color sorting further helps in removing contaminated peanuts which appear darker after roasting. A total "kill step" using heat treatment to remove all microbial contamination is still a challenge. Presence of heat-sensitive ingredients like milk components and vitamins in the finished product makes heat treatment challenging. Generally, manufacturers are not concerned about the presence of antinutritional factors in the product or else they use more bioavailable forms of ingredients to remain competitive in the market. However, the manufacturers are willing to incorporate changes to the product/process if specifications are made applicable industry-wide. Supplementary feeding (e.g. small amounts of LNS) with improved formulas that limit the presence of known toxins and food-borne pathogens seems to be a better approach as long as it does not have "therapeutic" connected to its name, thus avoiding the more stringent guidelines associated with therapeutic foods.

Getting nutrition is not the sole aim of consuming food—people also derive pleasure from the very act of eating food. It must be pleasant to the taste and to the eye. Because of this, there should be variety in food so that it is readily consumed and people reap its full benefits. The crux of USAID and food aid programs is to reach as many people in need as possible. Currently, a child is fed the food aid product for a certain number of weeks and then, once the child is considered to be healthy, the food is stopped and the normal/regular food follows. If we prioritize the product tastewise, then there will not be problems of acceptability and the food will deliver as much benefit as possible.

Along these lines, the question must be raised as to whether we have enough information about the food aid basket. Is it a question of optimizing the current products and looking at what works or what does not work? A low-hanging fruit would be to encapsulate the ingredients so that they can have a shelf life that is longer than 18 months. Would extending the shelf life of foods to 24 months through encapsulation of nutrients make the product prohibitively expensive or would the cost increase be manageable? Currently, the industry makes the products closer to when they are needed and do not necessarily keep amounts of the product in stock because of gaps in production and final consumption. An improved method was suggested—create these products for multiple use. Plumpy'Nut, for example, could be used in school lunch programs as a supplementary food. Additionally, there should be another target group of people lined up to consume the product when the current population of Plumpy'Nut consumers has enough of the product in reserve. Foods should also be made in local community facilities so that when the food situation is bad, the facility can manufacture the therapeutic product, as well as other foods. Countries with stable governments should be identified and technology must be transferred to these countries to make products using local resources which can be customized at cost and sustainable. If this method is put into effect, shorter product shelf life would be possible since transportation to local sites would faster, easier and more efficient.

If the formulation of premixes is stable enough, then the sachets can be added directly to foods which are being consumed on a daily basis. Technology should be examined regarding how to make the micronutrients strong enough to withstand the shelf life of 24 months in hot and humid conditions. Possibilities include packaging the products in different bundles–e.g. water-soluble vitamins in one bundle, oil-soluble vitamins in another bundle, etc. Foods for regular use and emergency use should be kept separate. The question still exists regarding the acceptability of foods made from GMO sources, regardless of whether or not the food crisis situation is severe. Providing nutritious food should be the only criteria in such cases, however politics also come into play and have an effect on the boundaries of food aid.

Another cause of malnutrition is parasitic infection. It is recommended that components which could fight or resist parasitic infection (including bioactives and drugs) be added to foods. Hygiene is also plays a strong role in nutrient delivery. For example, a person infected with roundworm, even if provided with nutritious and bioavailable food, may not be able to utilize its benefits—because of the infection, nutrient delivery is not effective. Before developing recommendations, there needs to be a clear understanding of whether we want to give more choices to the beneficiaries (like flavors and forms). Do we want to better target nutrition needs? Or are we simply trying to provide food to as many people as possible (quantity of beneficiaries versus quality of the foods)? What specifically needs to be improved within each current food aid product in order for its benefits to be more successful?

Nutrient Delivery Techniques Recommendations

The establishment of clear goals would allow the manipulation of various aspects of foods to achieve acceptability, longer shelf life and other desirable outcomes.

- **Acceptability of newly-designed foods.** Acceptability is a big factor in determining the overall effect of a food. The examination of a food aid product's acceptability should be a priority. A well-designed and nutritionally-efficient food would not be of any benefit in addressing undernutrition concerns if it is not considered an acceptable food by the recipients.
- **Shelf life.** Shelf life should be examined from the point of retaining the nutrient activity until the date printed on the food packet. In addition, efforts to increase the shelf life of the foods distributed should be initiated to provide better food usability. Understanding nutrient availability from current products/conditions would help us identify the limitations in the current food matrices.
- **Study pathways of nutrient absorption and impact of changes in nutrient profile.** Examining other questions like the stability of the nutrients in the products, how the nutrients are absorbed, how much of the nutrients are actually being absorbed, what factors (food matrix effects) impact absorption, and what would aid in formulating better products which can deliver nutrients effectively. For example, lowering the amount of zinc in the food would reduce cost but there is concern about whether the products would still be effective.
- **Versatile food products.** Creating new food aid products that are multifunctional, repurposing emergency foods and improving follow-up would increase the opportunities to use these products. Instead of specific situation-based applications, these foods would cater to a wider audience who have a variety of nutritional needs. To further improve the usability of foods, there should be a clear repurpose plan for emergency foods once the emergency has passed. The transition phase from that of emergency to a normal state should be as smooth as possible and aid must not be stopped after the emergency

is over. Having a superior food matrix for the delivery of nutrients is not sufficient in the greater scheme of things.

- **Address infections in the body.** Infections in the host body reduce the effectiveness of nutrition and thereby contribute to malnutrition. In light of this issue, the addition of components and processes like prebiotics, antimicrobials, bioactive compounds, fermentation, sprouting would help prevent infections and address food safety issues as well. However, all the changes should be considered from a cost-effectiveness point of view. Judgement should be made about whether or not the new changes would be economical and whether the incremental changes in food design would have a better nutritional outcome than the current food matrices. We should be looking for short-term solutions as well as long-term solutions in order to be most effective.

IV-e Bioavailability of nutrients

Quantifying nutrient bioavailability

The focus of many USAID food aid activities is to improve the nutritional status, and thus the health and wellbeing, of its recipients. Given this intention, research evidence is needed to determine the efficacy of changes and interventions. However, only certain types of research provide what is needed to determine whether the intervention will improve nutritional status. Models such as the in vitro digestion/Caco-2 model, human, and animal bioavailability studies provide useful information, but do not provide the evidence needed to determine whether nutritional status will be improved with long-term consumption of the food aid product. This differentiation in evidence has become clearer in studies suggesting that individuals might adapt to the consumption of poorer bioavailable forms of micronutrients or poorer quality proteins, and by the disconnect between outcomes in vitro digestion/Caco-2 model, acute human/animal bioavailability studies, and studies that measure nutritional status. An example of this phenomenon is found in differences between impact of antinutritional factors such as tannins on iron bioavailability versus status. In vitro digestion/Caco-2 model and bioavailability studies indicate that tannins inhibit iron bioavailability; however, food tannins have little impact on iron status[38].

Elements impacting bioavailability

Many factors can affect the bioavailability of nutrients. These could range from the overall matrix, nutrient interactions, processing effect and storage effects. For example, studies on the effect of denatured and hydrolyzed plant proteins have shown that processes that cause protein denaturation or hydrolysis (i.e. cooking, baking and possibly extrusion) promote starch-protein interaction, and thus constrains starch hydration and enzymatic cleavage[39]. Acceptability is another important factor for these products which is another sensory attribute which should be further evaluated within the broader desired programmatic outcomes. The taste of the foods should be as close to cultural tastes as possible. Ideally there should be different recipes to cater to different norms and expectations. Instead of one-type-fits-all, health status should dictate the type of food that will be provided. Due to the heterogeneity in malnourished populations with people having different disease states along with malnutrition (undernutrition), it would be expensive to formulate foods that cater to every specific person's status. It will be more useful to formulate foods for the population who fall within the major region of a bell curve.

Formulation plan

Furthermore, there is very little evidence which points to an optimized R&D solution for each cohort. Because of this, there is a need to conduct an economic assessment to discover which R&D solutions are the most economically viable or which provide the most ROI. Recently, a WHO report emphasized reducing the sugar content in food aid products and in keeping with the findings of that report, it was suggested that foods with a low glycemic index be designed like foods high in resistant starch.

Another aspect to consider while formulating the foods is what percentage of daily calories the food provides. If it is more than 90 percent, then greater attention must be paid to food formulation. Perhaps not so much attention should be given in these foods if they only meet a part of the person's diet, say 30 to 50 percent of the daily calorie intake. Effective formulations would be those that are designed for young children since their caloric requirements are higher. The satiation levels of foods should be in accordance to the population being served the food. High satiety foods may cater to overnourished (obese) populations whereas lower satiety foods may be formulated for the undernourished.

Standardized analytical methods are an important tool to evaluate the nutritional levels and status accurately. As has been the case for protein quality, further harmonization of micronutrients assessment methods will assist in the accurate interpretation of outcomes. Additionally, the various methods used for micronutrients quantification should be validated specifically for the matrices in question to address any possible micro-macro interaction due to the matrix and its process. This will greatly assist in adopting the same test features for specified micronutrients, making the interpretation of results straightforward and uniform.

Products used for humanitarian response are usually transported and stored at conditions typical of tropical regions (i.e. very high temperatures and very high relative humidity) for extended periods. These conditions could exert substantial stress to the integrity of the product and its packaging. These products do not have the benefit commercial products have, for instance, more favorable storage conditions and quicker turnaround time. However, very little public research exists that assesses the effects of storage and transport under conditions typical of these products. The reality is that models which are not necessarily representative of conditions in the field or at transport are utilized, giving inaccurate results. This is especially prevalent in the case of water soluble vitamins and mineral content and their interactions with macronutrients over time. This type of evidence can play a significant role not only in product design for humanitarian response but also in countries' national fortification policy-making.

Preliminary studies in fortified rice matrices in Cambodia suggested that rice fortification with iron and zinc could be an effective strategy to improve micronutrient status, while these conditions did not necessarily favor the use of vitamin A in this matrix. The investigation showed that the vitamin A retention was significantly affected by storage and the type of process involved in the manufacture of micronutrient kernels used as fortificant for rice. After 12 months of storage at 40 ± 5 °C and humidity of 75 percent (which is still lower than the average storage temperatures in other regions) losses of vitamin A were 40 percent to 50 percent for extruded premix and 93 percent for coated premix after six months[40]. A key component of shelf life that is usually not well understood is the relationship of packaging and the product. Not much evidence exists to date which could result in cost-effective packaging solutions for humanitarian products. More research is needed to better understand and optimize packaging under these conditions to minimize waste and improve shelf life. Also, it is key that end users understand the importance of the utilization of these products according to their storage instructions and before their shelf life ends. This would enable stretching the use of the product to its maximum.

Challenges in interpreting research outcomes

The efficacy measurement of foods by ranking them on the basis of in vitro and in vivo tests would provide useful information on the nutritional efficiency of food products/matrix and which should be taken to the community to inform them about the quality of foods distributed to them. This could increase the confidence in and adherence to the product by the consumers.

Ideally, research intended to improve micronutrient status would examine the impact of food aid consumption in long-term human interventional studies within a population similar to where food aid will be utilized. In certain cases, the use of surrogate biomarkers is justified instead of direct measure of nutrient status. However, performing this type of research is costly, and therefore not feasible. Alternatively, long-term human intervention studies in more easily-accessible populations or animal studies which look at nutrition status impact can provide evidence needed to make cost-effectiveness decisions for food aid programming. Unfortunately, there are not standardized methods or models to conduct this type of research, and there are differences of opinion on the quality of outcomes among researchers. While there are multifaceted approaches to these views/concerns, ideally no single method or model need be the only approach used to obtain evidence. Instead, it is more important that the correct level of evidence is collected and utilized, potentially using multiple methods and models to provide stronger efficacy evidence.

A broader assessment of nutritional status than for randomized control trials (RCTs) should be conducted to have better information on the population profile and help to make better decisions on the type of food/intervention to be provided. Assessment of the demographic profile before intervention would help determine the right group of people and whether they are single or multiple micronutrient deficient. Wherever possible, the use of technology to measure nutrient status should be preferred and newer technologies must be developed to cater to this assessment. Animal studies should be used to measure nutrient status and cost-effectiveness and should not be based on in vitro tests.

Bioavailability of Nutrients Recommendations

- **Focus on essential nutrients.** Given this efficacy-based, cost-effectiveness focus, it is also important that the primary focus of research/formulation should address essential nutrients rather than nonessential nutrients/components, which are less likely to improve the health and wellbeing of food aid recipients than improving nutrition status. In addition, while efficacy evidence is important, acceptability evidence is also key to collect and consider, given the likelihood of micronutrient status improvement is low if recipients are not going to make the effort to obtain or consume the food aid product.

- **Track the developments in food industry.** The knowledge of previous interventions would provide key insight to future interventions. To address some of the research gaps, it will be prudent to explore similar research that has been done by the food industry so that those experiences can be piggy backed upon and provide an early start to a new product/process/distribution.

- **Test essential micronutrients.** It is suggested that from the entire list of micronutrients, the essential nutrients should be selected and tested for bioavailability and stability. This information should then be used for understanding the food matrix. So essentially, in vitro tests should be conducted, followed by continually evaluating the process, ingredients and storage conditions.

- **Nutrition status of target population.** Before considering a food aid product for a reformulation, information on nutrition status improvement is needed. This information would be beyond the in vitro/bioavailability/protein quality results. These tests could be of value as a part of the initial research. The primary focus should be on essential nutrients–both macro and micro. It's of primary importance to identify research gaps and communicate them to USDA-NIFA and other funding agencies for funding support to successfully carry on research in the identified field.

IV-f Bioactive and functional compounds

Feeding the colon strategy

An important step in this topic area would be to list the bioactive and functional compounds which hold the potential for enhancing the nutritional value of fortified foods. The commercial availability of these identified products and regulations for its use would be a determinant in using the ingredient further. Feeding the colon strategy could be one of the directions for boosting the quality of fortified foods. The byproducts of milling should be explored as a strategy to address this issue. Rice bran, which contributes about eight to 10 percent[41] of the rice grain, can be a potential candidate for being used as prebiotic. However, it must be stabilized to prevent its rancidity which sets in quickly due to its inherent high fat content of 15 to 20 percent[42] and potent lipase enzyme. A study on piglets has been conducted showing the benefits of stabilized rice bran using extrusion for enzyme deactivation in gut health[43]. In keeping with these findings, rice bran is a good source of oil, protein, vitamins and improves gut health.

It would be appropriate to consider the possibility of utilizing some components of nutrients which could be given to mothers as opposed to babies. These essential nutrients would be transferred to babies through the mother when the child is breastfed, much like omega -3, probiotics, Ig (immunoglobulin) components are. Not only are probiotics commercially available but they enhance the immune system and many studies have illustrated their benefits.

Understandably, there is a great deal of confidence in the positive effects of probiotics but it is still challenging to pinpoint the proper dosage and strain/type of lactobacillus which should be given to achieve the desired effect. To keep the probiotics themselves viable requires proper storage since probiotics require low storage temperatures (similar to the temperature of the human body) and low humidity. The shelf life of these microbes in absence of water in ideal conditions is one year[44]. Because probiotics are not robust in nature, there can be interactions between minerals and other ingredients from the premix if a probiotic is added to the premix, so caution must be taken in their inclusion.

Prebiotics are better vehicles in food systems because they are more resistant and pass through the small intestine undigested and are fermented in the colon. The most popular prebiotic is inulin. Natural sources of prebiotics include chicory, rice bran, beet pulp, sorghum bran, citrus fibers and other soluble fibers. If colonic microbiome is an important factor in nutrient absorption, then supporting those organisms with food or fuel also becomes very important. A combination of prebiotic to probiotic would be the next level of discovering their synergistic effects. However, in finding the right combination of their synergies there exists a research gap. The economics/cost of such a formula will also be an important determinant of its inclusion in food aid products. As an alternative, the use of legumes such as cowpeas in the formula has been considered. Since cowpeas have oligosaccharides (2 to 4 percent), they act like prebiotics. They have been successfully used in animals to improve performance. Mannan oligosaccharides found in brewer's yeast, which are low-cost and have a very stable shelf life, can be used for reducing pathogen-causing organisms in the body.

Animal proteins

Another potential source of nutritional ingredients which can be added are the vast supply base of animal organs like livers, hearts and tongues. However, people can be a bit squeamish about eating these foods. The time is ripe to utilize this stream of nutritionally-rich components, at least from a food security stand point. Animal organs are widely used in pet food diets[45]. Cheaper protein alternatives are more promising than animal proteins since animal protein inclusion would make more sense if storage was a problem. For example, designing food for space travelers where storage space is limited. A comparison of the inclusion of dairy protein in cereal-based fortified food and RUSF-type (lipid-based) products is underway in the Sierra Leone study. This study will assess the difference between two products or a comparison of the different times it takes the two products to achieve the same outcome. This will help in calculating the economics of the product. In a study in Guinea Bissau, RUSF-type products with different levels of dairy proteins were provided to preschoolers, babies and mothers for three months. They found that dairy at 33 percent was more effective than dairy at lower levels (15 percent) over a three-month period[46] in preventing anemia and wasting. The role of dairy should be further examined as compared to some other animal source proteins.

Other alternate sources of animal protein could be eggs, insects, marine sources and seaweed. Bringing in marine source protein would also provide a fraction of omega-3, especially the long chain which is good for eye and brain development and is also a good source of iodine. A number of studies have been conducted to look into bioavailability aspects of nutrients but most of these studies compare product A versus product B and not as a whole on a long-term basis. The omega-3 bioavailability (ALA – alpha-linoleic acid and DHA – docosahexaenoic acid) from plants and animal sources are different[47].

Example of fortified rice

Rice has been identified as an effective and practical vehicle to carry micronutrients with large population coverage for improved nutrition in rice-consuming countries. The current fortified rice nutritional profile set by World Food Program and USDA includes eight micronutrients (vitamin A, vitamins B1, B3, B6 and B12, folic acid, iron and zinc) with the aim of improving the general public's nutritional status. These nutrients can be either added to rice flour and form extruded fortified kernels using extrusion technology or added to the natural rice grain surface and form coated to fortified kernels using coating technology. Both types of fortified kernels are highly concentrated and can be added to regular rice at 0.5 percent to 2 percent to produce the finished fortified rice. With the same approach, other types of micronutrients, bioactive compounds and sensory improvement agents, such as those discussed in this subgroup (vitamin D, vitamin K, choline, probiotics, enzymes, flavors and colorants, and others), can also be added to rice to provide health benefits tailored to specific health conditions, enhancing nutrient absorption and encouraging fortified rice consumption.

When designing such "multifunctional fortified rice," one should keep in mind that most rice-consuming countries have the custom of rinsing or washing the rice before cooking it. Since fortified rice will be consumed after cooking, the optimum outcome of the design relies on: 1) selecting active compounds that are heat stable; 2) controlling potential chemical interactions; and 3) applying technologies that help retain the activity or potency of selected bioactive and functional compounds during rice cooking preparation. On the other hand, consumers' acceptance of multifunctional fortified rice can be a challenge. Any sensory property of fortified rice which is perceived as a deviation from traditional white rice, such as changes in appearance, color, shape or texture, can result in consumer rejection and failure in program implementation. Advanced technology development, persistent consumer education and market promotion need to be continued to overcome this challenge.

The above fortified rice product example indicates that understanding the physical, chemical and sensory properties of bioactive and functional compounds is the key for successful product development.

Additional research and funding

Phytase is one enzyme which can improve iron and zinc bioavailability by degrading phytic acid and act as boosters to fortified foods. The use of phytase should also be explored. The focus should be on compounds which can improve gut health and reduce inflammation along with planning to add phytase, amylase, citric/ascorbic acid and cost-effective animal proteins. Additionally, the effects of sweetened foods given to children should also be scrutinized on long-term basis.

Funding is the most essential component to explore and study these new alternatives to improve the bioavailability of nutrients from food aid products. USDA, NIFA and AFRI Foundational: Food Safety, Nutrition and Health can fund studies on the function and efficacy of nutrients (one or more bioactive component or whole foods) and its influence on inflammation and gut heath as a research element. Solicitation appears every year, with July being the cutoff month.

Another funding opportunity is a joint program with NIH-food-specific profiles and biomarkers of health. NIH has previously funded a project on rice bran and navy beans, examining their profiles as it relates to health biomarkers in cancer. Since the program is through NIH, there are three different grant recipients each year. Additional funding opportunities can be found through private foundations. The Center for International Programs acts as a liaison between internal NIFA institutes and foreign agency services. Although they do not have a large budget, in the last Farm Bill, increasing international engagement was mentioned. Although NIFA cannot provide funds to international partners, there is the possibility that they could fund the domestic arm of the project.

Bioactive and Functional Compounds Recommendations

- **Reach out to funding agencies.** Funding opportunities with USDA-NIFA should be explored on different aspects of food–including bioavailability, sensory and stability/shelf life. The direction of research should be on food function, specifically texture, sensory and stability. Processing aids like sodium bicarbonate (a leavening agent) which helps in expansion during extrusion and other sources of protein, like mushroom proteins, should be investigated. The WHO recommendations on sugar reduction calls for identifying fungible product which can be used in place of sugar. The addition of amylase may lower the use of sugar by releasing natural glucose. Flavors are generally driven by cultural exposure. It is most discernable in child-based products where flavor plays a very crucial role. Branching out from the current sweet flavor to other flavors by using ingredients like turmeric, cinnamon, rosemary and herb blends could enhance the flavor of food aid products. Alternate single-serve food formats other than porridges—like cookie bars and textured protein chunks (some work has been done with chickpeas and peas)—should be created,

- **A multipronged approach to improve the bioavailability, and thus, the nutritional quality of food aid products.** An area of focus should be on the "feed-the-colon" strategy and the optimization of ingredients such as prebiotics from already-existing production streams. Not only does this have the potential to keep down costs but probiotics will also enhance gut health. The use of enzymes like phytase, amylase and oligosaccharides would help improve the nutritional quality of foods. Another area of interest would be to target health/wellness outcomes. In this approach, attention must be given to having ingredients like lecithin, choline and chloride which can boost brain/cognitive development, improving immune health by lowering inflammation with omega-3 (DHA) from fish oil and supplements. Improving overall bone and skeletal health by incorporating ingredients that would provide for calcium, vitamin K, vitamin K enhancers, vitamin D3 and quality protein should also be explored.

- **Choice of compounds for a food matrix.** When using food aid products as carriers for bioactive and functional compounds, the following technical considerations should be included in the strategic planning: compound selection, the effect of food processing conditions on the stability of these compounds, potential changes in sensory properties of the carrier and consumer acceptance of the final food aid products. A decision on the most optimum food matrix to carry these ingredients as a whole or in different foods should be the next step. Finally, the role of food function and nutrient delivery would help achieve better nutritional efficiency of new foods with some or all of the above ingredients incorporated into them. "Structure follows strategy" seems to be the best approach, where the strategy of delivering nutrients is planned first, followed by the structure of food capable of delivering the foods' benefits in the most efficient way.

V. CONCLUSIONS

There is an increased realization that the food matrix has a role to play in the release of nutrients from the matrix and subsequent absorption by the body. Enhanced efforts focused on the food matrix will lead to improved nutritional efficiency of food aid products. There is no single approach to attain improved bioavailability of nutrients from food matrices but improved understanding of the causative factors for lower bioavailability of nutrients would certainly assist in creating a food matrix with the potential of being more effectively utilized by the body.

The food aid basket consists of food products ranging from staples to processed foods. Increasing the share of processed food products in the food aid basket would provide more opportunities to formulate products with better "nutrient release" features. Staples, or foods that are prepared and consumed locally, may contain higher levels of antinutritional factors, mycotoxin contamination. These lower the levels of added micronutrients and also affect the bioavailability of nutrients. In addition to proper formulation of processed food products, attention needs to be given to gut health. As most of the nutrient absorption, including protein, carbohydrates, water, vitamins and minerals occur in the gut, its functionality becomes an important part of the nutrient absorption flow path.

An additional area of interest should be the stability and the interactions of micronutrients in the food aid products. The focus must be on the integrity of the micronutrients throughout the product's entire shelf life and the prevention of any interactions which can negatively impact the bioavailability of micronutrients. The solutions to enable better nutrient release from the food matrix and subsequent absorption in the body must be determined in close cooperation with food technologists, nutritionists and the industry. It should be understood that no one food product would be able to provide complete nutrition to all beneficiaries over a period of time. Tailor-made formulations should be designed with the overall aim of maximizing the nutritional benefits that are received by the beneficiary. An important consideration to be kept in mind while trying to improve the nutritional efficiency of foods is that they should also have sensory acceptability.

There exists a tremendous scope for improving the quality of food aid products by improving the nutrient bioavailability. Some of the modifications can be undertaken in the current food aid products without any change in the existing production and logistics, whereas other changes would require funding and field trials before being fully accepted and incorporated into food aid products. Improvement in nutrient bioavailability would boost the overall cost-effectiveness of food aid products in terms of the health gain per beneficiary per unit of food consumed.

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ANNEX VII-a Summary of Recommendations

Processing
1. Increase the processed food portfolio in the food aid basket. 2. Use efficient technologies which can adjust to local requirements. 3. Explore local country/community involvement.
Macronutrients
1. Identify new sources of macronutrients.
Micronutrients
1. Improve the stability of vitamin C. 2. Use water as a vehicle for fortification of water-soluble vitamins. 3. Long-term studies should be conducted to validate results from smaller trials. 4. Cost-effectiveness of the micronutrient form.
Nutrient delivery techniques
1. Acceptability of the food aid products. 2. Increase the shelf life of the foods. 3. Create food aid products which are multifunctional. 4. Address infections in the body of the beneficiary.
Bioavailability of nutrients
1. Focus on essential micronutrients. 2. Learn from similar work done by the food industry. 3. Assimilate facts on nutritional status improvement needed before reformulation.
Bioactive and functional compounds
1. Use ingredients that can boost brain/cognitive development. 2. Adopt feed-the-colon strategy to promote gut health. 3. Select compounds based on stability, sensorial changes and effect on processing.

ANNEX VII-b Meeting Agenda

Agenda: *(Each presentation, including Q&A, would be 15 minutes)*
8:30–9:00 am: Registration and introduction

AM session: State-of-the-Art in Food Aid

9:00–9:30 am: Introduction (Keynote by Johnson for Perez; with moderators)
9:30–10:30 am:

- Food Aid Scenario–Scope for improvement (Webb)
- Iron-Bioavailability issues in food matrices (Moretti)
- Challenges to improve nutritional value of food aid products using animal proteins (Alavi)
- Role of processed macronutrients in overall nutrients bioavailability (Singh)

10:30–10:45 am: Coffee Break; Discussion guidance (Moderators)
10:45–11:45 am: Roundtable Discussion #1 (State-of-the-Art)
11:45–12:45 pm: Working Lunch and Roundtable Discussion #2 (Gaps and Challenges vis-à-vis Food Aid)

PM session: Looking Ahead, Making Food Aid More Effective

12:45–1:45 pm:

- Maximization of vitamin A, folic acid and other micronutrient utilization in body (McBurney)
- Nutrient delivery techniques (McClements)
- The role of processing in altering food matrices and influencing bioavailability of nutrients (Wu)
- USDA-NIFA–Promoting evidence-based research (Carter)

1:45–2:00 pm: Coffee Break; Discussion guidance (Moderators)
2:00–3:00 pm: Roundtable Discussion #3 (Next steps)
3:00–3:30 pm: Wrap-up and closing remarks (Moderators)

Moderators: Sajid Alavi (Kansas State University), Farida Mohamedshah (Institute of Food Technologists) and Quentin Johnson (Quican Inc.)

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