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Effect of Cooking Methods and Formulation of Fortified Blended Foods on the Food Matrix and Nutrient Bioavailability: An Experiment from The Food Aid Quality Review, Sierra Leone Four Foods Study

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ACRONYMS

α	Alpha
°C	degrees Celsius
CSB+	Corn Soy Blend Plus
CSWB	Corn Soy Whey Blend
FAQR	Food Aid Quality Review
FBF	Fortified blended food
g	grams
MAM	Moderate acute malnutrition
ml	milliliter
mm	millimeter
oil	Fortified Vegetable Oil
PVO	Private Voluntary Organization
RUSF	Ready to-use- supplementary food
SC+A	Super Cereal Plus with amylase
USAID	United States Agency for International Development
USDA	United States Department of Agriculture

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I. EXECUTIVE SUMMARY

Understanding the role of food matrices¹ and nutrient bioavailability in food aid products is important to assure that the products are efficient in providing the maximum possible nutritional benefit to recipients. In order to explore the role of food matrices on the health outcomes of food aid recipients, three isocaloric fortified blended foods (FBFs) being used in the Food Aid Quality Review (FAQR) field study in Sierra Leone were tested for differences in food matrices, measured by formulation and viscosity of porridges, when prepared by the caregivers of study participants. The Sierra Leone Treatment of Moderate Acute Malnutrition (MAM) Four Foods study was designed to determine the relative effectiveness and cost effectiveness of four supplementary foods in the treatment of MAM in children ages 6 to 59 months. Three FBFs are being studied: Corn Soy Whey Blend (CSWB) and Corn Soy Blend Plus (CSB+), both prepared with fortified vegetable oil (oil) and Super Cereal Plus with amylase (SC+A).

Standardized preparation methods for the porridges, developed from field observations, were replicated in laboratory settings to collect data on the changes in the viscosity of the porridge that occurred during cooking. When cooked, CSB+ and CSWB were more viscous than SC+A due to differences in formulation. The higher viscosities lead to thicker porridges. The thicker porridges are harder to consume or sip out of a cup, leave more residue in the cup and provide a satiated feel for a longer period of time. All of this predisposes the children in the CSB+ and CSWB groups to ingest less of these porridges and/ or other foods that they will normally consume during the course of the study. On the other hand, caregivers might dilute these thick porridges by adding more water than recommended during cooking in order to make them thinner, which in turn will reduce the concentration of nutrients that can be consumed by the children in one serving. This too will have an unintended negative impact on the outcomes. Also review of the formulation of the FBFs indicated that the inclusion of dairy proteins in CSWB and SC+A may improve linear growth, compared to CSB+. These two FBFs also have twice the level of micronutrients as compared to CSB+.

It was concluded from this study that although the cooking method for the FBFs varied, it was primarily the differences in formulation that led to different physical properties of the porridge food matrices. These differences, in combination with the nutrient profile of the FBFs, would affect nutrient availability and effectiveness of the food aid products. SC+A has a greater likelihood of it being the most effective amongst the FBFs in terms of health outcomes because it is the least viscous, has a higher micronutrient profile and dairy protein. Next in order would be CSWB, even though it has high viscosity similar

¹ The Food matrix is defined as the nutrient and non-nutrient components of food and their molecular relationships, i.e. chemical bonds, to each other (USDA NAL Glossary, 2015)

to CSB+, due to inclusion of dairy protein and higher level of micronutrients. CSB+ is likely to be least effective. However, this experiment is not able to predict whether the higher levels of micronutrients and inclusion of dairy proteins at the current levels are enough to show measurable changes in health outcomes for recipients.

II. BACKGROUND

The food assistance programs administered by the U.S. government through implementing agencies such as multilateral organizations, private voluntary organizations (PVOs), or local non-profit organizations, tend to provide food or other means to make food accessible to populations suffering from chronic undernutrition. Chronic undernutrition has long-lasting effects in the body. Due to lack of proper nourishment the body is more susceptible to illnesses and not able to fully utilize the nutrients provided from specially formulated food aid products. It is very important that food aid programs look at the products from a food science lens, so that bioavailability of nutrients are optimized and undernourished populations are able to get the most out of food aid products made available to them.

Since 2009 the USAID Office of Food for Peace (FFP) Food Aid Quality Review (FAQR) project, implemented by Tufts University, has recommended ways to improve the nutritional quality of food aid products (Webb et al. 2011). Some of these recommendations have been tested in field trials to assess their practical implications. One FAQR field study is the Sierra Leone Treatment of Moderate Acute Malnutrition (MAM) Four Foods study which seeks to determine the relative effectiveness and cost-effectiveness of four supplementary foods in the treatment of MAM (moderate acute malnutrition) in children 6-59 months. The isocaloric study foods included three fortified blended flours (FBFs), Corn Soy Blend Plus (CSB+) prepared with fortified vegetable oil (oil), Corn Soy Whey Blend (CSWB) prepared with oil, and Super Cereal Plus with amylase (SC+A), and a lipid-based ready-to-use supplementary food (RUSF).

When interpreting results in relation to intended health outcomes the overall food matrix² that is formed when using the associated cooking methods for each FBF should be considered. The hypothesis is that the final food matrix, including its physical properties (such as viscosity), of each cooked FBF would impact nutrient absorption and may affect health outcomes at the end of the study period. This hypothesis should be tested because health outcomes in individuals are affected by several factors including the type of food consumed, nutrient density of the foods, overall health of the person, environmental factors, etc. Almost no study to date has looked at the physical

² Nutrient and non-nutrient interactions within a food and that which is affected by its ingredients and processing, including cooking.

properties of the food matrix as a contributor to the overall health outcomes for the recipients of food aid. This experiment analyzed the changes in the food matrix due to preparation practices in the Sierra Leone study and considered how that may affect nutrient bioavailability and influence health outcomes.

III. METHODS

To gather data on the food matrix and nutrient bioavailability of the three FBFs used in the Sierra Leone Four Foods study product formulations were reviewed and viscosity testing completed. A detailed review of the commodity specifications was completed to understand the composition of the different food matrices.

Observational data, including the techniques and steps used when cooking the FBFs into porridges, were recorded from visits to homes of food aid recipients' receiving the FBFs in the Sierra Leone Four Foods Study. The data was summarized and a standardized preparation method was made based on the most common practices being adopted for each FBF. The standardized methods were then replicated in laboratory settings to understand the changes in food matrices, particularly the viscosity of the porridge, that occurred during cooking. All FBFs were provided by Didion Milling, Inc. (Wisconsin, USA).

All the FBFs were cooked into porridges (1) as per the protocol depicted via pictograms on the respective FBF bags and consistent with ingredient weights listed in the USDA commodity specifications documents; and (2) using standardized cooking practices developed from in-home observations. At the end of cooking, the porridges were cooled to 55°C and then poured into the Bostwick meter to measure their flow. The standardized cooking methods for the FBFs are as mentioned below.

CSB+ and CSWB

To maintain a solids ratio of 13.76% as stated in the commodity specifications document (USDA, 2014) 41.5 grams (g) of FBF and 14.5 g of soybean oil³ was weighed using a weighing balance (Ohaus NVL5101/1, Ohaus Corporation, USA) and kept separately. The total water of 245.5 g was divided to 1/3 (81.8 g) and 2/3 (163.7 g) parts and weighed into two beakers separately to match the preparation steps in the field. All the quantities measured were sufficient to make 301.5 g of porridge which filled approximately half of the beaker used in the experiment. The beakers were of 600 milliliter (ml) capacity and had a diameter of 95 millimeter (mm) and height of 120 mm.

The beaker containing 2/3 of the cooking water (Beaker A) was covered on the top with an aluminum foil as a lid and placed for boiling on a stirring hotplate (Corning PC-620D) maintained at 325°C (degrees Celsius) with the stirring system switched off. The

³ Soybean oil was used instead of fortified vegetable oil, as fortified vegetable oil was not available.

dry FBF powder was added to the other beaker containing 1/3 water (Beaker B). The dry powder was mixed thoroughly with the water to make a paste. Once the water inside Beaker A started boiling, the lid was removed and the paste from Beaker B was transferred into the boiling water. A part of the boiling water was removed from Beaker A prior to the transfer of the paste and poured into Beaker B to clean and remove the paste that remained on the walls of the beaker. The removed paste bits were poured into Beaker A. The contents were mixed thoroughly to form a uniform blend inside Beaker A. Oil was then poured into the Beaker A and mixed thoroughly using a 4-pronged dinner fork. Beaker A was covered and remained boiling. Intermittent stirring was done to prevent the porridge from sticking to the bottom of the beaker and burning. Once the porridge started boiling, it was boiled for 10 minutes followed by 2 minutes of simmering. Then the Beaker A with its lid on was removed from the hotplate and placed in a water bath (Isotemp 220, Fisher Scientific, USA) with digital control that was maintained at 55°C. Once the cooked porridge was cooled to 55°C, it was poured into the reservoir of a leveled Bostwick consistometer (CSC Scientific Company, Inc., Fairfax, Virginia, USA) until it overflowed. The porridge in the reservoir was levelled using a spatula and left undisturbed for 30 seconds for it to settle, after which the reservoir's lever was released to open the gate and allow the flow of porridge for 30 seconds (USDA, 2014). The distance travelled in 30 seconds by the porridge was recorded. The measurement was recorded in increments of 5mm (i.e. if the flow at the end of 30 seconds was between two markings on the Bostwick scale, then the higher measurement would be recorded).

SC+A

In order to have a 23% solids concentration (USDA, 2016 draft) in the porridge, 75 g of FBF was added to 250g water. The water was separated out in two beakers of 600 ml capacity each with one beaker having 83.3 g (1/3) and the other beaker having 166.7 g (2/3) of water. All the weighing was done using the weighing scale mentioned previously. Dry FBF powder was added into the beaker containing 1/3 water (Beaker C). The mix was stirred vigorously to form a smooth paste. The paste was then transferred to the beaker with 2/3 water (Beaker D) and some water from it was used to wash the paste that was sticking to the walls of Beaker C. After all the paste was transferred to Beaker D, the entire blend was mixed thoroughly using a 4-pronged dinner fork. The Beaker D was then covered with an aluminum foil lid and placed on the hotplate maintained at 325°C as mentioned previously. Intermittent mixing of the porridge while heating was done to prevent any solids from sticking to the bottom of the beaker and burning. The lid was always placed back on top of the beaker after each mixing. Once the porridge started boiling, it was cooked while boiling for 10 minutes and then for 2 minutes on simmer with intermittent mixing. After cooking, Beaker D was placed in a water bath maintained at 55°C and covered with lid. Bostwick analysis was conducted and recorded

on the porridge as described above after the porridge cooled down to 55°C.

IV. RESULTS AND DISCUSSION

The Bostwick flow rates for all the FBFs are presented in [Table I](#). The flow rate indicates the viscosity of the prepared porridges at 55°C. The flow rate can also be used to interpret the consumption of the final food matrix, based on the ease of ingestion, which is the first step towards utilizing the FBFs nutritional benefits.

Table I: Bostwick flow rates of FBFs

FBFs	Bostwick flow rate at 55°C/30 seconds (mm)
CSB+	45
CSWB	35
SC+A	>240

FBFs = Fortified Blended Foods, CSB+ = Corn Soy Blend Plus, CSWB = Corn Soy Whey Blend, SC+A = Super Cereal Plus with amylase, mm = millimeter

It is evident from the table that CSB+ and CSWB are very viscous as compared SC+ A because they have lower Bostwick flow rates of 45 and 35 mm/30s respectively, than SC+A (>240 mm/30s). Flow properties are an important part of porridge preparation and consumption. A thicker porridge may be diluted by the preparer in order to bring it to a drinkable consistency. This would increase the volume of the porridge while lowering the nutrient density. The digestion of solid food depends on disintegration of food and dissolution of nutrients in the gastric juice (Kong and Singh, 2008). It has been reported (Mackie et al., 2013; Zhu et al., 2013; Clegg and Shafat, 2014) that a viscous matrix slows down the kinetics of food transit through the digestive system, with longer time needed for gastric emptying. It is important to note that this finding is not universally agreed upon (Vist and Maughan, 1995; Shimoyama et al., 2007). The effect of longer gastric emptying time means that the food remains in the stomach for a longer amount of time. This delays absorption (Kong and Singh, 2008) in the small intestine where the maximum absorption of nutrients occurs, both macro- and micro-nutrients, occur (Bryant and Hampton, 1992) and also creates a sense of fullness.

It has also been reported that calories have a greater effect than viscosity on determining gastric emptying time (Menard et al., 2018). Some recent studies have also shown that isocaloric foods given with the same amount of water have nearly identical gastric emptying curves (Okabe et al., 2015; Okabe et al., 2017). All of the FBFs used in the Four Foods study were isocaloric, but they have different amount of water (or solids) after preparation and also different viscosities. CSB+ and CSWB had much lower Bostwick flow rates as compared to SC+A. Therefore, the effect of viscosity would seem to be pre-dominant in determining the food travel time inside the body.

While the differences in composition of the FBFs and the recommended solids ratio for preparation of the porridge has a major impact on the viscosity of the food matrix, evaporation of water during cooking further changes the ratio of solids and added oil to water. An increase of the ratio of solids and oil to water due to evaporation will lead to an even more viscous matrix. FBF data from the field trials showed that during the process of cooking, there was a loss approximately 27% of water due to evaporation from CSB+ and CSWB. A loss of around 21.5% was observed for SC+A.

The SC+A is made using extrusion process (Kampstra et al., 2018) and has α -amylase enzyme in the formulation to break down the starch. This has a thinning effect on the porridge (Kampstra et al., 2018), even during cooking. This also led to faster boiling and shorter cooking time (approximately 10 minutes) as compared to the cooking times (around 15 minutes) for CSB+ and CSWB which are thicker or more viscous even at lower solids level. This might be one reason was less evaporation of water in the case of SC+A.

The composition of the FBFs are presented in [Table 2](#). Even though these foods are isocaloric (after taking into account oil added during preparation of CSB+ and CSWB), they have compositional differences in order to reach the desired nutritional profile for the FBF.

Table 2: Ingredients in the study foods

Ingredients	CSB+ (% by weight)	CSWB (%by weight)	SC+A (% by weight)
Corn (white or yellow)	78.47	68.34	58.17
Whole soybeans	20.00	21.13	--
Vitamin/mineral	0.20	0.40	0.40
Tri-calcium phosphate	1.16	0.72	1.16
Sodium-chloride [#] /Potassium chloride	0.17	0.29	0.27
WPC80	--	3.00	--
De-hulled soybeans	--	--	20.00
Dried skim milk powder	--	--	8.00
Sugar	--	--	9.00
Vegetable oil [#] /Refined soybean oil	--	5.50 [#]	3.00
Potassium monophosphate	--	0.62	--
Amylase*	--	--	As specified

α -amylase was added to SC+A at the rate of 80g or 90g or 95 g based on the supplier Suntaq Amylase, Novozymes amylase, or Sinobios Amylase, respectively from, 4.83% oil is added to CSB+ and CSWB during preparation of porridge, CSB+ = Corn Soy Blend, CSWB = Corn Soy Whey Blend, SC+A = Super Cereal Plus with amylase, [#] = values for CSWB. (USDA, 2014; USDA-CSWB, 2016 draft; USDA-SCPA, 2016 draft)

The major ingredients in the FBFs are corn and soy. The highest amount of corn is present in CSB+, followed by CSWB and SC+A in decreasing order. The relatively

lower amount of corn (and thus starch) in the formulation, breaking down or hydrolysis of starch due to amylase action, presence of sugar in the formulation and lower water evaporation all contributed to the runny consistency and much lower viscosity of SC+A, which makes it easier to consume/drink as compared to the other two FBFs. This is despite the fact that SC+A has more solids (23%) in the porridge mix as compared to the other two FBFs (13.76%). The thinner porridge (SC+A) has higher chance of being consumed fully because all of the content can be more easily ingested by the recipient and nothing remains sticking to the glass/jug from which it is consumed.

The primary source of protein in CSB+ was from soy. CSWB has both whey and soy protein sources and SC+A had soy and dry skim milk powder as protein sources. Soy and dairy proteins are complete proteins with all the nine essential amino acids present. However, the relative concentration of the essential amino acids differs in these two sources. Dairy proteins are rich in the amino acids lysine and methionine which promote muscle growth and accelerated fat loss. The addition of dairy protein, by replacing part of the cereal (corn) content, also helps in reducing anti-nutritional factors (Hoppe et al., 2008) and improves the bioavailability of nutrients from the modified food matrix. Additionally, SC+A and CSWB have the same levels of micronutrients and higher than the levels in CSB+. In addition to the above factors that influence the food matrix and nutrient bioavailability, the addition of sugar in SC+A would improve the flavor (Fleige et al., 2010) and acceptability of the product over the other two FBFs. The likelihood of it being consumed by children is potentially higher, yielding better absorption of nutrients.

V. CONCLUSIONS

The experiment showed that formulation affected the viscosity of the porridges made from FBFs more than the cooking methods used. The food matrices of porridges are affected by several factors such as ingredients and their relative proportion (or formulation), processing, and cooking. This experiment showed that the most influential factor contributing to nutrition absorption through improved bioavailability are ingredients and formulation. Based on the simple flow test of Bostwick analysis, SC+A should lead to greater absorption of nutrients (due to lower viscosity, ease of ingestion and less residuals in serving container, less satiety and gastric filling, and higher solids and presence of dairy powder and higher level of micronutrients) as compared to CSB+ and CSWB. It is also potentially more palatable due to the added sugar in the specification. The dairy protein in SC+A and CSWB may contribute to more positive health outcomes as compared to CSB+. Overall, based on the FBF formulations and Bostwick flow rates, it seems that SC+A would have maximum bioavailability of nutrients, followed by CSWB and CSB+ respectively. As this experiment was not a part of the original study design, further studies need to be planned to better understand the effect of food matrices of food aid products on health outcomes of recipients.

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