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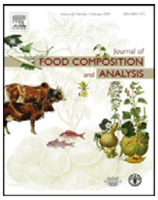

Original Article

Effect of end-user preparation methods on vitamin content of fortified humanitarian food-aid commodities

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ABSTRACT

The effect of cooking on vitamin stability in common fortified food-aid commodities was evaluated: corn–soy blend (CSB), cornmeal (CM), soy-fortified bulgur (SFB), and vegetable oil (VO). Thin CSB porridge, thick CM and SFB porridges, and dumplings fried in VO were prepared using average preparation parameters determined from the data collected in the field. Vitamin levels in pre- and post-cook samples were tested. In CSB thin porridge, vitamins C and E showed cooking losses of 53% and 18%, respectively; thiamin, folic acid, riboflavin, pantothenic acid, pyridoxine HCl, vitamin A, and vitamin B12 showed no significant losses. In CM thick porridge, thiamin, folic acid, riboflavin, and vitamin A showed no significant changes during cooking. In SFB, vitamin A was reduced by 33%, while thiamin, folic acid, and riboflavin showed no significant changes during cooking. In VO that was used to prepare dumplings, vitamin A losses of 6% occurred after one frying cycle. Vitamin A content of the dumplings, however, increased significantly during frying. With the exception of vitamins C and E in CSB and vitamin A in SFB and VO, typical cooking had little effect on vitamin stability.

1. Introduction

In 2005, the United States Agency for International Development (USAID) distributed nearly 1 million metric tons of fortified programmed food-aid, valued at over US$440 million. The most commonly distributed fortified commodities included vegetable oil (VO), corn–soy blend (CSB), cornmeal (CM), and bulgur (U.S. Department of Agriculture, Foreign Agricultural Service, 2005); each of which is fortified with certain vitamins and minerals intended to prevent and alleviate micronutrient deficiencies.

The value of micronutrients in the fortification of humanitarian food-aid cannot be overstated. The World Health Organization (WHO) estimates that one-third of the world's population is affected by vitamin and mineral deficiencies (World Health Organization, 2006). Micronutrient deficiencies can result in impaired growth and cognitive development, poor immune response, loss of energy and productivity, and increased morbidity and mortality. A joint Micronutrient Initiative (MI)/United Nations Children's Fund (UNICEF) report estimated that on an annual basis, inadequate intake of key micronutrients results in the deaths of more than one million children, 250,000 birth defects, and the deaths of approximately 50,000 young women during pregnancy and childbirth (Micronutrient Initiative and United Nations Children's Fund, 2005). Humanitarian food-aid is typically distributed to those at greatest risk of micronutrient deficiency. Furthermore, such food assistance often constitutes a significant percentage of beneficiaries' total diet. It is imperative, therefore, that distributed food-aid delivers the range of micronutrients needed at appropriate levels. While the fortification of cereals at the time of manufacture is an important step in delivering essential micronutrients to vulnerable populations, it alone does not insure adequate vitamin delivery at the time of consumption by the end user. Most foods undergo thermal processing of one sort or another before they are consumed, and this processing potentially affects many nutrients (Burlingame, 2006).

Ranum and Chome (1997) observed minimal retention of vitamin C in samples collected from home preparations of CSB in Tanzania, with five of nine samples having vitamin C levels below detectable limits. Atwood et al. (1995) studied the stability of vitamin A used in fortified CSB and VO and found losses of 0–25%, depending on heating time. CSB, however, is fortified with 11 vitamins to provide a more complete response to various micronutrient deficiencies. No research has been conducted on the cook-stability of the other vitamins present in CSB; nor was the

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level of vitamin A uptake during frying quantified in the finished product, when using fortified VO as a frying medium.

Rubin et al. (1977) reported good retention of thiamin, riboflavin, pyridoxine, niacin, and folic acid in fortified cornmeal after cooking; a slight loss of vitamin A, however, was observed. It should be noted that the cornmeal used in the study was not cornmeal distributed for programmed food-aid and preparation methods were not necessarily typical of those used by food-aid beneficiaries. No published research has investigated the stability of vitamins present in bulgur or closely related soy-fortified bulgur (SFB) during typical preparation methods. While general trends in vitamin stability are available (Leskova et al., 2006), generalized conclusions on vitamin stability are oversimplifications that may not represent stability under all circumstances (Gregory, 1996).

The objective of this study was to determine the stability of vitamins added to CSB, CM, SFB, and VO, as well as the degree of absorption of vitamin A in fried products prepared with fortified VO, as affected by typical food preparation methods used by beneficiaries in the field.

2. Materials and methods

2.1. Observation of typical commodity preparation methods

Prior to undertaking the laboratory work reported in this study, field work was carried out to determine the typical methods used by beneficiaries to prepare the commodities being evaluated. Detailed data collected from the field study has been published previously (Rowe et al., 2008). USAID food-aid distribution data from fiscal year 2004 was used to evaluate overall commodity distribution levels in countries receiving food-aid from the United States (U.S. Department of Agriculture, Foreign Agricultural Service, 2004). Based on the availability of cooperating, in-country, private voluntary organizations (PVO) and travel feasibility and safety, three countries were chosen for the field studies: Guatemala (representing Latin America), Malawi (representing Southern Africa), and Uganda (representing East Africa).

The field studies were carried out in July and August, 2005. Commodity preparation data was collected from over 100 households and two wet-feeding sites in 32 different villages spread across different regions of the three countries evaluated.

Both interview data and observational data were collected at each site visited (data not shown). Interview questions related to household demographics, commodity utilization and storage, water sources used, and quality concerns with the commodities. Observational data was collected as the food-aid commodities were actually being prepared for consumption, and included specific mass and/or volume of ingredients used, cook times and temperatures, cooking vessels used, and other preparation details. The field study was approved by the Brigham Young University Institutional Review Board for Human Subjects and beneficiaries provided informed consent.

A wide variety of product preparations were observed for the different commodities; however, due to resource constraints only the most widely prepared and consumed product for each commodity was selected for laboratory simulation. Product preparations simulated in the laboratory included: a thin, drinkable CSB porridge; a thick, spoonable CM porridge or mush; a thick, spoonable SFB porridge (mush); and dumplings made from unfortified CSB and fried in fortified VO. In order to quantify the vitamin A being absorbed from the VO, a specially prepared batch of unfortified CSB was used for the dough. For a given product, the average formulation, and average cook times and temperatures observed in the field study were simulated in the lab. Details of these preparation methods, including formulations, times, and temperatures are described hereafter.

2.2. Fortified commodities

All commodities were procured from commercial production runs of suppliers filling USAID orders. Product in unopened industrial packaging, as shipped to PVO sites, was obtained from each of two different commercial lots for each commodity evaluated.

CSB was shipped in 25 kg bags from Bunge Milling, Inc. in Danville, IL. CSB is composed of cornmeal, processed and gelatinized (69.6%, w/w); soy flour, defatted and toasted (21.9%, w/w); soybean oil, refined, deodorized, stabilized (5.5%, w/w); minerals (3.0%, w/w); and vitamin–antioxidant (BHA/BHT) premix (0.1%, w/w). CSB is fortified with calcium, zinc, iron, magnesium, iodine, thiamin, riboflavin, pyridoxine hydrochloride, niacin, pantothenate, folic acid, vitamin B12, vitamin A palmitate, vitamin D, alpha-tocopherol acetate, and ascorbic acid in a dry blended premix (U.S. Department of Agriculture, 2006a). Unfortified CSB, separated prior to enrichment, was also provided by Bunge Milling, Inc. in a 10 kg bag.

CM was shipped in 25 kg bags from Bunge Milling, Inc., in Atchison, KS. CM is composed of yellow corn, which has been shelled, dehulled, degermed, ground and fortified with a dry-blended premix containing folic acid, thiamin, riboflavin, niacin, vitamin A, calcium, and iron (U.S. Department of Agriculture, 2005b).

SFB was shipped in 50 kg bags from Bunge Milling, Inc., in Crete, NE. SFB is composed of 85% bulgur and 15% soy grits and is fortified with folic acid, thiamin, riboflavin, niacin, vitamin A, calcium, and iron in a dry blended premix (U.S. Department of Agriculture, 2005a).

VO (soy) was shipped in 4-L steel cans from each of two commercial production lots provided by Lake Charles Food Products, LLC, in Lake Charles, LA. The oil source in fortified VO is typically soybean, and it is fortified with retinol palmitate (U.S. Department of Agriculture, 2006b).

2.3. Experimental design

Product from the separate CSB, SFB, and CM lots was mixed for 2 min using a Patterson-Kelly Co. Twin Shell Dry Blender (V-blender) to insure homogeneity. Two sub-samples were then taken from each lot (a total of 4 samples per commodity) and each was prepared according to field study commodity preparation averages for ingredient mass/volume and cook times/temperatures. Vitamin analysis of pre- and post-cook samples (1 analysis per sample) was conducted by Covance Laboratories, Madison, WI. Moisture analysis was also performed in conjunction with vitamin analysis to allow for the comparison of vitamin content on a dry weight basis. Differences in vitamin content between pre- and post-cook samples were compared statistically using a paired *t*-test ($\alpha = 0.05$).

2.4. Preparation methods

Cooking observed in the field study was typically done in an aluminum pot on a wood burning fire. In this study, a gas stove was used to provide heat from an open flame at a consistent level. While heating differences between a wood fire and gas stove may exist, come-up times were closely regulated to simulate those observed in the field. All commodities were cooked in 7.1 L aluminum pots.

2.4.1. *Corn–soy blend thin porridge*

Tap water (2490 mL) was heated to 67 °C and 415 g of CSB was stirred in by hand using a wooden spoon. This mixture was brought to the boil 4 min after the CSB had been added. During boiling, the porridge was kept between 94 and 95 °C until it was removed from the heat, 26 min after CSB addition. The porridge was allowed to cool at room temperature until it reached 70 °C (consumption temperature for an adult), at which point a 200 g sample was removed, placed in a plastic sample bag and held at −23 °C until vitamin analysis.

Preliminary studies indicated that vitamins C and E in cooked CSB samples were adversely affected by frozen storage prior to analysis. Consequently, CSB porridge samples for vitamins C and E analysis were prepared at Covance Laboratories for each CSB lot, according to the protocol described above with the freezing step omitted. Vitamin extraction and analysis was initiated immediately after the sample had cooled to 70 °C.

2.4.2. *Cornmeal thick porridge*

The typical preparation of thick CM porridge (mush) in the field involved two separate CM additions. In the laboratory, the first addition weighed 200 g and was added to 2048 mL tap water previously heated to 73 °C. This mixture was brought to the boil 4 min after the CM addition, and maintained between 90 and 94 °C for 5 min. Nine minutes after the initial CM was added, an additional 440 g CM was added to the porridge. As more CM was added, the porridge temperature typically dropped to 80–84 °C. The CM porridge was removed from the heat 13 min after the initial CM addition, with a final temperature ranging from 83 to 87 °C. The porridge was then cooled at room temperature to 70 °C, at which point 200 g samples were removed and held at −23 °C until vitamin analysis.

2.4.3. *SFB thick porridge*

SFB (437 g) was added to 1200 mL boiling tap water. This mixture was cooked for 10 min, during which time the temperature was maintained between 91 and 95 °C. After 10 min, the SFB porridge was removed from the heat and cooled at room temperature to 70 °C. Samples (200 g) were then removed and held at −23 °C until vitamin analysis.

2.4.4. *Dumplings fried in vitamin A-fortified vegetable oil*

Unfortified CSB (189 g) was mixed by hand with 214 g tap water to make a dough, which was then separated into 15 g balls. These balls were rolled to a height of 7 mm using wooden guide sticks. Four hundred milliliters fortified VO, reaching a depth of 1 cm in the frying pan, was heated to 185 °C. Dumplings were added to this oil and fried for 4 min (2 min on each side). The VO temperature dropped after the addition of the dumplings and was maintained between 164 and 177 °C. After 4 min of frying, the dumplings were removed from the VO, cooled at room temperature to 70 °C and a 200 g sample was taken and held at −23 °C until vitamin analysis. After the removal of the dumplings, the remaining VO was cooled to room temperature and a 200 g sample was stored at −23 °C until vitamin analysis.

2.5. *Vitamin, moisture, and fat analysis*

Frozen samples were shipped by overnight courier to Covance Laboratories for micronutrient analysis. All analyses were completed within 8 days of sample collection.

For CSB thin porridge, vitamin A (retinol), vitamin C, vitamin E (as alpha-tocopherol), thiamin, pyridoxine hydrochloride, folic acid, riboflavin, vitamin B12, pantothenic acid, and moisture were analyzed in the frozen samples. Vitamins C and E were also measured in the unfrozen CSB porridge prepared by Covance. For CM and SFB thick porridges, vitamin A, thiamin, folic acid, riboflavin, and moisture were analyzed. For the VO fried dumplings, vitamin A, moisture, and fat were analyzed; vitamin A was also analyzed in the used oil.

Vitamin, moisture, and fat contents were quantified using AOAC (2005) and other published methods. Vitamin A was measured according to AOAC methods 974.29, 992.04, and 992.06 and the method of Thompson and Duval (1989). Vitamin E was measured according to the methods of Cort et al. (1983), Speek et al. (1985), and McMurray et al. (1980). Vitamin C was measured according to AOAC method 967.22 and thiamin according to AOAC methods 942.23, 953.17, and 957.17. Pyridoxine hydrochloride was measured by the AOAC method 961.15. Folic acid was measured according to AOAC methods 960.46 and 992.05. Riboflavin was measured by AOAC methods 940.33 and 960.46. Vitamin B12 was measured by AOAC methods 952.20 and 960.46. Pantothenic acid was measured using AOAC methods 945.74 and 960.46. Moisture was measured by the 925.09 and 926.08 AOAC methods and fat by the 922.06 and 954.02 AOAC methods.

Niacin, which is considered extremely stable in these types of cooking matrices and preparation conditions (Ball, 2006), was not analyzed in any of the commodities evaluated.

3. Results and discussion

3.1. *Corn–soy blend thin porridge*

The majority of the vitamins used to fortify CSB remained stable during the preparation of thin porridge. Thiamin, folic acid, riboflavin, pantothenic acid, and pyridoxine showed no significant difference in pre- and post-cook levels (Table 1). Statistically significant increases in vitamins A and B12 were observed. However, these increases, 48.1 μg vitamin A/100 g (dry weight) porridge and 0.02 μg vitamin B12/100 g porridge (dry weight), are probably related to analytical or sampling variation and are not considered practically significant. Significant losses of vitamins C (53%, w/w) and E (18%, w/w) were observed in the cooked porridge.

Vitamin C is known to be extremely labile in a neutral pH, liquid matrix. Cooking losses depend on the degree of heating, surface area exposed to water and oxygen, pH, presence of transition metals, and other factors that facilitate oxidation (Eitenmiller and Landen, 1999). It is not uncommon for vitamin C cooking losses to reach 100% (Gregory, 1996). Ranum and Chome (1997) observed vitamin C levels below detectable limits in five of nine cooked CSB samples collected in the field.

Vitamin E is also known to be highly labile under typical preparation practices. In their review, Leskova et al. (2006)

Table 1
Vitamin and moisture content of dry commodity and thin porridge prepared from fortified corn–soy blend expressed per/100 g.[a]

Analyte	Pre-cook	Post-cook
Moisture (g)	7.4 ± 0.10	83.3 ± 0.38
Vitamin C (mg)	31.6 ± 5.0a	14.9 ± 3.0b
Vitamin E (mg)	7.9 ± 0.38a	6.48 ± 0.38b
Thiamin (mg)	0.48 ± 0.06a	0.42 ± 0.01a
Folic acid (μg)	336 ± 15.9a	332 ± 28.8a
Riboflavin (mg)	0.74 ± 0.02a	0.66 ± 0.06a
Vitamin B12 (μg)	0.14 ± 0.02a	0.16 ± 0.02b
Pantothenic acid (mg)	4.2 ± 0.28a	3.7 ± 0.41a
Vitamin A (μg)	547 ± 16.8a	595 ± 15.0b
Pyridoxine HCl (mg)	0.87 ± 0.07a	0.95 ± 0.05a

Like letters within rows indicate no significant difference ($p > 0.05$).

[a] Values are mean ± standard deviation ($n = 4$). Vitamin values are reported on a dry weight basis.

indicated that high losses of vitamin E could result from common heat treatments. Eitenmiller and Landen (1999) reported that oxidative losses of vitamin E can become substantial quite rapidly, and losses are accelerated by heat, various metals (primarily iron and copper), and by the presence of free radicals in the lipid fractions that can initiate autoxidation. These findings indicate the potential instability of vitamin E during the cooking of a fortified cereal blend such as CSB. Nevertheless, the results of this study indicate that 82% of the vitamin E originally present in CSB would still be available at the time of consumption.

The stability of vitamin A in CSB reported in this study is supported by the work of Atwood et al. (1995), who also observed good stability with an overall increase (109%) in vitamin A during initial cooking. However, after cooking for 30 min, the authors reported a 25% loss.

No other comparable research on the stability of vitamins during the cooking of CSB has been published; although stability of thiamin, riboflavin, pyridoxine, and folic acid was found to be good during cooking of fortified cornmeal (Rubin et al., 1977), a major component of CSB.

While no literature has been published on the stability of pantothenic acid and vitamin B12 in matrices closely related to CSB, the observed stability of these vitamins in this study are supported by other general trends. Leskova et al. (2006) noted that pantothenic acid is quite resistant to heat at pH 5–7 (the pH of CSB porridge falls in this range), though it is sensitive to extended cooking in water. Vitamin B12 is generally considered to be stable under most food processing conditions (Ottaway, 2002).

3.2. Cornmeal thick porridge

In CM thick porridge, all of the vitamins used in fortification remained stable during cooking (Table 2). Thiamin, folic acid, riboflavin, and vitamin A showed no significant differences between pre- and post-cook levels. The findings of Rubin et al. (1977) concur with these CM vitamin stability results, with the exception that a 10–15% loss in vitamin A was reported in their study. The greater vitamin A stability exhibited during cooking of CM in this present study is possibly due to its encapsulation, as required by the USDA specification for the premix.

3.3. Soy-fortified bulgur thick porridge

Traditional preparation of SFB resulted in no statistically significant changes in thiamin, riboflavin, and folic acid when comparing pre- and post-cook levels. However, vitamin A was significantly reduced during cooking, exhibiting a 33% (w/w) loss from initial levels (Table 3).

As with CSB, SFB is rarely used for purposes other than humanitarian food-aid and there is little published literature on vitamin stability in this matrix. However, the results presented here concur with general stability trends. Thiamin, for example, is generally stable except in alkaline conditions (Leskova et al., 2006). Riboflavin is resistant to dry heat and air, but highly sensitive to light (Leskova et al., 2006). Riboflavin losses have been reported, however, after lengthy boiling (Maskova et al., 1996). Folic acid is sensitive to oxygen and heating in acidic solutions, and losses during cooking typically result from decomposition during extended heating (Leskova et al., 2006). It appears that typical preparation methods are not severe enough to cause such losses of riboflavin or folic acid in cooked SFB.

Table 2
Vitamin and moisture content of dry commodity and thick porridge prepared from fortified cornmeal expressed per/100 g.[a]

Analyte	Pre-cook	Post-cook
Moisture (g)	9.9 ± 0.19	74.7 ± 0.56
Thiamin (mg)	0.71 ± 0.1a	0.80 ± 0.2a
Folic acid (μg)	201 ± 29.9a	229 ± 17.7a
Riboflavin (mg)	0.45 ± 0.02a	0.45 ± 0.03a
Vitamin A (μg)	988 ± 138.1a	1033 ± 126.1a

Like letters within rows indicate no significant difference ($p > 0.05$).

[a] Values are mean ± standard deviation ($n = 4$). Vitamin values are reported on a dry weight basis.

Table 3
Vitamin and moisture content of dry commodity and thick porridge prepared from fortified soy-fortified bulgur expressed per/100 g.[a]

Analyte	Pre-cook	Post-cook
Moisture (g)	7.4 ± 0.08	67.2 ± 0.70
Thiamin (mg)	0.71 ± 0.06a	0.61 ± 0.02a
Folic acid (μg)	221 ± 48.1a	250 ± 21.7a
Riboflavin (mg)	0.55 ± 0.09a	0.56 ± 0.1a
Vitamin A (μg)	673 ± 114.1a	454 ± 111.1b

Like letters within rows indicate no significant difference ($p > 0.05$).

[a] Values are mean ± standard deviation ($n = 4$). Vitamin values are reported on a dry weight basis.

The significant loss of vitamin A in cooked SFB was unexpected, given the stability of this nutrient in CSB. Generally, vitamin A is stable in an inert atmosphere; however, it can rapidly lose activity when heated in the presence of oxygen, especially at higher temperatures (Leskova et al., 2006). Atwood et al. (1995) concluded that the stability of vitamin A in CSB is highly variable, suggesting that the observed variability could be related to the fortificant itself, the mixing process, distribution of the antioxidants, and/or the presence of degradative factors in soy and corn flours. These same factors could play a role in the stability of vitamin A in SFB. Manufacturing records for the commodities utilized in this study indicate that the micronutrient premixes used in CSB and SFB were obtained from different suppliers. It is possible that the differences in supplier encapsulation technologies may have contributed to the reduced stability of vitamin A in SFB.

3.4. Vitamin A-fortified vegetable oil fried dumplings

As noted previously, the most common use of VO observed in the field was as a frying medium. Therefore, the objectives of this study were to evaluate the degree of uptake of vitamin A in the fried food during the frying process; and to assess the loss of vitamin A in the oil during frying.

Vitamin A analysis of unfortified CSB dough before and after frying indicated that there was a significant uptake of fat and vitamin A by the dough during frying (Table 4). This transfer of vitamin A from oil to finished product was also observed by Simonne and Eitenmiller (1998), who found that retinyl palmitate concentrations increased in chicken nuggets and breaded shrimp fried in retinyl palmitate fortified oil.

Table 4
Effect of frying on composition of unfortified corn–soy blend dumplings cooked in fortified vegetable oil expressed per/100 g.[a]

Analyte	Uncooked dough	Fried dumplings
Moisture (g)	56.0 ± 0.22	34.9 ± 0.58
Fat (g)	11.5 ± 0.5a	33.0 ± 2.1b
Vitamin A (μg)	nd[a]	466 ± 39.0b

Like letters within rows indicate no significant difference ($p > 0.05$). nd = not detectable.

[a] Values are mean ± standard deviation ($n = 4$). Vitamin values are reported on a dry weight basis.

A small, but statistically significant loss (6%, w/w) of vitamin A was found in the frying oil after one frying cycle. Vitamin A content dropped from 17.3 μg/g in fresh oil to 16.2 μg/g in fried oil. These results concur with the findings of Atwood et al. (1995), who found that the vitamin A content in oil decreased by 7% after 15 min of heating and by 10% after 30 min of heating.

4. Conclusions

The results of this study indicate that typical preparation conditions used by food-aid beneficiaries have little effect on the stability of most vitamins present in CSB, CM, SFB, and VO. With the exception of vitamins C and E in CSB and vitamin A in SFB and used VO, no vitamins showed significant losses after cooking.

Some possibilities for improving nutrient delivery in humanitarian food-aid commodities as consumed include recommending shorter cook times (with educational support from distributing PVOs), increased vitamin overages, or enhanced vitamin encapsulation. Because of the high cost of fortification and vitamin encapsulation, it appears that the most cost-effective solution for preventing vitamin loss may be the use of reduced cook times by end-users. Additional work is needed to determine the effect of different cooking times and temperatures on vitamins C and E in CSB, a critically important commodity widely used for complementary feeding and critical care situations. If milder conditions are found to improve post-cooking retention of vitamins C and E, effective training of end-users on proper cooking procedures could improve micronutrient delivery.

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