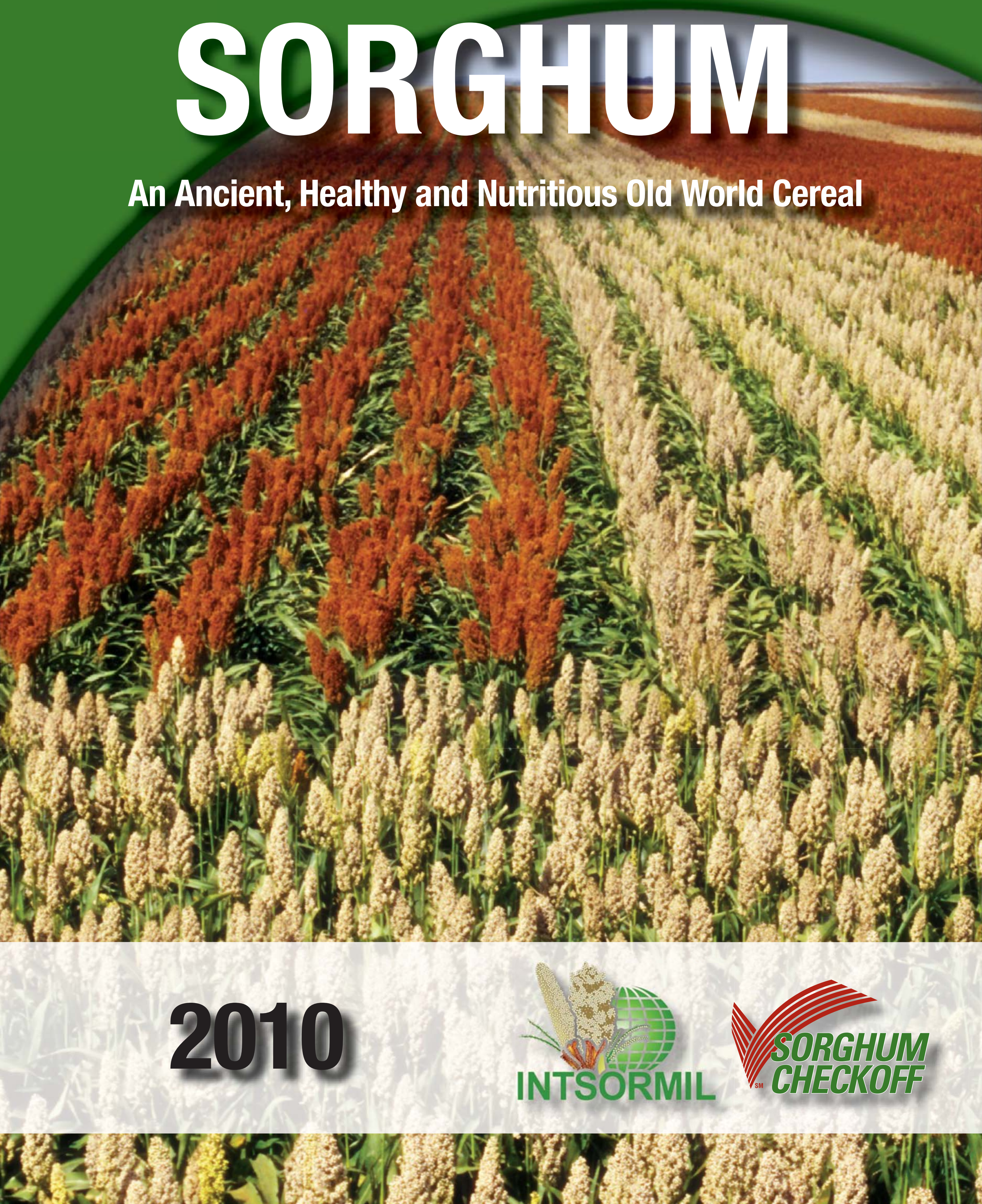
SORGHUM

An Ancient, Healthy and Nutritious Old World Cereal



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SORGHUM CHECKOFF

Sorghum: An Ancient, Healthy and Nutritious Old World Cereal
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Introduction

Sorghum is Africa's contribution to the small number of elite grains that supply about 85% of the world's food energy. Only four other foods rice, wheat, maize, and potatoes are consumed in greater amounts by the human race. Sorghum is the dietary staple of more than 500 million people in more than 30 countries of the semi arid tropics, thus being one of the most familiar foods in the world (Board on Science and Technology for International Development, 1996). Sorghum is a truly ancient grain. Dahlberg and Wasylikowa (1996) reported on sorghum remains found in the Nabta Playa archaeological site in the Western Desert, southern Egypt dating back to 8000 B.C.E.

Sorghum is valued for its grain, stalks and leaves. Many people in the U. S. are familiar with sorghum for the syrup made from the sweet juice in stalks of certain sorghum varieties or for the use of sorghum in silage or for pastures. Sorghum is used extensively worldwide in food production systems (Rooney and Waniska, 2000). In food aid programs the emphasis is on grain sorghum, with particular emphasis on the white and hybrid varieties, as listed in the USAID Commodity Reference Guide (CRG).

The U.S. has promoted "Food Grade Sorghums" as a white colored grain grown on a "tan" plant that produces light colored glumes that can be used to easily produce a white, bland flour. In other parts of the world, all types and colors of sorghum are used to produce various types of traditional foods and beverages. Unfermented bread, such as chapatti and roti are common in India, while tortillas are made from sorghum in Central America and Mexico. Fermented breads such as kisra and dosa are found in Africa, Sudan, and India, while injera is popular in Ethiopia. Stiff porridges called ugali, tuwo, karo, and mato are found throughout Africa, India and Central America, while thin porridges such as ogi, koko, and akasa can be found in Nigeria and Ghana. Couscous from sorghum can be found throughout West Africa, and boiled whole or pearled sorghums are consumed in Africa, India, and Haiti. Worldwide, snack foods are produced from sorghum and can be found in the markets of Japan. All types of alcoholic beverages and sour/opaque beers can be found in markets worldwide.

In Africa, the major staple foods are cassava (118 million tons), maize (53 million tons), yam (50 million tons), sorghum (25 million tons), plantains (24 million tons), rice (23 million tons), wheat (21 million tons), millet (20 million tons), sweet potato (14 million tons), and bananas (12 million tons) (FAOSTAT, 2008). Among these staples, however, sorghum occupies a unique position due to its hardiness as a crop. Sorghum is particularly unique in that it grows in both temperate and arid climates. It is photosynthetically efficient because it is a C4 plant (plants that use the C4 carbon fixation pathway), rapidly maturing and may provide more than one harvest per year (Board on Science and Technology for International Development, 1996).

Sorghum is drought-tolerant and resistant to water-logging (Doggett, 1988), and grows in various soil conditions (Dillon, et al. 2007). These characteristics contribute toward it being the staple crop of Africa's most food-insecure people, who live in the desert-margin, semiarid tropics—about 300 million people. Like maize, sorghum does not have a true hull or husk (Taylor, 2003). Because of its similarity to maize (hard and floury endosperm and large fat-rich germ), sorghum can be processed using technologies of dry and wet milling applied to maize (Taylor, 2003). The recent elucidation of the genome sequence will enhance future production and nutritional quality of sorghum (ICRISAT, 2009).

If sorghum is so well known and accepted in Africa, why is it not more available to alleviate hunger in African populations? Some researchers (Board on Science and Technology for International Development, 1996) say part of the problem is that sorghum has not been developed into products for major urban areas, and thus lacks markets. In Africa, it remains mostly a crop of small cultivators and is consumed locally where it was grown. A consumption restraint has been the lack of commercially available foods such as flours, breads, cereals and other products for those who are not farmers and who cannot devote time to making flour from sorghum grain. However, the urban marketplace is changing as the food industry is beginning to develop and sell sorghum products.

Sorghum has the added advantage of being inherently gluten-free and has been demonstrated to be safe for people with celiac disease (Ciacci et al. 2007), therefore a benefit for those with celiac sprue or possibly other gastrointestinal disorders. Gluten enteropathy or celiac disease is caused by sensitivity of the gut to the grain storage protein, gluten. Gluten is a component of wheat, and gluten-like proteins are found in oats, barley and rye that are also toxic. Diarrhea occurs in 70% of patients usually up to 3-4 times per day (Connon, 1994) with nutrient and fluid losses. Celiac disease results in malabsorption of nutrients and thus weight loss in many patients. In an already nutritionally vulnerable person, celiac disease can be devastating. The treatment for individuals with celiac disease is to avoid all foods containing gluten (Thompson, 2000).

Nutritional Contributions of Sorghum

Nutrient Values for Sorghum

The USAID CRG and USDA Database have many missing values for the nutrients in sorghum. Efforts are underway to correct the impression that nutrient data is not available. Various tables in this paper display the existing USDA or USAID CRG nutrient values with additional data from published sources as noted on each table. One problem is that the USAID CRG ***PDF download-version*** of sorghum contains incorrect nutrient data. Another problem is that the USAID CRG nutrient data for sorghum-soy fortified is incorrect. The sorghum-soy fortified commodity does not include the inherent value of sorghum and soy added to the fortification nutrients (personal communications, USAID, S. Moody, 2010). One should be aware of these sorghum USAID CRG errors for diet planning purposes.

In many countries where populations are food-insecure, residents know how to use sorghum and they readily accept it in their diets. Sorghum is an excellent source of energy, mainly in the form of complex carbohydrate. Complex carbohydrate (fibers, starches) is usually slowly digested and therefore provides satiety and delayed hunger. Grain sorghum contains more fat than wheat, rice and cassava and about the same percent of protein as other grains. Table 1 shows how 100 g of Commodity Sorghum (USAID CRG, 2010) meets the World Health Organization (WHO) Recommended Nutrient Intakes (RNI) for three different age categories of children up to age 9 years (FAO/WHO 1998, 2001, 2007). The assumption in Table 1 is that over a day, at least 100 g or about 3 oz of grain sorghum is consumed.

Micronutrients: Rich in Sorghum

The eleven nutrients in commodity sorghum shown in Table 1 considered *good* or *excellent* sources in meeting the WHO RNI or the US RDA (2001) are highlighted in green with all but one of the highlighted values in the *excellent source* category for all age groups. Across the three age categories, eleven critical nutrients are present in amounts ranging from16% (Table 1) to 245% (footnote, Table 1) of the WHO RNI or US RDA, nine of which are micronutrients.

The WHO does not suggest RNI amounts for manganese or copper, but the Food and Nutrition Board of the National Academy of Sciences (2001) does provide a Recommended Dietary Allowance (RDA) of 1.5 mg and 440 mcg for children ages 4-8 years for manganese and copper respectively. Using the US RDA of 1.5 mg for manganese and 440 mcg for copper, the percent of RDA for children 4-8 years of age for manganese (sorghum =1.63 mg/100g) is 92% and for copper (sorghum = 1080 mcg/100g) is 245%. Adequate dietary copper is essential for the proper metabolism of iron, thus both dietary iron and copper play a major role in preventing anemia, a serious problem in developing countries.

Iron and zinc are two of the four micronutrients (iron, zinc, iodine and vitamin A) identified by the Committee on Micronutrient Deficiencies (1998) as limiting in developing countries. Sorghum is an excellent source of both iron and zinc, even when calculated at 10% bioavailability for iron and moderate bioavailability for zinc.

Sorghum is rich in B-complex vitamins. The B-complex vitamins play key roles in energy metabolism. Sorghum's high-energy content and ready supply of B-complex vitamins are a perfect combination for energy utilization. Sorghum is rich in thiamin, riboflavin, niacin, pantothenate, and vitamin B-6. For children ages 1-9 years, sorghum provides 47 to 26% of the WHO RNI recommendations for thiamin, 28 to 16% for riboflavin, 49 to 24% for niacin, 63 to 31% for pantothenate, and 118 to 59% for vitamin B-6. The highlighted values in Table 1 show how rich sorghum is in essential nutrients. Sorghum provides eleven essential nutrients in the *good to excellent* category, nine of which are micronutrients.

Evaluating foods in forms *as eaten* is the most reliable approach for determining bioavailability. Iron, zinc and copper content and extractable iron, zinc and copper in sorghum flour and *as eaten* in fermented bread (injera) were analyzed by Mohammed et al. (2010). They reported the iron, zinc and copper content for sorghum flour as 2.24 mg/100 g, 0.75 mg/100 g and 0.61 mg/100 g and the extractable iron, zinc and copper as 34%, 52% and 34% respectively. For the fermented injera on a dry basis, the iron, zinc and copper content amounts were 3.95 mg/100 g, 0.64 mg/100 g and 0.61 mg/100 g and the extractable amounts were 34%, 62% and 38% respectively. These data are specific for the Tabat sorghum variety (Mohammed et al. 2010). Other varieties may show different mineral levels and bioavailability due to variety, geographic region cultivated and other methods of processing. However, Mohammed et al.'s (2010) finding that fermentation may increase mineral bioavailability is useful in countries where fermented foods are widely eaten.

Table 1
Commodity sorghum compared to the WHO RNI of children ages 1-9 years

Nutrient	Unit	Sorghum 100 g	RNI 1-3 y	%RNI 1-3 y	RNI 4-6 y	%RNI 4-6 y	RNI 7-9 y	%RNI 7-9 y
Energy	kcal	339.0	997	34	1301	26	1629	21
Protein	g	11.3	12.25	92	16.65	68	26.05	43
Total Fat	g	3.3						
Carbohydrate	g	74.6						
Fiber°	g	2.7						
Calcium	mg	28	500	6	600	5	700	4
Iron*	mg	4.4	5.8	73	6.3	70	8.9	49
Magnesium°	mg	0.19	60	<1	76	<1	100	<1
Phosphorus	mg	287						
Potassium	mg	350						
Sodium	mg	6						
Zinc* °	mg	1.54	4.1	38	4.8	32	5.6	28
Copper°	mg	1.08		**		**		**
Manganese°	mg	1.63		**		**		**
Iodine	ug	n/a	90		90		120	
Selenium∞	mcg	trace	17	<1	22	<1	21	<1
Vitamin C∂	mg	2	30	<1	30	<1	36	<1
Thiamin	mg	0.237	0.5	47	0.6	40	0.9	26
Riboflavin	mg	0.142	0.5	28	0.6	24	0.9	16
Niacin	mg	2.927	6.0	49	8.0	37	12.0	24
Pantothenate°	mg	1.25	2.0	63	3.0	42	4.0	31
Vitamin B-6°	mg	0.59	0.5	118	0.6	98	1.0	59
Folate, total°	mcg	0.02	150	<1	200	<1	300	<1
Vitamin B-12	mcg	0	0.9	0	1.2	0	1.8	0
Biotin	ug	n/a	8.0		12.0		20.0	
Vitamin A∂	IU	16	1333	1	1500	<1	1666	<1
Vitamin D	ug	n/a	5		5		5	
Vitamin E a-TE°	mg	1.2	5	<1	5	<1	7	<1
Vitamin K	mcg	n/a	15		20		25	

FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements. 1998.
FAO/WHO/UNU Report of a Joint Expert Consultation on Human Energy Requirements. 2001
WHO/FAO/UNU. Protein and Amino Acid Requirements in Human Nutrition. 2007
Nutrient Data from Commodity Reference Guide, with additional published sorghum data as noted.
° Waniska and Rooney (2000)
∞ Neucere and Sumrell (1980)
∂ Barrow-Agee Laboratories, LLC, Memphis, TN (2010)
* Iron RNI based on 10% bioavailability; Zinc RNI based on moderate bioavailability.
n/a = not applicable or not available
Good source = 10-19% of RNI; Excellent source = > 20% of RNI
** Using the US RDA of 1.5 mg for copper and 440 mcg for manganese, the percent of RDA for children 4-8 years of age for manganese (1.63 mg/100g) is 92% and for copper (1080 mcg) is 245%.

The Special Role of Carbohydrates in Diets and Sorghum

For the first time in 2002, the Food and Nutrition Board (2002) of the Institute of Medicine (IOM) published Recommendations for all macronutrients. The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate, protein and fat were determined as a percent of total kilocalories needed to maintain body weight. The AMDR for carbohydrate was set at 45 to 65% of kilocalories for ages from one year to > 70 years. This is particularly relevant to sorghum with its 75% carbohydrate content. The minimum amount of carbohydrate of 130 grams (520 kilocalories) per day was recommended for both children and adults, as this amount is needed to produce glucose, primarily for brain function. The Food and Nutrition Board (2002) stated that at least 50% of the carbohydrate should be derived from complex carbohydrate sources and no more than 25% of carbohydrate should come from added sugars. The carbohydrate recommendations were reconfirmed by the recent Report of the Dietary Guidelines Advisory Committee on the Dietary Guidelines for Americans (2010). The 2010 Dietary Guidelines recommended more whole grains within the recommended carbohydrate amount while keeping the overall AMDR recommendation for carbohydrate the same.

The importance of carbohydrate is that the first and most compelling need of the body is for energy. If adequate dietary calories are lacking, the relatively small amount of recommended protein [5-35% = AMDR for protein (2002)] may be utilized for energy, thus preventing protein's amino acids from being used for growth, repair and maintenance.

Protein in Sorghum

There are questions regarding the percent of protein requirements that are met by sorghum due to varying protein digestibility values derived by varying methods. Upon wet cooking, sorghum protein digestibilities range from 36.4 to 74% as reported by Henley et al. (2010). Arguing that a pepsin digestion model was preferred, Mertz et al. (1984) reported digestibility values up to 79% for decorticated/extruded sorghum (variety 954062). Researchers disagree regarding the best model for determining protein digestibility for sorghum since some say that rat models are not suitable for evaluating sorghum for human nutrition. For food label protein claims, the U.S. Food and Drug Administration (FDA) requires true-digestibility studies using rats for determination of protein quality via Protein Digestibility Corrected Amino Acid Score (PDCAAS) (Henley and Kuster, 1994).

Research, both in breeding and processing is ongoing to improve the bioavailability of lysine, the limiting amino acid in ***all grains***, and the amino acid in grains that determines their PDCAAS. Fermented foods are popular in many African countries thus Mohammed et al. (2010) evaluated the nutritional effects of processing sorghum flour into injera, a popular fermented bread. Mohammed et al. (2010) analyzed amino acids and conducted *in vitro* (pepsin) protein digestibility during injera processing and found that fermentation improved both. Dietary diversity (and adequate kilocalories), such as the addition of pulses or beans to grain-based diets insures adequate protein. Sorghum with its carbohydrate/high-energy value and high amounts of B-complex vitamins helps insure that its inherent protein and other dietary protein is spared and used for protein's needed functions.

Commodity Sorghum Grits, Soy-Fortified

Food aid professionals may designate "commodity sorghum grits, soy-fortified" in emergency programs where populations are at risk for both protein and micronutrient deficiencies. The micronutrient enriched soy-fortified sorghum is 85% grain sorghum grits and 15% soybeans (cracked, defatted, roasted). The protein content of 100 g of commodity sorghum grits, soy-fortified is 17.3% compared to 11.3% for commodity sorghum. Table 2 shows the nutrient content of commodity sorghum, sorghum-soy-fortified and soy-fortified cornmeal that is another commodity grain. Table 3 shows how the enriched soy-fortified sorghum meets protein requirements for children of three different age categories one year to nine years of age (FAO/WHO, 1998, 2001, 2007). The sorghum grits-soy fortified product fits well within the ARMD for protein.

The micronutrient values for sorghum grits-soy fortified shown in Table 2 and sorghum grits-soy fortified in Table 3 are **under-reported** since the USAID CRG shows only values for the added enrichment micronutrients rather than the sum of the enrichment nutrients plus the inherent nutrients of the 85% sorghum/15% soy product (personal communications, USAID, S. Moody, 2010). Table 3 nutrients meeting either good or excellent sources are highlighted in green. The percentages would be higher if the true nutrient values (inherent + added) were compared to nutrient requirements.

A comparison of Table 1 showing sorghum's nutrient % contributions to children's diets with Table 3 showing sorghum-soy's nutrient % contributions to children's diets demonstrates the need for including the inherent nutrient content of the 85% sorghum grits + the 15% soy flakes in diet planning.

Table 2
Nutrient Comparison of sorghum; sorghum grits-soy fortified; & cornmeal-soy fortified

Nutrient	Unit	Sorghum* 100 g	Sorghum** 100 g	Sorghum grits, soy-fortified 85/15 100g	Cornmeal, soy-fortified 85/15 100g
Energy	kcal	339.0	339.0	337.2	360.2
Protein	g	11.3	11.3	17.3	14.9
Total Fat	g	3.3	3.3	3	1.6
Carbohydrate	g	74.6	74.6	68.5	71.1
Fiber°	g	n/a	2.7	n/a	8.92
Calcium	mg	28	28	110	110
Iron	mg	4.4	4.4	2.9	2.9
Magnesium°	mg	n/a	0.19	n/a	77.50
Phosphorus	mg	287	287	345	173
Potassium	mg	350	350	655	495
Sodium	mg	6	6	8.1	5.6
Zinc°	mg	n/a	1.54	n/a	1.0
Copper°	mg	n/a	1.08	n/a	0.7
Manganese°	mg	n/a	1.63	n/a	0.5
Iodine	ug	n/a	n/a	n/a	n/a
Selenium∞	mcg	n/a	trace	n/a	7
Vitamin C∂	mg	0	2	0	0
Thiamin	mg	0.237	0.237	0.44	0.44
Riboflavin	mg	0.142	0.142	0.26	0.26
Niacin	mg	2.927	2.927	3.53	3.53
Pantothenate°	mg	n/a	1.25	n/a	0.6
Vitamin B-6°	mg	n/a	0.59	n/a	0.3
Folate, total°	mcg		0.02	150	150
Vitamin B-12	mcg	0	0	0	0
Vitamin A∂	IU	0	16	2205	2205
Vitamin D	ug	n/a	n/a	n/a	n/a
Vitamin E	mg-ATE	0	1.2	0	0.3

*Nutrient data from Commodity Reference Guide, updated 2006.
** Nutrient data from Commodity Reference Guide with additional published sorghum data as noted.
° Waniska and Rooney (2000)
∞ Neucere and Sumrell (1980)
∂ Barrow-Agee Laboratories, LLC, Memphis, TN (2010)
Micronutrient data **under-reported for sorghum/soy blend**; USAID ignores inherent micronutrient content of sorghum + soy.

Table 3
Comparison of sorghum- soy fortified* to the WHO RNI of children aged 1-9 years

Nutrient	Unit	Sorghum-soy fortified 100 g	RNI 1-3 y	%RNI 1-3 y	RNI 4-6 y	%RNI 4-6 y	RNI 7-9 y	%RNI 7-9 y
Energy	kcal	337.2	997	34	1301	26	1629	21
Protein	g	17.3	12.25	141	16.65	104	26.05	66
Total Fat	g	3.0						
Carbohydrate	g	68.5						
Fiber	g	n/a						
Calcium	mg	110	500	22	600	18	700	16
Iron**	mg	2.90	5.8	58	6.3	46	8.9	33
Magnesium	mg	n/a	60		76		100	
Phosphorus	mg	345						
Potassium	mg	350						
Sodium	mg	8.1						
Zinc**	mg	n/a	4.1		4.8		5.6	
Copper	mg	n/a						
Manganese	mg	n/a						
Iodine	ug	n/a	90		90		120	
Selenium	mcg	n/a	17		22		21	
Vitamin C	mg	0	30	0	30	0	36	0
Thiamin	mg	0.44	0.5	88	0.6	73	0.9	49
Riboflavin	mg	0.26	0.5	52	0.6	43	0.9	29
Niacin	mg	3.53	6.0	59	8.0	44	12.0	29
Pantothenate	mg	n/a	2.0		3.0		4.0	
Vitamin B-6	mg	n/a	0.5		0.6		1.0	
Folate, total	mcg	150	150	100	200	75	300	50
Vitamin B-12	mcg	0	0.9	0	1.2	0	1.8	0
Biotin	ug	n/a	8.0		12.0		20.0	
Vitamin A	IU	2205	1333	165	1500	147	1666	132
Vitamin D	ug	n/a	5		5		5	
Vitamin E a-TE	mg	0	5	0	5	0	7	0
Vitamin K	mcg	n/a	15		20		25	

FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements. 1998.
FAO/WHO/UNU Report of a Joint Expert Consultation on Human Energy Requirements. 2001
WHO/FAO/UNU. Protein and Amino Acid Requirements in Human Nutrition. 2007
*Data from USAID Commodity Reference Guide; micronutrient data and % values are under-reported since USAID ignores inherent micronutrients in fortified sorghum-soy grits displaying only added micronutrients.
** Iron RNI based on 10% bioavailability; Zinc RNI based on moderate bioavailability.
n/a = not applicable or not available
Good source = 10-19% of RNI; Excellent source = > 20% of RNI

Phytochemicals: A Sorghum Plus
Considering only nutrients in plant foods today is to ignore the benefits that plant foods provide relative to phytochemicals. Research into the health benefits of phytochemicals is among the most exciting research of the past 15 years. Sorghum is a powerhouse of these special compounds. Sorghum, depending on the variety, provides good to excellent sources of such phytochemicals as phenolic acids, anthocyanins, phytosterols and policosanols. These compounds are familiar to the public as a result of health claims around sterols and stanols (heart health) and the publicity attributed to the anti-oxidant properties of anthocyanins (pigmented berries-blueberries, strawberries, etc.). Awika and Rooney (2004) provide an excellent review of the potential health benefits of phytochemicals in sorghum.

Tannins: Not a problem
US sorghums processed into foods are red or white but they do not contain condensed tannins. Grain color is not a good indicator of tannin content. Grain color, expressed in the pericarp (the thick outer covering) is determined by genes that are independent of the genes that express for presence of condensed tannins (Hahn and Rooney, 1986). Moreover, U.S. sorghum varieties and most sorghum produced elsewhere contain no tannins (Awika and Rooney, 2004) *regardless of grain color*. Many of the myths about tannin sorghums are reviewed and explained in detail at the United Sorghum Checkoff Program's Web Site (http://www.sorghumcheckoff.com/resources).

Sorghum has a wide variety of phenolic compounds that include phenolic acids, flavanoids, 3-deoxyanthocyanins and condensed tannins. The condensed tannins are not present in U.S. grade sorghum and white sorghum. Sorghums vary in color from white, yellow, red and brown. In the U.S., very little if any tannin grains are grown and market classes limit tannin kernels to less than 2% in sorghum. Tannin sorghums have a pigmented layer just below the outer covering of the grains that can be easily distinguished by bleaching the red non-tannin grains from those with the condensed tannins. Again, color of sorghum is not a good indicator of tannins because some white appearing grains have tannins in the pigmented layer below the pericarp.

Tannin sorghums have very high levels of antioxidants with levels in the bran that are comparable to blueberries. There is growing evidence that some of these sorghums have high anti-inflammatory and anti-colon cancer activities. Special sorghums have been identified with very high levels of the rare 3-deoxy anthocyanins that have unique color stability and potential health applications (Dykes and Rooney, 2006).

Macronutrient and Micronutrient Malnutrition

Special populations such as infants and children, pregnant and lactating women, and the elderly are at nutritional risk in affluent developed countries, but their vulnerability increases when food-insecurity, diseases such as HIV/AIDs, malaria, intestinal worms, or poverty, civil unrest, and drought are imposed. These populations are at risk for both macronutrients (protein, fat, carbohydrate) and micronutrients (vitamins and minerals). Problems with adequate clean water compound the problem.

Child malnutrition is the first indication that hunger problems exist in countries. Children are dependent on others for food and among the first to feel food-insecurity thus they are the first group examined for signs of hunger and malnutrition. Even though the incidence of global childhood malnutrition is declining, the incidence of childhood malnutrition in Africa has not.

De Onis et al. (2004) reported on global malnutrition trends and prevalences for the years 1990-2005. His group looked at underweight and stunting data using WHO developed methodology to plot and predict trends at country levels. They found that stunting and underweight prevalences declined from 34 to 27% and 27 to 22% respectively. Yet, in Africa the situation is not improving. The numbers of stunted and underweight children increased from 40 to 45 million and 25 to 31 million respectively. Africa and sub-regions have extensive protein-energy malnutrition (PEM) in children less than 5 years of age (FAO, 2008, 2009). FAO 2009 food security statistics show the percentages of children who are moderately and severely malnourished in the underweight category in Burkina Faso, Kenya, and South Africa—representing countries from west, east and southern Africa—are 32, 25 and 15% respectively. In the stunting category, the combined percentages of children who are moderately and severely malnourished are 36, 50 and 39% and in the category of wasting the combined percentages of moderately and severely malnourished children are 19, 7, and 7% respectively. Beyond growth retardation, under-nourished children are at risk for infectious diseases, diarrhea and diminished mental development.

De Onis et al. (2004) suggest that the lack of progress in Africa may be due partly to the effects of the human immunodeficiency virus (HIV), which results in the disease AIDS. In sub-Saharan Africa, an estimated 333,000 children below 5 years of age died in 1999 with HIV infection and an estimated 11 million were orphaned because of AIDS. The United Nations International Children's Fund (UNICEF, 2009) reported that in sub-Sahara Africa in 2007 the annual number of under-5 deaths was 4,480,000 and the life expectancy at birth was only 50 years. There are many reasons for deaths in children under 5 years of age, shortened life spans, stunting, and underweight, but major among them is an inadequate or inappropriate diet. Recently, Williams et al. (2010) reported on HIV deaths and the presence of the mycotoxin, fumonisin in corn as a contributing agent for transmission of the virus.

A Role for Sorghum in Food Aid

All humans regardless of age, health status, or environment, need nutrients and adequate calories to sustain life. Populations at risk, such as weaning infants; rapidly growing children; the elderly; people with HIV/AIDs, gastrointestinal diseases, malaria, parasite infections; and pregnant and lactating women have special needs.

For Example:

- Infants and young children need high-energy dense, high-nutrient dense, palatable diets to support rapid growth. Sorghum's familiar taste and high carbohydrate content is a suitable base for weaning foods and young children. Where needed sorghum-soy-fortified flour/food may be used.

- Pregnant women require an extra 300 kilocalories per day over the course of gestation; plus extra protein, vitamins, minerals, and water compared to non-pregnant women (Food and Nutrition Board, 2002). An additional 100 g of micronutrient enriched sorghum-soy-fortified per day per woman can help meet the additional kilocalories, protein and extra micronutrients needed for pregnant women.

- Lactating women need on average, an extra 500 kilocalories per day, plus extra protein, vitamins, minerals, and water compared to non-lactating women (Food and Nutrition Board, 2002). Micronutrient enriched sorghum-soy-fortified can help meet the additional kilocalories, protein and micronutrient needs of lactating women.

- People with HIV/AIDs need adequate nutritional support with varying amounts of additional kilocalories, protein and micronutrients per day depending on drug protocols, age, pregnant or lactating status, and co-morbidities (Family Health International, 2007; American Dietetic Association, 2010). Research on nutrition support in this area is ongoing and recommendations change as studies verify the best nutrient support to accompany drug protocols and situations. Gluten-free sorghum products, fortified or not, depending on the specific needs of the individual, is a good choice for people with HIV/AIDs. Many HIV/AIDs patients have appetite issues and need familiar, favorite nutritious foods.

- People with gastrointestinal (GI) disorders and or diarrhea are at risk for malnutrition and dehydration. Infants, children and the elderly are at most risk for dehydration as their body water stores are limited and death can occur rapidly. Gluten-free sorghum foods (porridges, soups) can help meet the needs of patients with GI disorders. Porridges and soups that provide safe water with added electrolytes (sodium, potassium) to aid recovery can be used.

Emergency Rations, a Role for Sorghum

The IOM's Subcommittee on Technical Specifications for High-Energy Emergency Relief Ration (2002) recommends nutrient content and product specifications for foods intended for emergency relief. The committee's charge was to propose specifications for a single food that could be used with a heterogeneous population as the sole source of nutrition for up to 14 days. Potable water is specified for use with the rations. The product recommendations were developed using nutrient and caloric density principles.

The recommended nutrients, except protein, per 1000 kilocalories (based on a minimum 2100 kilocalorie intake per day) were determined by examining adequate intakes, recommended intakes and tolerable upper intake levels as developed by the Food and Nutrition Board of the IOM (2002) and protein recommendations as developed by FAO/WHO (2007). An examination of each nutrient across ages and genders resulted in the selection of the highest value for a specific population (considered the limiting nutrient), and subsequently compared to the tolerable upper intake level for all ages and genders to ensure that no populations would be harmed. Specific nutrients recommended per 1000 kcal are summarized in the IOM publication *High-Energy Nutrient-Dense Emergency Relief Food Product* (2002).

One example given for a 50 g bar includes 233 kilocalories with the following macronutrients: 23-35 g carbohydrate, 9-12 g fat, and 7.9 g protein. A 2100 kilocalorie intake would require 9 of these bars with a total of 207 g to 315 g carbohydrate (828 to 1260 kilocalories). Sorghum flour would be an excellent ingredient choice for emergency ration bars with its inherent gluten free characteristic.

Commodity Sorghum Compared to Staples of Developing Countries

Sorghum along with wheat, corn, and rice are among the elite grains that provide most of the world's food energy. In Africa, on a tonnage basis however, cassava provides more than two times as much as the next staple, corn (cassava's high water content adds weight.). Because of the high African cassava consumption, cassava is compared in Table 4 along with commodity sorghum, wheat, corn, and rice. All nutrient data were taken from the USDA Nutrient Database. Cassava is not a grain, and therefore cannot be directly compared with the grains in Table 4. However, where cassava is the major dietary staple without grains and pulses, children are at risk for protein malnutrition (Stephenson et al. 2010). Stephenson et al. (2010) researched cassava intake in children 2-5 years of age in Kenya and Nigeria where cassava is the dietary staple. Among 656 Nigerian children, 13% had inadequate protein intake and among the 449 Kenyan children, inadequate protein was present in 53%. They showed that when dietary cassava intake increased, protein intake decreased, placing young children at risk for protein malnutrition. In Chad, Ethiopia and Sudan whose food baskets are analyzed in the following section, cassava is not a major staple.

Table 4
Commodity sorghum* compared to African staples: wheat, corn**, rice** and cassava****

Nutrient	Unit	Commodity Sorghum 100 g	Wheat 100g #20074	Corn 100g #20014	Rice 100g #20450	Cassava 100g #11134
Energy	kcal	339.0	342	365	360	160
Protein	g	11.3	11.31	9.42	6.61	1.36
Total Fat	g	3.3	1.71	4.74	0.58	0.28
Carbohydrate	g	74.6	75.90	74.26	79.34	38.06
Fiber°	g	2.7	12.2	7.3	n/a	1.8
Calcium	mg	28	32	7	9	16
Iron	mg	4.4	4.56	2.71	0.81	0.27
Magnesium°	mg	0.19	93	127	35	21
Phosphorus	mg	287	355	210	108	27
Potassium	mg	350	432	287	86	271
Sodium	mg	6	2	35	2	14
Zinc°	mg	1.54	3.33	2.21	1.16	0.34
Copper°	mg	1.08	0.363	0.314	0.110	0.100
Manganese°	mg	1.63	3.821	0.485	1.100	0.384
Iodine	ug	n/a	n/a	n/a	n/a	n/a
Selenium∝	mcg	trace	n/a	15.5	n/a	0.7
Vitamin C∂	mg	2	0.0	0.0	0.0	20.6
Thiamin	mg	0.237	0.387	0.385	0.070	0.087
Riboflavin	mg	0.142	0.108	0.201	0.048	0.048
Niacin	mg	2.927	4.381	3.627	1.600	0.854
Pantothenate°	mg	1.25	0.954	0.424	1.342	0.107
Vitamin B-6°	mg	0.59	0.368	0.622	0.145	0.088
Folate, total°	mcg	0.02	38	19	9	27
Vitamin B-12	mcg	0	0.0	0.0	0.0	0.0
Vitamin A∂	IU	16	9	214	n/a	13
Vitamin D	ug	n/a	0.0	0.0	0.0	0.0
Vitamin E°	mg-ATE	1.2	1.01	0.49	n/a	0.19

*Data from USAID Commodity Reference Guide with additional published sorghum data as noted.
**Data from USDA Nutrient Database.
° Waniska and Rooney (2000)
∞ Neucere and Sumrell (1980)
∂ Barrow-Agee Laboratories, LLC, Memphis, TN (2010)

Food Baskets of Chad, Ethiopia and Sudan

Agricultural Production
Chad, Ethiopia and Sudan are within the top 20 producers of sorghum worldwide. According to FAOSTAT (2007a) their worldwide ranks and production levels for 2007 were:

Chad—# 17 at 685,430 MT
Ethiopia—# 8 at 2,316,041 MT
Sudan—# 2 at 3,869,000 MT

The top four food items produced in Chad, Ethiopia, and Sudan by weight in 2007 (FAOSTAT, 2007b) in descending order were:

Chad—Groundnuts with shells, cereal, millets, sorghum
Ethiopia—Roots and tubers, cow milk, maize, chilies and peppers
Sudan—Cow milk, sorghum, goat milk, groundnuts with shells

Nutrient Intake
Analyses of the kilocalorie contributions per capita per day of the major staples in the diets of Chad, Ethiopia and Sudan are shown in Table 5. Table 6 shows the energy and nutrient (protein, fat, carbohydrate) consumption per capita per day for Chad, Ethiopia and Sudan (FAOSTAT, 2007c). The carbohydrate grams and energy were calculated using data from Tables 5 and 6. All values are rounded.

The majority of kilocalories consumed in Chad and Ethiopia are derived from vegetable sources. It is not surprising in Sudan that 509 kilocalories per capita per day are from non-vegetable sources, considering that cow milk and goat milk are among the top 4 food items produced in 2007. Sudan consumes sorghum (612 kcal/day), at about 27% of total kilocalories per day per person and may use it in their dairy industry as animal feed. In Chad, about 19% of daily energy is derived from sorghum and in Ethiopia about 13%. Both Chad and Ethiopia consume more calories from grains other than those listed in Table 5 than Sudan. Ethiopia consumes about 13% *other* grains; Chad consumes about 15%, while Sudan consumes almost no other grains than those listed on Table 5.

Injera, a popular fermented bread (considered the national food of Ethiopia) can be made using sorghum, corn, tef, finger millet or barley. Tef is the major cereal grain used in Ethiopia for making injera with sorghum as the second most preferred grain for injera (Kebede and Menkir, 1984). Tef is not widely distributed across Africa, thus outside of Ethiopia, other grains are typically used. Nutritional evaluation of diets requires study of foods *as eaten*. Since sorghum contributes a major source of proteins, kilocalories, and minerals in the food baskets of millions of people in Africa and Asia, and is frequently used for making injera, Mohammed et al. (2010) studied the nutritional effects on sorghum during the processing of injera.

In addition to other assays, Mohammed et al, (2010) analyzed sorghum (Tabat variety), and samples of flour before and after fermentation and injera for amino acids, nutriceutical factors, total and extractable (%) minerals and in vitro protein digestibility. Mohammed et al. (2010) found that protein content on a dry basis decreased from 12.25% in sorghum flour to 11.55% in the injera, and the fat content decreased from 4.24% in the flour to 2.4% in the injera. The nutriceutical factors (tannin, phytate, polyphenols) declined in the fermented injera resulting in increased extractable mineral values for iron, zinc and copper of 34, 38, and 62% respectively.

Table 5
Dietary staples per capita kcal consumption for 2007 in Chad, Ethiopia and Sudan

Staple	Chad	Ethiopia	Sudan
Sorghum	389	251	612
Millet	312	34	154
Wheat	71	252	351
Maize	103	387	21
Cassava	64	No data	1
Cereal, other	305	262	<1
Groundnuts shelled	178	6	37
Yams	67	8	8
Tubers, roots-dry	158	264	21
Rice	60	7	18
Alcohol, all sources	6	16	20
Total vegetable sources	1930	1884	1773
Total kcal	2056	1980	2282
Non-veg sources, calculated	126	96	509

FAOSTAT (2007). Values are rounded.

In 2004–06, the percentages of undernourishment in Chad, Ethiopia, and Sudan were 38, 44, and 20% respectively and the food deficients in kcal/person/day for the undernourished were 290, 310 and 240 respectively (FAOSTAT, 2009). Clearly, grain sorghum can play a role in meeting these additional calorie needs while contributing a rich supply of micronutrients.

Table 6
Energy Consumption per capita per day for 2007 in Chad, Ethiopia, and Sudan

Item	Chad	Ethiopia	Sudan
Total kcal	2056	1980	2282
Protein grams	61	57	73
Protein kcal	244	228	292
Fat grams	49	21	66
Fat kcal	441	189	594
Alcohol, kcal all sources	6	16	20
Carbohydrate grams, calculated	341	387	344
Carbohydrate kcal	1365	1547	1376

FAOSTAT (2007), Values are rounded.

Sorghum Compared to other Commodity Grains used in Food Aid

Nutrient Comparison of Commodity Grains
In addition to sorghum, other grains used in food aid include wheat, corn and rice. A comparison of the nutrient content of these four grains (Data from USAID CRG, except as noted) is shown in Table 7. Sorghum is similar in total calories to the other grains; similar to wheat in protein content, but higher in protein than corn and rice. Sorghum is higher in total fat content than wheat or rice, but lower than corn.

Sorghum is similar in iron content to wheat but higher in iron content compared to corn and rice. Zinc content in sorghum is similar to wheat and corn content, but higher than rice. Manganese content in sorghum is higher than corn and rice, but lower in manganese than wheat. Sorghum is higher in copper and pantothenate content than all the other grains.

Table 7.
Nutrient comparison of the commodity grains: sorghum*, wheat, corn, and rice

Nutrient	Unit	Sorghum 100 g	Wheat 100g	Corn 100g	Rice 100g
Energy	kcal	339.0	333.5	365	365
Protein	g	11.3	11.7	9.4	7.1
Total Fat	g	3.3	1.8	4.7	0.7
Carbohydrate	g	74.6	73.3	74.3	80.0
Fiber°	g	2.7	12.45	n/a	1.3
Calcium	mg	28	32	7	28
Iron	mg	4.4	4.28	2.71	0.8
Magnesium°	mg	0.19	108	127	25
Phosphorus	mg	287	345	210	115
Potassium	mg	350	399	287	115
Sodium	mg	6	2	35	5
Zinc°	mg	2.3*	3.1	2.2	1.1
Copper°	mg	1.08	0.4	0.3	0.2
Manganese°	mg	1.63	3.7	0.5	1.1
Iodine	ug	n/a	n/a	n/a	n/a
Selenium∝	mcg	trace	35	16	15.1
Vitamin C∂	mg	2	0.0	0.0	0.0
Thiamin	mg	0.237	0.40	0.39	0.07
Riboflavin	mg	0.142	0.11	0.20	0.05
Niacin	mg	2.927	5.12	3.63	1.60
Pantothenate°	mg	1.25	0.9	0.4	1.0
Vitamin B-6°	mg	0.59	0.3	0.6	0.2
Folate, total°	mcg	0.02	39	19	17.0
Vitamin B-12	mcg	0	0.0	0.	0.0
Vitamin A∂	IU	16	0	469	n/a
Vitamin D	ug	n/a	n/a	n/a	n/a
Vitamin E°	mg-ATE	1.2	1.01	0.8	n/a

*Data from USAID Commodity Reference Guide with additional published sorghum data as noted.
° Waniska and Rooney (2000)
∝Neucere and Sumrell (1980)
∂ Barrow-Agee Laboratories, LLC, Memphis, TN (2010)

Physical/Chemistry Characteristics of Commodity Grains
In order for grains to be used successfully by consumers and food industries, knowledge of their unique chemistry is required. Taylor (2003) reviewed the importance of sorghum in Africa and provided information on chemistry for several

grains. Table 8 shows a comparison of food chemistry for sorghum with other grains.

Table 8.
Chemistry of sorghum compared to wheat, rice, maize and barley

Sorghum	**Other Cereals**
Some varieties contain condensed tannins *(No U.S. varieties contain tannins)**	Not present in wheat, rice and maize, perhaps very low levels in barley
All varieties contain greater or lesser amounts of polyphenols	Present in wheat, rice, maize and barley, but generally in lower amounts
Many varieties highly pigmented *(White food sorghum available in the U.S.)**	Some varieties of wheat, rice, maize and barley also highly pigmented
High starch gelatinization temperature	Rice starch the same temp Maize starch slightly lower, wheat and barley starch considerably lower
Endosperm non-starch polysaccharides predominantly insoluble	Rice and maize the same Barley rich in soluble non-starch polysaccharides Wheat contains both insoluble and soluble types
Endosperm protein rather inert	Maize protein similar Rice and barley protein somewhat less inert Wheat protein will form visco-elastic dough
Protein quality poor, deficient in lysine	Maize, barley and wheat similar Rice protein quality is better
Protein digestibility reduced after wet cooking	Rice similar? Wheat, maize and barley protein digestibility reduced to a lesser extent
Fat content quite high	Maize even higher Wheat and barley low Rice very low
Malt contains low levels of ß-amylase	Maize similar Rice higher Wheat and barley high levels

Table from Taylor (2003).
* Added to table

Unique physical and chemical, and other features dictate how grains are used in finished products. For example, gluten found in wheat helps provide structure (visco-elastic dough). Since sorghum, maize, rice and barley have a rather inert endosperm protein and do not form elastic doughs, they are used in wheat flour mixtures or in products such as injera that rely on other agents for structure. On the other hand, wheat contains gluten, a protein some people cannot tolerate so food products without wheat must be developed for that population.

Mycotoxins and Commodity Grains
Aspergillus
Researchers (Brandyopadhyay et al. 2007, Williams et al. 2010) questioned the wisdom of increasing maize consumption in Africa relative to its aflatoxin content and health consequences. Williams et al. (2004) reviewed the toxicology, exposure, potential health consequences and interventions for aflatoxin contamination of cereal crops. Aflatoxins produced by *Aspergillus* are associated with and may cause cancer, liver disease, immune suppression, retarded growth and development and death. Aflatoxin levels are limited in the European Union (4 ppb) and in the U.S. (20 ppb) and developing countries including Nigeria (20 ppb) (FAO 2004). In many countries, however, contaminated foods may enter the food supply either because of no local regulations or as a result of food scarcity.

Bandyopadhyay et al. (2007) compared *Aspergillus* contamination and aflatoxin levels in maize, sorghum and pearl millet grown side-by-side by subsistence farmers in Africa. The results showed that kernels of maize were four- and nine-times more likely to be contaminated with *Aspergillus* than comparable samples of sorghum and pearl millet respectively.

Fumonisin and Corn
Williams et al. (2004) proposed that Africa's HIV epidemic may be aided by exposure to mycotoxins, but that hypothesis remains to be proven. A contributing factor of mycotoxin contaminants toward HIV infection may be impairment of the immune system since chronic aflatoxicosis is associated with immune suppression (Jiang et al. 2005). More recently, Williams, et al. (2010) reported that they found HIV transmission frequency to be positively associated with maize consumption in Africa. Their work suggests that the relation between cancer and food in Africa is fumonisin contamination of maize rather than aflatoxins. Fumonisin is primarily a contaminant of maize (Kpodo and Bankole, 2008) resulting from fungal growth (*Fusarium verticillioides*) after damage by pests such as the cornstalk borer (*Busseola fusca*). Williams' group (2010) looked at four mycotoxin-prone foods (maize, peanuts, rice, cassava) in the 1993 diets of Sub-Saharan Africa. Average time to death in Africa from HIV infection is 11 years, thus death data for 2004 were used relative to diets dating back to 1993.

Figure 1 taken from Williams et al. (2010) shows the annual consumption in selected African countries for the four mycotoxin-prone staples; maize, peanuts, rice, and cassava for 1993. Other factors thought to be associated with HIV transmission were also evaluated, including male circumcision (used Muslim faith for this measure) and gross domestic product as a measure of socioeconomic status. Cassava is mostly eaten fresh so was eliminated as a fumonisin risk in their model.

In countries with a relatively high Muslim population (linked to lower HIV rates), and high corn consumption the HIV rate was 291 per 100,000. However, in high Muslim population countries with low corn per capita consumption, the rate per 100,000 was 74. Williams et al. (2010) also reported that higher maize consumption was associated with higher esophageal cancer rates, a finding previously reported for fumonisin (Marasas, 2001), and an indicator that Williams' et al. (2010) populations were indeed exposed to fumonisin. The researchers (Williams, et al. 2010) concluded that the maize-factor (fumonisin) needs further research and that removing or reducing it (or consuming alternate foods) could avoid up to 1,000,000 transmissions of HIV annually, or cut transmission rates by 58%. Emphasis on traditional African crops such as sorghum or millet rather than an introduced crop such as maize needs more consideration.

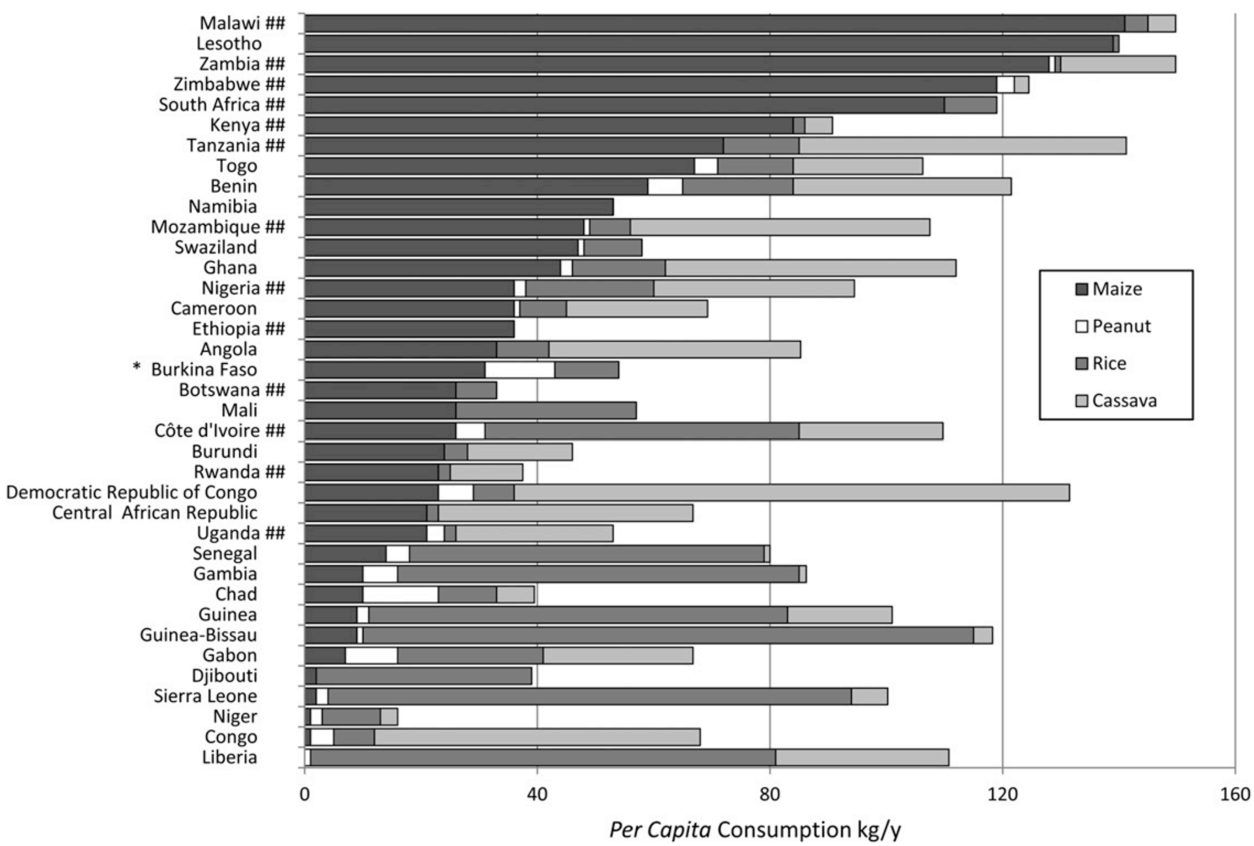

FIGURE 1.
Per capita consumption of 4 mycotoxin-prone foods in sub-Saharan African countries in 1993
***Denotes median country for maize consumption. ##Denotes 2004 President's Emergency Plan for AIDS Relief country. Figure from Williams et al. (2010)**

Value of Sorghum
Sorghum is competitively priced compared to other grains used in food aid. In general, its price is lower than corn, wheat or rice. In countries such as Sudan, Ethiopia and Chad, with a history of sorghum agriculture, dietary sorghum should be continued to be encouraged and in countries heavily dependent on corn as shown in Figure 1, more variety in grains should be encouraged and made available.

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