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Global maize production, utilization, and consumption

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Maize (*Zea mays*), also called corn, is believed to have originated in central Mexico 7000 years ago from a wild grass, and Native Americans transformed maize into a better source of food. Maize contains approximately 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g and is grown throughout the world, with the United States, China, and Brazil being the top three maize-producing countries in the world, producing approximately 563 of the 717 million metric tons/year. Maize can be processed into a variety of food and industrial products, including starch, sweeteners, oil, beverages, glue, industrial alcohol, and fuel ethanol. In the last 10 years, the use of maize for fuel production significantly increased, accounting for approximately 40% of the maize production in the United States. As the ethanol industry absorbs a larger share of the maize crop, higher prices for maize will intensify demand competition and could affect maize prices for animal and human consumption. Low production costs, along with the high consumption of maize flour and cornmeal, especially where micronutrient deficiencies are common public health problems, make this food staple an ideal food vehicle for fortification.

Keywords: maize; corn; production; consumption; varieties

Introduction

Cereal grains are the fruits of cultivated grasses. They provide humankind with more nourishment than any other food class and nearly half of the total caloric requirement. While there are about a dozen cereal crops used for food, only wheat, maize, and rice are important human food sources, accounting for 94% of all cereal consumption.[1] The consumption of these cereals varies widely by region; wheat is the preferred cereal in Central Asia, the Middle East, South and North America, and Europe. Rice is the major cereal in Asia, while maize (also referred to as corn) is preferred in Southern and Eastern Africa, Central America, and Mexico.

The way in which maize is processed and consumed varies greatly from country to country, with maize flour and meal being two of the most popular products.[2]

The actual human consumption of these cereals is somewhat lower than the estimated figures because of waste, use in nonfood products, and because milling removes some of the outer layers, or bran, which is generally used as animal feed. As with all cereals, most micronutrients are concentrated in the outer layers of the maize grain; thus, removing these layers in the milling process results in the loss of most vitamins and minerals.[2,3]

Consumption can be better estimated by adjusting the values of cereal crops used for food and human food sources by considering the extraction rate (i.e., the proportion of flour or meal produced from the whole-grain cereal). In most countries, the extraction rate for maize varies from 60% to 100% depending on the product. The range for yellow maize goods is 60–65% in the United States. Higher extraction rate levels are found in other countries. In South Africa, for example, the extraction rates for super, sifted, and unsifted maize are 62%, 79–89%, and 99%, respectively.[4] Newly developed maize varieties with a very short growing season produce a softer, smaller kernel of white maize. These varieties (smaller and softer) can also cause tremendous problems in the milling process,

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leading to a poor extraction rate.[5] The changes in nutritional profile (ash, fat, and fiber content) at the lower extraction rates will be less than those observed at the higher extraction levels, as in the case of wheat.[6,7]

Maize contains about 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g,[8] as compared to rice and wheat, but has lower protein content. Maize provides many of the B vitamins and essential minerals along with fiber, but lacks some other nutrients, such as vitamin B12 and vitamin C, and is, in general, a poor source of calcium, folate, and iron. Iron absorption, particularly the nonheme iron present in maize, can be inhibited by some components or foods in the diet, such as vegetables, tea (e.g., oxalates), coffee (e.g., polyphenols), eggs (e.g., phosvitin), and milk (e.g., calcium).[6,8] In countries where anemia and iron deficiency are considered moderate or severe public health problems, the fortification of maize flour and cornmeal with iron and other vitamins and minerals has been used to improve micronutrient intake and prevent iron deficiency.[9]

History of maize

In the Western world, the term *maize* is used interchangeably with corn. The reason for this is that all grains were called corn under early British and American trade and the name was retained for maize because it was the most common grain in commerce. Although the origin of the word maize is also controversial, it is generally accepted that the word has its origin in Arawac tribes of the indigenous people of the Caribbean. On the basis of this common name, Linnaeus included the name as species epithet in the botanical classification Zea (*Zea mays L.*).[10]

It is considered that maize was one of the first plants cultivated by farmers between 7000 and 10,000 years ago, with evidence of maize as food coming from some archaeological sites in Mexico where some small corn cobs, estimated at more than 5000 years old, were found in caves. The discovery of fossil pollen and cave corncobs in archaeological areas support the position that maize originated in Mexico. Other theories describe maize as originating in the region of the Himalayas in Asia, the product of a cross between *Coix spp.* and some Andropogoneas (probably of the Sorghum species), both parental chromosomes with five pairs, or in the high Andes of Bolivia, Ecuador, and Peru, as evidenced by the presence of popcorn in South America and the wide genetic diversity present in the Andean maize, especially in the highlands of Peru.[10,11]

Biological and archaeological approaches to determine where and when maize was initially domesticated continue to evolve through the use of genetic research and complex methodologies.[12,13] Some authors consider maize to have started from a wild grass, called *teosinte*, which is quite different from the maize of today, while others suggest the formation of a hybrid of two wild grasses—a perennial subspecies of teosinte (*Zea diploperennis*) and a species of Tripsacum. By systematically collecting and cultivating plants best suited for human consumption, Native Americans transformed maize over a couple 1000 years to a plant with larger cobs and more rows of kernels, making it a better source of food.[13] This provided enough food for the bulk of their diet for an entire year, allowing people to live in one location for an extended period of time.

The spread of maize from its center of origin in Mexico to various parts of the world has been remarkable and rapid with respect to its evolution as a cultivated plant and as a variety of food products. The inhabitants of several indigenous tribes in Central America and Mexico brought the plant to other regions of Latin America, the Caribbean, and then to the United States and Canada. European explorers took maize to Europe and later traders took maize to Asia and Africa.[14–16]

One limitation with maize is that while it contains the vitamin niacin, it is in a bound form that is not readily available to the body. It is also low in tryptophan, a niacin precursor. In order for niacin to be released from the bound form, it needs to have the pH increased before entering the low pH of the stomach. Early natives in Latin America stumbled upon a process, called nixtamalization, which involved soaking the whole maize in a lime solution (calcium hydroxide), followed by grinding to produce a paste, called *masa*, from which tortillas are made.[17] This process had two benefits: it converted the hard maize kernels into a more digestible form and released the bound niacin. Without this process there would have been much higher incidences of pellagra due to niacin deficiency.[18] In Europe, North America, and Africa, where the nixtamalization process was not used, pellagra became a problem in some areas. One of the real success stories of cereal fortification was the addition of niacin to maize meal beginning in 1941, which contributed to the elimination of pellagra as a major health problem in the Southeastern United States. Pellagra was not a public health problem in other parts of the world, perhaps because they had a more varied diet that provided sufficient amounts of niacin.[19]

Types of maize

Different types of maize are grown throughout the world, with one important difference being color. Maize kernels can be different colors ranging from white to yellow to red to black. Most of the maize grown in the United States is yellow, whereas people in Africa, Central America, and the southern United States prefer white maize. Yellow maize is not popular in Africa for reasons associated with the perception of social status: apparently it is associated with food-aid programs and is perceived as being consumed only by poor people. Also, the feed industry consumes mostly yellow maize in the manufacture of animal feed.[4] But the main reason for the preference for white maize is simply one of tradition: people are used to eating a white product in these countries, usually the whiter the better. This preference means a lower consumption of β-carotene and β-cryptoxanthin, vitamin A precursors, present in higher concentrations in yellow and orange maize. This also shows up in the preference for meal and flour made with higher extraction rates, which are whiter than the whole-grain products, but also with lower contents of fiber, vitamins, and minerals.[20] The quality of white maize is important since it affects the milling performance, grading, and yield of high-quality products.

There is a classification of maize on the basis of the size and composition of the endosperm, resulting in an artificial definition by kernel type as follows: dent, flint, waxy, flour, sweet, pop, Indian, and pod corn. Another difference or classification criterion is the sweetness or amount of sugar. The amount of residual sugar depends on the variety of maize and when it is harvested from the field. Sweet maize stores poorly and must be eaten fresh, canned, or frozen before the kernels age, becoming small, tough, and starchy. Sweet varieties cannot be fortified.[15,16]

Genetically modified (GM) herbicide-resistant maize (e.g., Bt corn, a variant of maize that has been genetically altered to express one or more proteins from the bacteria, *Bacillus thuringeiensis*) has become the major type of maize grown in many countries, including the United States where 85% of the crop is GM. European and African countries originally banned GM maize, but while still very controversial, this position may be changing as the benefits of Bt corn become accepted. In fact, as of 2011, herbicide-resistant GM maize was grown in 14 countries.[21] By 2012, 26 varieties of herbicide-resistant GM maize were authorized for import into the European Union,[22] and in 2012, the European Union was reported to import 30 million tons of GM crops. The GM maize MON810 was cultivated on almost 89,000 hectares in five European countries, particularly in regions with high infestation levels of maize borer (a pest affecting both the quality and quantity of the harvest).[22]

There does not appear to be any nutritional difference with Bt maize; therefore, its presence or absence should have no effect on fortification technology or policy.[23–26] Other recent papers address maize milling and the different types of milled products made from maize. The main products, all of which can and are being fortified, are meal, flour, precooked meal, dry masa or hominy flour, and breakfast cereals. In addition, there are mixtures with other ingredients, such as Corn Soy Blend, used for infant and food-aid feeding. Some products, such as corn chips and masa dough, may not be suitable for fortification.[6]

Maize production, utilization, and economics

Maize is grown throughout the world, although there are large differences in yields (Table 1). The Food and Agriculture Organization (FAO) of the United Nations indices of agricultural production include commodities that are considered edible and contain nutrients, and show the relative level of the aggregate volume of agricultural production for each year in comparison with the base period 1999–2001. It is estimated that in 2012, the total world production of maize was 875,226,630 tons,[27] with the United States, China, and Brazil harvesting 31%, 24%, and 8% of the total production of maize, respectively.

Food balance sheets developed by the FAO are commonly used as a data source for estimating patterns, levels, and trends of national diets, and are referred to as the FAOSTAT food balance sheets, in reference to the database that gathers the data.

Table 1. Corn production in 2012 by country, FAOSTAT[27]

Country	Maize production in 2011 (million MT/year)
United States of America	274
China	208
Brazil	71
Mexico	22
Argentina	21
India	21
Ukraine	21
Indonesia	19
France	16
Canada	12
South Africa	12

It presents a comprehensive picture of the pattern of a country's food supply during a specified reference period. The FAOSTAT food balance sheets show maize availability for human consumption, which corresponds to the sources of supply and its utilization. The total quantity of maize produced in a country added to the total quantity imported and adjusted to any change in stocks that may have occurred since the beginning of the reference period gives the supply available during that period. On the utilization side, a distinction is made between the quantities of maize exported, fed to livestock and used for seed, losses during storage and transportation, and supplies available for human consumption. The per capita supply of maize available for human consumption is then obtained by dividing the respective quantity by the related data on the population actually partaking in it. Data on per capita maize supply are expressed with respect to quantity and by applying appropriate food composition factors for maize, including dietary energy value, protein, and fat content.[27] Owing to the low cost and high accessibility of FAOSTAT food balance sheet data, they have historically been the main data source of food fortification program design–related information. However, their ability to identify potentially fortifiable or already fortified foods is constrained by the fact that the data are limited to maize as a primary commodity and do not capture processed potential vehicles, such as maize flour and cornmeal, or distinguish the proportion of these items consumed that are purchased.[28] Also, the national-level data from FAO food balance sheets do not provide any information on food consumption by individuals or populations.[29]

Maize data reported in FAOSTAT food balance sheets are reported at the farm-level with respect to grains. Although of interest for a maize flour fortification program, the FAOSTAT food balance sheet does not report data on the amount of maize flour available for consumption and the data must be calculated manually. In order to calculate the amount of flour available for consumption (and the daily g/capita availability) in a country, the extraction rate reported by the milling industry is applied. For maize flour, the extraction rate varies in different countries depending on the type of flour. Some procedures have been established to estimate food balance sheet data for maize flour and cornmeal; although these procedures are not discussed explicitly in the Food Balance Sheet Handbook, they would follow the same protocol outlined for wheat flour data.[28]

An important part of maize production is being used to generate ethanol fuel (ethyl alcohol), the same type of alcohol found in alcoholic beverages. It is most often used as a motor fuel, mainly as a biofuel additive for gasoline. Maize is the primary feedstuff used to produce ethanol. Strong demand for ethanol production has resulted in increased maize prices and has provided incentives to increase maize acreage. There are various social, economic, environmental, and technical issues with biofuel production and use, including the effect of moderating oil prices and the "food versus fuel" debate.[30]

Both maize dry-milling and wet-milling methods of producing ethanol generate a variety of economically valuable coproducts, the most prominent of which is distillers' dried grains with solubles, which can be used as a feed ingredient for livestock.

The United States is the world's largest producer of maize and dominates world maize trade. Exports account for a relatively small portion of demand for U.S. maize—approximately 15%. Experts consider that the low demand for exports means that maize prices are largely determined by supply and demand relationships in the U.S. market, and the rest of the world usually adjusts to prevailing U.S. prices. The large influence of U.S. maize supply makes world maize trade. Argentine farmers plant their maize after discovering the size of the U.S. crop, thereby providing a quick,

Table 2. **Domestic corn use in the United States from 1980 to 2013 in billion of bushels**

Corn use	1980	1990	2000	2010	2013
Animal feed and residual	4.16	4.75	5.73	4.79	5.00
Food, seed, and industrial	0.81	1.08	1.15	1.25	1.46
Ethanol production	0.02	0.42	0.83	5.00	5.00
Total	4.99	6.25	7.71	11.04	11.46

Source: Adapted from the United States Department of Agriculture (USDA).[31]

market-oriented supply response to short U.S. crops. Several countries, including Brazil, Ukraine, Romania, and South Africa, have had significant maize exports when crops were large or international prices were attractive.[31] China has been a significant source of uncertainty in world maize trade, swinging from being the second largest exporter in some years to occasionally importing significant quantities. China's maize exports are largely a function of government export subsidies and tax rebates, because the prices in China are mostly higher than those in the world market. While a large maize producer, Mexico processes much of its production of white maize into human food products, but has turned to imported yellow maize for livestock feed to support increased meat production.[31]

The analysis of the use of maize in the United States for the last 30 years shows that it has been used mainly for animal feeding, followed by human consumption and alcohol production (Table 2). However, in the last 10 years, the use of maize for fuel production significantly increased.[32] As the ethanol industry absorbs a larger share of the maize crop, higher prices for maize will intensify demand competition among domestic industries and external buyers. This could also affect maize prices for animal and human consumption, although maize has historically been one of the least expensive foods and food ingredient available. It is estimated that nearly 40% has been used in recent years to make ethanol for fuel. Of this, 27% becomes ethanol and 12% is the distillers' dry grain residue that goes to animal feed, making the total animal feed use at 50%.[32] Exports accounted for 13% and 4% are used to make high-glucose corn syrup. Part of the remaining 7% is used to make corn oil, cornstarch, corn syrups, and other industrial applications, while some is used to make whiskey and other alcoholic beverages.

Maize consumption by country and World Health Organization region

Estimated maize consumption in grams per person per day in countries where maize is considered an important food source (i.e., above 50 g/person/day) were corrected for an average 80% extraction rate, using the FAOSTAT food balance sheets with 2009 data by World Health Organization (WHO) region (Table 3). It is clear that maize is a staple in the African region where the consumption ranges from 52 to 328 g/person/day and the region of the Americas where the highest consumption was 267 g/person/day in Mexico. The results may vary according to the extraction rate, which varies in each country by type of flour milled as well as by the maize type used. No consumption above 50 g/person/day was estimated in the Western Pacific Region.

Other data sources to estimate maize flour consumption have been proposed. Household Consumption and Expenditures Surveys, which include Household Income and Expenditure Surveys, Living Standards Monitoring Surveys, and National Household Budget Surveys, can help to address the food consumption information gap. Some countries such as Zambia have introduced specific food item categories in order to be able to obtain more precise data with which to assess the feasibility of or to design fortification programs. In 2006, the Zambia Living Standards Measurement Study asked about households' consumption of maize with a focus on breakfast mealie meal, roller mealie meal, and hammer-milled meal, in addition to maize grain, in order to be able to distinguish those maize meal consumers who purchase their product from large-scale, modern roller mills.[29]

Major importers of maize in 2009 were Japan, South Korea, and Mexico.[27] Experts from the U.S. Department of Agriculture[31] consider Japan, while producing almost no coarse grains, to be a very large

Table 3. **Countries with the highest maize consumption (g/person/day) by WHO region**

WHO region	Country	Maize consumption (g/person/day)
African region	Lesotho	328
	Malawi	293
	Zambia	243
	Zimbabwe	241
	South Africa	222
	Kenya	171
	Togo	160
	Swaziland	152
	Tanzania	128
	Namibia	127
	Benin	119
	Mozambique	116
	Burkina Faso	107
	Ethiopia	94
	Angola	81
	Botswana	78
	Cameroon	75
	Cape Verde	72
	Central African Republic	71
	Mali	70
	Seychelles	69
	Senegal	62
	Nigeria	60
	Ghana	53
	Uganda	52
Region of the Americas	Mexico	267
	Guatemala	187
	Honduras	169
	El Salvador	157
	Nicaragua	148
	Venezuela	135
	Paraguay	121
	Colombia	92
	Bolivia	86
	Cuba	66
	Uruguay	63
	Belize	61
	Brazil	55
	Panama	53
	Haiti	50
Southeast Asia region	Timor-Leste	190
	Nepal	98
	Korea, DPR	93
	Morocco	84
	Indonesia	79
European region	Bosnia and Herzegovina	181
	Romania	85
	Slovenia	75
	Israel	64
	Macedonia	59
	Kyrgyzstan	58
Eastern Mediterranean region	Egypt	127

NOTE: Estimated at 80% extraction from 3-year average (2007–2009) FAOSTAT[1] data.

meat producer; therefore, the country is a steady buyer of maize, with attention to quality. In recent years, Japanese imports of maize for livestock feed have declined, while imports for industrial use and starch manufacturing have increased. South Korea, the second largest importer of maize in the world, is price conscious and willing to buy maize from the cheapest source or switch to wheat or other grains. Mexico is a growing importer.

World production of maize has shown a slight but steady increase over the years, but human consumption of the grain has remained steady. It is thought that the majority of the increase in production has corresponded to an increase in the use of maize for animal feed. However, maize is still a staple food for many people, especially in Africa.

Maize has food, feed, and industrial uses. It is a major component of livestock feed. The amount of maize used for feed also depends on the crop's supply and price, the amount of supplemental ingredients used in feed rations, and the supplies and prices of competing ingredients.

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Conflicts of interest

The authors declare no conflicts of interest.

References

1. FAO. 2012. FAOSTAT, Food Supply. Cited October 10, 2013. http://faostat.fao.org/site/345/default.aspx.
2. USAID Micronutrient Programs and DSM Nutritional Products. 2002. Fortification basics. Maize Flour/Meal. Accessed December 2013. https://www.dsm.com/en_US/nip/public/home/downloads/Corn.pdf.
3. Milazzo, A. 1986. Corn milling profile. *Assoc. Oper. Millers Tech. Bull.* 4651–4662.
4. National Chamber of Milling, South Africa. 2008. Cultivars: Maize. Cited December 23, 2013. www.grainmilling.org.za.
5. National Agricultural Marketing Council (NAMC). Report on the investigation of the effects of deregulation on the maize industry. Section 7: Committee evaluating the deregulation process. Pretoria, South Africa 2003. Accessed October 2013. http://www.grainmilling.org.za/2008%20MAIZE%20SECTION%207%20REPORT1.pdf.
6. Dale, E. & F.F. Niernberger. 1982. Economic models of dry corn milling: part I-model design and system specifications. *Assoc. Oper. Millers Tech. Bull.* 3994–3402.
7. World Health Organization and Food and Agriculture Organization of the United Nations (WHO/FAO). 2006. *Guidelines on Food Fortification with Micronutrients.* L. Allen, B. de Benoist, O. Dary & R. Hurrell, Eds. Geneva: World Health Organization.
8. Nuss, E.T. & S.A. Tanumihardjo. 2010. Maize: a paramount staple crop in the context of global nutrition. *Compr. Rev. Food Sci. Food Saf.* **9:** 417–436.
9. WHO, FAO, UNICEF, GAIN, MI, & FFI. 2009. Recommendations on wheat and maize flour fortification. Meeting Report: Interim Consensus Statement. Geneva, World Health Organization. Cited October 1, 2013. http://www.who.int/nutrition/publications/micronutrients/wheat_maize_fort.pdf.
10. Smith, B.D. 2001. Documenting plant domestication: the consilience of biological and archaeological approaches. *Proc. Natl. Acad. Sci. U. S. A.* **98:** 1324–1326.
11. Piperno, D.R. & K.V. Flannery. 2001. The earliest archaeological maize (Zea mays L.) from highland Mexico: new accelerator mass spectrometry dates and their implications. *Proc. Natl. Acad. Sci. U. S. A.* **98:** 2101–2103.
12. Food and Agriculture Organization of the United Nations (FAO). 2000. *Tropical maize. Improvement and production.* Food and Agriculture Organization of the United Nations (FAO) Plant Production and Protection Series, Vol. 28. R.L. Paliwal, Ed.: 1–363, Rome: Food and Agriculture Organization of the United Nations.
13. Food and Agriculture Organization of the United Nations (FAO) and International Plant Genetic Resources Institute. 2002. The role of women in the conservation of the genetic resources of maize—Guatemala. Rome: FAO. Accessed February 13, 2014. ftp://ftp.fao.org/docrep/fao/004/y3841e/y3841e00.pdf.
14. Vollbrecht, E. & B. Sigmon. 2005. Amazing grass: developmental genetics of maize domestication. *Bioch. Soc. Trans.* **33:** 1502–1506.
15. Brown, W. & L. Darrah. 1985. *Origin, Adaptation, and Types of Corn. National Corn Handbook. Cooperative Extension Service.* Iowa: Iowa State University. NCH-10.
16. Gibson, L. & G. Benson. 2002. Origin, History, and Uses of Corn (Zea mays). Iowa State University, Department of Agronomy. Accessed October 14, 2013. http://agron-www.agron.iastate.edu/Courses.
17. Caballero-Briones, F., A. Iribarren, J. Pena, *et al.* 2000. Recent advances on the understanding of the nixtamalization process. *Superficies y Vacío* **10:** 20–24.
18. FAO. 1992. *Maize in Human Nutrition.* FAO Food and Nutrition Series No. 25. 1–160. Rome: FAO.
19. Rajakumar, K. 2000. Pellagra in the United States: a historical perspective. *South Med. J.* **93:** 272–277.
20. Doebley, J. 2004. The genetics of maize evolution. *Ann. Rev. Gen.* **38:** 37–59.
21. James, C. 2011. ISAAA Brief 43, Global Status of Commercialized Biotech/GM Crops: 2011. ISAAA Briefs. Ithaca, New York: International Service for the Acquisition of

Agri-biotech Applications (ISAAA). Cited December 23, 2013. http://www.isaaa.org/resources/publications/briefs/43/executivesummary/default.asp.

22. GMO Compass. Genetically modified food and feed: the EU regulatory process. European Commission, Health and Consumers, EU register of authorized GMOs. Accessed March 3, 2014. http://www.gmo-compass.org/eng/regulation/regulatory_process.
23. Nestel, P., H.E. Bouis, J.V. Meenakshi & W. Pfeiffer. 2006. Biofortification of staple food crops. *J. Nutr.* **136:** 1064–1067.
24. Banziger, M. & J. Long. 2000. The potential for increasing the iron and zinc density of maize through plant breeding. *Food Nutr. Bull.* **21:** 397–400.
25. Graham, R., D. Senadhira, S. Beebe, *et al.* 1999. Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. *Field Crops. Res.* **60:** 57–80.
26. Bouis, H. & R. Welch. 2010. Biofortification—a sustainable agricultural strategy for reducing micronutrient malnutrition in the Global South. *Crop. Sci.* **50:** S20–S32.
27. FAO. 2012. FAOSTAT, Production. Cited February 12, 2014. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor.
28. GAIN. 2012. Applying dietary assessment methods for food fortification and other nutrition programs. GAIN Working Paper Series No. 4. Geneva: Global Alliance for Improved Nutrition. Accessed February 13, 2014. http://www.gainhealth.org/reports/gain-working-paper-series-no-4.
29. Dary, O. & B. Imhoff-Kunsch. 2012. Measurement of food consumption to inform food fortification and other nutrition programs: an introduction to methods and their application. *Food Nutr. Bull.* **33**(3 Suppl.): S141–S145.
30. Committee on World Food Security. High Level Panel of Experts (HLPE). 2013. Biofuels and food security. A report by the High Level Panel of Experts on food security and nutrition of the Committee on World Food Security. Rome. Accessed December 17, 2013. http://www.fao.org/fileadmin/user_upload/hlpe/hlpe_documents/HLPE_Reports/HLPE-Report-5_Biofuels_and_food_security.pdf.
31. United States Department of Agriculture (USDA). Economic Research Service. Corn Trade. Cited February 12, 2014. http://www.ers.usda.gov/topics/crops/corn.aspx.
32. Wallington, T., J. Anderson, S. Mueller, *et al.* 2012. Corn ethanol production, food exports, and indirect land use change. *Environ. Sci. Technol.* **46:** 6379–6384.

