IMPROVING THE NUTRITIONAL QUALITY OF MAIZE AND WHEAT FOR HUMAN CONSUMPTION

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Contents

Summary

Micronutrient malnutrition, specifically iron deficiency, is prevalent throughout the developing world. Zinc deficiency is assumed to be widespread, but there is no quantitative assessment of the magnitude of the problem. As overall diet diversity is low and cereal staples comprise a high proportion of daily caloric intake among the poor, increasing the iron and zinc levels of these staples could potentially have a significant impact on the nutriture of the world's poor. Current research in maize and wheat breeding has explored the agricultural potential of this approach. Genetic variation in kernel-iron and -zinc concentration has been found for both maize and wheat, and crosses between promising materials were initiated to develop more nutritious breeding stocks. Research has included the evaluation of novel nutrition-

related traits such as the multiple aleurone gene in maize and the genes from alien species in wheat. These materials are being developed by breeders and are being adapted to regions where iron and zinc deficiencies are prevalent. Consumption information indicates that the projected increases in iron and zinc kernel concentrations could significantly increase the amount of both iron and zinc in the diet. Educating target producers and consumers, and policy makers, about the nutritional benefits of these improved materials is integral to its adoption in at-risk regions.

1. Introduction

Over four and a half billion people live in the developing world and subsist predominantly on maize, wheat and rice, with wheat and maize being the second and third most widely consumed staple cereals in the developing world. Maize is the primary staple cereal in the diet of people in sub-Saharan Africa (SSA), Central America and large parts of South America (Table 1). Wheat, as the predominant staple, is consumed by people in West Asia and North Africa (WANA), and in Central Asia (Tables 2, 3 and 4). In terms of consumption as a proportion of all cereals consumed, wheat is also significant in countries such as Chile, Bulgaria and Albania; while in China and India, the total amount of wheat consumed is quite large due to the populations of these countries. It should be recognized that human wheat consumption worldwide is less confined to specific regions than is the case for maize consumption. To illustrate the potential impacts of micronutrient enhanced maize and wheat, the focus of this article will be on the production and consumption of maize and wheat in the Sub-Saharan African and WANA regions, respectively.

Over the past 40 years, the increase in population in WANA and SSA has decreased the per capita amount of land available for cultivation, and has increased the cultivation of more marginal lands (derived from FAO statistics 1960 to1990). Concomitantly, the consumption patterns of people in these areas have changed in that the total daily caloric intake from cereal staples (maize in SSA and wheat in WANA) has increased (derived from FAO statistics 1960 to 1995).

The nutritional status of people in SSA and WANA is contingent on factors including diet diversity, the seasonality and cost of foods, and nutrition-related knowledge and information. Considering the role of maize and wheat in the diets of people in SSA and WANA, increased dependency on these staples necessitates approaches in which the food system can be modified to meet not only basic caloric needs, but also the requirements for essential nutrients that are usually low in staple cereals, such as certain essential amino-acids and micronutrients.

Fortification and supplementation programs have been successfully implemented in some instances to alleviate micronutrient deficiencies. The complex nature of improving the nutriture of people in developing countries, however, asks for additional complementary and preferably more sustainable approaches. Improving the nutritional quality of cereal staples through plant breeding could be a sustainable and cost-effective component of a more holistic approach. Addressing micronutrient deficiencies through plant breeding is aimed at developing micronutrient-dense staple crops that can be cultivated under the production conditions of resource-poor farmers who often have limited access to inputs.

Country	**Population**	**GNI 1999**	**Poverty index:**	**Per capita**	**Calories from maize**	**Maize consumption**	**Infant**	**Prevalence**	**Anemia rate**
	1999 (millions)	per capita US$	% pop. with <$1/day PPP	Maize consumption (kg)	as % of total daily caloric intake	as % of all cereals	mortality rate	of child malnutrition	among preg-nant women, %
Notes	a	b	a[1]	c	c	c	a[2]	a[3]	d
Sub-Saharan African countries									
Malawi	10.8	180	…	146	62	91	132	30	55
Zambia	9.9	330	64	139	57	87	114	24	34
Lesotho	2.1	550	43	134	52	67	92	16	7
Zimbabwe	11.9	530	36	122	46	74	70	16	33*
Kenya	29.4	360	27	94	42	78	77	22	35
Tanzania	32.9	260	20	72	32	67	95	31	59
Mexico & Central American countries									
Honduras	6.3	760	41	85	34	67	34	25	14
Mexico	96.6	4,440	12	127	34	72	29	8	41
El Salvador	6.2	1,920	26	91	33	58	30	12	14
Guatemala	11.1	1,680	10	115	47	76	40	24	45

NOTES: "…" indicates no data available.

(a) Source: World Bank, World Development Indicators 2001, tables 1.2, 2.1 and 2.6.

(1) Data represent % of population with less than US$1 per capita income (PPP:purchasing power parity).

(2) Number of deaths of infants less than one year old per 1000 live births

(3) Percentage of children under five years old whose weight for age is more than two standard deviations below the median of the reference population.

(b) Source: World Bank web site 2001, www.worldbank.org

(c) Source: FAO, Food Balance Sheets, 1994-1997 (all figures are averages for period 1994-97).

(d) Source: World Bank, World Development Indicators 2001, Table 2.18. Data represent % of pregnant women below the norm for hemoglobin; rough proxy indicator for iron deficiency in broader population.

* indicates data from *Central African J. of Medicine* (1998) vol 44 p297-305

Table 1. The Importance of Maize in Diets of Maize-Consuming Regions

Country	Population 1999 (millions)	GNI 1999 per capita (US$)	Poverty index: % pop. with <$1/day PPP	Per capita wheat con- sumption (kg)	Wheat con- sumption as % of all cereals	Calories from wheat as % of all calories	Protein from wheat as % of all protein	Infant mortality rate	Prevalence of child malnutrition	Anemia rate among preg- nant women (%)	Prevalence of Vitamin A deficiency
Notes	a	b	a[1]	c	c	c	c	a[2]	a[3]	d	e
LOW INCOME COUNTRIES											
Sudan	29.0	330	...	42	28	16	15	67	34	36	5
Yemen	17.0	360	16	121	70	45	51	79	46	…	5
Mongolia	2.4	390	14	113	94	42	31	58	13	45	...
India	997.5	440	44	55	31	19	23	71	45	88	5
Pakistan	134.8	470	31	129	83	49	52	90	38	37	4
Mauritania	2.6	390	29	83	47	26	26	88	23	24	5
China	1253.6	780	19	82	36	22	24	30	9	52	3
Albania	3.4	930	...	131	81	42	42	24	8	…	...

NOTES: "…" indicates no data available.
(a) Source: World Bank, World Development Indicators 2001, tables 1.2, 2.1 and 2.6.
(1) Data represent % of population with less than US$1 per capita income (PPP: purchasing power parity).
(2) Number of deaths of infants less than one year old per 1000 live births
(3) Percentage of children under five years old whose weight for age is more than two standard deviations below the median of the reference population.
(b) Source: World Bank web site 2001, www.worldbank.org
(c) Source: FAO, Food Balance Sheets, 1992-1994 (all figures are averages for period 1992-94).
(d) Source: World Bank, World Development Indicators 2001, Table 2.18. Data represent % of pregnant women below the norm for hemoglobin; rough proxy indicator for iron deficiency in broader population.
(e) Source: FAO Agrostat database 1992. (5) = clinical Vitamin A deficiency; (4) = severe subclinical deficiency; (3) = moderate subclinical deficiency; (2) = mild subclinical deficiency; (1) = no measurable problem.

Table 2. Prevalence of Malnutrition and Role of Wheat in Diet of Selected Low Income Countries

Country	**Population 1999 (millions)**	**GNI 1999 per capita (US$)**	**Poverty index: % pop. with <$1/day PPP**	**Per capita wheat con-sumption (kg)**	**Wheat con-sumption as % of all cereals**	**Calories from wheat as % of all calories**	**Protein from wheat as % of all protein**	**Infant mortality rate**	**Prevalence of child malnutrition**	**Anemia rate among preg- nant women (%)**	**Prevalence of Vitamin A deficiency**
Notes	a	b	a[1]	c	c	c	c	a[2]	a[3]	d	e
LOWER MIDDLE INCOME COUNTRIES											
Iran	63.0	1810	...	172	81	46	53	26	11	17	3
Iraq	22.8	...	...	97	60	36	46	101	...	18	5
Egypt	62.7	1380	3	144	57	36	41	47	11	24	2
Bolivia	8.1	990	29	66	54	22	24	59	8	54	3
Morocco	28.2	1190	<2	172	67	43	48	48	…	45	2
Syria	15.7	970	...	215	94	52	60	26	13	52??	2
Bulgaria	8.2	1410	<2	158	96	39	41	14	...	…	...
Kazakhstan	14.9	1250	2	161	76	41	38	22	8	27	...
Jordan	4.7	1630	<2	141	87	73	43	26	5	50	2
Algeria	30.0	1550	<2	206	90	53	59	34	13	42	1
Tunisia	9.5	2090	<2	194	94	49	56	24	9	38	4
Peru	25.2	2130	16	47	44	16	21	39	8	53	2
Lebanon	4.3	3700	...	125	90	31	32	26	3	49	2
Turkey	64.4	2900	2	207	90	44	50	36	8	74	2

NOTES: "…" indicates no data available.
(a) Source: World Bank, World Development Indicators 2001, tables 1.2, 2.1 and 2.6.
(1) Data represent % of population with less than US$1 per capita income (PPP: purchasing power parity).
(2) Number of deaths of infants less than one year old per 1000 live births
(3) Percentage of children under five years old whose weight for age is more than two standard deviations below the median of the reference population.
(b) Source: World Bank web site 2001, www.worldbank.org
(c) Source: FAO, Food Balance Sheets, 1992-1994 (all figures are averages for period 1992-94).
(d) Source: World Bank, World Development Indicators 2001, Table 2.18. Data represent % of pregnant women below the norm for hemoglobin; rough proxy indicator for iron deficiency in broader population.
(e) Source: FAO Agrostat database 1992. (5) = clinical Vitamin A deficiency; (4) = severe subclinical deficiency; (3) = moderate subclinical deficiency; (2) = mild subclinical deficiency; (1) = no measurable problem.

Table 3. Prevalence of Malnutrition and Role of Wheat in Diet of Selected Lower-Middle Income Countries

Country	Population 1999 (millions)	GNI 1999 per capita (US$)	Poverty index: % pop. with <$1/day PPP	Per capita wheat con-sumption (kg)	Wheat con-sumption as % of all cereals	Calories from wheat as % of all calories	Protein from wheat as % of all protein	Infant mortality rate	Prevalence of child malnutrition	Anemia rate among preg- nant women (%)	Prevalence of Vitamin A deficiency
Notes	a	b	a[1]	c	c	c	c	a[2]	a[3]	d	e
UPPER MIDDLE INCOME COUNTRIES											
Libya	5.4	...	...	165	85	38	45	22	5	…	...
South Africa	42.1	3170	12	56	31	16	19	62	9	37	4
Mexico	96.6	4440	12	43	25	10	10	29	8	41	4
Mauritius	1.2	3540	...	97	54	24	25	19	15	29	…
Brazil	168.0	4350	9	44	38	11	12	32	6	33	4
Chile	15.0	4630	<2	123	87	35	34	10	1	13	...

NOTES: "…" indicates no data available.
(a) Source: World Bank, World Development Indicators 2001, tables 1.2, 2.1 and 2.6.
(1) Data represent % of population with less than US$1 per capita income (PPP: purchasing power parity).
(2) Number of deaths of infants less than one year old per 1000 live births
(3) Percentage of children under five years old whose weight for age is more than two standard deviations below the median of the reference population.
(b) Source: World Bank web site 2001, www.worldbank.org
(c) Source: FAO, Food Balance Sheets, 1992-1994 (all figures are averages for period 1992-94).
(d) Source: World Bank, World Development Indicators 2001, Table 2.18. Data represent % of pregnant women below the norm for hemoglobin; rough proxy indicator for iron deficiency in broader population.
(e) Source: FAO Agrostat database 1992. (5) = clinical Vitamin A deficiency; (4) = severe subclinical deficiency; (3) = moderate subclinical deficiency; (2) = mild subclinical deficiency; (1) = no measurable problem.

Table 4. Prevalence of Malnutrition and Role of Wheat in Diet of Selected Upper-Middle Income Countries

Strategic research to increase the micronutrient density of the main staples is currently being undertaken by members of the Consultative Group for International Agricultural Research (CGIAR) (see *The Economics of Plant Breeding as an Agricultural Strategy for Reducing Micronutrient Malnutrition*). Germplasm improved for these traits by the CGIAR centers remain in the public domain. This enables national agricultural research systems and the private seed industry in the developing world to use these germplasm in cultivars and to contribute to a sustainable solution to micronutrient malnutrition.

This paper gives an overview of the possibilities and constraints of a plant breeding approach in maize and wheat at effectively alleviating micronutrient deficiencies in humans living in SSA and WANA. Findings from the on-going research at the International Maize and Wheat Improvement Center (CIMMYT) are presented.

2. Micronutrient Malnutrition in Maize and Wheat Growing Areas

2.1. Impact and Prevalence of Micronutrient Malnutrition

Iron and zinc deficiencies are amongst the most prominent causes for human malnutrition. Iron deficiency increases child morbidity and mortality, reduces worker performance and productivity, and impairs psychomotor development (see *Iron Nutrition in Man: Global Perspectives on Iron Deficiency and Malnutrition*), while zinc deficiency inhibits child growth and development, and general health (see *Global Importance of Zinc Deficiency in Humans: its Relation to Malnutrition and Strategies for its Prevention*). It is difficult to accurately assess zinc status in humans, and therefore, to definitively link deficiency to adverse health consequences. Zinc has demonstrated catalytic, structural and regulatory functions in cells and there is an abundance of evidence in the literature that links low zinc intake and poor health outcomes.

Worldwide, it is considered that at least one-half of anemia is a direct result of insufficient dietary iron intake. As food sources for iron are also generally rich in zinc, limited consumption of iron-rich foods can result in deficiencies in both nutrients. The prevalence of iron and zinc deficiency is widespread throughout SSA and WANA. Anemia affects more than 30 % of women and children in Africa and the eastern Mediterranean. Anemia in SSA is caused predominantly from insufficient sources of bioavailable iron in the diet. Zinc deficiency is thought to be an underlying cause for maternal mortality, and studies in Malawi and Egypt reported a low zinc status for pregnant women. Zinc deficiency has been reported in children and women in Turkey, where soils have low levels of plant-available zinc.

2.2. Population Impacts on Land Usage

The mounting population pressure in the developing world has increased the demand for food. Even though the total area of land for agriculture has increased, available land per capita has decreased. The overall per capita land area for agricultural usage has decreased by 62 % in SSA and 54 % in the Near East. These trends are seen despite the increase in the total area of land used for agriculture with increases of 3 % and 20 % in SSA and the Near East, respectively (derived from FAO statistics 1961 to1998).

Often, the per capita decrease in available land for cultivation cannot be compensated for by productivity increases. Thus, staple crops may be produced on a relatively larger portion of a farmers land. This ensures the farmers ability to meet the basic caloric requirements of the family, yet farmers may forgo production of nutritionally valuable crops, such as vegetables, due to limited land availability.

A similar feature may be observed in areas where labor limits per capita cultivated land area. This is seen in low productivity environments or where adults migrate from rural to urban areas in search of employment, as was documented, for example, for Zimbabwe.

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Biographical Sketches

Jennifer K. Long is a post-doctoral researcher in the Department of Community Health Sciences at the School of Public Health, University of California – Los Angeles. She earned her Ph.D. from the Department of Plant Breeding at Cornell University in Ithaca, New York. Her doctoral studies focused on both maize breeding and human nutrition. As part of her doctoral thesis, she was a Pre-Doctoral Fellow at CIMMYT-Zimbabwe pursuing maize breeding research within the CGIAR Maize Micronutrient Project during 1999-2000. She earned a B.A. degree in the Biological Sciences from Smith College in Northampton, Massachusetts. In her current research, she is analysing the effects of meat and milk consumption on growth and development outcomes of rural Kenyan children enrolled in a controlled feeding intervention trial.

J. Ivan Ortiz-Monasterio is a Senior Scientist in the Wheat Program at CIMMYT. He earned the B.S. degree from the Monterrey Institute of Technology in Mexico and M.Sc. and Ph.D degrees from the University of Illinois at Urbana-Champaign. Dr. Ortiz-Monasterio has been working on ways to improve nutrient use efficiency in wheat, both from the breeding as well as the crop management perspective. He has published three chapters, 17 refereed journal articles, and 50 abstracts. Dr. Ortiz-Monasterio has served as a consultant to the IAEA, International Atomic Energy Agency. He is a member of the Mexican Academy of Sciences as well as the National Academy of Agricultural Sciences. He is currently serving as Project Coordinator in Frontier Project 4 – Biofortified Grain for Human Health - at CIMMYT.

Marianne Bänziger is senior scientist at the International Maize and Wheat Improvement Research Center (CIMMYT). She earned her Ph.D. from ETH (Federal Institute of Technology) Zurich, Switzerland, and went as a postdoctoral fellow to CIMMYT in Mexico. Since her Ph.D. she has been involved in the improvement of crops for abiotic stress tolerance and coordinates today CIMMYTs global program 'Maize for sustainable production in stressed environments'. Since 1994, she has been responsible for CIMMYTs research on the development of maize with improved grain micronutrient content. She serves on the editorial board of the *European Journal of Agronomy*, has published 16 refereed journal articles and book chapters, has contributed to 60 conferences with published proceedings or abstracts, and has (co-) edited eight CIMMYT special publications.