Opportunities for nutritionally enhanced maize and wheat varieties to combat protein and micronutrient malnutrition

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Abstract

Naturally occurring variation detected in the germplasm of maize and wheat, two of the top three cereal crops in the world, provides options for incorporating higher levels of iron, zinc, and β-carotene into these grains. In addition, quality protein maize (QPM) has been developed from naturally occurring variation; its seed contains enhanced levels of lysine and tryptophan, two essential amino acids lacking in cereals. The International Maize and Wheat Improvement Center, along with its many partners, has identified several maize and wheat varieties with 25% to 30% higher grain iron and zinc concentrations. Wild relatives of wheat have been found to contain some of the highest iron and zinc concentrations in the grains. Although these accessions are often low yielding and have poor grain quality, backcrossing to bread wheat could result in highly nutritious cultivars. Options are now available for conventional and biotechnology-assisted improvement of the nutritional content of maize and wheat germplasm.

Key words: Nutritionally enhanced, maize, wheat, micronutrient malnutrition

Maize and wheat are two of the top three cereal crops in the world. Maize is the preferred staple of more than 1.2 billion consumers in sub-Saharan Africa and Latin America, where 30% to 50% of the population, particularly the poor and women and children, are affected by malnutrition. In Africa alone, many poor people subsist on a maize-based diet low in iron and zinc [1]. As an example, 30% of pregnant and lactating women in Zimbabwe are thought to be iron deficient [2]. Wheat is an important staple in the low- to lower-middle-income countries, where the annual per capita consumption ranges from 40 kg to more than 200 kg. Wheat contributes significantly to the caloric and protein requirements of consumers in these countries.

The International Maize and Wheat Improvement Center (CIMMYT), based in Mexico, has conducted research on nutrition-related traits for more than two decades and has arrived at several options for addressing nutritional deficiencies through maize and wheat improvement. In collaboration with governments and national agricultural research institutions in several countries (such as Brazil, China, El Salvador, Ethiopia, Ghana, Guatemala, Malawi, Mexico, Mozambique, and Uganda), CIMMYT has been promoting the use of quality protein maize (QPM). QPM is visually indistinguishable from normal maize, but it is of superior nutritional value because the levels of lysine and tryptophan are effectively doubled. Varieties of QPM have been released in several countries. It is estimated that they are currently grown on almost 1 million hectares, and the area is increasing. Apart from providing better-balanced protein, lysine is a known promoter of iron and zinc absorption in humans. Even with an unchanged iron or zinc concentration, iron and zinc uptake in humans consuming QPM is expected to increase.

Few if any studies have investigated whether a more balanced amino acid profile is feasible in wheat, but it should be. One difficulty may lie in the fact that wheat is usually processed into breads or other baked products. It is known that flour quality is greatly affected by changes in the protein composition of the grain. Thus, amino acid modifications in wheat would need to be carefully studied for their effect on grain quality.

More than one-third of the world's population is iron deficient, and some 1.2 billion people are anemic. The problem for women and children is more acute because of their greater physiological need for iron. Zinc deficiency has received less attention than other micronutrient deficiencies, but zinc deficiency is assumed to be widespread. Since the early 1990s, CIMMYT has been evaluating maize and wheat accessions and varieties for

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genetic variability of grain iron and zinc concentration. Experimental maize hybrids and varieties with 25% to 30% higher grain iron and zinc concentrations than are found in currently grown cultivars have been identified. Similar studies in wheat have indicated that iron and zinc concentrations in cultivated varieties can differ by 30% to 40%.

Some of the best sources of high iron and zinc concentrations in wheat are the wild relatives: *Triticum dicoccon, T. boeoticum*, and *Aegilops tauschi*. These are often low yielding, with poor grain quality, but through backcrossing to bread wheat, good cultivars can be obtained. Preliminary feeding studies carried out using rats have indicated a positive correlation between higher iron in the grain and higher levels of bioavailable iron in the diets fed to the rats. Further studies are under way to develop appropriate genetic populations for genomic studies of high iron and zinc concentrations in maize and wheat.

The World Health Organization reported in 1994 that 3.2 million preschool-age children have eye damage as the result of vitamin A deficiency and that another 228 million are subclinically affected at a severe or moderate level. CIMMYT and its sister institute, the International Institute of Tropical Agriculture, are exploring avenues for overcoming vitamin A deficiency resulting from maize-based diets. Yellow maize contains naturally occurring and significant amounts of provitamin A carotenoids (e.g., β-carotene) that can be converted to vitamin A in humans. Unfortunately, most consumers in sub-Saharan Africa and a considerable proportion in Latin America reject yellow maize for cultural and historic reasons. These consumer preferences might be overcome by promoting the consumption of high-β-carotene (yellow) maize as fresh, boiled, or roasted maize, or by developing high-β-carotene maize with a distinctive yellow grain color. CIMMYT has found considerable amounts of carotenoids in landraces of maize with sun-red grain color. There are plans to introduce these grain colors, along with higher β-carotene levels, into local varieties and to assess consumer preferences for elite, tasty, and more nutritious maize. A higher-technology solution may be via the genetic engineering of β-carotene production only in the embryo. This should lead to a less yellow-colored grain, which may be more acceptable. Issues surrounding the use of genetic engineering and grain processing (the grain is often degermed for storage) will need to be addressed.

There are already high-yielding varieties of both bread and durum wheat that are yellow in color, although the levels of provitamin A carotenoids are still being determined. Only a small fraction of the wheat genetic resources available have been screened appropriately for the level of carotenoids. It is possible that significant variation does exist and could be used to increase the level of β-carotene in elite varieties. One interesting observation is that wheat does produce detectable levels of β-carotene [3]. These levels are detected early in grain development but are absent in the fully developed grain. Thus, it appears that wheat possesses all of the necessary enzymes for β-carotene production, but that it processes β-carotene to other products in the carotenoid pathway (e.g., luteins). Given that all of the major enzymes in the carotenoid pathway are known and have been cloned [4], it should be feasible to block the pathway immediately after β-carotene production and thus elevate the levels of β-carotene in the grain. Other enzymatic steps may also need to be modified to produce the highest and most stable levels of β-carotene while not affecting other characteristics of the grain.

Enhanced nutritional quality of staple grains is of high priority. The naturally occurring variation already detected in maize and wheat germplasm provides options for incorporating higher levels of iron, zinc, provitamin A, and better-balanced protein into the grain of these important cereals. Genomic approaches, including genetic engineering, offer novel ways to further enhance these traits, especially those involving micronutrients such as iron, zinc, and β-carotene. Providing nutritionally enhanced cereals to resource-poor populations in developing countries offers an excellent opportunity to combat many of the devastating nutritional-deficit diseases affecting the world.

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