Genetic Engineering of Crops for Improved Nutritional Quality

Samuel S.M. Sun¹, Qiaoquan Liu¹,², and Rebecca M.L. Chan¹

¹Department of Biology, the Chinese University of Hong Kong, Hong Kong, China.
²State Key Laboratory of Plant Functional Genomics of the Ministry of Education, Yangzhou University, Yangzhou, China.

The world population was predicted to increase from 6.1 billion in 2001 to 7.2 billion in 2015 and 8.3 billion in 2030. Facing pressure from this continuous population growth and shrinking agricultural lands, the challenges are not only to meet the future food needs of humans but also to deal with the need of nutritionally balanced crops/foods. Major shortages of basic nutrients in the parts of world restricted to a diet based exclusively on staple foods include vitamin A, iron, iodine, zinc, and quality protein, and deficiencies in these nutrients cause micronutrient and protein-energy malnutrition throughout much of the developing world. Thus enhancing the nutritional quality of crops is an important undertaking for future food security and the nutritional well-being of world population.

Solving nutritional deficiencies can be achieved by supplementation or food fortification. However alternative approach through developing staple food crops with balanced/enhanced nutrients (bio-fortification) would offer sustainability. Conventional plant breeding method thus has been applied, for a long history, in an effort to enhance a specific nutrient which is deficient in the crop. A well known example is the development of the high-lysine corn through identification of natural variation/mutation. However this effort was hampered by the associated undesirable traits with the mutation.
(Bright and Shewry, 1983). Thus far, new crop varieties developed through conventional plant breeding method to contain significantly increased specific nutrient(s) for practical use are not common. For mineral nutrients, with progress in elucidating their absorption, transportation, distribution, deposition and homeostatic regulation in plants at physiological and molecular level, and the available methodology including molecular marker-assisted breeding (MAS), quantitative trait loci (QTL) analysis, and genetic intervention, plant breeding and even transgenic approaches can now be attempted to enhance the content of minerals in plants (Ghandilyan et al., 2006). However, increasing the content of a specific mineral may not always be effective to increase its bioavailable content in food, due to the presence of a variety of anti-nutritional compounds in plants, such as phytic acid and polyphenols, which inhibit mineral bioavailability to humans. Efforts thus are necessary also to reduce the content of anti-nutrients in plants. Advances in understanding the biosynthesis and regulation of vitamins in plants, likewise, have allowed the manipulation of their contents in plants (Lucca et al., 2006; DellaPenna and Last, 2006). A good example is the engineering of rice to produce pro-vitamin A (β−carotene) in its endosperm (GoldenRice) with an initial concentration of 1.6 µg/g endosperm (Ye et al., 2000). More recently, through further engineering, the β−carotene content was greatly increased (over 20 folds) to 36 µg/g endosperm in the second generation Golden Rice (Paine et al., 2005).

Plant proteins are the primary source of dietary protein consumed by humans and livestock. Unfortunately plant proteins, including those of major staple crops, are known for their inherent deficiency in certain essential amino acids (EAAs), making their proteins nutritionally unbalanced. In general, cereals are deficient in lysine while methionine is the first limiting essential amino acid in legumes. Attempts to enhance the EAAs in crops through plant breeding in the past 50 years have been less than satisfaction and the development of high lysine corn is a better known effort and example. With advancements in plant molecular biology and biotechnology, various strategies have been experimented in an effort to correct the deficiency of EAAs in food crops. Three strategies in this regard are recognized, namely 1) to enhance the protein-bound EAAs; 2) to