Bio fortification: Enhancing Nutrition in Agricultural Crops

Suvendhu S. Dutta[1], A. Pattanayak[2], Shantanu Das[3]

[1]School of Crop Improvement, College of Post Graduate Studies, Central Agricultural University, Umiam -793 103, Meghalaya, India

[2]Centre for Biotechnology, ICAR Research Complex for NEH Region, Umiam -793 103, Meghalaya, India

[3]Department of Plant Breeding and Genetics, Assam Agricultural University, Jorhat-785 013, Assam, India

Abstract: ***More than half of the human population worldwide has no access to healthy food. In developing countries, peoples are mainly reliant on a staple diet of cereals, such as rice or maize, due to lack in common fresh fruit, vegetables, meat and fish. Unfortunately all of our major food crops lack certain essential vitamins and minerals; as milled cereal grains are poor sources of lysine, vitamin A, folic acid, iron, zinc and selenium, which are essential for normal growth and metabolism. Malnutrition is a significant public health issue in most of the developing world like Africa and Asian countries. One of the ways to address this problem is through the enhancement of staple crops to increase their essential nutrient content. A potentially cost-effective and sustainable way to increase a crop's nutritional value is known as bio fortification. This technique is relatively new, which use plant breeding and genetic engineering techniques to enhance the nutrient content of staple foods. The major aim of the bio fortification is to increase the nutrient content of the food. To increase the nutritional value requires some form of metabolic engineering with the aim of increasing the amount of this desirable compound, decreasing the amount of a competitive compound or even extending an existing metabolic pathway to generate a novel product. Here, we review the current developments in bio fortification for the improvement of major agricultural crops.***

Keywords: Bio fortification, Genetic Engineering, Minerals, Nutrients, Vitamins,

1. Introduction

The nutrients in the human diet ultimately come from plants. In addition to providing calories for energy, humans require over 20 minerals and 40 nutrients to be supplied from food in order to be healthy. Unfortunately, human diets often lack adequate supplies of these essential nutrients, also termed micronutrient malnutrition, which frequently leads to under nutrition. Maternal and child malnutrition is pervasive in lower income countries and is the underlying cause of 3.5 million deaths each year. Genetic modification of crops has enabled plant breeders to modify plants in novel ways and has the potential to overcome important problems of modern agriculture. The field of agricultural biotechnology has developed rapidly due to the greater understanding of DNA as the chemical double-helix code from which genes are made. Genetic modification of crops has enabled plant breeders to modify plants in novel ways and has the potential to overcome important problems of modern agriculture. The field of agricultural biotechnology has developed rapidly due to the greater understanding of DNA as the chemical double-helix code from which genes are made.

ISAAA (International Service for the Acquisition of Agri-biotech Applications) recommends the 3D strategy for the survival of the world's one billion poor people, recognizing that the indignity that they unnecessarily suffer is unacceptable in a just society.

DEVELOP innovative crop biotechnology applications recognizing that sharing knowledge amongst partners stimulates innovation.

DEREGULATE innovative biotech crop applications under the aegis of a science-based, cost and time effective deregulation system.

And DEPLOY innovative biotech crop products in a timely mode to minimize opportunity costs and to optimize their contribution to food security, and alleviation of poverty.

Global area under biotech crops increased from 1.7 million hectares in 1996 to 175.2 million hectares in 2013. The US continued to be the lead producer of biotech crops globally with 70.1 million hectares followed by Brazil (40.3 mha), Argentina (24.4 mha), India (11 mha), Canada (10.8 mha) and China (4.2 mha). Moreover, stacked traits occupied ~25% of the global 175.2 million hectares (Source: ISAAA Brief 46-2013: Executive Summary).

Supplementation and fortification of food products have been in use for decades, such as iodine added to salt or vitamin D to milk. In recent years, scientists have been very successful in enhancing a plant's nutritional properties in a process known as bio fortification. Unlike food fortification that requires the purchase of commercial foods, bio fortification offers consumers in rural areas the ability to produce higher-nutrient foods that stay within the community. This is a relatively new technique, using plant breeding and genetic engineering techniques to enhance the nutrient content of staple foods. Bio fortification is a long-term strategy, as there are high costs to develop and test these enhanced crops. However, once these crop varieties are released, continued investment will no longer be required and large numbers of people will benefit from increased nutrition in products they consume.

2. Enhancing Nutrition in Agricultural Crops

2.1 Golden Rice

Mammals make vitamin A from β-carotene, a common carotenoid pigment normally found in plant photosynthetic membranes. Here, the idea was to engineer the β-carotene pathway into rice. Professor Ingo Potrykus and Peter Beyer discovered that geranyl geranyldiphosphate (GGPP), a precursor of carotenoids, was present in rice seeds. Subsequently, genes (two Daffodil genes and single bacterial gene) that code for enzymes that were necessary to create carotene from GGPP were introduced into the rice genome (Beyer *et al.*, 2002). It appeared that the daffodil *psy* gene needed to be replaced with a better functioning or more active version in order to increase the production of carotenoid. The rice endosperm with the maize *psy* gene exhibited an increase in carotenoid production of about 12 fold to those with the daffodil *psy* (Figure 1).

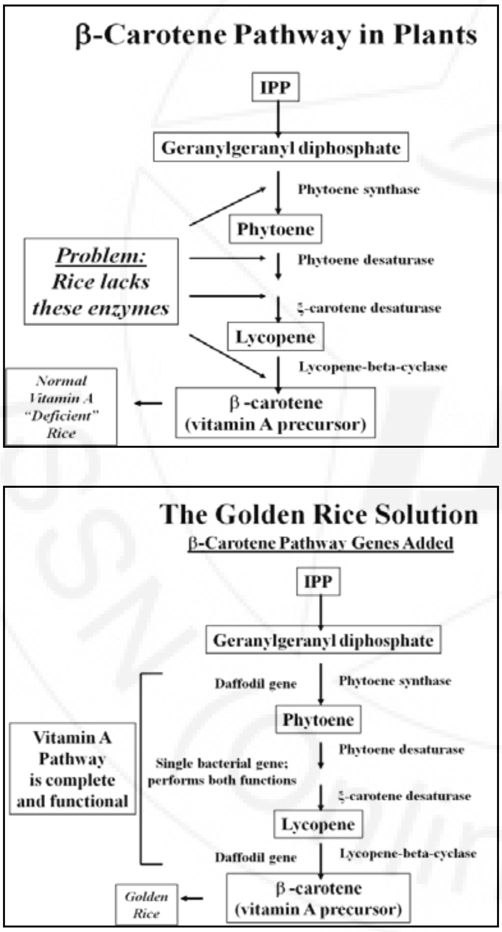

Figure 1: *β-carotene pathway in golden rice*

2.2 Golden mustard

Golden mustard also may yield provitamin A which would enrich cooking oil. New varieties of corn, sorghum and wheat are being developed to provide more lysine, an important dietary protein.

2.3 Quality protein maize

Opaque2 + kernel modifiers = QPM. The lysine value of QPM is 3.5 g/100g of protein. A typical mature maize kernel contains a small embryo and a much larger endosperm, which are 90% starch and 10% protein. Approximately 70% of this protein is composed of several types of prolamin known as zeins that are alcohol-soluble. Scientists at CIMMYT (International Center for Wheat and Maize Improvement), Mexico have successfully developed SSR markers for *opaque2* allele and phenotypic selection for kernel vitreousness for conversion of normal maize lines into QPM. Three SSR markers utilized are *umc1066, phi057 and phi112*. MAS based on SSR markers for conversion of normal maize lines into QPM is simple, rapid, accurate, efficient, cost-effective method (Gupta *et al.*, 2009).

2.4 Vitamin E- Maize

Barley HGGT gene was found to be over-expressed in maize seeds, leading to a 20-fold increase in tocotrienol level, which translated to an eight-fold increase in total tocols (tocopherols and tocotrienols). HGGT (Homogentisic acid Geranylgeranyl transferase) catalyzes an analogous reaction to HPT, only it is highly specific for GGDP whereas HPT uses PDP as its prenyl substitute. Results from the expression of barley HGGT in transgenic plants suggest that this enzyme has strong substrate specificity for geranylgeranyl diphosphate, rather than phytyl diphosphate. Expression of HGGT enzyme in tobacco calli and Arabidopsis leaves resulted in accumulation of Vitamin E antioxidants in the form of tocotrienols, principally as γ-Tocotrienols, and generated little or no change in the content of Tocopherols (Cahoon *et al.*, 2003).

2.5 DHA biosynthetic pathway in transgenic plants

Recent progress has also been made in the reconstitution of the DHA (Docosahexaenoic Acid) biosynthetic pathway in transgenic plants. For example, transgenic Arabidopsis seeds with total fatty acids containing up to 0.5% DHA were produced by expressing a bifunctional zebrafish D6/D5-desaturase and a dipteran D6-elongase in the seed, producing EPA for subsequent conversion into DHA by enzymes from the alga *Pavlova salina*.

2.6 Engineering higher folate (vitamin B9) levels in rice endosperm:

Storozhenko *et al.* (2007) engineered rice using targeted expression of Arabidopsis GTP-cyclohydrolase I (GTPCHI) and aminodeoxychorismate synthase (ADCS) to increase folate biosynthesis in seeds. The strategy worked best when GTPCHI and ADCS were expressed together from a single locus, resulting in 15- to 100-fold increases in folate levels in different independent transgenic lines compared to non-transgenic siblings.

2.7 Soybeans with improved oils:

The demand for soybean oil has increased steadily as vegetable oil is consumed globally. There are two specific examples of how seed researchers are working to improve the oil composition of soybeans to benefit the consumer.

The United States Department of Agriculture (USDA) and the Canadian Food Inspection Agency recently approved a high-oleic soybean for cultivation. This variety, developed by Pioneer Hi-Bred, contains oils that are more stable at high cooking temperatures and are healthier to consumers, containing no Trans fats and 20% less saturated fat than the commodity versions. To produce this variety, a section of the coding region of the soybean omega-6 desaturase gene-1 (FAD2-1) was introduced into the soybean genome. This insertion acts to suppress the native omega-6 desaturase gene, resulting in the high oleic oil9. Field and oil testing in both the U.S. and Canada are still continuing with commercialization expected shortly.

Despite the known health benefits of omega-3 fatty acids, primarily obtained to date from fish, the availability and consumption of fish is not sufficient to meet the demand. The Monsanto Company, in collaboration with Solae, has genetically engineered oil-producing crops with increased omega-3 properties10, 11. Stearidonic acid (SDA) omega-3 soybeans are one of the first technology products which will directly benefit the consumer instead of the farmer. Oil from SDA soybeans have the potential to benefit consumers by increasing the available dietary sources of this heart healthy acid, as well as reducing pressure on native fish populations which are currently being over-harvested. Monsanto and Solae have incorporated SDA soybean oil into several food products to create prototypes, including snack bars and salad dressings. This variety is still undergoing field testing and a commercialization target has not yet been announced.

2.8 Tomatoes with increased anthocyanins

Anthocyanins are present in many foods and have been shown to reduce the risk of several diseases. As very few peoples consume the recommended portions of vegetables and fruits daily, improving the nutritional value of those that are most frequently consumed has the potential to improve human health. Tomatoes are an important crop worldwide; however, their levels of flavonals (which includes anthocyanins) are considered sub-optimal. By increasing the health-promoting compounds in tomatoes, consumers will receive increased nutritional components, which is particularly important when the daily recommended values are not being met. Cathie Martin and colleagues expressed two transcription factors from snapdragon (Del and Ros1 under control of the E8 promoter) which dramatically increased the level of anthocyanins and produced purple-colored tomatoes. Initial feeding studies in mice found that these high-anthocyanin tomatoes significantly increased the average lifespan compared to animals fed normal tomatoes. Further studies are needed to determine the potential beneficial role of these purple tomatoes in human health.

2.9 Iron fortification of rice seed

The ferritin gene has been isolated and sequenced in plants, including soybean, French bean, pea, and maize. Ferritin is thought to play two main roles in living cells; one is to provide iron for the synthesis of iron proteins such as ferredoxin and cytochromes. The other is to prevent damage from free radicals produced by iron/dioxygen interactions. The entire coding sequence of the soybean ferritin gene was transferred into *Oryza sativa* (L. cv. Kita-ake) and obtained a three-fold increase in iron concentration from 8.6-14.3 ppm to 13.3-38.1 ppm (Lucca *et al*., 2001).

2.10 AmA 1 Potato

Potato is the most important non cereal food crop that lacks the essential amino acids lysine, tyrosine, and the sulfur-containing amino acids methionine and cysteine. Seed albumin gene AmA1 from *Amaranthus hypochondriacus* was cloned and introduced into potato (Chakraborty *et al.*, 2010). The AmA1 protein is non allergenic in nature and is rich in all essential amino acids. AmA1 gene improves the nutritive value of potato.

2.11 High-iron bio-fortified pearl millet

ICRISAT’s high-Iron pearl millet variety ICTP-8203Fe was released as Dhanshakti in Maharashtra state of India early this year. The history of this variety goes back to 1988, when ICTP 8203, an open-pollinated variety of pearl millet developed at ICRISAT in 1982 from selection within an iniadi landrace from northern Togo, was released for cultivation in peninsular India in 1988. It was rapidly adopted by farmers, occupying about 800,000 ha at the peak of its adoption in 1995. This variety was found to have the highest level of iron density among a diverse range of populations, open-pollinated varieties and hybrids in several trials conducted during 2004-2008. By exploiting intra-population variability for iron density within it, one of its improved versions, ICTP 8203 Fe-10-2 (ICTP 8203 Fe for short), was developed.

3. Future Prospects

Bio fortification is a multi-stage process which involves evaluation in every step of the way – precaution in practice. But the consumer will judge, whether it improves human health. In this regard, bio fortification plays very important role in improving nutrient quality of staple food crops; which will reduces the incidence of heart disease, anemia in women, blindness in children, early death globally. As malnutrition is one of the major problem in worldwide; these bio fortification programme along with conventional breeding and nutritional modification will become the first choice of the researchers for crop improvement in future.

References

[1] E. B. Cahoon, S.E. Hall, K.G. Ripp, T.S. Ganzke, W.D. Hitz, S.J. Coughlan, “Metabolic redesign of vitamin E biosynthesis in plants for tocotrienol production and increased antioxidant content”. Nature Biotechnology 21, 1082 – 1087, 2003.

[2] H. S. Gupta, K. Agrawal, V. Mahajan, G. S. Bisht, A. Kumar , P. Verma, A. Srivastava, S. Saha, R. Babu, M. C. Pan, V. P. Mani, “Quality protein maize for nutritional

security:rapid development of short duration hybrids through molecular marker assisted breeding". Current science, vol. 96, no. 2, 2009.

[3] ISAAA Brief 46-2013: Executive Summary. Global Status of Commercialized Biotech/GM Crops: 2013

[4] P. Beyer, S. Al-Babili, X. Ye, P. Lucca, R. Schaub, P. Welsch, I. Potrykus, "Golden Rice: Introducing the -Carotene Biosynthesis Pathway into Rice Endosperm by Genetic Engineering to Defeat Vitamin A Deficiency". American Society for Nutritional Sciences, 2002.

[5] P. Lucca, R. Hurrell, I. Potrykus, "Genetic engineering approaches to improve the bioavailability and the level of iron in rice grains". Theor Appl Genet 102:392–397, 2001.

[6] S. Chakraborty, N. Chakraborty, L. Agrawal, S.Ghosh, K. Narula, S. Shekhar, S. Kash, P. Naik, P.C. Pandec, S. K. Chakrborti, A. Datta, "Next-generation protein-rich potato expressing the seed protein gene AmA1 is a result of proteome rebalancing in transgenic tuber". PNAS | vol. 107 | no. 41 | 17533–17538, 2010.

[7] S. Storozhenko, V. De Brouwer, M. Volckaert , O. Navarrete, D. Blancquaert, G. F. Zhang, W. Lambert, D. Van Der Straeten, "Folate fortification of rice by metabolic engineering". Nat Biotechnol. 2007 Nov; 25(11):1277-9. Epub 2007 Oct 14.

Author Profile

Mr. Suvendhu S. Dutta received the M.Sc. (Agri.) degrees in Molecular Biology and Biotechnology from Acharya N. G. Ranga Agricultural University-Hyderabad. Presently he is a PhD Scholar under School of Crop Improvement, CPGS, Central Agricultural University- Meghalaya. He has 3 publications in National & International Journal.

Dr. A. Pattanayak is the principle scientist and Head of the Centre for Biotechnology, ICAR Research Complex for NEH Region Meghalaya-India. He is a rice breeder and has developed many varieties of hill rice.

Mr. Shantanu Das completed his M. Sc. (Agri.) in Plant Breeding and Genetics from Assam Agricultural University, Jorhat in 2013. Presently he is serving as Senior Research Fellow under PPV & FR project at National Seeds Project, Department of Plant Breeding and Genetics, Assam Agricultural University, Jorhat 785013. Mr. Das is also working on NUE in rice for his Ph. D. Programme. He has 2 publications in National & International Journal; presently doing PhD from same university.