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Alleviation of malnutrition by Biofortification of crops

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ABSTRACT: *This review completely based on biofortification of different food crops like rice,maize etc and This supports the approach like transgenics, breeding approach to improve nutritional quality of food and how this beneficial to humans and other life forms to decrease the ratio of malnutrition and the nutritional deficiency related to that respective vitamins and minerals. This approach helps to improve health.*

I. INTRODUCTION

Many people do not get enough food as per to get their daily need and many times these people suffer from diseasic condition or a deficiency of a malnutrients this is because they do not get enough vitamins, protein and other necessary nutrients from the food this condition also called as hidden hunger and it include blindness, stunting, disease condition, premature death.[76]malnutrition is a major problem for the whole world and for the developing and industrial countries. On the other hand the second problem is low birthweight and the ratio is high it is high in industrialized countries.[1] Vitamin A, zinc, vitamin E,folate etc.content of this nutrient are low in food and because of that deficiency of this nutrient are occure in developing countries this nutrients can be provided by biofortification and with the other stratergy like genetically modified crops and also we can not ignore the other micronutrients like zinc, folate, vitB_{12},riboflavin it is also important to consider these micronutrients for health issues .

Micronutrient malnutrition is often less obvious for the people have an impact on, which is also why the term *hidden hunger* is now and then used.. The major reason for the high prevalence of insufficient micronutrient intakes is the lack of dietary diversity among the poor. Typical diets in not enough income households are conquered by staple crops, which are low-cost sources of calories but only provide small amounts of vitamins conquered and minerals. In addition to income constraints, lack consciousness and cultural factors also often limit the consumption of more nutritious food. biofofication is the process by which the essential daily micronutrition can be given by staple food.[4,5]. Plants are most important source for essential nutrients and can be taken easily.[6]

Plant-based foods like rice, wheat, cassava and maize most in large quantities consumed by at-risk populations contain levels of more than a few micronutrients that are deficient to meet minimum daily requirements. Furthermore, sometimes these nutrients are not in enough quantity as per the need.[7] For case, iron present in rice leaves it's concentration is high but lower in polished rice grain. In anoter case that is provitamin A which is higher in rice leaves. Biofortification efforts are directed toward increasing the levels of specific, limiting micronutrients in edible tissues of crops by combining crop management.

II. BIOFORTIFICATION THROUGH DIFFERENT APPROCHES

- **Biofortification Through Fertilizer Application**

It is a simple kind of method, the biofortification of crops through the application of fertilizers which contain essential mineral micronutrients, is complex method and can be given by following method like soil composition, mineral mobility in the plant and its gathering site. So it is successful for some minerals but not for all and the success rate varies according to the environmental condition. Such as, both iodine and selenium are mobile in soil and in plants, thus biofortification with iodine [14] and selenium [15]fertilizers has been used to increase mineral levels, with particularly encouraging results for selenium biofortification in Finland and New Zealand. large amount of this metal can affect on plant and related organism like N_2 fixative bacteria. In less obtainable nutrient ecosystems iodine and selenium are mobile in soil and in plants, fertilizers can be use to increase nutrient level .zinc (Zn) is also highly mobile, zinc given as a fertilizer as $FeSO_4$ can increase the concentration of Zn in soil and the content also increase in grain.[17] In another case in iron (Fe) has a low mobility in soil because Fe(II) which given as $FeSO_4$ bound by soil particles and converted into Fe(III); so it gives or Fe fertilizers gives less effect to plant [16]. In larger amount this metal can give not good effect to plant in some case it gives opposite effect too.

The role of fertilisers is to provide nutrients that plants need in order to grow, principally nitrogen, phosphorus and potassium. Enhanced fertilisers provide additional nutrients needed by the people who eat the plants. Successful examples include enrichment with iodine in China, selenium in Finland and zinc in Thailand. This approach has an important advantage – it works quickly. But as a long-term strategy for improving public health, enhanced fertilisers have serious limitations.They are expensive and have to be applied regularly. So the poor people cannot afford this.The two other forms of biofortification raise issues of their own, but they do overcome these problems. The system planned for both is an initial, subsidized distribution, a one-off cost. Farmers could then harvest and use seed for future years, as they do with existing varieties now. The potential of biofortified crops, therefore, is to provide a continuing supply of micronutrients to large numbers of people, without recurrent costs minakshi et al

- **TRANSGENIC APPROACHES FOR BIOFORTIFICATION**

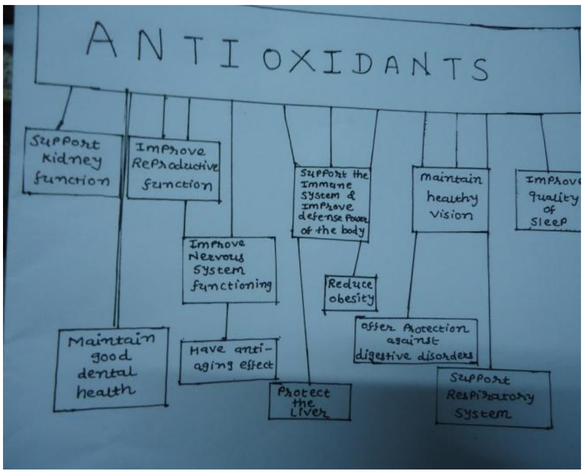
In the absence of genetic variation in nutrient content among varieties, breeders have nothing to work with.This is where transgenic approaches can be a suitable alternative option [7,8]. Nutritional genomics studies the association between genomes, nutrition, and health [11,12]. The ability to quickly understand and recognize gene function and then can be used for improve nutritional quality in food [10]. This was made possible by the DNA sequencing,metabolomics,genome analysis,whole genome sequencing etc [13], other functional mechanism from bacteria and other organisms can also be introduced into crops to develope alternative pathways for metabolic engineering [9]

These technologies provide a powerful tool that is unconstrained by the gene pool of the host [18]. In addition, the genetic modifications can be targeted to the edible portions of commercial crops [19,20,22].

Although the possibilities associated with transgenic approaches keep plant biologists hopeful regulatory hurdles associated with this technology make commercial applications difficult [21,23,24,25,26]. Nearly all transgenic plants have patented or patentable inventions
associated with them; however, there has been a movement to work around patents to deliver biotechnology to the poor farmers of the world [23]. Unfortunately, the current political and economic landscape is not receptive to this technology being widely applied to a host of different crops. Even with these current limitations, the potential for genetic modifications to improve hunger warrants support of this technology among both scientists and citizens.

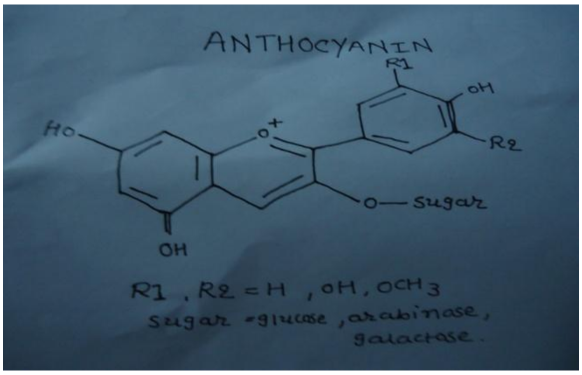
III. ANTIOXIDANTS

The consumption of fruits and vegetables has been shown to raise plasma antioxidant levels in human . Fruits and vegetables contain a wide range of antioxidants including anthocyanins and carotenoids such as lycopene and β-carotene and vitamins C and E [71,74]. Carotenoids, along with a variety of other compounds as well as sterols and tocopherols, are derived from the general isoprenoid biosynthetic pathway. Colored carotenoids are found in fruits, flowers, and roots, where they probably act as attractants to pollinators and for seed dispersal.

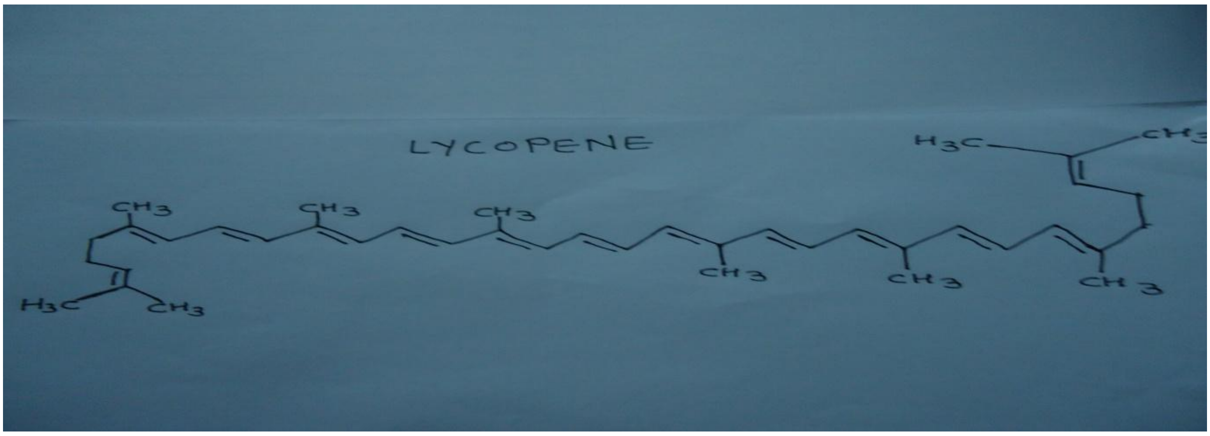


IV. ANTHOCYANIN

They are water-soluble pigments that may appear red, purple, or blue. They belong to class flavonoids. Fruits of most tomatoes contain slight amount of anthocyanin during the process of fruit coming off this removes.Currently, blackberries and raspberries are among the best sources of dietary anthocyanins, but both are not affordable and are consumed in less amount than tomatoes. Potentially, these engineered tomatoes can serve as good source of antooxidants.[31]

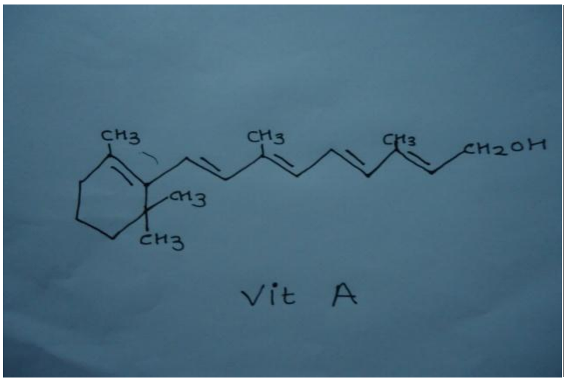


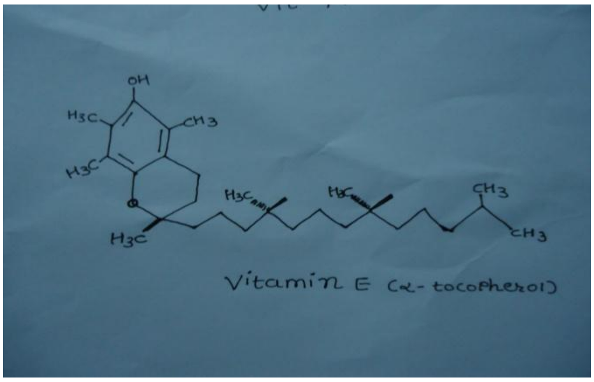
LYCOPENE



Tomatoescontain higher level of lycopene, and because of that major attentive source [27]. Natural mutants of tomato are available, such as a high-pigment variety that has been used in breeding strategies to alter lycopene levels 28. Expression of bacterial genes and yeast genes in transgenic tomatoes has also significantly altered lycopene levels [29,30.]

VITAMIN A & E





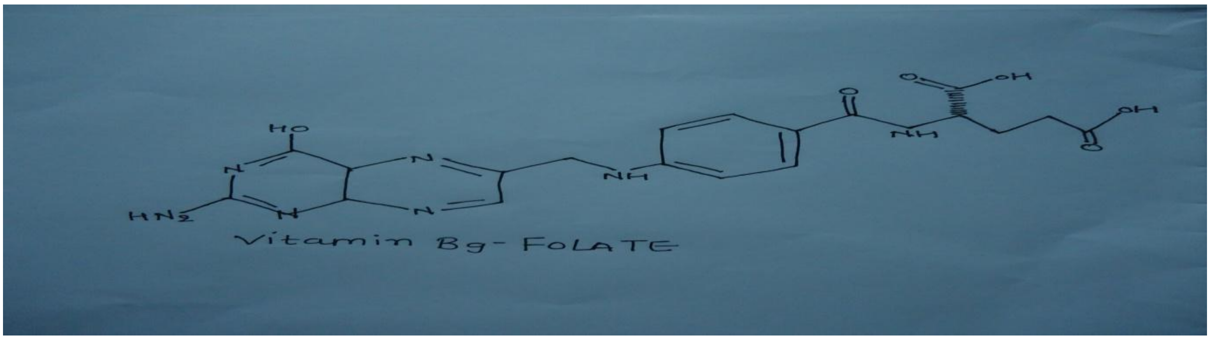
Vit a

Vitamin A deficiency is prevalent in the developing world and is probably responsible for the deaths of two million children annually. In surviving children, vitamin A deficiency is a leading,and can cause blindness in Humans, vit A can provided with the precursor molecule b-carotene a pigment found in many plants which is not present in cereal grains. Therefore, a strategy was devised to introduce the correct metabolic steps into rice endosperm to facilitate b-carotene synthesis .

An initial breakthrough was the development of a rice line expressing a daffodil phytoene synthase, enabling the accumulation of the vitamin A precursor phytoene in the endosperm [32], followed shortly thereafter by the original 'Golden Rice' variety, expressing two daffodil enzymes which reconstituted the entire pathway and enabled the rice endosperm to accumulate b-carotene, resulting in its eponymous golden color [33]

FOLATE

Folate is a generic term for tetrahydrofolate (THF) and its derivates. Folates are B vitamins; the recommended dietary allowance for folate ranges from 400 to 600 μg per day for pregnant women [49]. Plant-based foods are the primary source of folate; however, plants vary in their folate levels, and cereals—particularly rice and wheat—contain very low folate levels. Folate is a complex molecule that is assembled from three different components: pteridine, para-aminobenzoic acid (PABA), and glutamate. These components are synthesized in special compartments within the plant cell, and the folate is synthesized from these precursors within the mitochondria [49].



Essential Amino Acids

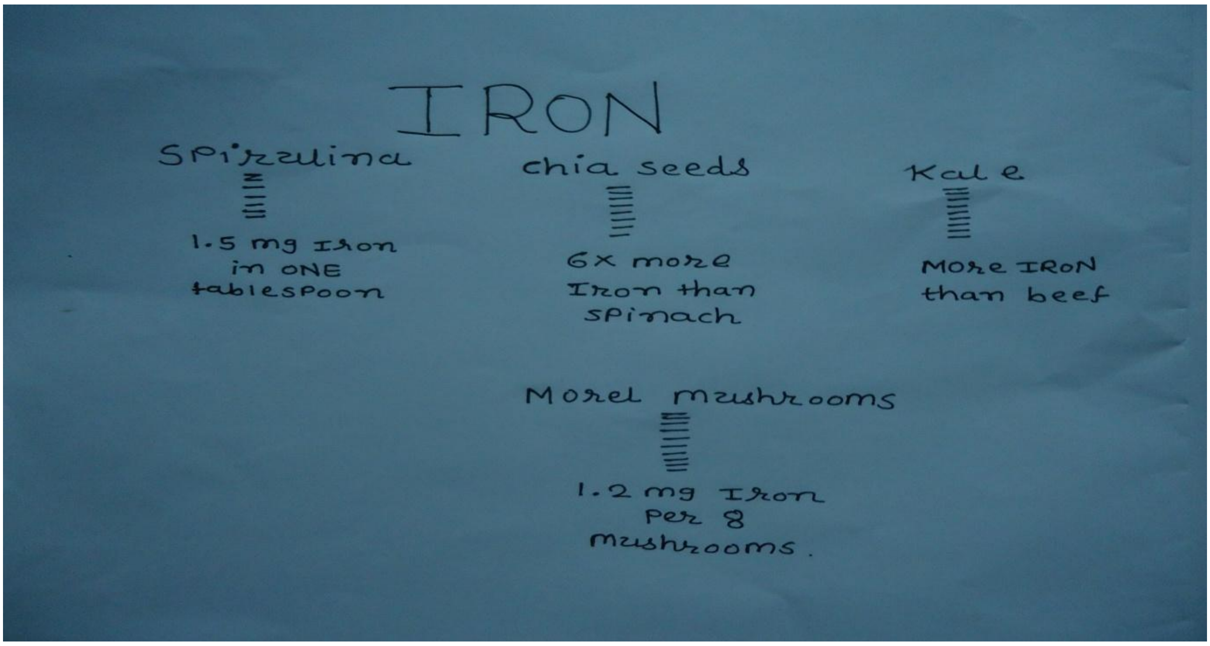
All aminoacid can not be present in one food crops; such as, legumes contain lesser amount of methionine and cysteine, while grains contain lesser amount of lysine and threonine [59,60,61,63.]People are majorly depended on legumes and cereals for their diet, plant biologists have used various methods to increase essential amino acids in these plants [61]. such as, expression of storage proteins that contain high levels of advantageous amino acids has raised lysine content in rice and wheat [65]. Similar approaches have raised essential amino acid content in potatoes [64]. However, attempts to raise sulfur-containing amino acids have not been as productive [66]. To address these issues, synthetic proteins have been expressed in cassava to match the amino acid requirements for humans

Mineral Biofortification

Although metabolic engineering is most appropriate for fortifying plants with organic nutrients, a different approach is required for minerals because they are not synthesized by the plant but rather are "mined" from the immediate environment. Two different approaches have been used to improve mineral content: 1. increase the efficiency of uptake and transport into edible tissues and 2. enhance the amount of bioavailable mineral accumulation in the plant [47,48].

Iron and Zinc

Engineering strategies to enhance the mineral content of plants have concentrated primarily on iron and zinc, which are most often deficient in human diets [35,36,37]. In fact, iron is most important as per the health issues and most leading problem in world today, affecting an estimated 2.7 billion people. Grasses having a different mechanism to obtain Fe(II) than do other plants [38]. However, all plants must first take Fe(III) that is easily avilable in the soils and convert it to Fe(II). Specific transporters are then used to absorb the minerals into the roots and transport the metal in complexes such as nicotianamine, which can chelate Fe(II) and mobilize the mineral to other locations within the plant [39,40]. The increased expression of some of these transport and chelating proteins in transgenic plants promotes metal accumulation



There appears to be some connection between iron- and zinc transport pathways because plants engineered to increase iron content also increases Zinc cotent in plant. This could reflect the enhanced synthesis of nicotianamine, which increases the mobility of both metals. In fact, treatment of nicotianamine in plants can double both zinc and iron levels in plants. The second approach to mineral biofortification is to express recombinant proteins that enable minerals to be stored in a more bioavailable form. Expression of ferritin, it is an iron-storage protein, in seeds causes a three to four fold increase in iron levels [41,42,43]. Although polishing of rice causes a decrease in mineral levels, ferritin-enhanced rice still has increased iron levels in the transgenic polished rice. Rats fed a diet containing the transgenic rice demonstrate that the iron in the rice had bioavailability equal to that found in diets containing FeSO4 at equal concentrations [44]. The removal of antinutrients from plants can also increase bioavailable mineral content. Phytic acid which is also known as phytate is an antinutrient that can chelate minerals and reduce their bioavailability in the gut [45]. A combined approach has been developed that involves the expression of iron-storage proteins and phytase (a fungal enzyme that breaks down phytate); this has been achieved in both rice and maize [46]. This combined approach for mineral biofortification should provide maximal levels of bioavailable iron.

Calcium

Calcium present in plant foods exists primarily as a complex, in which it is bound to substances such as oxalate, phytate, fiber, lactate, fatty acid, protein, and other anions [50,51]. Phytic acid is often considered as an antinutrient because it forms insoluble complexes with

Minerals such as zinc, calcium, magnesium, and iron [52,53,54]. Furthermore, it is not fastly digestible by nonruminant livestock or by humans. This can cause major problems in the management of phosphorus in livestock production and in human nutrition. One approach to studying the nutritional impact of phytic acid in feed and food, and to studying the biology of phytic acid in plants and seeds, is to isolate low-phytic-acid mutants in such plants as maize. Normally, phytic acid is present in large quantities in maize kernels.

- **CONVENTIONAL BREEDING**

Large differences exist among the many varieties of the same plant, in nutritional characteristics as well as many other traits. Accelerating since the 1960s, seed banks have been developed to collect and catalogue these variations. The International Maize and Wheat Improvement Centre in Mexico (CIMMYT) is a leading example. From such collections, it is possible to develop, through conventional breeding, new variants of staple crops with better nutrient profiles, based on lines that have proven suitable for the growing conditions in specific areas. Breeding to improve food crops goes on all over the world, mainly focussed on improving yields rather than nutrient profiles. The most significant, systematic and symbolic programme of biofortification through conventional breeding is HarvestPlus. It focuses on breeding increased levels of three nutrients (iron, zinc and pro-vitamin A) in seven staple crops (beans, cassava, maize, rice, wheat, sweet potato and pearl millet). The HarvestPlus programme is funded principally by grants from foundations, governments and international agencies. Started in 2003, within the Consultative Group on International Agricultural Research (CGIAR), it works with specialist institutes in that network and with outside, public sector and academic researchers. In HarvestPlus's conception, biofortification is a ten-step process, with assessment at each stage, If successful, the crops tested in the initial biofortification projects will be disseminated to numerous 'spillover countries' with similar growing conditions, including areas of Latin America. The first results from the first project, sweet potato biofortified with pro-vitamin A, are expected in 2010

- **IMPACT ON PLANT PRODUCTIVITY AND THE ENVIRONMENT**

Assessments of the potential alterations in plant metabolism following biofortification efforts have rarely been analyzed. Altering metabolic fluxes through a specific pathway may affect plant growth and productivity. for instance, changes in metal content may alter enzyme activities and metabolism. It is thus imperative to establish whether a specific alteration in plant metabolism is cost effective. Useful biofortification efforts should increase nutrient content while maintaining low cultivation and production costs. Fortunately, improved metabolomic and metabolic modeling techniques should facilitate such analysis [64]. The experimental parameters used to test genetically modified foods should resemble clinical trials with a novel pharmacological agent. Interactions with other nutrients in the plant matrices, potential allergic responses of the consumer, and alterations of plant stress responses are some of the parameters that need

IV. FACTORS INFLUENCING FUTURE IMPACTS

Whether biofortification is an important factor for health concern but it also depended on some circumstances. Important factors influencing the impact in a given setting include local dietary patterns as well as technology efficacy and coverage.Local dietary patterns should determine the crop species to be targeted. Biofortification can only make a difference when the crop in question is an important local staple food, which is repeatedly consumed in relatively huge quantities. Therefore, the appropriate crop choice may vary regionally. Technology efficacy will be determined by the amount of the micronutrient in the crop, micronutrient retention after processing, and its bioavailability. Coverage, defined as the share of biofortified varieties in total quantities consumed of the crop, is mainly a function of farmer adoption and consumer acceptance.[77]

REFERENCES

[1]. United Nations Administrative Committee on Coordination/Sub-Committee on Nutrition. 4th Report on the world nutrition situation: nutrition throughout the life cycle. Geneva: ACS/SCN/WHO, 2000.

[2]. International Bank for Reconstruction and Development/ World Bank. World development report 2000/ 2001: attacking poverty. New York: Oxford University Press, 2001

[3]. Matin Qaim, Alexander J. Stein and J. V. Meenakshi

[4]. Bouis HE. 2000. Enrichment of food staples through plant breeding: a new strategy for fighting micronutrient malnutrition. Nutrition 16:701–4

[5]. Bouis HE. 2005. Micronutrient fortification of plants through plant breeding: Can it improve nutrition in man at low cost? Proc. Natl. Acad. Sci. USA 62:403–11

[6]. Atanassov A, Bahieldin A, Brink J, Burachik M, Cohen JI, et al. 2004. To reach the poor: results from the ISNAR-IFPRI Next Harvest study on genetically modified crops, public research, and policy implications (no. 116). In EPTD Discussion Paper. Environment and Production Technology Division, International Food Policy Research Institute,Washington, DC, pp. 1–57

[7]. Zhu C, Naqvi S, Gomez-Galera S, Pelacho AM, Capell T, Christou P. 2007. Transgenic strategies for the nutritional enhancement of plants. Trends Plant Sci. 12:548–55

[8]. Brinch-Pedersen H, Borg S, Tauris B, Holm PB. 2007. Molecular genetic approaches to increasing mineral availability and vitamin content of cereals. J. Cereal Sci. 46:308–26

[9]. Newell-McGloughlin M. 2008. Nutritionally improved agricultural crops. Plant Physiol. 147:939–53

[10]. Christou P, Twyman RM. 2004. The potential of genetically enhanced plants to address food insecurity. Nutr. Res. Rev. 17:23–42
[11]. DellaPenna D. 1999. Nutritional genomics: manipulating plant micronutrients to improve human health. Science 285:375–79
[12]. Brigelius-Flohe R, Joost HG. 2006. Nutritional Genomics: Impact on Health and Disease. Weinheim, Germany:Wiley-VCH Verlag
[13]. Galili G, Galili S, Lewinsohn E, Tadmor Y. 2002. Genetic, molecular, and genomic approaches to improve the value of plant foods and feeds. Crit. Rev. Plant Sci. 21:167–204
[14]. Dai, J-L. et al. (2004) Selecting iodine-enriched vegetables and the
[15]. residual effect of iodate application to soil. Biol. Trace Elem. Res. 101, 265–276
[16]. Hartikainen, H. (2005) Biogeochemistry of selenium and its impact on food chain quality and human health. J. Trace Elem. Med. Biol. 18,309–318
[17]. Frossard, E. et al. (2000) Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J. Sci. Food Agric. 80, 861–879
[18]. White, P.J. and Broadley, M.R. (2005) Biofortifying crops with essential mineral elements. Trends Plant Sci. 10, 586–593
[19]. Davies KM. 2007. Genetic modification of plant metabolism for human health benefits. Mutat. Res. 622:122–37
[20]. Agrawal PK, Kohli A, Twyman RM, Christou P. 2005. Transformation of plants with multiple cassettes generates simple transgene integration patterns and high expression levels. Mol. Breed. 16:247–60
[21]. Shewmaker CK, Sheehy JA, Daley M, Colburn S, Ke DY. 1999. Seed-specific overexpression of phytoene synthase: increase in carotenoids and other metabolic effects. Plant J. 20:401–12
[22]. Weil J-H. 2005. Are genetically modified plants useful and safe? IUBMB Life 57:311–14
[23]. Yang SH, Moran DL, Jia HW, Bicar EH, Lee M, Scott MP. 2002. Expression of a synthetic porcine alpha-lactalbumin gene in the kernels of transgenic maize. Transgenic Res. 11:11–20
[24]. Powell K. 2007. Functional foods from biotech???an unappetizing prospect? Nat. Biotechnol. 25:525–31
[25]. Int. Life Sci. Inst. (ISLI). 2008. Nutritional and safety assessments of foods and feeds nutritionally improved through biotechnology: case studies. Compr. Rev. Food Sci. Food Safety 7:50–99
[26]. Johnson KL, Raybould AF, Hudson MD, Poppy GM. 2007. How does scientific risk assessment of GM crops fit within the wider risk analysis? Trends Plant Sci. 12:1–5
[27]. Freese W, Schubert D. 2004. Safety testing and regulation of genetically engineered foods. Biotechnol. Genet. Eng. Rev. 21:299–324
[28]. Rosati C, Aquilani R, Dharmapuri S, Pallara P, Marusic C, et al. 2000. Metabolic engineering of β-carotene and lycopene content in tomato fruit. Plant J. 24:413–19
[29]. Santos CA, Simon PW. 2002. QTL analyses reveal clustered loci for accumulation of major provitamin A carotenes and lycopene in carrot roots. Mol. Genet. Genomics 268:122–29
[30]. Mehta RA, Cassol T, Li N, Ali N, Handa AK, Mattoo AK. 2002. Engineered polyamine accumulation in tomato enhances phytonutrient content, juice quality, and vine life. Nat. Biotechnol. 20:613–18
[31]. Fraser PD, Romer S, Shipton CA, Mills PB, Kiano JW, et al. 2002. Evaluation of transgenic tomato plants expressing an additional phytoene synthase in a fruit-specific manner. Proc. Natl. Acad. Sci. USA 99:1092–97
[32]. Butelli E, Titta L, Giorgio M, Mock H-P, Matros A, et al. 2008. Enrichment of tomato fruit with health-promoting anthocyanins by expression of select transcription factors. Nat. Biotech. 26:1301–8
[33]. Burkhardt, P.K. et al. (1997) Transgenic rice (Oryza sativa) endosperm expressing daffodil (Narcissus pseudonarcissus) phytoene synthase accumulates phytoene, a key intermediate of provitamin A biosynthesis. Plant J. 11, 1071–1078
[34]. Ye, X. et al. (2000) Engineering the provitamin A (b-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science 287, 303–305
[35]. Meenakshi J, Johnson N, Manyong V, Degroote H, Javelosa J, Yanggen D, Naher F, Gonzalez C, Garcia J and Meng E. (2010). How cost effective is biofortification in combating micronutrient malnutrition? An ex ante assessment, World Development, (1), 64-7 Shetty P. (2009). nutritional considerations when addressing food insecurity. Food Security, 1, 431-40.
[36]. Curie C, Briat JF. 2003. Iron transport and signaling in plants. Annu. Rev. Plant Biol. 54:183–206 Vit a e
[37]. Lucca P, Hurrell R, Potrykus I. 2002. Fighting iron deficiency anemia with iron-rich rice. J. Am. Coll. Nutr. 21:184–90S
[38]. Palmgren MG, Clemens S,Williams LE, Kr¨amer U, Borg S, et al. 2008. Zinc biofortification of cereals: problems and solutions. Trends Plant Sci. 13:464–73
[39]. Ishimaru Y, Suzuki M, Tsukamoto T, Suzuki K, Nakazono M, et al. 2006. Rice plants take up iron as an Fe3+-phytosiderophore and as Fe2+. Plant J. 45:335–46
[40]. Grotz N, Guerinot ML. 2006. Molecular aspects of Cu, Fe and Zn homeostasis in plants. Biochim. Biophys. Acta 1763:595–608
[41]. Ramesh SA, Choimes S, Schachtman DP. 2004. Over-expression of an Arabidopsis zinc transporter in Hordeum vulgare increases short-term zinc uptake after zinc deprivation and seed zinc content. Plant Mol. Biol. 54:373–85
[42]. Vasconcelos M, Datta K, Oliva N, Khalekuzzaman M, Torrizo L, et al. 2003. Enhanced iron and zinc accumulation in transgenic rice with the ferritin gene. Plant Sci. 164:371–78
[43]. Goto F, Yoshihara T, Saiki H. 2000. Iron accumulation and enhanced growth in transgenic lettuce plants expressing the iron-binding protein ferritin. Theor. Appl. Genet. 100:658–64
[44]. Goto F, Yoshihara T, Shigemoto N,Toki S,Takaiwa F. 1999. Iron fortification of rice seed by the soybean ferritin gene. Nat. Biotechnol. 17:282–86
[45]. Murray-Kolb LE,Takaiwa F, Goto F, Yoshihara T, Theil EC, Beard JL. 2002.Transgenic rice is a source of iron for iron-depleted rats. J. Nutr. 132:957–60
[46]. Denbow DM, Grabau EA, Lacy GH, Kornegay ET, Russell DR, Umbeck PF. 1998. Soybeans transformed with a fungal phytase gene improve phosphorus availability for broilers. Poult. Sci. 77:878–81
[47]. Drakakaki G, Marcel S, Glahn RP, Lund EK, Pariagh S, et al. 2005. Endosperm-specific coexpression of recombinant soybean ferritin and Aspergillus phytase in maize results in significant increases in the levels of bioavailable iron. Plant Mol. Biol. 59:869–80
[48]. Frossard E, Bucher M,M¨achler F, Mozafar A, Hurrell R. 2000. Potential for increasing the content and bioavailability of Fe, Zn and Ca in plants for human nutrition. J. Sci. Food Agric. 80:861–79
[49]. Colangelo EP, Guerinot ML. 2006. Put the metal to the petal: metal uptake and transport throughout plants. Curr. Opin. Plant Biol. 9:322–30
[50]. DellaPenna D. 2007. Biofortification of plant-based food: enhancing folate levels by metabolic engineering. Proc. Natl. Acad. Sci. USA 104:3675–76

[51]. Linder MC. 1991. Nutritional Biochemistry and Metabolism:With Clinical Applications. New York: Elsevier. 2nd ed.
[52]. Wilson DS, Clifford AJ. 1990. Bioavailability: How the nutrients in food become available to our bodies. In Nutrition: Eating for Good Health, Bulletin 685, ed. DT Smith, pp. 72–77.Washington, DC: U.S. Dep. Agric.
[53]. Raboy V. 2001. Seeds for a better future: "low phytate" grains help to overcome malnutrition and reduce pollution. Trends Plant Sci. 6:458–459
[54]. Hambidge KM, Krebs NF, Westcott JL, Sian L, Miller LV, et al. 2005. Absorption of calcium from tortilla meals prepared from low-phytate maize. Am. J. Clin. Nutr. 82:84–87
[55]. Adams CL, Hambidge M, Raboy V, Dorsch JA, Sian L, et al. 2002. Zinc absorption from a low-phytic acid maize. Am. J. Clin. Nutr. 76:556–59
[56]. Fraser PD, Romer S, Shipton CA, Mills PB, Kiano JW, et al. 2002. Evaluation of transgenic tomato plants expressing an additional phytoene synthase in a fruit-specific manner. Proc. Natl. Acad. Sci. USA 99:1092–97
[57]. Mehta RA, Cassol T, Li N, Ali N, Handa AK, Mattoo AK. 2002. Engineered polyamine accumulation in tomato enhances phytonutrient content, juice quality, and vine life. Nat. Biotechnol. 20:613–18
[58]. Rosati C, Aquilani R, Dharmapuri S, Pallara P, Marusic C, et al. 2000. Metabolic engineering of β- carotene and lycopene content in tomato fruit. Plant J. 24:413–19
[59]. Santos CA, Simon PW. 2002. QTL analyses reveal clustered loci for accumulation of major provitamin A carotenes and lycopene in carrot roots. Mol. Genet. Genomics 268:122–29
[60]. Newell-McGloughlin M. 2008. Nutritionally improved agricultural crops. Plant Physiol. 147:939–53
[61]. O'Quinn PR, Nelssen JL, Goodband RD, Knabe DA,Woodworth JC, et al. 2000. Nutritional value of a genetically improved high-lysine, high-oil corn for young pigs. J. Anim. Sci. 78:2144–49
[62]. Sautter C, Poletti S, Zhang P, Gruissem W. 2006. Biofortification of essential nutritional compounds and trace elements in rice and cassava. Proc. Nutr. Soc. 65:153–59
[63]. Rapp W. 2002. Development of soybeans with improved amino acid composition. In 93rd AOCS Annual Meeting and Expo, Montreal, May 5–8, pp. 79–86. Champaign, IL: Am. Oil Chem. Soc.
[64]. Hartwig EE, Kuo TM, Kenty MM. 1997. Seed protein and its relationship to soluble sugars in soybeans. Crop Sci. 37:770–73
[65]. Egnin M, Prakash CS. 1997. Transgenic sweetpotato expressing a synthetic storage protein gene exhibits high level of total protein and essential amino acids. In Vitro Cell Dev. Biol. 33:52A
[66]. Christou P, Twyman RM. 2004. The potential of genetically enhanced plants to address food insecurity. Nutr. Res. Rev. 17:23–42
[67]. Dinkins RD, Reddy MSS, Meurer CA, Yan B, Trick H, et al. 2001. Increased sulfur amino acids in soybean plants overexpressing the maize 15 kDa zein protein. In Vitro Cell Dev. Biol. Plant. 37:742–47
[68]. Brigelius-Flohe R, Joost HG. 2006. Nutritional Genomics: Impact on Health and Disease. Weinheim, Germany:Wiley-VCH Verlag
[69]. Brinch-Pedersen H, Borg S, Tauris B, Holm PB. 2007. Molecular genetic approaches to increasing mineral availability and vitamin content of cereals. J. Cereal Sci. 46:308–26
[70]. DellaPenna D. 1999. Nutritional genomics: manipulating plant micronutrients to improve human health. Science 285:375–79
[71]. Zhu C, Naqvi S, Gomez-Galera S, Pelacho AM, Capell T, Christou P. 2007. Transgenic strategies for the nutritional enhancement of plants. Trends Plant Sci. 12:548–55
[72]. Yu O, Jung W, Shi J, Croes RA, Fader GM, et al. 2000. Production of the isoflavones genistein and daidzein in nonlegume dicot and monocot tissues. Plant Physiol. 124:781–94
[73]. Newell-McGloughlin M. 2008. Nutritionally improved agricultural crops. Plant Physiol. 147:939–53
[74]. Galili G, Galili S, Lewinsohn E, Tadmor Y. 2002. Genetic, molecular, and genomic approaches to improve the value of plant foods and feeds. Crit. Rev. Plant Sci. 21:167–204
[75]. Botella-Pav´ıa P, Rodriguez-Concept´ıon M. 2006. Carotenoid biotechnology in plants for nutritionally improved foods. Plant Physiol. 126:269–81
[76]. Weaver CM, Proulx WR, Heaney R. 1999. Choices for achieving adequate dietary calcium with a vegetarian diet. Am. J. Clin. Nutr. 70(3 Suppl.):543–48S
[77]. from harvestplus paper
[78]. Economics of biofortification Matin Qaim, Alexander J. Stein and J. V. Meenakshi