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Improving Food Nutritional Quality and Productivity through Genetic Engineering

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Abstract

Genetic engineering has provided new tools for effectively ensuring food and nutritional security to improve agriculture across the world. Conventional agricultural practices can be assisted by molecular biology and biotechnology tools to develop crops with superior traits in a relatively fast way. Genetic engineering allowed solving important problems in many crops such as susceptibility to pests, diseases, environmental stress and development of crops with higher productivity and enhanced nutritional quality. Genetically-modified (GM) crops can prove to be powerful complements to those produced by conventional methods for meeting the worldwide demand for quality foods.

Keywords: Genetically modified food; Nutritional quality; Post-harvest stability; Stress tolerance; Crop productivity; Genetic engineering

Introduction

To feed the booming world population the corresponding increase in food production is necessary. The food derived from plants act as major source of nutrition in human diet by providing certain essential amino acids and vitamins that cannot be synthesized de novo by humans. Thus, malnutrition is a complex problem for human health, causing the loss of countless lives in many countries. To be healthy, our daily diet must include ample high quality foods with all of the essential nutrients, in addition to foods that provide health benefits beyond basic nutrition. Adverse environmental conditions including drought, salinity, flooding, low and high temperature, disease causing pests and pathogens etc significantly affect the crop productivity.

The challenge is to increase the food production by maintaining high productivity under various stresses as well as developing new crop varieties with enhanced nutritional quality. Genetically-modified (GM) crops can prove to be powerful complements to those produced by conventional methods for meeting the worldwide demand for quality foods. The modern plant biotechnological tools allowed the manipulation of genes from various sources and insertion of these genes into plants to impart desirable traits in economically important crops. Crops developed by genetic engineering can not only be used to enhance yields and nutritional quality but also for increased tolerance to various biotic and abiotic stresses. Despite the diverse and widespread beneficial applications of genetically engineered products, the concerns have been expressed regarding unintended and unpredictable pleiotropic effects of these products on human health and the environment [1]. However, genetically engineered products are no different in terms of possible unintended harmful effects on human health and the environment [2,3].

Enhancement of nutritional quality

Genetic engineering has been hugely utilized for the nutritional enhancement of crops either by enriching it with novel nutrients or increasing the content of the prior existing nutrients or decreasing/eliminating anti- nutrients/toxins. Rice is an important staple food crop, but lacks β-carotene which acts as a precursor to vitamin A. Ye et al. [4] developed nutritionally valuable 'Golden rice' with β-carotene expression in the rice endosperm. Similarly, super bananas with increased level of β-carotene were also developed by transforming a phytoene synthase (PSY2a) gene from the asupina banana variety [5]. Potato is an important non-cereal starchy crop with poor nutritive value due to lack of essential amino acids, such as lysine, tyrosine, and the sulfur-containing amino acids methionine and cysteine. In order to increase the free essential amino acids in potato, AmA1 gene from Amaranthus (rich in proteins with balanced amino acid composition) was isolated and expressed in seven commercially important potato varieties that were adapted to different agro-climatic regions [6]. In transgenic potato tubers expressing AmA1, besides increase in the levels of several essential amino acids, a 60% increase in total protein content, enhanced rate of photosynthesis along with increase in total biomass and a moderate increase in tuber yield was observed [7]. It was found to be non-allergenic and safe for consumption suitable for commercial cultivation on the basis of field performance and biosafety assessment [7]. Legumes such as soya bean and grass pea seeds constitute the main source of proteins to the majority of human diets but they also consist of anti-nutrient oxalic acid (OA) [8]. OA can lead to kidney stones, hypocalcemia and coronary disease in humans [9] and is also a known precursor of β-N-oxalyl-L-α, β-diaminopropionic acid (β-ODAP), a neurotoxin found in grass pea that causes neuro-lathyrism characterized by limb paralysis, convulsions, and death [10]. Constitutive and seed-specific expression of an oxalate-degrading enzyme, oxalate decarboxylase of *Flammulina velutipes* (FvOXDC) led to reduction in oxalic acid level in soya bean (up to 73%) and grass pea (up to 75%) along with associated increase in the seeds micronutrients such as calcium, iron and zinc [11]. Moreover, significant reduction of β-ODAP level (up to 73%) was also observed in grass pea seeds [11]. Multiple desirable traits like increased iron and beneficial polyunsaturated fatty acid (PUFA) content, enhanced drought tolerance, resistance to phytopathogen has been achieved in tomato by expressing a single gene C-5 sterol desaturase from *Flammulina velutipes* (FvC5SD) [12].

Post-harvest stability

Fruits and vegetables are important components of human diet. The post-harvest decay process of fruits and vegetables affects shelf-life and limits transportation and storage resulting in post-harvest losses upto 50% of the total produce [13]. Therefore, enhancement of fruit shelf life by slowing down of post-harvest decaying process is among the targets of crop genetic improvement efforts. Meli et al. [13] targeted the suppression of two N-glycan processing enzymes, α-mannosidase (α-Man) and β-D-N-acetylhexosaminidase (β-Hex) through RNAi approach in tomato, a climacteric fruit which requires ethylene to complete ripening process. Analysis of transgenic tomato revealed the enhanced fruit firmness and shelf life, due to the reduced rate of fruit softening. Similarly, RNAi-mediated suppression of α-Man and β-Hex in non-climacteric fruit of capsicum delayed the fruit deterioration by ~7 days and RNAi fruits of α-Man and β-Hex were ~2 times firmer than control [14].

Moreover, the promoters of α-Man and β-Hex genes are also fruit ripening specific and could be useful tools in regulating gene expression related studies during fruit ripening [15,16]. All these reports suggest that manipulation of N-glycan processing enzymes can be of strategic importance to reduce post-harvest losses in both climacteric and non-climacteric fruits. Moreover, enhanced shelf life and post-harvest stability of fruits and vegetables were also observed by silencing of the genes involved in the biosynthesis of ethylene [1-aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase] and abscisic acid (9-cis-epoxycarotenoid dioxygenase) that initiates and accelerates fruit ripening, and genes (polygalacturonase, expasin) that involved in fruit softening by degrading cell wall components [17-20]. Cold storage of fruits and vegetables delays post-harvest decay, however, it also results in accumulation of undesired metabolites. It has been demonstrated that RNA silencing of the vacuolar acid invertase gene (*VInv*) can prevent reducing sugar accumulation during cold storage and therefore, prevents cold-induced sweetening, improves processing quality and lowers acrylamide formation [21,22].

Stress tolerance

The growth and productivity of crops are severely affected by various biotic (disease causing pathogens including bacteria, viruses, fungi etc.) and abiotic stress (salinity, drought, low and high temperature, metal toxicity etc). Therefore, genetically modifying the crops to increase their tolerance to these stresses would stabilize the crop production and significantly contribute to food security. The various genetically engineered crops expressing several stress-inducible genes have been developed showing increased tolerance to drought, cold and salinity stresses [23,24].

Wu et al. [25] developed transgenic rice plants by expressing OsWRKY11 under the control of rice heat shock protein promoter HSP101. These plants showed the longer survival and less water loss compared to wild-type plants when exposed to drought stress. Similarly, the enhanced tolerance to dehydration and salinity stress was also observed in the rice plants transformed with AtDREB1A and rice DREB1B, respectively [26]. Kamthan et al. [12] expressed C-5 sterol desaturase from *Flammulina velutypes* (FvC5SD) in tomato resulting increased deposition of epicuticular wax which conferred drought resistance to the transgenic tomato plants by reducing the percentage of water loss due to transpiration. As tomato is the natural host of Sclerotinia sclerotiorum, the potential of the fungus to infect the leaves of transgenic plants and wild-type plants were also tested. These tomato transgenic lines also showed the slow progress of disease caused by *Sclerotinia sclerotiorum* compared to the wild-type plants because of the thicker wax layer on the outer leaf surface [12].

The expression of another gene from *Flammulina velutypes,* FvOXDC in tobacco, tomato, lathyrus and soybean led to increased resistance to the pathogen *Sclerotinia sclerotiorum* which uses oxalic acid during the host colonization [27,11] Recently, Shukla et. al. [28] developed transgenic cotton plants by expressing an insecticidal protein (Tma12) from an edible fern *Tectaria macrodonta*. This protein is insecticidal to whitefly (*Bemisia tabaci*) which damages field crops by sucking sap and transmitting viral diseases. These transgenic cotton lines were resistant to whitefly infestation in contained field trials without yield penalty and were also protected from whitefly-borne cotton leaf curl viral disease.

Photosynthetic efficiency and crop yield

Recently it has been reported that expression of a transcription factor HYR (HIGHER YIELD RICE) in rice led to higher grain yield

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under normal, drought and high-temperature stress conditions [29]. HYR being a master regulator enhances photosynthesis by direct activation of photosynthesis genes, transcription factors and other downstream genes involved in photosynthetic carbon metabolism. An exciting experimental approach to increase crop yield radically is to change components of plant biochemistry with respect to introducing the C4 type of photosynthesis into a C3 plants such as Arabidopsis [30] and potato [31].

In addition to above, genetic engineering has also emerged as a tool to improve herbicide tolerance, production of sugar and starch, production of pharmaceuticals and vaccines in crop plants [32]. Most recently, genome editing and genome engineering technologies significantly pace up the development of genetically improved varieties with enhanced yield, nutrition and tolerance to biotic and abiotic stresses by modifying existing genes and target transgenes to specific sites in the genome, respectively [33-35].

Conclusion

Genetic engineering has the potential to be used as an efficient tool to address the various problems in agriculture and society. Genetic engineering is being used to minimize yield losses due to various stresses (biotic and abiotic), biofortification of food crops by enrichment with quality proteins, vitamins, micronutrients, carotenoids, anthocyanins etc. Moreover, postharvest stability of fruits and vegetables has also been increased significantly to reduce the post-harvest losses. While the global area under GM crops continues to expand every year, no harmful effects of these crops have been documented even after several years of extensive cultivation in diverse environments and widespread human consumption [2,3]. Thus, genetic engineering serves as an efficient tool to introduce desirable characteristics in plants in a rapid and precise way. In spite of associated biosafety issues, if designed and developed thoughtfully, it can help to solve the major world problems of malnutrition and food insecurity in combination with conventional breeding programs.

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