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Review Article

Insights into Transgenic Vegetables: Progress and Prospects

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Abstract

Vegetables play a significant role in the daily diet of human being as they contain essential vitamins, minerals, dietary fibres, and key phytochemical compounds that help to enhance human health, good vision and a minimum risk of heart chronic diseases. Geographical region and local traditions differ widely with the intake of vegetable supplements to the diet. The production of vegetables suffers from abiotic and biotic stress responses. To enhance the host plant resistance or tolerance against these stresses and enrich the vegetables with prolonged shelf-life, high nutritional status, it is essential to produce genetically modified vegetables. In the 21st century, genetically modified transgenic vegetable crops have a major contribution to food and nutritional security. This study explores the potential prospects of the global vegetable scenario and the methods to develop genetically engineered vegetable crops by transgenic technologies. © 2022 Friends Science Publishers

Keywords: GM Vegetables; Transgenic plant; Biosafety; Food safety

Introduction

The alarming population growth, global warming, continued overexploitation of natural resources have led to severe threats to food security. Innovative product development and improved sustainable farming methods can bridge the massive gap of food scarcity from limited natural resources (Ashraf and Akram 2009). Traditional breeding has a limited scope; instead, it can be tackled within the realm of genetic engineering (Brookes and Barfoot 2015). Transgenic technology is used to deploy the gene(s) of interest either from the primary gene pool or even unrelated organisms and deliver to the host plant genome with the desired trait expression (Alsadon *et al.* 2021). Vegetables are significant sources of essential nutrients for human health. Besides, it serves as a source of income, and as such, its cultivation is economically viable owing to the short cropping period and prime demand in each household. Thus, the vegetable sector has significantly improved human health, livelihood and the economy of a country.

However, the pace of crop improvement is much slower in vegetables than what has been achieved in cereals. Farmers stress upon optimal yield coupled with resistance to biotic and abiotic stresses, while the products' appearance, nutritional value, quality, and shelf-life are of paramount importance in turns of consumers' perspectives (Dias and Ryder 2011). Vegetables are the most perishable food items. Hence, there is a need to re-orient the breeding strategy in vegetable crops for ease in cultivation and meet the requirement of marketing and general consumption (Dias and Ryder 2011). One important strategy to mitigate the shortage of nutrients is bio-fortification which makes zinc, iron, carotenoids and provitamin-A breeding extremely vital (Hotz and McClafferty 2007). In combination with the knowledge available about genes and their properties, plant biotechnologists can develop various genetically modified

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vegetable crops using plant transformation protocols. This can solve the issue of the most difficult biotic and abiotic limitations faced by farmers worldwide. In this review, the global scenario of vegetables and the strategies for genetic modification using transgenic technology are elaborated with its prospects.

Global vegetable production scenario

Vegetables are cultivated on diverse land and climate on both small and large scales around the world. Over the last decade, the world's vegetable production has undergone a considerable increment accounting for a turnover of about 3% annually (FAOSTAT Database 2013). The total vegetable production around the globe reached 1 billion tons in 2011 (FAOSTAT Database 2013). From 52.7 million ha, Asia has produced 671 million tons of vegetables and has covered a share of about 74.7% of the total vegetable production across the globe. Among the countries in the world, China is the largest producer of vegetables, sharing 50% of global export (FAOSTAT Database 2013). A survey on different countries in which vegetable crops are cultivated for the year 2017–2018 revealed that China has the prominent area of vegetable growing, which is 19.96 million ha, followed by India, which has 1.02 million ha (Fig. 1). Suppose the production and consumption (Fig. 2) of vegetable crops is considered in 2017–2018. In that case, China stands for the first position, followed by India, the USA, Turkey, Russia, Nigeria, Vietnam, Mexico, Egypt and Iran. This analysis revealed that vegetables are the most important crops that need to be addressed for more cultivation and production (Vasileva and Dinev 2021). Global vegetables cultivated on arable land are grown at 31% (Fig. 3) per year, followed by fiber crops, fruits, cereals, root crops, and pulses (FAOSTAT Database 2013). India stands second in the list of vegetable-producing countries, but it represents six times lower than China.

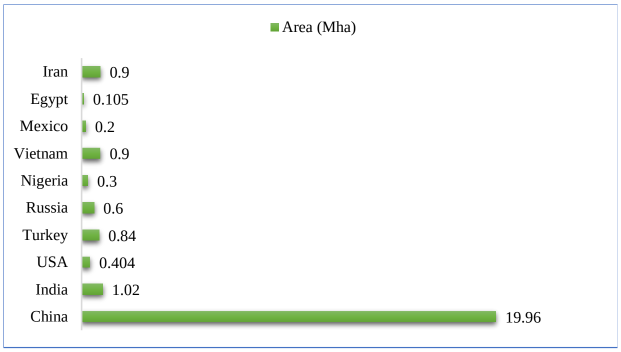

Fig. 1: Area (Million ha) under vegetable cultivation across vegetable growing countries (Statistica 2021)

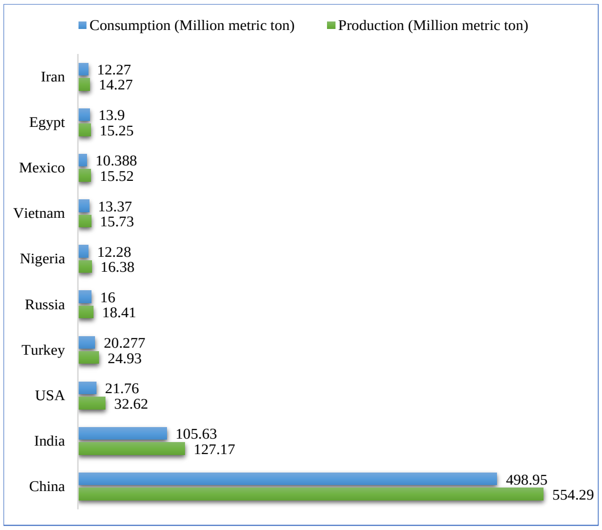

Fig. 2: Production and consumption of vegetables across some vegetable growing countries (Statistica 2021)

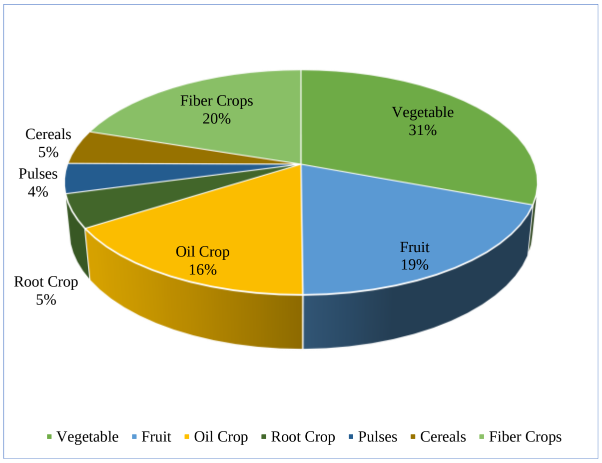

Fig. 3: Global vegetable cultivated on arable land as compared to other crops (Statistica 2021)

Nevertheless, in the last three decades, India has made remarkable progress on the agricultural point of view. Potato is ranked first (Fig. 4), subsequently followed by other essential vegetable crops, such as cabbage, cauliflower, tomato, brinjal and onion. Among a total of 1,596 high-yielding varieties and horticultural crop hybrids, 485 are vegetables alone. In both developed and developing countries, the quick adoption of transgenic crops reflects the multiple advantages gained by all classes of farmers, enabling commercial cultivation of transgenic crops (James 2015). This favourable adoption rate is the norm, giving both small and large farmers and consumer's resilience, longevity and significant benefits. According to the ISAAA (International Service for the Acquisition of Agri-biotech Applications) GM approval database, the highest number of major GM vegetable crop events is approved by the USA, followed by Canada, Australia and New Zealand (ISAAA 2021). Maximum crop events are approved for potatoes, followed by tomatoes and minor events approved for eggplant globally. Recently only one event has been in progress in Canada for genetically modified eggplants. According to the same GM approval database of ISAAA,

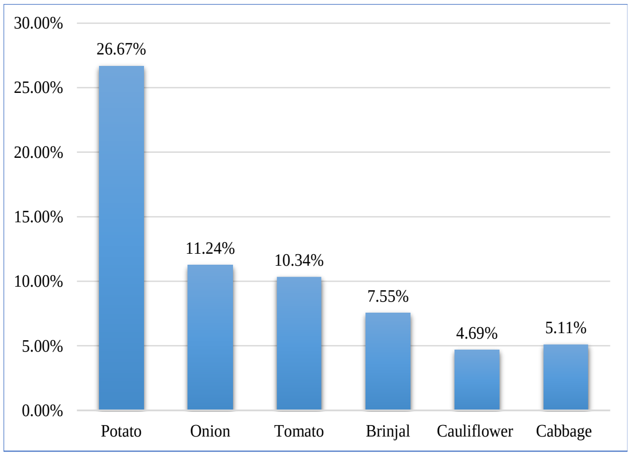

Fig. 4: Important vegetables cultivated in India (Vegetable Statistics 2021)

for commercial traits in GM vegetables, the events are approved in more numbers for potatoes followed by tomatoes and eggplants (ISAAA 2021).

Need of the transgenic vegetable production

By the end of this century, the dramatic global climate change would lead the way towards an increase of surface air temperature of about 1.8–4.0°C, thereby increasing the frequent occurrence of extreme climate events such as droughts, heat, floods and cold waves (Pimentel *et al.* 1997). Global climate change, resulting in high temperature increases and severe weather conditions has a significant adverse impact on diverse horticultural crops so also nutritional security provided by them which, in turn, hampers sustainable farm revenue. Therefore, considering and promoting adaptation measures is very important by implementing acceptable cultural strategies such as differential crop growing times, use of resistance varieties, regular crop rotation, adequate irrigation and drainage facilities. Identification of the resistance gene (s) and the QTLs (quantitative trait loci) for resistance towards biotic and abiotic stresses will overcome the problems of resolving the issues associated with biotic and abiotic stresses. Usually, plants become infested with pathogens and pests. Sometimes, dramatic reduction in yield has been recorded by several bacteria, fungi and viruses; those are well known to cause different plant diseases.

In the world, there are more than 70,000 insect species, 10 percent of which are considered serious pests (Pimentel *et al.* 1997). Despite of the ubiquitous use of pesticides, varied diseases, insects and weeds have continued the crop yield reduction that is close enough to 40 percent (Tarafdar *et al.* 2014). Several pre-harvest crop losses comprised of 15% from insect pests, diseases covering 13% while 12% noted from weeds (Pimentel *et al.* 1997). Vegetables are quite sensitive and difficult as compared to that of field crops because of their frequency of production, disease and pests. Climate change, a growing population and slow growth have led to major challenges for the population. By 2025, the entire population around the globe is expected to reach about 8.5 billion. A major problem is feeding the rising population with inadequate land, water and limited natural resources. Several works have been carried out via conventional breeding programmes in the production of novel crop cultivars, but they are quite slow-going processes consuming of about 8–10 years of time or more. The parental gene and the recipient's origin and life serve as the deciding factor for the time taken in order to pass the desired gene into the crop plants (Jauhar 2006). The secondary and tertiary gene pool consists of some wild crops and landraces, which are rich gene pools for several agronomic characteristics such as resistance to diseases or pests whose genes can be used for improvement. However, between donor and crop species, pre and post fertilization barriers may impede sexual hybridization which can worsen the issue of alien gene transmission (Jauhar 2006). In such instances, the integration of a certain characteristic by conventional means may not even be possible because a suitable donor may not be available. Genetic engineering technology therefore gives access, leaving aside the limitations of sexual compatibility to a broader gene pool.

Timeline of development and the current global status of transgenic vegetables

In 1994, the first transgenic vegetable approved to be cultivated commercially in the United States was the FlavrSavr tomato (Bruening and Lyons 2000). *Bt* potato (AMFLORA potato) resistant to insect pests and squash and papaya virus-resistant was subsequently approved for commercial cultivation. *Bt* brinjal was also approved for commercial production in Bangladesh for the first time on October 30, 2013. The timeline of transgenic vegetable production and development is indexed in Fig. 5, which indicates the importance of transgenic vegetable for commercialization. In United States, the transgenic bruise-resistant potato cultivar has got approval in November 2014.

Potatoes are the world's fourth most significant food staple that plays a major role in strengthening the food security of Asian countries for instance China covering 6 million ha of potatoes, 2 million ha of potatoes covered in India whereas Bangladesh is having 0.5 million ha of potatoes. During the commercialization of transgenic technology in early 20 years (1996–2015), the required commitment of transgenic technology for the wellbeing of agriculture sector has been noted to be fulfilled satisfactorily (Qaim 2016). Transgenic crops have paved a way for significant economic, social, agricultural, health and environmental benefits not only to farmers but also to the society as a whole (Areal *et al.* 2013).

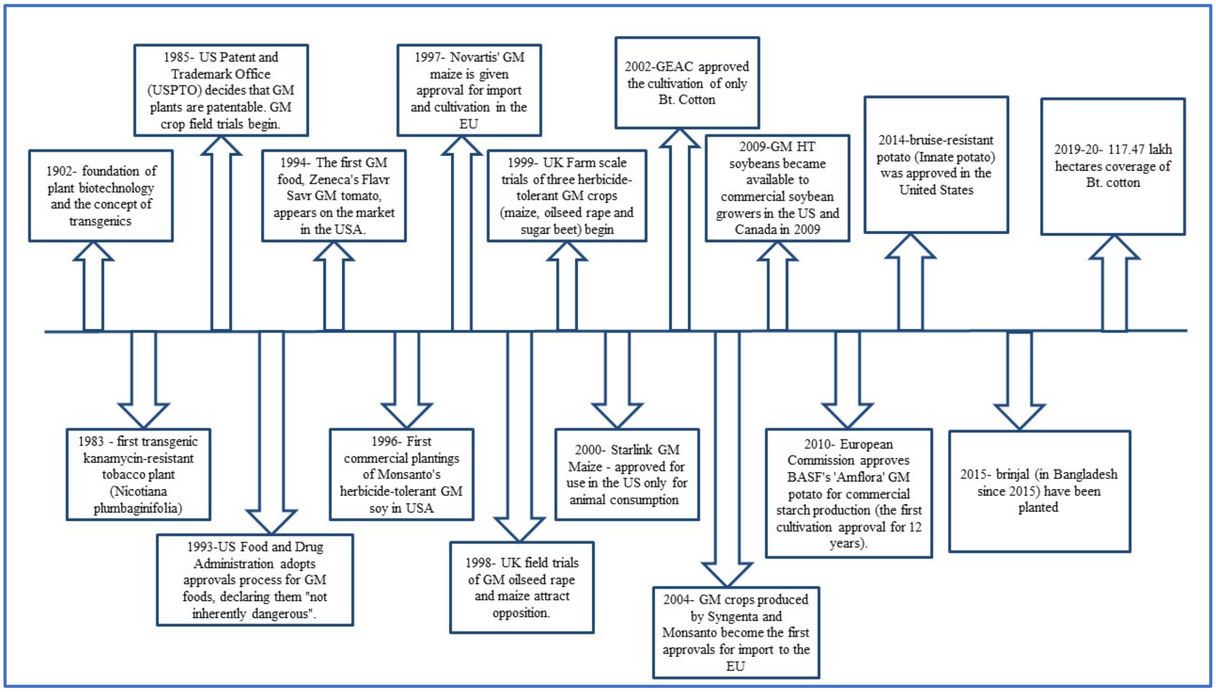

Fig. 5: Timeline of transgenic vegetable production and development

Criteria for trait selection for development of transgenic vegetable

An important approach to crop improvement is transgenic manipulation. Through different viewpoints, there are several biosafety issues associated with transgenic crops. However, by carefully selecting crops, their traits, techniques along with government policies, transgenic crops can be produced as well as implemented under the purview of biosafety standards to attain global agricultural goals. During the transgenic improvement of crop varieties, the following points should be considered.

Presence of wild relatives and vegetable landraces

Interbreeding between crop cultivars and their wild relatives may sometimes lead to pollen leakage. This poses a possibility for escape of transgene to wild relatives where genetically engineered crops are raised in crop origin or diversity centers. It is difficult to predict the accurate effects of such transgene escape on biodiversity and will be dependent on the characteristics bestowed by the transgenes as well as the climate. Keeping an eye on the poor consequences of transgenic escape, these modified crops are not authorized for commercial release in areas where wild relatives are being developed. Since India is considered to be one of the major centers of crop biodiversity, prioritization of transgenic development is needed. In transgenic crops, on the other hand, sufficient countermeasures should be implemented to avoid transgene escape.

Breeding behavior of vegetables

From the perspective of transgene motion, the biology of the crop plant presumes significance. The possibility of issue of escape of transgene in the case of plants propagated asexually such as pointed gourd, potato and sweet potato is wisely reduced. Similarly, restricted transgene movement has been found in the case of crops such as tomato, eggplant, peas, etc. which are highly autogamous or do self-pollination. In comparison, it presents severe challenges to prevent transgenic movement in crops such as maize, pearl millet, mustard etc. which exhibit allogamy or cross-pollination. Thus, crop choice from the transgene movement viewpoint would be propagated vegetative > autogamous > allogamous. Biotechnology provides new means of altering crop breeding activity and thus enables successful options for resolving transgenic movement concerns.

Achievements in transgenic vegetable approach

Enhancing shelf-life period of vegetables

The use of antisense RNA technology using the 1-aminocyclopropane-1-carboxylic acid deaminase gene that reduces 1-aminocyclopropane-1-carboxylic acid to ethylene and contributes to maturation and the suppression of the polygalacturonase enzyme that naturally takes place in the cell walls and induces vegetable and fruit softening (Gerszberg *et al.* 2015), which are two means to raising the shelf-life of vegetable crops. The first approved transgenic vegetable for commercial sale, FlavrSavr tomato, produced

Table 1: Transgenes for the improved storage period in vegetables

Target Gene	Target Trait	Crop	Reference
β-Glucuronidase, Pectin methylesterase, Polygalacturonase	Storage shelf-life, juice viscosity	Tomato	Powell *et al.* (2003); Moon and Callahan (2004)
β-Glucuronidase and Deoxyhypusine synthase, Polygalacturonase and expansin	Storage shelf-life, Postharvest softening delaying and senescence	Tomato and Pea	Kalamaki *et al.* (2003); Powell *et al.* (2003); Xiong *et al.* (2005); Ruma *et al.* (2009)
ACC synthase	Enrichment in production of Ethylene	Pea and Tomato	Romagnano (2008)
Deoxyhypusine synthase	Senescence, male sterility and Postharvest softening delaying	Tomato and Pea	Wang *et al.* (2005)
Pectin methylesterase	Juice viscosity enrichment and reduction in pectin hydrolysis	Tomato and Pea	Thakur *et al.* (1996)
hpRNAi ACO1 gene, LeERF1 and Nr gene overexpression	Low ethylene production, less sensitivity to ethylene, longer shelf life	Tomato and Pea	Ciardi *et al.* (2000); Li *et al.* (2007); Behboodian *et al.* (2012)
S-adenosylmethionine decarboxylase proenzyme	Lycopene content increment and increase in fruit juice quality	Tomato and Pea	Bapat *et al.* (2010)

Table 2: Transgenes for high nutritional quality in vegetables

Target Gene	Target Trait	Crop	Reference
Chalcone isomerase, S1MYB12	Flavonoid enrichment, solid soluble content, fruit color enrichment	Tomato	Ballester *et al.* (2010); Maligeppagol *et al.* (2013)
SlAco3b, L-Galactono-1,4-lactonedehydrogenase	Carboxylic acids and Ascorbic acid content enrichment	Tomato	Garza *et al.* (2007); Morgan *et al.* (2013)
Lycopene b-cyclase, Phytoene desaturase, Phytoene synthase	Increase in beta-carotene and lutein	Tomato	Rosati (2000); Fraser *et al.* (2002)
SAM decarboxylase, Phytoene synthase, ySAMdc; spe-2	High lycopene, improved juice quality, *β*- carotene	Tomato	Mehta *et al.* (2002); Kisaka and Kida (2003); Singh *et al.* (2015)
GaIUR, scax	Vitamin C and Calcium content	Carrot, Lettuce	Park and Kang (2004); Lim *et al.* (2008); Singh *et al.* (2015)
Or, Pr, MYB, Ore, IbMYB1	*β*- carotene, Anthocyanin	Cauliflower	

by Calgene in Davis, California, was attempted for a delayed ripening trait. However, the fruits remained firm after harvest. Some transgenic vegetables with enhanced shelf-life periods are indexed in Table 1 along with the target genes.

Improvement in quality and nutritional value of vegetables

Most individuals in developing countries suffer from micronutrient deficiency. This is one of the most significant risk factors that impact human health and the root cause of most illnesses. So, there has always been a need to combat such a deficiency problem more wisely. The use of recombinant DNA technology can now produce transgenic crops with improved nutritional value. Modifying plant nutritional value by transgenic technology can be accomplished by improving the purity, structure and nutrient (protein, carbohydrate and fatty acid along with antioxidants) levels of different crops (Gerszberg *et al.* 2015). A significant output of the transgenic approach for advanced nutritional value is golden rice to combat vitamin A deficiency. In addition, genes have been identified associated with superior fruit quality and nutritional value of vegetables (Table 2).

Transgenic vegetables for abiotic and biotic stress tolerance

The environmental stresses, referred to as abiotic stresses, most often led to a decrease in the growth and productivity of vegetable crops below optimum levels. Furthermore, abiotic stresses most often cross-talk, showing the result of an expected deficit of cellular water; also known as osmotic stress effects (Nandhakumar *et al.* 2020). These contribute to the minimization of cell turgor osmotic potential and retention. Till now, significant steps have been taken by the researchers for the identification and utilization of transgenes for combating several abiotic stresses (Table 3). A significant prospect includes trans-grafting (Kharal *et al.* 2021), which exploits a genetically engineered climate-resilient genotype as rootstock grafted onto a commercial scion. Trans-grafting has the prospects to widen the traits facilitated by grafting since the advantages acquired from the transgenes can be utilized (Kharal *et al.* 2021). Thus, transgenic DNA free scion could enable the arrival of GE crops into commercial production since the deregulation of every scion cultivar would likely not be obligatory by USA, Turkey, Russia, Nigeria, Vietnam, Mexico, Egypt and Iran. This analysis revealed that vegetables are the most important crops that need to be addressed for more cultivation and production (FAO/WHO 2009; Vasileva and Dinev 2021;). Plant diseases including fungal, bacterial, viral diseases and insect pests pose significant challenges to growth and productivity of vegetables. Therefore, it is essential to target genes for resistance to biotic stress in vegetable crops (Table 4 and 5).

Ethical and biosafety issues for transgenic vegetables

The cultivation of GM crops is consistently increasing (James 2015). With dramatic economic and environmental

Table 3: Transgenes for abiotic stress tolerance in vegetables

Crop	Genes Responsible	Target trait	Reference
Bean	P5CS	Drought stress	Chen *et al.* (2009a)
Tomato	ATHB-7	Drought stress	Mishra *et al.* (2012)
Potato	StPUB17	Salt stress	Ni *et al.* (2010a)
Tomato	Choline oxidase	Salt stress	Goel *et al.* (2011)
Tomato, Brinjal	MtlD	Drought stress	Khare *et al.* (2010)
Tomato	BcZAT12	Drought stress	Rai *et al.* (2013)
Tomato	cAPX	Temperature stress	Wang *et al.* (2006)
Tomato	GlyII	Salt stress	Viveros *et al.* (2013)
Tomato	SAMDC	Salt, cold and drought	Alcazar *et al.* (2010)
Tomato	LeERF2	Freezing stress	Zhang *et al.* (2010)
Tomato, Brinjal	PtADC	Drought stress	Wang *et al.* (2011)
Tomato	SpMPK1, SpMPK2, SpMPK3	Drought stress	Rai *et al.* (2013)
Tomato	Osmotin	Cold stress	Patade *et al.* (2013)
Tomato	MdVHA-B	Drought stress	Hu *et al.* (2012)
Tomato	CBF1	Cold and drought	Lee *et al.* (2003)
Tomato	Trehalose-6- phosphate synthase	Drought and oxidative stress	Cortina and Culianez- Macia (2005)
Tomato	HAL1 gene	Salt stress	Gisbert *et al.* (2000)
Tomato	NHX1	Salt stress	Zhang and Blumwald (2001)
Tomato	Betaine aldehyde dehydrogenase	Salt stress	Jia *et al.* (2002)
Tomato	Heat shock factor, hsfA1b	Chilling tolerance	Lee *et al.* (2003)
Tomato	Choline oxidase	Oxidative stress	Park and Kang (2004)
Tomato	sHSP (mitochondrial)	Temperature stress	Nautiyal *et al.* (2005)
Tomato	CAPX (cDNA)	Heat stress	Wang *et al.* (2006)
Tomato	Cys-2/His-2 zinc finger protein-TF	Cold stress	Seong *et al.* (2007)
Tomato	ACC deaminase	flooding stress	Grichko and Glick (2001)

Table 4: Transgenes for resistant to fungal, bacterial and viral disease in vegetables

Target Gene	Target microorganism	Crop	Reference
Endochitinase	Soil-borne fungus	Potato	Lorito *et al.* (1998)
Lactoferrin, Defensins	*Ralstonia solanacearum*	Tomato, potato	Gao *et al.* (2000)
Cathelicidin	Bacteria	Tomato	Jung (2013)
amiR-AV1-3	leaf curl virus	Tomato	Vu *et al.* (2013)
StPUB1, RB gene	*Phytophthora infestans*	Potato	Ni *et al.* (2010b)
Bs2 gene	Bacteria (*Xanthomonas* spp.)	Tomato	Horvath *et al.* (2012)
CHIAFP	*Botrytis cinerea*	Tomato	Chen *et al.* (2009a)
rep; AC1, TrAP; AC2, REn; AC3, and BC1	Golden mosaic virus	Common bean, Cucurbits	Aragao and Faria (2009)
Coat protein	Cucumber mosaic virus	Tomato	Fuchs *et al.* (1996)
Replicase	Ringspot virus	Papaya	Kumari *et al.* (2015)
Coat protein	Cucumber mosaic virus	Cucumber, melon	Nishibayashi *et al.* (1996)
Coat protein	Ringspot virus	Papaya	Davidson (2006)
N gene	Spotted wilt virus	Tomato	Goldbach *et al.* (2003)
ScFv antibodies	Cucumber mosaic virus	Tomato	Villani *et al.* (2005)
ScFv antibodies	Potato virus Y	Potato	Gargouri-Bouzid *et al.* (2006)
Serine acetyltransferase	Cucumber mosaic virus	Tomato	Stommel *et al.* (1998)
Stilbene synthase	*Phytophthora infestans*	Tomato	Thomzik *et al.* (1997)
Endochitinase	*Verticillium dahliae*	Tomato	Tabaeizadeh *et al.* (1999)
Oxalate decarboxylase	*Sclerotinia sclerotiorum*	Tomato	Kesarwani *et al.* (2000)
Nonexpresser of PR genes	Tomato Mosaic Virus resistance, bacterial wilt and fusarium wilt	Tomato	Lin *et al.* (2004)
Thi2.1	*Ralstonia solanacearum* and Fusarium wilt	Tomato	Chan *et al.* (2005)
Glucanase	*Alternaria solani*	Tomato	Schaefer *et al.* (2005)
Serine or threonine-protein kinase	*Xanthomonas campestris* pv. *Vesicatoria*, *Cladosporium fulvum*	Tomato	Tang *et al.* (1999)
Glycoprotein	*Ralstonia solanacearum*	Tomato	Lee *et al.* (2002)
Magainin	*Pseudomonas syringae*	Tomato	Alan *et al.* (2004)
Thi2.1	*Ralstonia solanacearum and Fusarium oxysporum*	Tomato	Chan *et al.* (2005)
Cys-2 or His-2 zinc finger protein-TF	*Pseudomonas syringae*	Tomato	Seong *et al.* (2007)
Ferredoxin-I protein	*Ralstonia solanacearum*	Tomato	Huang *et al.* (2007)
ToMV coat protein	Chimeric Tomato mosaic virus	Tomato	Motoyoshi and Ugaki (1993)
Capsid protein	Delayed disease symptoms	Tomato	Kunik *et al.* (1994)
CMV satellite RNA	Tolerance to CMV infection	Tomato	McGarvey *et al.* (1995)
Coat protein	Resistance to infection by CMV-WL and CMV-China	Tomato	Xue *et al.* (1994)
Nucleoprotein	A hypersensitive response	Tomato	Whitham *et al.* (1996)
TSWV nucleoprotein	High levels of resistance to Tomato spotted wilt virus	Tomato	Haan *et al.* (1996)
Capsid protein	Reduced infection of CMV under natural conditions	Tomato	Murphy *et al.* (1997)
rep protein	Tomato yellow leaf curl virus	Tomato	Brunetti *et al.* (1997)
Coat protein	CMV	Tomato	Kaniewski *et al.* (1999)
Coat protein	Physalis mottle tymo virus	Tomato	Vidya *et al.* (2000)
Truncate replicate gene	CMV stain Ta-8	Tomato	Nunome *et al.* (2002)
PR genes	ToMV, BW, FW, GLS, BS	Tomato	Lin *et al.* (2004)
Coat protein	TLCV	Tomato	Raj *et al.* (2005)
cDNA of RCC2	*Botrytis cinerea*	Cucumber	Tabei *et al.* (1998)

benefits, transgenic crops are an essential tool for disease and pest control (Brookes and Barfoot 2015). Transgenic technology caused increased agricultural productivity in developing countries, along with the development of

Table 5: Transgenic vegetables resistant to insect

Target Gene	Target Insect	Crop	Reference
cry3a	*Leptinotarsa decemlineata*	Potato	Alyokhin *et al.* (2008)
CpTi	*Lacanobia oleracea*	Potato	Gatehouse *et al.* (1999)
Alpha-amylase	*Callosobrunchus* spp.	Pea	Ishimoto *et al.* (1996)
Kchip LnvRNAi-2214	Insect resistance	Tomato	Tarafdar *et al.* (2014)
Cry 1b, Cry1Ac, Cry 1Ab	Lepidopteran insects	Okra	Kim *et al.* (2016)
Bt toxin	*Leptinotarsa decemlineata*	Tomato	Rhim *et al.* (1995)
Arginase	*Manduca sexta* larvae	Tomato	Chen *et al.* (2009b)
Serine-proteinase	*Heliothis obsoleta* larvae	Tomato	Abdeen *et al.* (2005)
Chitinase	*Leptinotarsa decemlineata*	Tomato	Lawrence and Novak (2006)
Chymotrypsin inhibitor	*Spodoptera littoralis*	Tomato	Lison *et al.* (2006)
PR protein	*Macrosiphum euphorbiae*	Tomato	Goggin *et al.* (2004)
cry1Ac	*Leucinodes orbonalis*	Eggplant	ISAAA (2008)

nutritional quality and nutritious foods that also have an increased shelf life. These advantages of GM crops have improved food security for the poverty-stricken people (Parvaiz *et al.* 2012). Thus, GM food promoters are environmentally friendly, pose minor disadvantages to humans' health and are highly beneficial to general farmers (Andreasen 2014). The GM proteins are also being added to the soil through crop residues which may lead to the decline of spraying of pesticides (Godfrey 2000).

However, some GM crops have antibiotic resistance genes and as a result, GM foods face potential adverse health effects (Gilbert 2013). This poses several areas of concern regarding the use of GM crops. There may be the possibility of occasional gene flow from GM crop-to-weed, making the latter resistant to herbicides, which is a major problem for the adoption of GM crops. So, each country must create a solid bio-safety framework for the cultivation and use of GM species. However, specific regulations have been formulated by many advanced countries and few developing countries. The duty of government regulatory agencies should be solely to ensure that there should not be any adverse effect of GM crops on environmental factors and human health (Rigaud 2008).

Conclusion

Several studies reveal that the agronomic and economic benefits associated with GM crops are far-reaching. With the shrinking area under cultivation, the principle of growing productive crop per unit area is an inertial and imperative global phenomenon. In this context, GM crops offer enhanced yield along with reduction in pesticide uses. Transgenic candidate cultivars also proved to be potential for breaking the yield and quality barriers in vegetable crops and hence, can solve food and nutritional security. However, the malnutrition rate has risen to around 20 percent over the past decade, in consonance with the FAO of the United Nations, and is projected to remain constant until 2022. In 2012, over 870 million individuals were officially chronically malnourished, with almost 250 million citizens in India. To address this issue associated with malnutrition, there is an urgent need for a shift to transgenic agriculture.

Author Contributions

JPS and UM planned the first draft and wrote the manuscript. SPB, LB, LJ, SS, APM, MPD, PP and NP checked the grammatical error of the manuscript. SKT, KCS and DL corrected and approved the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability

Not Applicable in this paper.

Ethics Approval

Not Applicable in this paper.

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