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# Transgenic vegetables: A review

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## Abstract

Transgenic crops, commonly referred to as genetically modified (GM), crops enable breeders to bring favorable genes, often previously inaccessible, into already elite cultivars, improving their value considerably and offer unique opportunities for controlling insects and other pathogens.

Many vegetable crops have been genetically modified to improve traits such as higher nutritional status or better flavour, and to reduce bitterness or anti-nutritional factors. Transgenic vegetables can be also used for vaccine delivery. Consumers could benefit further from eating more nutritious transgenic vegetables, e.g. an increase of crop carotenoids by metabolic sink manipulation through genetic engineering appears feasible in some vegetable. Transgenic approaches provide us with access to identify the candidate genes, miRNAs, and transcription factors (TFs) that are involved in specific plant processes, thus enabling an integrated knowledge of the molecular and physiological mechanisms influencing the plant tolerance and productivity. The advantages of GM technology such as to improve vegetables, reduce pesticide use, increase yields, add health benefits, and lower production costs should provide incentive for integration of this technology into vegetable breeding and commercial crop production, if consumer resistance can be overcome or mollified.

**Keywords:** transgenic, vegetable, transgenic crops, genetically modified crops

## Introduction

Vegetables are considered vital components in achieving nutritional security because they have a shorter maturity cycle, higher productivity, nutritional richness, economic viability, and also provide a valuable source of income, leading to improved livelihood. Thus growth in the vegetable sector has played an important role in India’s food and nutritional security, health, and economic development. Vegetables contain valuable food ingredients that can be successfully utilized to build up and repair the body. They are rich in carbohydrate, vitamin, mineral, and fiber content. Vegetables make up a significant proportion of the human diet and their production plays a significant role in ensuring the nutritional security of human beings (Dias and Ortiz, 2014) [4]. The genetic improvement of vegetables should address and suit the needs of both consumers and farmers (Dias and Ryder, 2011) [5]. The general objectives for farmers are quality and uniform produce, higher yield, and tolerance to diseases, pests, and abiotic stresses, whereas the needs of consumers are quality, appearance, shelf-life, taste, and nutritional value (Dias and Ryder, 2011) [5]. However, few vegetable cultivars are resistant to diseases, pests, and abiotic stresses. Resistance may also be unstable because of the insurgence of pathogens and pests. Furthermore, insects, including aphids, whiteflies, thrips, and leafhoppers, are also very important for limiting vegetable production because they are vectors of many viruses. Improvement of postharvest traits, mainly transport quality, shelf-life, and pleasing appearance, is of increasing importance in vegetables (Dias and Ryder, 2011) [5]. In the past, conventional plant breeding approaches were considered the backbone of vegetable genetic improvement strategies, but they have a number of limitations. The power of plant transformation, coupled with the vast available information about genes and their products, has attracted plant biotechnologists to develop transgenic vegetables to address some of the most challenging biotic and abiotic constraints faced by farmers worldwide, challenges that are not easily addressed through conventional vegetable breeding alone (Tarafdar *et al.*, 2014) [39]. Transgenic breeding offers a suitable alternative to conventional breeding to achieve plant genetic improvements. Transgenic approaches provide us with access to identify the candidate genes, miRNAs, and transcription factors (TFs) that are involved in specific plant processes, thus enabling an integrated knowledge of the molecular and physiological mechanisms influencing the plant tolerance and productivity. Transgenic crops, commonly referred to as genetically modified (GM), crops enable breeders to bring favorable genes, often previously inaccessible, into already elite cultivars, improving their value considerably and offer unique opportunities for controlling insects and other pathogens. Many vegetable crops have been genetically modified to include resistance to insects, other pathogens (including viruses), and herbicides and for improved features, such as slow ripening, higher nutritional status, seedless fruit, and increased sweetness. Recently, Dias and Ortiz did a review (based on 372 articles) about the status of transgenic vegetables to improve their production. They analyzed the advances and potentials in transgenic research until 2010 on tomato, eggplant, potato, cucurbits, brassicas, lettuce, alliums, sweet corn, cowpea, cassava, sweet potato, and carrots. Some experimental transgenic vegetables show host plant resistance to insects, nematodes, fungi, bacteria, and viruses, extended shelf-life of the produce, herbicide tolerance, enhanced nutritional status, and seedless fruit and better flavor.r United States vegetables farmers are benefiting from growing transgenic squash cultivars resistant to *Zucchini yellow mosaic virus*, *Watermelon mosaic virus*, and *Cucumber mosaic virus*, which were deregulated and commercialized since 1996. Genetically engineering carrots containing increased calcium (Ca) levels may boost Ca uptake, thereby reducing the incidence of Ca deficiencies such as osteoporosis. Fortified transgenic lettuce with zinc will overcome its deficiency that severely impairs organ function. Transgenic lettuce with improve tocopherol, and resveratrol composition may prevent coronary disease and arteriosclerosis and can contribute to cancer chemo preventative activity. Folates deficiency, which is regarded as a global health problem, can also be overcome with transgenic tomatoes with folate levels that provide a complete adult daily requirement (Dias and Ortiz, 2012) [3]. Likewise, food safety can be enhanced through transgenic approaches, e.g. resource-poor people in rural Africa will benefit eating cyanide-free cultivars of cassava—a main staple in their diets (Siritunga *et al.*, 2004) [38]

## Transgenic Vegetables

### 1. Tomato

Delaying Fruit Ripening: Tomato is an important vegetable because of its nutritional value and widespread use as a processed food. Its production and marketing is affected by various biotic and abiotic stresses and there is an urgent need to remove these limitations. The recent advancement in biotechnology may help to increase production as well as its nutritional and market value. The first commercially grown transgenic crop was Flavr Savr™ tomato, which was released by Calgene in 1994. This tomato contains an antisense version of the *polygalacturonase* (*PG*) gene. The use of this gene ensued after many years of research on several genes involved in fruit development and tomato ripening. They were identified, cloned, and characterized to breed transgenic tomato cultivars (Kramer and Redenbaugh, 1994). However, Flavr Savr™ tomato failed in the market since this cultivar was considered inferior by growers, and was rapidly withdrawn from the market. Plant genetic engineers learned an important lesson after this failure: the importance of cooperation with plant breeders. There has been further research conducted to manipulate fruit ripening, texture and nutritional quality using transgenic approaches. Many of the genes targeted include ethylene because of its role in fruit ripening (Dias and Ortiz 2012) [3]. Enzymes that regulate ethylene biosynthesis in plants are: S-adenosyl methionine (SAM) synthase, 1-aminocyclo propane-1-carboxylate (ACC) synthase, and ACC oxidase. The genes encoding these enzymes as well as those that metabolize SAM or ACC have been targeted in order to manipulate ethylene biosynthesis, thereby regulating fruit ripening. It has been clearly shown that modulation of ethylene biosynthesis using genetic engineering can yield tomato fruits with predictable ripening characteristics. Tomato fruit ripening manipulation has been however achieved by introducing anti-ripening genes (*rin* and *nor*) in heterozygous genotypes. These genes have been incorporated in many fresh and processing tomatoes (Dias and Ortiz, 2012) [3]. Disease resistance: For the viral disease resistance, coat protein and satellite RNA have been extensively utilized to produce viral disease resistance plants in tomato. Nel-son *et al.* (1987) [24] produced transgenic tomato using coat protein of the U1 strain of tobacco mosaic virus and expressor plants were protected against symptom development after inoculation with TMV strain U1 or PV230 and TMVstrain 2 and 22. Tumer *et al.* (1987) [41] introduced a chimaric gene encoding the alfalfa mosaic virus (AMV) coat protein into tomato plants. Transgenic plants significantly delayed the disease development. *Agrobacterium*-mediated transformation of the coat protein gene of cucumber mosaic virus white leaf (CMV-WL) strain (Xue *et al.* 1994) [46] and it was reported that transformed plants exhibited high level of resistance to systemic infection by virus strain CMV-WL and CMV-China.

### 2. Potato

The chloroplastic and cytosolic Cu, Zn-SOD gene of tomato transferred into potato resulted in expression of this enzyme and transgenic potato clones were tolerant to a superoxide generating herbicide, paraquat (Perl *et al.*, 1993) [28]. The transgenic strategy for drought tolerance came from analysis of plants that grow under desert (xerophytic) or extreme saline (halophytic) conditions. Transgenic potato producing fructans (water stress sugar) in leaves and tubers showed better drought tolerance (Rober *et al.*, 1996) [32]. Starch is the primary storage component of carbohydrate in potato tubers accounting up to 70% of tuber dry matter. Genetic engineering of starch biosynthesis in potato may lead to modification of starch granule shape, amylose to amylopectin chain length which can in turn alter significantly properties of starch like crystallinity, gelling properties, phosphorylation, lipid contents etc., for use in both food and non-food industries. The biosynthetic steps required for starch biosynthesis involve three enzymes, ADP glucose pyrophosphorylase (ADPGP Pase), starch synthase (SS) and starch branching and debranching enzymes. ADPGP Pase catalyses the syntheis of ADP glucose from glucose-1-phosphate. ADP glucose is the precursor for synthesis of both amylose and amylopectin. Therefore, the ADPGP Pase regulation would determine the sink strength of tuber and its over expression would produce tubers with high starch content. Bacterium *Escherichia coli* gene glg C16. Encoding bacterial ADPGP Pase when transferred into potato, the transgenic plant showed high starch content in the tubers. Transgenic potato was produced through antisense technology exhibited reduced level of amylose content in starch (Salehuzzaman *et al.*, 1994). Two amylose free transgenic cultivars, released in the Netherlands during 1996, showed improved gel stability and paste clarity (Visser *et al.*, 1997) [42]. Essential amino acid content is an important constituent of quality protein. Gene transfer technology offers a novel approach to improve the nutritional quality of potato through modification of essential amino acid composition of plant protein.

### 3. Eggplant

Resistance to Fruit and Shoot Borer: Leucinodes orbonalis Guenée, is a major insect pest of eggplant, Solanum melongena L. Damage due to ESFB (Eggplant shoot and fruit borer) can often be severe and couse up to 65% yield loss (Mall *et al.*, 1992) [22]. It has been reported that third- and fourth-instar larvae of Fruit and Shoot Borer are mainly responsible for the damage to eggplant (Sandanayake and Edirisinghe, 1992) [34]. The ESFB larvae bore into tender shoots which ultimately wilt and die leading to reduced fruit bearing capacity. In addition, the larvae bore into fruits making them unmarketable. Control measures for this pest rely mainly on the application of insecticides, which are often ineffective since the larvae remain concealed within fruits and shoots, and therefore, escape contact with the insecticide. SFB (shoot and fruit borer) -resistant *Bt* eggplant was genetically engineered by Mahyco (Maharashtra Hybrid Seed Company, India) under a collaborative agreement with Monsanto and the first *Bt* transgenic eggplant with resistance to SFB was produced in 2000. This GM eggplant incorporates the *cry1Ac* gene expressing insecticidal protein from *Bacillus thuringiensis* (the same protein has long been used by organic growers), that confers resistance against FSB. This *Bt*-eggplant was effective against SFB, with 98% insect mortality in *Bt*-eggplant shoots and 100% in fruits compared to less than 30% mortality in non-*Bt* counterparts (ISAAA, 2008) [9]. Rai *et al.* 2013 studied that cry1Aa3 gene was introduced into eggplant cv. Kashi Taru through Agrobacterium-tumefaciens mediated transformation. Hypocotyl explants from 7 day-old seedlings were pre-cultured for two days and inoculated with Agrobacterium strain EHA105 harboring a synthetic mcry1Aa3 gene with full codon-modification in a binary vector. PCR and Southern blot analyses confirmed the presence of single copy insertions of the cry1Aa3 gene in plants of four independent transformation events. In addition, single copy gene insertions were confirmed by segregation analysis of T1 seedlings. Expression of the cry1Aa3 transcripts was confirmed by qRT-PCR; and ELISA revealed presence of Cry1Aa3 protein in fresh leaves (30.9e44.3 ng g_1) and fruits (20.5e35.7 ng g_1). Expression of the Cry1Aa3 protein resulted in high ESFB larval mortality in the shoot as well as fruit tissues of the transformed eggplant lines. Such transgenic eggplant lines possessing resistance to the ESFB could reduce dependency on pesticide use for ESFB control, leading to a safer environment and eggplant fruits.

## 4. Summer Squash

Multiple Virus Resistance: Virus-resistant transgenic summer squash (*Cucurbita pepo* spp. *ovifera* var. *ovifera*) have been successfully developed and commercialized in United States (Johnson *et al.*, 2007) [11]. This was the first disease-resistant transgenic crop to receive exemption status in the United States. Plants of transgenic squash ZW-20 express the coat protein (CP) gene of Zucchini yellow mosaic virus (ZYMV) and Watermelon mosaic virus (WMV) and are highly resistant to single and mixed infection by ZYMV and/or WMV, as shown by multiple field trials in different locations (Klas *et al.*, 2006) [15]. The reaction of transgenic and conventional summer squash plants to infection by ZYMV and WMV in 1994 and 1995 was reported previously (Klas *et al.*, 2006) [15].

## 5. Peppers (Capsicum sp.)

Capsicum is an important vegetable as well as spice crop of the world. Agronomically important traits have been introduced into the pepper by conventional breeding, but the application is currently limited by the lack of genetic resources or by sexual incompatibility between species. Genetic transformation of the plant has become an important alternative for both basic and commercial plant breeding programs. Once transgenic plants have been established, the transgenes should be stably integrated and expressed over generations. However, the expression level and patterns of transgene inheritance vary widely among transformed plants. Factors responsible for transgene instability include the site of integration in the genome, the transgene copy number, transgene rearrangement, transformation system (Agrobacterium-mediated, micro projectile bombardment, or PEG, and so on), the selection strategy, and the plant tissue culture system. Kim *et al.* (1997) [13] in hot pepper cv. Golden tower transferred satellite-RNA resistance against cucumber mosaic virus. To improve the fungal disease resistance ribosome inactivating proteins (RIPs) are known to be important because of their cytotoxic activity on eukaryotic cells.

## 6. Cassava

As a major source of food, cassava (*Manihot esculenta* Crantz) is an important root crop in the tropics and subtropics of Africa and Latin America, and serves as raw material for the production of starches and bioethanol in tropical Asia. With the development of cassava biotechnology, the use of functional genomics and genetic engineering to solve them problems associated with the germplasm enhancement of cassava plays a major role in promoting cassava cultivation and industrial application all over the world. The first transgenic cassava plants became available in the mid-1990s as plants with reduced cyanogenic content (Siritunga *et al.*, 2004) [38] which can benefit resource-poor people in rural Africa where this starchy root crop is the base of their diet. To date, improved agronomic traits of cassava achieved by transgenic technology include virus resistance, improved nutritional quality, reduced cyanide content, improved biomass, and delayed post-harvest physiology deterioration in storage roots. The improvement based on these traits will be the major trends in cassava molecular breeding in the future. Transgenic technology, as a powerful tool, also plays an important role in obtaining virus resistant cultivars. Chellappan *et al.* (2004) [2] used pILTAB9001 and pILTAB9002 harboring the wild-type and mutant *AC1* genes of ACMV-Kenya, which were regulated by the cassava vein mosaic virus promoter and the pea Rubisco terminator for the production of transgenic TMS60444 lines with increased resistance to mosaic disease. The initial inoculation assay revealed that these transgenic plants were resistant to several cassava gemini virus diseases from Africa. However, these transgenic plants lost their resistance to CMD infection in a closed-field trial in Kenya.

Improved stress resistance: Based on a recent study in our laboratory, the high expression of the C-repeat/dehydration-responsive element-binding factor 3 gene regulated by a low temperature inducible or Ca MV 35S promoter can significantly improve cold resistance in transgenic cassava (Zhang *et al.*, 2011) [47]. Intermittent drought in tropical and subtropical regions is another important factor that affects the growth and yield of cassava. To adapt to this change in the environment, cassava sheds its leaves to maintain its life. Using the leaf senescence induced promoter, SAG12, to express the *ipt* gene, transgenic cassava showed not only prolonged leaf life, but also improved resistance to drought stress. This study provides a useful strategy for the improvement of cassava drought resistance and yield.

## 7. Pea

There are numerous reports on transgenic pea development mainly against diseases. The only report to our knowledge on insect resistance was the transgenic pea expressing a bean alpha-amylase inhibitor and the transgenic seeds exhibited resistance against the principal insect pest, pea weevil (Schroeder *et al.,* 1995) [35]. In general, however, little attention has been given to the development of insect resistance in pea. So far, there is no report on transgenic pea expressing cry genes to improve insect resistance. The different groups of cry toxins provide a practical and immediate solution to the problem. The major field pests in the order Lepidoptera can be addressed by developing transgenic pea expressing a cry1 toxin while the cry3 toxin can be used to target the major storage pests in the order Coleoptera. Furthermore, these cry toxins can be stacked into single pea plants so that both the field and storage pests can be controlled. Negawo *et al.,* 2013 [23] reported the development of insect resistant transgenic peas expressing a plant codon optimized cry1Ac gene from Bacillus thuringiensis. The transgenic nature of regenerated in vitro plants and their segregating progenies has been confirmed through molecular analyses (PCR, Southern blot, RT-PCR and immune strip assay). The introduced transgene was inherited up to the T4 generation. Insect bioassay using larvae of tobacco budworm indicated total larval mortality and significantly reduced feeding damage on the developed transgenic pea plants as compared to 85% larval survival and heavy feeding damage on non-transgenic control plants. The developed transgenic lines can be used for further studies such as gene stacking and field trials.

## 8. Carrot

Carrot is a member of the Umbelliferae, a large family that includes parsley, parsnip, celery, fennel, anise, dill, cumin, and coriander as just some of the better known vegetables and spices that make up this economically important family. Carrot is a biennial with only a few annual forms known and is diploid with nine pairs of chromosomes. The commercial carrot has an orange-colored flesh resulting from its high carotene content but its selection originated in the Netherlands in the seventeenth century from the anthocyanin-containing carrot of the Near East. Carrot accumulates low levels of glycine betaine naturally, but chloroplastic over expression of endogenous BADH resulted in enhanced glycine betaine levels. These transgenic carrots were able to grow on soil containing physiologically very high salt levels. In the breeding research on carrots, the genetic engineering method was also adopted. The approach based on over expressing functional genes was widely used. In the research of Wally *et al.*, functional genes (*OsPOC1*, *OsPrx114*, and *AtNPR1*) from other species were over expressed in carrots to enhance fungal and disease resistance. The transgenic lines over expressing *OsPrx114* displayed high disease resistance compared with the control. In addition to resistance breeding, genetic engineering was also used to accumulate some special components by over expressing characteristic genes in carrots. In a research *HuINFα-2b* was over expressed in carrots to enhance the accumulation of human interferon alpha-2b protein. The transgenic lines expressing *HuINFα-2b* were thought to be useful in curing various viral diseases (Que *et al.*, 2019)

## 9. Onion

Transgenic onion plants with an antisense version of the bulb alliinase gene under *CaMV35s* promotional control have been produced. Biochemical pyruvate analysis showed that some transgenic plants, containing this gene construct, had significantly reduced alliinase activity. More detailed analysis of individual clones indicated that the reduced alliinase activity was only apparent in some plants suggesting that either chimeric plants were produced; escapes were regenerated along with transformants; differential gene silencing occurred; or there was a huge environmental variation in alliinase expression. The biochemical data was supported by multiplex RT-PCR that indicated a reduction in alliinase transcript in some lines. In at least one line, an approximate 10-fold reduction in alliinase transcript was detected. This corresponded to bulb material that was shown to have no measurable alliinase activity. In one further test, SNuPE analysis of the alliinase transcript present in the RNA was performed to determine whether a particular alliinase gene member had been silenced. The results indicated that all alliinase transcripts were equally silenced. Molecular fingerprinting techniques are now being developed to match the plants sacrificed for this analysis to their ‘real’ clones and offspring so that phenotypic assessment of reduced alliinase plants can be undertaken. (Eady *et al.,* 2005) [6].

## 10. Garlic

Garlic is reproduced vegetatively and does not form true seeds, for this reason, there is no genetic recombination that would allow selection of resistant genotypes to the fungus therefore, genetic transformation is a feasible alternative for garlic improvement. There are a few reports of garlic transformation using biolistic particle delivery or mediated by Agrobacterium tumefaciens. Kondo *et al.* (2000) [17] were the first to use A. tumefaciens for the genetic transformation of garlic. They were able to develop a stable transformation system of garlic using highly regenerative calli. Park *et al.* (2002) [26] obtained transgenic plants resistant to herbicide chlorsulfuron after bombarding calli of garlic ’Danyang’ cultivar with ALS gene coding for acetolactate synthase. Garlic yield and quality have decreased due to white rot disease caused by *Sclerotium cepivorum* Berk. A transformation protocol to introduce tobacco chitinase and glucanase genes into garlic embryogenic calli using *Agrobacterium tumefaciens* has been established. LBA4404 strain having pC2301CHGLU plasmid with *TaCh*, *glu*, *gus* and *nptII* genes (coding for chitinase, glucanase, β-glucuronidase and neomycin phosphotransferase, respectively) was used. 30 putative transgenic clones were obtained from inoculated calli after six months. Histochemical assay revealed high *gus* activity in 43% of the clones. Molecular analysis of transgenic plants showed 92% of the clones carried *TaCh* gene. Eight culture media for plant regeneration from transgenic calli were evaluated; MTDZ-1 (thidiazuron 1 mg/l) medium induced the highest number of plants (38.4 plants). Transgenic plants were grown in the greenhouse and they developed normally. *S. cepivorum in vitro* bioassays showed 41 to 60% of mycelial invasion in the transgenic plants, and 80% in non-transgenic plants (control). Transformed plants were not completely resistant, but they showed a delay in fungal infection. This is the first report on the introduction of fungal resistance genes in garlic (Erika Lagunes-Fortiz *et al.*, 2013) [7].

## 11. Sweet potato

Sweetpotato is the seventh most important food crop in the world. To date, an *Agrobacterium tumefaciens*-mediated transformation system has been developed for a wide range of sweetpotato genotypes. Several genes associated with salinity and drought tolerance, diseases and Pests resistance, and starch, carotenoids and anthocyanins biosynthesis have been isolated and characterized from sweetpotato. Gene engineering has been used to improve abiotic and biotic stresses resistance and quality of this crop. Transgenic herbicide-resistant sweet potato plants were also produced using the Agrobacterium-mediated transformation system (Jin Choi, 2007) [10]. This technology may allow a more convenient and efficient weed control in the field than was previously available.

**Table 1:** List of genes used in the development of Transgenic Vegetable crops

| Crop | Gene/ Gene product | Target | References |
|---|---|---|---|
| Potato | *Bt cry 1Ab* | Resistance to potato tuber moth | Kumar *et al.* 2010 |
| | *Ama1* | Protein rich potatoes | Chakraborty *et al.* 2010 |
| | δ1-Pyrroline-5-carboxylate synthetase(P5CS) | Tuber yield | Hmida-Sayari *et al.* 2005 |
| Tomato | Antisense version of the polygalacturonase (PG) gene | Delay fruit ripening | Kramer and Redenbaugh, 1994 |
| | Coat protein/ Replicase gene | TLCV resistance | Raj *et al.* 2005 |
| | *Chitinase and glucanase* | Fungal disease resistance | Jongedijk *et al.*1995 |
| Brijnal | *Cry 1 Ab* | Lepidopteran resistance | Pal *et al.*, 2009. |
| Cauliflower and Cabbage | *Cry 1 Ab* | Diamond black moth resistance | Kim *et al.* 2016 |
| Pea | α-amylase, | *Resistance to Callosobrunchus* spp. | Shade *et al.* 1994 |
| Summer squash | CP genes | Zucchini yellow mosaic virus (ZYMV) | Klas *et al.* 2011 |
| pepper | CP gene | Resistance against CMV-Kor and pepper mild mottle virus (PMMV) | Shin *et al.* 2002 |
| Sweet potato | *CuZnSOD, APX* | Drought tolerance | Li *et al.* 2006 |
| | *IbAATP* | Improved Starch structure and composition | Wang *et al.* 2016 |
| | *IbMYB1* | Improved Anthocyanin content, antioxidant activity | Park *et al.* 2015 |
| cassava | *AC1* genes | resistance to mosaic disease | Chellappan *et al.* 2004 |
| | *ipt* gene, | prolonged leaf life and improved resistance to drought stress | Zhang *et al.* 2010. |
| Onion | *CaMV35s* | Reduced alliinase activity | Eady *et al.* 2005 |
| Garlic | chitinase and glucanase | tolerance white rot disease | Erika Lagunes-Fortiz *et al.* 2013 |
| | ALS gene | Resistant to herbicide chlorsulfuron | Park *et al.*, 2002 |

## Conclusion

Transgenic breeding offers a suitable alternative to conventional breeding to achieve plant genetic improvements. This approaches provide us with access to identify the candidate genes, miRNAs, and transcription factors (TFs) that are involved in specific plant processes, thus enabling an integrated knowledge of the molecular and physiological mechanisms influencing the plant tolerance and productivity. Many vegetable crops like onion, Tomato, sweet potato, pea, Summer Squash and potato have been genetically modified to include resistance to insects, other pathogens (including viruses), and herbicides and for improved features, such as slow ripening, higher nutritional status, seedless fruit, improve quality and increased sweetness.

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