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Vegetable Grafting: A Surgical Approach to combat biotic and abiotic stresses- A review

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ABSTRACT

Vegetables are nutritionally rich, high-valued crops and remunerative enough to replace subsistence farming. However, vegetables are highly sensitive to climatic vagaries and sudden irregularities in weather factors at any phase of crop growth can affect the normal growth, flowering, fruit development and subsequently the yield. Grafting in vegetable has emerged as a promising surgical alternative over relatively slow conventional breeding methods aimed at increasing tolerance to biotic and abiotic stresses. It provides an opportunity to transfer some genetic variations of specific traits of rootstocks to influence the phenotype of scion. Thus, genetic potential of various rootstocks in vegetable crops has proven to be a better alternative to chemical sterilants against many soil-borne diseases. The higher physiological activities like antioxidant content, lipoxygenase activity, osmotic adjustment, membrane selectivity, development of adventitious root and aerenchymatous tissue in plants grafted onto potential rootstocks provide broad insight into stress response mechanisms and thus, grafting is proposed to mitigate the adverse impact of climate change on productivity and quality of vegetables crops.

Key words: Climate change, Genetics, Grafting, Physiological mechanism, Surgical approach, Vegetables.

INTRODUCTION

Vegetables are nutritionally rich, often referred as 'Protective food' and remunerative enough to replace subsistence farming.Vegetable crops are very sensitive to climatic vagaries, so fluctuation in climatic parameters at any phase of crop growth can affect the normal growth, flowering, fruit development and subsequently the yield (Afroza *et al*., 2010). Grafting in vegetable has emerged as a promising and an alternative tool to the relatively slow conventional breeding methods aimed at increasing tolerance to biotic and abiotic stresses (Bahadu r*et al*., 2015).

Landmarks in grafting: Landmarks in any technology are the ways forward to explore the possibilities in relevant direction.Production of grafted vegetable was first started in Japan and Korea in late 1920s, where scions of water melon grafted onto pumpkin rootstock. In 1930, scions of water melon were grafted onto rootstocks of bottle gourd to overcome the yield decline problems due to soil-borne diseases like *Fusarium* wilt.In 1947, Grafting was done on melon in Netherlands to overcome the problem related to *Fusarium* wilt. In 1950, brinjal was grafted for the first time onto scarlet eggplant (*Solanum integrifolium* Poir.) to control diseases.In 1959, scions of brinjal were grafted onto *Solanumintegrifolium*to avoid the injury caused by soil-borne diseases such as *Verticillium* wilt, *Fusarium* wilt, bacterial wilt and nematodes. In 1960, cucumber grafting started to strengthen low-temperature tolerance and *Fusarium* wilt resistance in Japan. In the same year, melon grafted onto *Benincasa* spp. to offset the effects of low soil temperatures in early greenhouse grown melons. In 1976, research on grafted melon and watermelon was startedin Spain, and by the end of 1980, melon and watermelon grafting experiments were performed in Italy.In 1990, percentage of grafted plants for the production of vegetables reached 59% of the area in Japan and 81% in Korea (Davis *et al*., 2008). In early 20thcentury, the first grafts were made in order to diminish soil borne pathogens such as *Fusarium oxysporum* on watermelons. Currently, cultivation of all the cucurbits under greenhouse conditions in Japan and Korea is based on grafting techniques.

Many private and public sector institutes in India have initiated progressive research works in this direction dealing various locations specific biotic and abiotic problems.

a. VNR SeedsPvt. Ltd., Raipur (Chhattisgarh) is one of the pioneer workers in grafting and working in close association with Asian Vegetable Research and Development Centre (AVRDC), Taiwan. They have now started their commercial venture in this aspect and are supplying grafted seedlings to the farmers within and adjoining states depending upon requirement of the farmers.

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b. Jarvi Seeds Pvt.Ltd., Bharuch (Gujarat) has been exploiting this technology commercially in cucurbits like musk melon, water melon and solanaceous vegetables namely, capsicum, tomato, brinjal.

c. Department of Vegetable Science, Chaudhary Sarwan Kumar Himachal Pradesh KrishiViswavidyalaya, Palampur, Himachal Pradesh is also working on grafting mainly against bacterial wilt which emerged as one ofthe devastating problems in some parts of the state and limiting the cultivation of Solanaceous vegetables in particular.

d. Division of Vegetable Production, Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh has also initiated a work on grafting and identified various rootstocks resistant to water logged conditions.

e. Department of Vegetable Science, ASPEE College of Horticulture & Forestry, NAU, Navsari, Gujarat started a work on grafting during 2013-14 with major emphasis to work out the feasibility of growing brinjal as well as tomato under high rainfall conditions of South Gujarat.

f. Very recently, scientists of AICRP on Vegetable Crops, Bidhan Chandra Krishi Viswavidyalaya, West Bengal have initiated the grafting of cultivated brinjal on the most tolerant wild rootstocks *Solanum torvum* and *Solanum sisymbriifolium* against bacterial wilt after a series of cross inoculation with most virulent strains of *Pseudomonas solanacearum.*

Grafting: A Surgical Alternative over Breeding: Now-a-days, grafting promises to be an effective alternative tool over slow conventional breeding methods against various biotic and abiotic stresses. The plants developed through conventional methods reflect the genotype (G) × environment (E) interaction only, whereas a grafted plant brings two different genotypes together and shows effective interaction of rootstock (R)× scion (S)× environment (E)thereby determining the positive and negative influence of rootstocks on plant performance and fruit quality of scion. Grafting not only provides vigour to the plant but also provides tolerance against adverse environmental conditions and soil-borne pathogens. It also improves resource uptake capacity of plant and increases its resource use efficiency. Grafting enhances the soil biological properties by increasing the population of bacteria and actinomycetes with a great potential to protect plants against many pathogens (Albacete *et al*., 2015).

Grafting: A Climate Resilient Technology: Climate has undergone significant changes showing increasing trends in annual temperature with an average of 0.56^{O}C rise over last 100 years. A rise in global temperature causes melting of glacier and ice-cap along with thermal expansion of water. The changing pattern of climatic parameters like rise in temperature, changes in precipitation patterns, excess UV radiation, higher incidence of extreme weather like droughts and floods are posing major threats for successful vegetable production (Tirado *et al*., 2010). To mitigate the adverse impact of climate change on productivity and quality of vegetables crops, grafting is proposed to serve as a climate resilient technology because of its ability to provide tolerance to salinity, drought, flood, thermal stress, heavy metal toxicity, diseases and pests (King *et al*., 2008; Garibaldi and Gullino, 2010; Savvasa, *et al*., 2010; Schwarz, *et al*., 2010; Guan and Zhao, 2012; Colla, *et al*., 2014 and Bahadur, *et al*., 2015).

What is grafting?: Grafting is an art and technique in which two living parts of different plants *i.e.*, rootstock and scion are joined together in such a manner that they would unite together and subsequently grow into a composite plant.There are different methods of grafting which can be employed in vegetable crops namely,Tongue approach grafting (Melon and Cucumber), Hole insertion grafting(Water melon), Splice grafting (Water melon), Cleft grafting (Tomato, Brinjal and Capsicum), Tube grafting ((Tomato, Brinjal and Capsicum), Apical wedge grafting (Capsicum), Micro Grafting (Tomato), Side grafting (Water melon) and Cut grafting (Water melon).

Physiology of graft union formation: For successful union to occur, it undergoes five stages of union formation:

a. Stage 1 and 2 include the lining up vascular cambium of both rootstock and scion and wound response process. A direct contact between the cambial layers of both rootstockand scion is the first and foremost step in healing wound process of grafting.

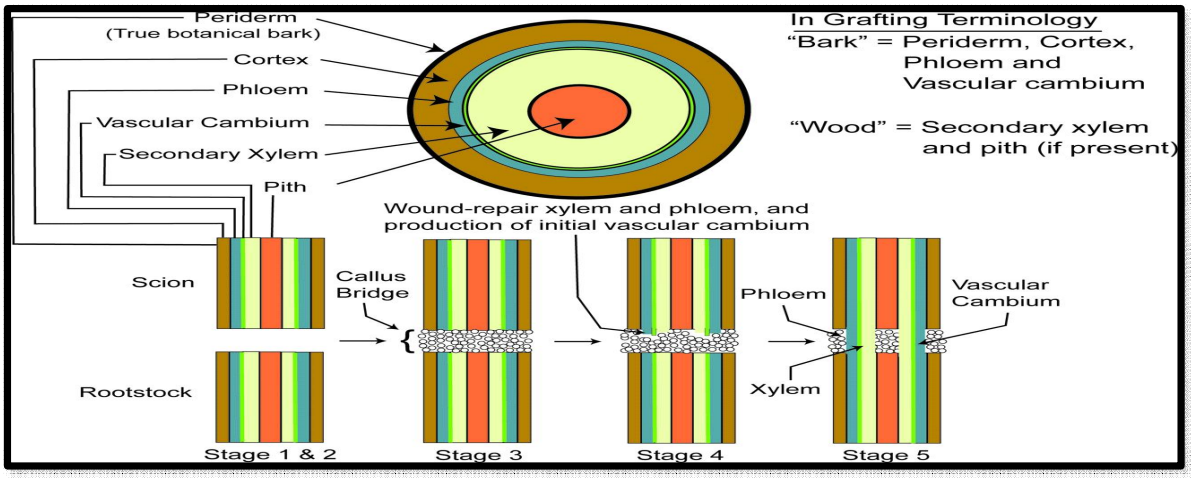
b. Stage 3 includes the callus bridge formation: During grafting operation, the living cells of both stock and scion are damaged resulting in the formation of necrotic plate, which separates the stock and scion from each other. However, some living cells in damaged cells initiate the formation of callus from the parenchymatous cells of phloem and xylem tissues, penetrating the thin necrotic layer and soon fill up the gap between the stock and scion and becomes interlocked.

c. Stage 4 is wound repair process between xylem and phloem, which is achieved with the production of vascular cambium across the callus bridge after 7 to 10 days of grafting. The development of these cells results in the formation of continuous cambial connection between the stock and scion.

d. Stage 5 is formation of secondary xylem and phloem from new vascular cambium. So, new xylem and phloem are formed inside and outside of the vascular cambium. Thus, the production of new xylem and phloem permits the vascular connection between the rootstock and scion throughout the life of grafting. (Sharma, 2002).

Important considerations for successful grafting:

- Selection of potential rookstocks.
- Compatibility between rootstock and scion.
- Applications of efficient grafting methods.



Source: Hartmann *et al*., 2010

Problems associated with grafting.

Factors	Category
Labour	Grafting operation and post-graft care
Techniques	Rootstocks selection
Management	Fertilizer application
Compatibility	Uneven senescence
Growth	Excessive vegetative growth and physiological disorders
Fruit quality	Size and shape, appearance, insipid taste, soluble solids, yellow band in flesh and internal decay
Expense	Rootstock seeds and labour
Scion rooting	External rooting, internal or fused rooting

Labour is one of the constraints in commercial success of grafting technology. So, some of the countries like South Korea, USA have developed semi automated grafted machine and grafting robots to overcome such problems and to strengthen commercial viability of technology. A semi automated can produce 350-600 grafts per hour with two operators while a fully automated grafting robot performs 750 grafts per hour with 90-93% success rate (Davis *et al*., 2008).

Potential rootstocks: Rootstocks have a potential to provide tolerance against various abiotic and biotic stresses (Table 1).

Genetic aspects of grafting: Understanding the genetic aspects of grafting, make it very easy to utilize the genetic potential of rootstock fully, which is generally governed by various resistant genes present in rootstock (Table 4). These are the some important diseases of solanaceous and cucurbitaceous crops governed by various genes which can be managed by grafting.Harada (2010) studied the genetic mechanism in rootstock-scion relationship and demonstrated it through the transfer of RNA transport system. He further observed that some of the specific RNA molecules are transferred from stock to scion through phloem tissues as genetic information to execute the organ growth and development.

Physiological aspects of grafting: To alleviate the adverse aspects of various stresses through grafting, it is very important to understand the physiological aspects of each stress for better execution of this technology.

Abiotic Stresses:

Salinity:

- It is one of the most important abiotic stresses, hampering the plant growth and development. High salt concentration causes an imbalance in cellular ions, resulting in ion toxicity and osmotic stress leading to the generation of ROS (Reactive Oxygen Species).

- ROS causes damage to DNA, lipids, proteins simultaneously causing chlorophyll degradation and membrane lipid peroxidation, hence decreasing membrane selectivity and fluidity.(Asada, 1999; Evans *et al*., 2004).

- To prevent the negative effect of ROS, plant has developed an antioxidant enzyme system. In grafted plant, the level of antioxidant is higher than the normal plants majorly governed by rootstock.(Ahmad and Prasad, 2012).

- Antioxidant enzymes like Catalase (CAT) and Peroxidase (POD) detoxify the toxic effect of Hydrogen Peroxide (H_2O_2). However, Superoxide dimustase (SOD)catalyse the superoxide and break down into water (H_2O) and oxygen(O_2). While the Ascorbate peroxidase (APX) reduces the level of H_2O_2 by using ascorbate as an electron donor in the ascorbate- gluthathione cycle (Kusvuran *et al*., 2016) and thus, provide the tolerance against salinity.

The compatibility between rootstocks and scion also affect the physiology of plants (Table 5). The higher production of antioxidant enzymes in compatible grafted plant, enables better and strong root growth in contrast to low level of antioxidant in incompatible grafted plant (Aloni *et al*., 2010).

Table 1: Potential rootstocks with special features of resistance against biotic and abiotic stresses

Crop	Species	Specific features
Tomato	*Solanum pennelli*	Tolerance to drought (Bolger *et al*., 2014 and salt (Shalata *et al*., 2001)Resistance to *Alternaria alternata* f. sp. *Lycopersici* (Van der Biezen *et al*., 1995)
	S. chessmanii	Resistant to salt (Rush and Epstein, 1976)
	S. habrochaites	Resistance to Pseudomonas syringe pv. tomato race 1 (Thapa *et al*., 2015)
	S. chilense	Resistance to drought and diseases (CMV, TYLCV) Zamir *et al.* (1994)
	S. neorickii	Resistant to *Botrytis cinerea* (Finkers *et al*., 2008)
	S. pimpinellifolium	Colour, quality, resistance to bacterial wilt (Danesh *et al,.* 1994), late blight (Pierce, 1971))
	S. lycopersicum var. *Cerasiforme*	Tolerance to humidity, resistance to fungi and root rot (Balint-Kurti *et al*.,1994)
	S. peruvianum	Resistance to tomato spotted wilt virus and RKN (Williamson *et al*., 1994; Rossi *et al*., 1998 ; Yaghoobi *et al*.,1995
Brinjal	*S. macrocarpon*	Tolerant to flooding (Bhatt *et al*., 2014)
	Solanum elaeagnifolium	Resistant to drought (Christodoulakis *et al*.,2009)
	S. torvum	Resistance to *Verticillium* wilt (Bletsos *et al*., 2003), Bacterial wilt, *Fusarium* wilt, RKN (Bagnaresi *et al*., 2013; Gousset *et al*., 2005) and tolerant to abiotic stresses (Giuffrida *et al*., 2015).
	S. incanum, S. xanthocarpun, S. khasianum and S. sisymbrifolium	Immune to shoot and fruit borer (Kale *et al*., 1986)
	S. gilo	High degree of resistance to shoot and fruit borer (Singh and Kalda, 1997)
	S. sisymbriifolium	Resistant to little leaf and *Verticillium* wilt (Bletsos *et al*., 2003)
	Solanum integrifolium and S. gilo	Resistant to little leaf disease (Chakrabarti and Choudhury 1975)
	S. khasianum, S.torvum and S. toxicarium	Immunity or high resistance to Root knot nematode (Ali *et al*., 1992)
	Solanum integrifolium	resistance to *Verticillium* wilt (King *et al*., 2010) and Root Knot Nematode (Gisbert *et al*., 2011)
Chilli	*Capsicum chinensis and C. baccatum*	Anthracnose resistant species (Silva *et al*., 2014; Mahasuk *et al.,* 2013; Ying *et al.,* 2015)
	C. baccatum, C. chinense and *C. frutescens*	Powdery mildew resistance species (de Souza and Cafe-Filho, 2003)
Potato	*S. desmissum*	*Resistant to late blight (Li et al., 1998)*
Cucumber	*Cucumis hystrix*	*Resistant to downy mildew (Chen et al., 2004)*
	Cucumis ficifolia	*Resistant to Fusarium wilt (Marukawa and Takatsu, 1969)*
	Cucurbita maxima x cucurbita moschata	*Tolerant to high temperature (Lee et al., 2010)*
Musk melon	*PI 124111 and PI 124112 (Cucumismelo var. momordica)*	*Resistant to DM (Thomas et al.,1987; Balass et al. 1992; Pirat et al., 1996)*
	Cucumistrigonus	*Resistant to fruit fly (Sambandam and Chelliah, 1972)*
	C. metuliferus	*Resistant to nematode (Wehner et al.,1991)*
	C. pustulatus	*Resistance to root-knot nematode and Fusariumwilt (Liu et al., 2015)*
Pumpkin	*Cucurbitalundelliana*	*Resistant to powdery mildew (Rhodes, 1964)*
Wax gourd	*Benincasahispida*	*Resistance to Fusarium wilt, resistance to nematodes and fungus Stagonosporopsis spp. (Galatti et al., 2013; Ito et al., 2009)*

Table 2: Commercial tomato rootstock cultivars for biotic stresses.

Rootstock	Disease resistance					
	Tomato mosaic virus	*Fusarium* Wilt		*Verticillium* wilt	Bacterial wilt	Nematodes
		Race 1	Race 2	Race 1		
Maxifort	High	Moderate	High	High	Susceptible	High
Beaufort	High	Moderate	High	High	Susceptible	High
Anchor-T	High	High	High	High	Moderate	High
Survivor	High	High	High	High	Moderate	High
Aegis	High	High	High	High	Moderate	High
Body	High	Susceptible	High	High	Susceptible	High
Robusta	High	Susceptible	High	High	Susceptible	Susceptible

Source: Louws *et al.* (2010)

Table 3: Commercial rootstocks for biotic stresses in cucurbits.

Rootstock	*Fusarium oxysporum*				Nematodes	
	sp. *niveum*	sp. *cucumerinum*	sp. *melonis*	sp. *lagenariae*	*M. incognita*	*M. halpa*
Shintozwa	HR	HR	HR	HR	S	S
Hongtozwa	HR	HR	HR	SR	S	S
Figleaf gourd	MR	SR	MR	SR	S	S
Bottle gourd	MR	HR	HR	SR	S	S
Wax gourd	HR	MR	HR	HR	S	SR
Bur cucumber	HR	HR	HR	HR	S	HR
AH cucumber	HR	HR	HR	HR	S	MR

Source: Davis *et al.* (2008)

Table 4: Genetic mechanism governing resistance against biotic stresses.

Crop	Disease	Organism	Gene of resistance	Reference
Cucumber	*Fusarium* wilt	*Fusariumoxysporum*	*Foc*	Pavlou *et al.,* 2002
	Phytophthora blight	*Phytophthoracapsici*	*Pcap*	Wang *et al.,* 2004
	Root-knot nematodes	*Meloidogyne* spp.	*Mi*	Giannakou and Karpouzas. 2003
	Verticillium wilt	*Verticilliumdahliae*	*Ve*	Paplomatas *et al.,* 2002
	Powdery mildew	*Erysiphecichoracearum*	*pm*-1	Sakata *et al*., 2006
Musk melon	*Fusarium*wilt	*Fusariumoxysporum*	*Form*-1, *Form*-2, *Form*-3	Zink and Gubler, 1985; Zink *et al*., 1983
Water melon	Virus complexes	CMV, ZYMV, PRSV, WMV-II		*Wmv,Zym-1, Zym-2* Wang *et al.,* 2002
Eggplant	Verticillium wilt	*Verticilliumdahliae*	*Ve*	Bletsos *et al*., 2003
	RKN	*Meloidogyne spp.*	*Mi, Mi-1*	Boiteux and Charchar, 1996
Tomato	Verticillium wilt	*Verticilliumdahliae*	*Ve*	Juvick *et al*., 1991
	Fusarium wilt	*Fusariumoxysporum*	*I-1, I-2, I-3*	Sarfatti *et al*., 1989, 1991; Bournival *et al*., 1989 ; Tanksley *et al.,* 1991
	Tomato yellow leaf curl	TYLCV	*Ty-1, Ty-2*	Zamir *et al*., 1994; Hanson *et al*., 2000
	Nematodes	*Meloidogyne spp.*	*Mi-1*	Medina-Filho and Stevens, 1980

Drought:

• Understanding the concept and component of drought resistant is a key factor for improving the drought tolerance in any crop.

• In plant, water deficient condition is first recognized by roots. But in grafted plant due to higher activity of H^+-ATPase enzyme, it promotes large and deep root system to acquire water from the soil.(Sze *et al*., 1999).

• They also start the osmotic adjustment by active accumulation of solutes within plant tissue in response to lowering of soil water potential and maintain the turgor of cell and leaf water potential (lwp). (Rana Munns, 2011).

• By maintaining lwp, it promotes the stomatal conductance to CO_2 and maintain the internal CO_2 concentration which ultimately increase the rate of net photosynthesis and promote growth(Roy and Basu, 2009).

Flooding:

• Now-a-days, flooding emerged as a one of the major threat for vegetable production.

• It causes O_2 starvation, which arises from the slow diffusion of gases in water and O_2 consumption by micro-organisms.

Table 5: Rootstocks for abiotic stresses in cucurbits

Rootstock	High salt Tolerance	Low Tolerance temperature	Graft compatibility Watermelon	Cucumber
Shintozwa	HR	HR	HC	HC
Hongtozwa	MR	MR	SC	HC
Figleaf gourd	HR	HR	IC	HC
Bottle gourd	MR	SR	HC	HC
Wax gourd	SR	SR	HC	HC
Bur cucumber	SR	SR	HC	MC
AH cucumber	SR	SR	HR	HC

HR- Highly resistant; MR- Moderately resistant; SR- Slightly resistant; HC- Highly compatible; MC- Moderately compatible; SC- Slightly compatible; IC- Incompatible. **Source:** Davis *et al*.(2008)

• Grafted plant shows depression in photosynthetic rate, stomatal conductance and transpiration rate under flooded condition.

• They also induce a chemical signal in xylem sap under low O_2 partial pressure condition and stimulate the synthesis of ethylene in roots. Ethylene helps in formation of adventitious roots at the sub-surface region of plant and it help in obtaining O_2 from air with enhanced nutrient assimilation (Schwarz *et al*., 2010).

• Due to the accumulation of ethylene in sub-merged parts of plants, it also stimulate the formation of aerenchymatous tissues, which favours the longitudinal transport of O_2 from aerial parts of plant to the sub-merged parts under anoxia condition (Roy and Basu, 2009).

Thermal stress:

(a) Low temperature:

• It affects the plant growth by affecting its root growth, nutrient absorption, translocation of water and osmoregulation, antioxidants *etc*.

• **Root growth and architecture**: Low temperature affects the plant root growth, size, architecture as well as functioning. Under sub-optimal condition, cold tolerant rootstocks maintain higher root growths than the sensitive ones and have a capacity to adjust their root/ shoot ratio (Venema *et al*., 2008). In grafted plant, due to higher activity of H^+- ATPase enzyme, it pumps the H^+ ion in the apoplast and maintain low apoplastic pH condition. This low apoplastic pH activate the expansion protein in the cell wall which helps in breaking the H-bond of cellulose and promote the cell growth and root elongation (Sze *et al*., 1999).

·**Nutrient absorption**: High root elongation in grafted plant helps in more nutrient uptake and transportation and also improves the phosphorous uptake capacity of plant. While in normal plant, phosphorous uptake is depressed at

decreasing root temperature and phosphorous starvation may induce ethylene production and decrease the cytokinin content in the root (Marschner, 1995).

• **Translocation of water and osmoregulation**: Cold tolerant rootstocks overcome the restrictions of water absorption by increased level of root hydraulic conductance, decreased induction of cell wall suberin layers, lipid peroxidation and closure of stomata (Lee *et al*., 2005).

• **Lipid peroxidation and antioxidants**: Low temperature stress increases the production of ROS in root of chilling sensitive plants, which may cause peroxidation of unsaturated membrane lipid and result in decreased membrane selectivity and fluidity and increased membrane rigidity which cause leakage of electrolytes, water and other soluble materials out of cell into the intercellular space of the roots (Gao*et al*., 2008). Cold tolerant rootstocks produce high amount of Abscisic acid (ABA) and cytokinin. Both ABA and cytokinin regulate the ROS scavenging system and provide tolerance against low temperature (Pogany *et al*., 2003). There are some commercial rootstocks in cucurbits which posses varies degree of resistance for low temperature and can successfully be employed for better response of cucurbits under such environment (Table 5).

(b) High temperature:

• It affects the plant morphology, physiology as well as biochemical properties. Under high temperature conditions, potential rootstocks start the accumulation of compatible osmolytes (Proline, Valine, Soluble sugars *etc*.) which is necessary to regulate the osmotic activities and protect cellular structures from increased temperature by maintaining the cell water balance, membrane stability and buffering the cellular redox potential. This also helps in better stomatal regulation and enhanced photosynthesis.

• Heat tolerant rootstocks also increase the production of antioxidants with decreased level of ROS generation in plant during stress conditions. It causes less photo-oxidative damage and maintains chloroplast membrane integrity and increases the photosynthetic rate (Waraich *et al*., 2012).

Heavy Metals:

• Chronic exposure of human beings to heavy metals causes lung cancer, osteomalacia, stomatitis, hypo-pigmentation *etc*.(Martin and Griswold, 2009).

• According to a survey conducted in Japan, approximately 7% of eggplant fruit contains more cadmium than the internationally acceptable limit.(Takeda *et al*., 2007).

• Heavy metal stress causes oxidative damage to plant through ROS formation. Excess Zn alter mitotic activity, affect membrane integrity and permeability. Rootstocks have ability to limits the heavy metal accumulation in aerial parts of plant (Kusvuran *et al*., 2016).

Selected review of research workon genetic and physiological aspects of grafting:

Genetic aspects:

Genetic potential: Bletsos (2006) at National Agricultural Research Foundation (NAGREF), Greece carried out a comparative analysis of soli sterilants and grafting against *Verticillium* wilt and observed that eggplant cultivar Tsakoniki grafted onto *Solanumtorvum* and the ones grown in soil treated with calcium cyanamide and methyl bromide exhibited significantly lower leaf symptom index (LSI) and diseases index (DI) in first year of study. However, in his second year of study, Methyl bromide showed a better performance for LSI and DI over grafted plant and the ones gown in soil treated with calcium cyanamide. Rootstock,*S. torvum* and Calcium cyanamide provided a high level of protection from *Verticillium* wilt as compared to control. The result indicated that Calcium cyanamide and grafting were effective in controlling *Verticillium* wilt. Although, Methyl bromide even gave a similar and better performance, but it is now banned. So, grafting eggplant onto the rootstock *S. torvum*may offer an alternative over chemical sterilantsfor the control of *Verticillium dahlia*.

Saccardo *et al*. (2006) at University of Tuscia, Central Italy studied the response of commercial rootstocks of pepper to soil-borne pathogens mainly *Phytophthoracapsici* and root knot nematode (RKN) and categorized Snooker as a potential rootstockgoverning resistance through *CaRGA2* gene for *P. capsici*.They further identified DRO-8801, ES-98-1, ES-00-40 and RX-600 as potential rootstocks carrying *Mi, Ma, Mj* genes of resistance for RKN. So, it can be established from his study that genetic potential of a particular rootstock plays an important role in governing the resistance.

Gilardi *et al*. (2011) at United State Department of Agriculture (USDA) took a study on disease reaction of different tomato rootstocks against different soil-borne pathogens like *Fusarium oxysporum*, *Ralstonia solani* and *Verticillium dahlia* and identified He-Man, Maxifort and Natalya as potential rootstocks for both the raceof*F. oxysporum*(race-1 and race-2) governing resistance through *I-1* and *I-2* genes. They also categorized He-Man, Maxifort, Beaufort, Unifort, 500267, 500292 and Spirit as resistant rootstock to *R. solani*.

Johnson *et al*. (2014) at Washington State University, USA carried out a comparative performance of grafted and ungrafted eggplant cv. Epic against *Verticillium* wilt in naturally infested field at Eltopia and greenhouse condition at Mount Vernon during 2010 and 2011 and observed that Epic grafted onto Beaufort rootstock had lowest *Verticillium* wilt severity at both the conditions during successive years of their study. However, *Verticillium* wilt severity was highest in both the years at Eltopia as compared

to Mount Vernon condition. The conclusion was drawn that grafting eggplant onto Beaufort may be effective strategy for managing *Vertilicillium* wilt and may offer an effective alternative over soil fumigation.

Mechanism of resistance: Wu *et al*. (2013) at Cankiri Karatekin University, Turkey carried out a study on DNA methylation levels in solanaceous vegetables upon inter-specific grafting by using Methylation Sensitive Amplified Polymorphism (MSAP) pattern and compared three kinds of methylation levels *viz*., CG, CHG and Total methylation level in hetero-grafted and self-grafted plant of tomato and eggplant and observed that all three kinds of methylation levels in hetero-grafted scion remain unchanged except in tomato hetero-grafted onto eggplant. They suggested that both hetero and self-grafting did not cause a general alteration in DNA methylation levels in solanaceous vegetables. Only in specific cases grafting may cause a significant reduction in methylation levels. So, grafting can produce a heritable and an extensive alteration in transfer of traits from rootstock to scion.

Physiological aspects

Salinity: Colla *et al.* (2012) at Lebanese University, Lebanon studied the effect of salt treatment of Na_2SO_4 and NaCl on stomatal conductance (g_s), Soil Plant Analysis Development (SPAD) index and electrolyte leakage of cucumber cv. Akito grafted on PS1313 and observed that grafted plant treated with Na_2SO_4 showed high stomatal conductance (188.5) and SPAD index (56.3) and low electrolyte leakage (27.6) followed by grafted plant treated with NaCl. Although the salt as well as graft combination individually significantly influenced all these parameters. Whereas the interaction between salt and graft combination was significant for electrolyte leakage only. So, they concluded that grafted plant provide tolerance to salinity by increasing the stomatal conductance, chlorophyll content and membrane selectivity.

Drought: Agele and Cohen (2009) at Fedral University of Technology, Nigeria demonstrated the effect of scion genotypes and graft types on leaf water potential (LWP)of grafted melon using Arava (AR) as a rootstock for two genotypes (RS-57 and RS-82) through side and V-method of grafting. They recorded change in lwp right from pre-drawn to 14 hrs periodically and observed highest LWP in self-grafted Arava followed by genotype RS-57 grafted on Arava through V-method of grafting.

They also studied the effect of scion genotypes and graft types on hydraulic conductance in grafted melon and recorded hydraulic conductance from 11 to 14 hrs day conditions and observed highest hydraulic conductance in self-grafted Arava followed by genotype RS-82 grafted on Arava through side method of grafting. So, conclusion drawn from both the observation that grafting induced modifications in root-shoot relationship, affecting hydraulic characteristics of sap pathway and water relations in grafted melon which can be useful for understanding the physiology of tolerance under drought conditions. This study also confirmed the possibility of Arava as rootstock under moisture stress conditionsto provide tolerance under drought condition.

Flooding: Bahadur *et al*. (2015) at Indian Institute of Vegetable Research, Varanasi studied the effect of flooding on grafted and un-grafted tomato at early and active vegetative stage and reproductive stage using IC-111056 and IC-354557 as rootstocks for cultivars Arka Rakshak and Arka Samrat by an exposure to waterlogged stress for 72 and 96 hrs. during vegetative and reproductive stage, respectively. Arka Rakshak grafted onto IC-111056 and ArkaSamrat onto IC-354557 were found to be the best option for survival under water logged conditions during all three stages of growth thereby highlighting inherent capabilities of these rootstocks.

Thermal stress

Low temperature: Lee *et al*. (2005) at Chonnam National University, Kwangju investigated the effect of low temperature on lipoxygenase specific activity in the root of cucumber (*Cucumis sativus*)and fig leaf gourd (*Cucurbita ficifolia*) and found significantly higher lipoxygenase activity in fig leaf gourd than cucumber. This enzyme catalyses the lipid peroxidation level which could increase the level of lipid unsaturation and increase membrane fluidity. So, the higher activity of lipoxygenase in fig leaf gourd has proven better response to low temperature stress and may provide broad insight into stress response mechanism.

Li *et al*. (2015) at Shangdong Agricultural University, China studied the effect of low temperature on change in electrolyte leakage rate in un-grafted and grafted cucumber cv. Xintaimici onto different rootstocks like Kilameki, Tielizhen and figleaf gourd having different tolerance level and observed lowest electrolyte leakage in cucumber grafted onto figleaf gourd which was at par with cucumber grafted on Tielizhen. They recommended the differential response of rootstocks for electrolyte activity driven by anti-oxidant defense system and suggest that figleaf gourd as a potential rootstock under such situation.

High temperature: Abdelmageed *et al*. (2004) at University of Khartoum, Sudan carried out a study on electrolyte leakage in grafted tomato under high temperature stress condition using heat tolerant cultivar 'Summer Set' and 'Black Beauty' as a rootstock and less heat tolerant cultivar UC-82-B as a scion under two different temperature regimes 38/27^{0}C and 30/22^{0}C. They observed significantly lowest electrolyte leakage in UC-82-B grafted onto Black Beauty shows under both temperature conditions thereby reflecting its tolerance to high temperature.

Heavy metal: Kumar *et al*. (2015) at Central Arid Zone Research Institute (CAZRI), Jodhpur studied the role of grafting and ArbuscularMycorrhiza (AM) on heavy metal tolerance in tomato by exposing two graft combination i.e., self-grafted Ikram and Ikram grafted onto Maxifort to different levelsof cadmium (0 and 25μM) in the absence or presence of AM and concluded that Ikram grafted onto Maxifort induces high antioxidant enzyme system and proline synthesis in absence of AM. They summarized that vigorous rootstock Maxifort could effectively mitigate the adverse effects of cadmium by increasing thesynthesis of antioxidant and proline.

CONCLUSION

Grafting has emerged as one of the promising tools to enhance plant performance of various vegetable crops with a capacity to deal with biotic and abiotic stresses. Grafting provides opportunities to transfer some genetic variations of specific traits of rootstocks to influence the phenotype of scion. Genetic potential of commercial rootstocks like Snooker and DRO8801, ES 98-1, ES 00-40, RX 600 can successfully be exploited against *Phytophthora* and root knot nematode, respectively in pepper. Grafting eggplant onto *Solanum torvum* has been found to express effective control for *verticillium* wilt and emerged as better alternative to chemical sterilants. Analysis of DNA methylation levels through MSAP marker has established that grafting can produce extensive and heritable alteration to transfer traits from stock to scion. PS1313 rootstock has shown inherent capacity against salt stress in cucumber by maintaining higher stomatal conductance, chlorophyll content (SPAD index) and membrane selectivity. Grafting melon with different graft types induces modifications in root-shoot relationships and thus, affects hydraulic characteristics of the sap pathway and water relations in grafted melon. IC-354557 is a potential tomato rootstock, which may improve water logging tolerance during vegetative as well as reproductive stages. The higher activity of lipoxygenase and low electrolyte leakage in figleaf gourd has proven better response to low temperature stress and may provide broad insight into stress response mechanisms. Similarly, exhibition of low electrolyte leakage in tomato cultivar grafted on rootstock Black Beauty reflect its tolerance to high temperature. Grafting tomato involving vigorous rootstock such as Maxifort could effectively mitigate the adverse effects of Cd stress by increasing the capacity of antioxidant enzymes and proline. Therefore, it is envisaged that various conventional and modern approaches of science should be collaborated to identify mechanism and pathway of rootstock-scion relationships for better understanding and execution of this technique.

Future Thrust:

- Breeding of appropriate rootstocks is still a matter of trial and error and the use of specific physiological parameters to select plants in the breeding process is unprecedented for future rootstock breeding.
- The molecular and physiological mechanisms involved in the advantageous response of specific stress-tolerant rootstocks are manifold and partly still unknown.
- There is a need to unravel functional physiology of grafting plant for providing a framework for early detection of incompatible grafts for commercial utility.
- Extensive research is required to understand various genetic and physiological aspects for better execution of this technology.
- Future research should focus on identification of the key-physiologically root-derived processes that are highly correlated to the rootstock traits of interest.
- The identified biomarkers can then be used as generic tools to develop an effective method for the selection of rootstocks which improve the adaptability of vegetable crops to thermal or water stress, organic pollutants or other abiotic stresses.

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