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REVIEW ARTICLE

Vegetable grafting – A Boon for soil-borne pest and disease management- A Review

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ABSTRACT

India is the second-largest populous country after China with an estimated population of 1.31 billion as of now and it will reach 1.7 billion by 2050. Moreover, the growing world population is projected to reach approximately 8.4 billion by mid-2030 and 9.7 billion in 2050. Hence, Agricultural productivity must increase by 60% to feed the expected population and it must be achieved through a socio-environmental sustainability of the natural resources. However,vegetable production around the world is being increasingly hampered by the unfavorable soil and environmental conditions that include abiotic constraints such as drought, extreme temperature, salinity, flooding, low nutrients, organic and heavy metals contamination, as well as biotic ones as soil-borne pests and diseases. This situation is aggravated by successive cropping, environmental policies, as the phase-out of the chemical soil disinfectants, and negative impacts of climate change. While, genetic breeding cannot always provide efficient solutions to mitigate the aforementioned problems. Nowadays Grafting is regarded as a rapid alternative tool to the relatively slow breeding methodology. The production and cultivation of grafted solanaceous and cucurbitaceous plants are ever increasing across Asia, Europe, and North America due to its ability to provide tolerance to biotic stress and abiotic stresses. However, the appropriate rootstock and scion cultivars and grafting techniques must be chosen with care to avoid post grafting losses due to incompatibility. This review discusses the source of potential rootstocks in solanaceous and cucurbitaceous vegetables to mitigate various biotic stresses, grafting techniques/methods and graft compatibility studies towards the improvement of vegetable production.

Keywords: *Grafting, biotic stress, root knot nematode, Fusarium wilt, compatibility*

INTRODUCTION

Grafting has been utilized in horticulture ever since the first millennium, especially in fruit crops. Nevertheless, vegetable grafting is gaining momentum in recent years among vegetable growers worldwide (Ashok Kumar and Kumar Sanket, 2017). In the recent past, grafting is recognized as a rapid alternative tool for sustainable vegetable production by using resistant rootstock which reduces dependence on agrochemicals (Rivard and Louws, 2008) to mitigate the soil-borne problems. Bahadur *et al.* (2015) stated that grafting in vegetables has emerged as a promising and alternative tool to relatively slow conventional breeding methods aimed at increasing tolerance to biotic and abiotic stresses. The first attempt in vegetable grafting was initiated in watermelon (*Citrullus lanatus*) with pumpkin (*Cucurbita moschata*) rootstock to combat *Fusarium* wilt problem during the late 1920s at Japan (Leonardi, 2016). Since then, the use of grafting in vegetable crops has spread around the world. Currently, the cultivation of all the cucurbits under greenhouse conditions in Japan and Korea is based on grafting techniques (Sanjeev Kumar *et al.,* 2018). Though, the benefits of using grafted plants are profuse, not all vegetable species are capable of being grafted, because genetic background, growth characteristics, anatomy, and physiological and biochemical factors of the species influence the success per cent of grafted plants (Martinez *et al.,* 2010; Goldschmidt, 2014; Fan *et al*., 2015; Gratao *et al*., 2015). Among vegetable crops, grafting is commonly and economically practiced in solanaceous and cucurbitaceous vegetables *viz.,* Tomato (*Solanum lycopersicum* L.), Eggplant (*S. melongena* L.), Sweet pepper, Watermelon [*Citrullus lanatus* (Thunb.) Matsum. and Nakai],

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Melon (*Cucumis melo* L.), Bitter gourd (*Momordica charantia),* and Cucumber (*C. sativus* L.).In this review, the information on purpose, prospects and dispute of grafting, grafting techniques/methods and graft compatibility among the rootstock and scions towards yield improvement and soil-borne pest and disease management in the aforementioned vegetable crops were described hereunder.

HISTORY of vegetable grafting In India

Though the grafting technique was invented by Chinese ancestors and recorded in an ancient book during the first century BC, vegetable grafting in India was initiated during the 19th century only. During recent years, the production and cultivation of grafted solanaceous and cucurbitaceous plants are ever-increasing across Asia, Europe, and North America due to its ability to provide tolerance to biotic stress and abiotic stresses. However, this technology is still infancy in India.

Grafting in vegetable crops has been initiated by the Indian Institute of Horticultural Research, Bangalore mainly to mitigate water logging. Moreover, they have conducted "short course on vegetable grafting" during 2013to create awareness among the scientist for the same. Recently they started working on rootstock breeding also.

The Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu initiated research on vegetable grafting in brinjal to mitigate root-knot nematode (*Meloidogyne* spp.) and dry root rot (*Macrophomina phaseolina*) incidence during 2008. The technology was standardized and released during the year 2016. Now the Department is producing grafted brinjal plants and supplying to the farmers on request basis @ 7 Rs per graft. The farmers are also much interested and coming forward for grafted brinjal cultivation due to its perennial nature, resistant to root-knot nematode and dry root rot pathogen. Moreover, cucumber, watermelon the research on grafting in bitter gourd, cucumber and tomato is in progress to manage soil-borne disease management. The research initiatives made in rootstock breeding also.

The National Bureau of Plant Genetic Resources (NBPGR) regional station, Trissur, Kerala attempted inter-specific grafting in a sweet gourd (*Momordica cochinchinensis*) by using female plants as scion and male plants as rootstock and recorded 98% graft success and higher production

The Department of Vegetable Science, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Viswavidyalaya, Palampur, Himachal Pradesh is also working on grafting in Solanaceous vegetable crops to manage bacterial wilt incidence which emerged as a most devastating pathogen in some parts of the state. They identified more than 22 rootstocks in brinjal, chilli, tomato, and cucurbits to impart resistance to bacterial wilt and nematodes.

Division of Vegetable Production, Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh has also initiated work on vegetable grafting and identified resistant rootstocks for waterlogging

The Department of Vegetable Science, ASPEE College of Horticulture and Forestry, NAU, Navsari, Gujarat started research work on grafting in brinjal and tomato during 2013-14 to enhance the production under high rainfall conditions of South Gujarat.

Bidhan Chandra Krishi Viswavidyalaya, West Bengal, has initiated research work on grafting in brinjal and tomato with *Solanum torvum* and *Solanum sisymbriifolium* against bacterial wilt pathogen under AICRP on Vegetable Crops.

Private seed companies also involved in commercial production and supply of grafted plants to the farmers. VNR Seeds Pvt. Ltd., Raipur (Chhattisgarh) started commercial venture for grafted plants production and supplying grafted seedlings of brinjal, tomato, cucumber, muskmelon and watermelon to the farmers within and adjoining states depending upon the requirement of the farmers to combat bacterial wilt incidence

Namdhari Seeds Pvt.Ltd., Bangalore, Jarvi Seeds Pvt.Ltd., Bharuch, Gujarat, and 'Takii Seed India Private Limited', Bangalore also exploiting this technology commercially in cucurbits like muskmelon, watermelon and solanaceous vegetables *viz.,* brinjal, capsicum and tomato.

ROOTSTOCKS EFFECT ON ROOT KNOT NEMATODE RESISTANCE

The root-knot nematode *Meloidogyne* spp. is one of the most important yield-limiting constraints in vegetable crops (Kalaiarasan, 2009) causing an estimated yield loss of 5–43% in the tropics and subtropics. The three nematode species *viz., Meloidogyne incognita*, *Meloidogyne javanica*, and *Meloidogyne arenaria*, widely prevalent in the tropical region between 35°S and 35°N latitudes (Pinheiro and Amaro 2010) and *M. hapla* are predominant in temperate regions (Taylor and Sasser 1978). Root-knot nematodes are obligate parasites that feed on the cytoplasm of living plant cells, damaging them and causing tumor-forming galls (Izuogu *et al.,* 2010). Due to the root-knot nematode infestation, the formation of typical root galls affects nutrients uptake and translocation of materials.

Solanaceous vegetables

Among the solanaceous vegetables, tomato, eggplant, and sweet pepper are amenable to grafting. Grafting is widespread in almost all greenhouse-produced tomatoes and eggplants. However, sweet pepper has compatibility with other solanaceous species and the cultivation of sweet pepper grafted plants was also meager and less widespread (Lucas *et al.,* 2018).

Brinjal

Brinjal is one of the important vegetable crops grown across India for its unique taste, nutritive value and texture. The consumer preference of brinjal varies with region to region, state to state and district to district based on size, shape, color and appearance. In India brinjal is cultivated in 6.7 lakh hectares and produced around 12.4 million tonnes with the productivity of 18.54 t/ha. (NHB,2018-19) West Bengal, Odisha, Gujarat, Madhya Pradesh and Bihar are the major brinjal producing states in India. In Tamil Nadu, brinjal is cultivated around 14.76 thousand hectares with a production of 196.11 thousand metric tonnes. (NHB,2018-19) However, brinjal is highly susceptible to root-knot nematodes and dry root rot causing a yield loss of up to 70%. These problems can be mitigated by implementing various management strategies *viz.,* development of resistant cultivars, cultural practices (Crop rotation), trap cropping, soil solarization *etc.* however, every strategy have some tailbacks. So for no varieties or hybrids available which are resistant to root-knot nematodes and soil-borne diseases. Chemical pest control is expensive, not always effective, and can harm the environment. Besides, the markets for organically grown produces increasing, where the use of chemicals is not allowed. Nowadays, the growers are looking for alternative non-chemical pest management practices. Vegetable grafting is gaining momentum in the recent past mainly to tackle biotic and abiotic stresses. These problems can be overcome by growing of grafted brinjal seedlings using a resistant rootstock. Ali *et al.* (1992) reported that immunity or high resistance for root-knot nematode was observed in *Solanum torvum, S. khasianum* and *S. toxicarium* even when grafted with susceptible brinjal plants. Garibaldi *et al.* (2005) noted that the use of eggplant grafted on nematode-resistant rootstock of *Solanum torvum* presented an exciting opportunity to control the root-knot nematode. Tzortzakakis *et al.* (2006) evaluated 39 eggplants (*Solanum melongena* L.) genotypes and one accession of *S. torvum* for resistance to the root-knot nematode. The results revealed that *S. torvum*, previously described as resistant to several root-knot nematode species (including *M. javanica, M. arenaria, and M. incognita*) was also confirmed as a source of resistance to this Brazilian population of *M. javanica.* Use of *S. torvum* as a rootstock for eggplant cultivar under the conditions of an unheated glasshouse in a soil infested with both *V. dahliae* and *M. incognita*, result in increased protection against pathogen infestations with less loss of quality and yield was reported by Curuk *et al*. (2009). Shery (2010) screened five wild species of *Solanum viz., S. torvum, S. viarum, S. xanthocarpum, S. incanum and S. elaegnifolium* against root-knot nematode through artificial inoculation *S. torvum* recorded the reaction category of 'resistant' based on lower root-knot index value. The different graft combinations with aforementioned rootstocks were also screened for nematode resistance indicated that the graft combination with *S. torvum* rootstock exhibited 'resistant' grade and COBH 2 on *S. torvum* recorded the least values for nematode characters. The biochemical studies on these wild *Solanum* species against root-knot nematode revealed that phenols, ortho-dihyroxy phenols, protein and ascorbic acid were highest in *S. torvum*. The species *S. torvum* showed superior performance for the host enzyme activity *viz*., peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, IAA oxidase and acid phosphatase at different hours after nematode inoculation. All the enzymes attained peak activity at 96 hours after nematode inoculation. Among the grafts, the plants with *S. torvum* as rootstock performed well and graft COBH 2 on *S. torvum* showed the highest values for all biochemical traits.

Tomato

Tomato (*Solanum lycopersicum* L.) is one of the most popular and widely used vegetable crops in the world. The significant biotic constraints in cultivation and production of tomato in India are the occurrence of pest and diseases causes considerable economic loss. Among the biotic factors, the incidence of root-knot nematode was observed to be the most devastating one which reduces the yield and quality of tomato drastically. Several wild Solanum species are resistant to soil-borne diseases like root-knot nematode, but attempt to incorporate this resistance through breeding is not been successful. One method to circumvent this problem is to graft the susceptible scion on to resistant rootstocks. Grafting on suitable rootstocks improves the resistance to root-knot nematode (*Meloidogyne* spp). Soil-borne diseases *viz., Fusarium* wilt, bacterial wilt, Verticillium wilt and root-knot nematode (Hamdi *et al*., 2009; Rivard *et al*., 2010; Polizzi *et al.,* 2015; Yin *et al*., 2015; Owusu *et al*., 2016). However, very scanty reports exist on the screening of wild Solanum species against root-knot nematode. Jaiteh *et al.* (2012) evaluated 33 tomato genotypes against RKN and observed variable responses in gall development and nematode reproduction rate. Owusu *et al*. (2016) screened 'Tropimech' and 'Power' tomato cultivars (susceptible to root-knot nematode) grafted onto three root-knot nematode-resistant rootstocks *viz*., 'Celebrity', 'Big Beef', and 'Jetsetter' both under pot culture and field condition and reported that nematode population levels were lower in 'Power' tomato cultivar grafted onto Celebrity, Jetsetter, and Big Beef rootstocks than non-grafted plants. Dhivya *et al.* (2016) screened eight wild Solanum rootstocks and two tomato hybrids against root-knot nematode through artificial inoculation and reported that three wild species *viz., S. sisymbrifolium, Physalis peruviana and S. torvum* showed a resistant reaction. The highest level of expression of phenolics and defense-related enzymes *viz.*, peroxidases, polyphenol oxidases, phenylalanine ammonia-lyase and acid phosphatase were also noticed in the aforementioned species and they suggested these rootstocks for grafting in tomato to impart root knot nematode resistance (Dhivya, 2014). Baidya *et al*. (2017) examined the tomato cultivars grafted onto *Solanum sisymbriifolium* rootstocks and non-grafted tomato cultivars for root-knot nematode resistance under pot culture condition and inferred that grafting with root-knot nematode rootstocks (*Solanum sisymbriifolium*) as an alternative technology to reduce the loss caused by the nematode incidence. Similarly, Benjamin *et al*. (2018) studied the response of four Solanum rootstocks *viz., S. aethiopicum* L., *S. macrocarpon* L., *S.lycopersicum* L."Mongal F_1," and *S. lycopersicum* L., "Samrudhi F_1") under pot culture and field infested with *Meloidogyne* spp. for two years. From this experiment, they find that *Solanum macrocarpon*, *S. aethiopicum*, and Mongal F_1 showed tolerant responses with reduced root galling and low to high reproductive factors both in pot and field experimentation. Although Samrudhi F_1 was resistant in both pot and field trials which recorded decreased nematode root galling (<1.00) and reproduction (Rf < 1.00). However, it failed to significantly increase the yield, as compared to tolerant rootstock which recorded the highest yield.

Cucurbitaceous vegetables

Due to the high market demand of cucurbitaceous vegetables, they are cultivated intensively in the same land both under open filed and poly house conditions. Successive cropping can increase salinity, the incidence of root-knot nematode, and soil-borne diseases like *Fusarium* wilt caused by *Fusarium* spp. These conditions cause various physiological and pathological disorders leading to severe crop loss. Chemical pest control is expensive, not always effective, and can harm the environment. Also, the markets for organically grown produces are increasing, where the use of chemicals is not allowed. Grafting a susceptible seedling onto a resistant or tolerant rootstock provides resistance or tolerance to commercial variety without the need for time-consuming and costly breeding programs. Cucurbitaceous vegetables like cucumber, watermelon, bitter gourd, muskmelon and other gourds are inter-graftable and this inter-graftability is being exploited. There are related graft-compatible wild and cultivated species are available within this family and these species could be used as rootstocks for biotic stress management.

Root-knot nematodes feed on the root systems of cucurbits and create abnormal, knotty growths on the roots, called galls. The galls, which can grow to be one inch or more, make it difficult for the plant to transmit water and nutrients from the roots to the above-ground plant parts. The galls produced in cucurbits are larger in size than that of solanaceous vegetables. As a result, cucurbit crops infested with nematodes are often stunted. They have yellow leaves and tend to wilt easily in warm weather, but the symptoms do not improve when the crop is irrigated. Infested plants produce fewer leaves, flowers, and fruits than healthy plants, and the fruits are of poor quality.

Bitter gourd

Bitter gourd (*Momordica charantia* L.) is one of the important cucurbitaceous vegetable grown in India. Among the cucurbits, it is considered a prized vegetable because of its high nutritive value, especially ascorbic acid and iron (Behera, 2004). The main problem with bitter gourd production in India is Fusarium wilt and root-knot nematode. (Tamilselvi, 2014). Among the root-knot nematode species *Meloidogyne incognita* is the most devastating one which causes significant loss and shows high pathogenic potential on bitter gourd (Singh *et al.* 2012, Gautam and Poddar, 2014). Bitter gourd grafting had been the vogue in China and Taiwan for the control of *Fusarium* wilt (Chung and Chin 1996), and also it increases the yield of bitter gourd (Chen *et al.,* 1998; Palada and Chang, 2003). Siguenza, et al. (2005) reported that *C. moschata* rootstock, having a high intensity of tolerance to root-knot nematode. Tamilselvi (2014) and Tamilselvi *et al.* (2015) screened about twelve cucurbitaceous rootstocks against *Meloidogyne incognita* under in vitro and reported that kumatikai (*Citrullus colocynthis*) followed by African horned cucumber (*Cucumis metuliferus*) and pumpkin (*Cucurbita moschata*) exhibited resistant reaction, while sponge gourd (*Luffa cylindrica*) and mithipakal (*Momordica charantia* var. *muricata*) showed moderately resistant reaction and these rootstocks were used for grafting with bitter gourd scions .These resistant reactions were again confirmed through estimation of biochemical compounds *viz.,* phenols, ortho-dihydroxy phenols and enzyme activities *viz*., peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, IAA oxidase and acid phosphatase at different hours after nematode inoculation. All the enzymes attained peak activity at 96 hours after nematode inoculation (Tamilselvi *et al.*, 2016).

Cucumber

Cucumber (*Cucumis sativus* L.) is one of the vegetable crops cultivated in plastic greenhouses because of the short growing cycle and its high economic value during off-season. Its cultivation in greenhouses is very often continuous and intensive, and soil-borne diseases, such as *Fusarium* wilt and root-knot nematode, limit the cucumber production adversely. In open field also, cucumber crop suffers from several infections by many serious fungal diseases and nematodes which results in severe losses of yield and quality. Siguenza *et al.* (2005) studied the responses of melon seedlings grafted onto *C. metuliferus* and *C. moschata* rootstocks and revealed that *C. metuliferus* found to be tolerant to root-knot nematode which had fewer root galls and recorded higher dry shoot mass under high nematode population densities than intact melon plants.

Screening study against root-knot nematode was conducted with seven cucurbitaceous rootstocks by Punithaveni *et al*. (2015) revealed that the lowest number of galls and egg masses were observed in *Citrullus colocynthis* followed by *Cucumis metuliferus* which exhibited resistant reaction with root-knot index (RKI) of 2. Whereas *Cucurbita ficifolia, Cucurbita moschata, C. maxima and Luffa cylindrica* were moderately resistant to root-knot nematode with root-knot index of 3. Among the moderately resistant species, *C. ficifolia* recorded the lower rate of nematode multiplication and suffered less damage than other species. Biochemical basis of resistance revealed that the higher amount of total phenols, OD phenols, peroxidase and polyphenol oxidase were observed in *C. colocynthis* and *C. metuliferus* which might be responsible to develop resistance against the infestation by *M. incognita* at different hours after artificial inoculation. The rootstocks, *C. maxima, C. ficifolia and C. moschata* recorded a considerable quantity of above biochemical compounds conferring moderately resistant reaction to root knot nematode (Punithaveni, 2015).

Thangamani *et al*. (2018) conducted a nematode screening study with cucurbitaceous species at the Department of Vegetable Crops, TNAU. The results revealed that *Cucurbita moschata, Cucumis metuliferus, Citrullus colocynthis* and *Cucumis callosus* were resistant having a RKI-2. *Cucurbita ficifolia, Cucurbita maxima, Cucumis melo sub sp. agrestis* were moderately resistant with a RKI-3. Total phenols content in roots indicates plant resistance to *M. incognita*. *Cucumis metuliferus* had the highest mean total phenols content followed by *Citrullus colocynthis* and *Cucurbita moschata* (15.37mg.g-1 of root). Resistant rootstocks possessed higher peroxidase and PPO activity than susceptible ones. *Cucumis metuliferus* had the highest value of peroxidase and PPO activity followed by *Citrullus colocynthis, Cucumis callosus* and *Cucurbita moschata,* Cucumber scions,'Green Long' and 'NS 408' had lower peroxidase and PPO activity. Resistant and moderately resistant cucurbitaceous species may be used for further studies possibly leading to improved yield.

ROOTSTOCKS EFFECT ON SOIL BORNE DISEASE RESISTANCE

Successive cultivation of vegetables is hampered by numerous serious fungal, bacterial, and viral diseases that cause severe yield loss. Control of these diseases relies primarily on crop rotation and the use of resistant cultivar. However, many soil-borne pathogens can survive in the soil for up to 10 or more years without a host, limiting the effectiveness of rotation. It has been reported that grafting with resistant rootstocks can improve resistance or tolerance to more than 10 different fungal, bacterial, and viral diseases. The available reports on resistant rootstock for soil-borne diseases are described hereunder pathogen wise. Ziad *et al*. (2009) stated that grafting seems to be the best solution to overcome these soil-borne pathogens.

(i) Dry root rot

Brinjal is widely cultivated in tropical and temperate regions around the world and it is prone to numerous diseases and parasites, particularly dry root rot (*Macrophomina phaseolina*), *Ralstonia solanacearum, Fusarium* and *Verticillum* wilt (Collonier *et al.,* 2001). Sherly (2010) stated that dry root rot or charcoal rot caused by *Macrophomia phaseolina* (Tassi) Goid is one of the major production constraints of brinjal in India as well as other brinjal producing countries. They reduce the yield and quality of the fruit drastically. Dry root rot is an anamorphic and soil-borne fungus is prevalent in arid, sub-tropical and tropical climates, especially in the areas with low rainfall and high temperature and it had wide host range includes legumes, cereals, vegetables, fruits and fibre crops (Smith and Carvil, 1997). Since it is a soil-borne fungus, management becomes a challenging task. Dry root rot of brinjal may incite a loss of 10 per cent in early harvested crop, which may go up to 70.5 per cent in the late-harvested crop exposed to hot weather conditions (Thirumalachar, 1953). Higher temperatures (30-35°C) and low moisture conditions favored the disease development caused by *M. phaseolina* (Chang and Tu, 1972). It has been reported that brinjal grafted onto wild Solanum species is an efficient technique to control various pathogens (King *et al.,* 2010). Sherly (2010) screened five wild *Solanum* species *viz., S. torvum*, *S. viarum*, *S. xanthocarpum*, *S. incanum* and *S. elaegnifolium* grafted with four brinjal accessions *viz*., HD 1, HD 2, HD 3 and COBH 2 against dry root rot pathogen both pot culture and field conditions and inferred that *S. torvum* as rootstock did not exhibit any symptom of root rot at 30, 45 and 60 days after planting (DAP). This resistance was confirmed with the estimation of biochemical compounds *viz.,* phenols, ortho-dihydroxy phenols and enzyme activities *viz*., peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, IAA oxidase and acid phosphatase at different days after pathogen inoculation under both pot and field conditions. This was the first report in India for the management of dry root rot incidence in brinjal in a sustainable manner.

(ii). Fusarium wilt

In India, brinjal, tomato, bitter gourd, and cucumber occupies broad acreage compare to other vegetables and their cultivation also more intense due to their nutritional benefits. However, successive cultivation of the aforementioned vegetables both under open field and protected structures (Tomato and cucumber) are hampered by soil-borne disease incidence especially *Fusarium* wilt caused by *Fusarium* spp. The disease is most common in China, South and southeast Asian countries. Conducive climate for disease occurrence are light, sandy, slightly to moderately acidic soils with poor drainage and high soil temperature (35-40°C) predispose plants to the infestation in the presence of inoculum. Lee and Oda (2003) and Pogonyi *et al*. (2005) stated that the primary purpose of vegetable grafting worldwide has to provide resistance to soil-borne diseases (corky root, *Fusarium* wilt, *Verticillum* wilt, Bacterial wilt) which cause damages in vegetable production especially in continuous cropping under greenhouses. The use of *Solanum torvum*as rootstock was reported to provide resistance to *Verticillium* wilt, *Fusarium* wilt, bacterial wilt and root-knot nematode (Sebahattin *et al.,* 2005) though generally grafting controls the common disease like *Fusarium* wilt in tomato plants (King *et al.,* 2008).

Grafting In bitter gourd is vogue in China and Taiwan for *Fusarium* wilt management (Chung and Chin, 1996), and also it increases the yield of bitter gourd (Palada and Chang, 2003). Similarly, Lin (2004) stated that Luffa (*Luffa* sp.), fig leaf gourd and pumpkin are common rootstocks and cleft grafting is an appropriate method for grafting in bitter gourd. He also inferred that Luffa sp. has been widely used for summer crops since it is resistant to *Fusarium* wilt. Moreover, 10 to 20% yield advantage is guaranteed by grafted bitter gourd plants over the non-grafted one. Grafting of cucumber onto *Cucurbita maxima*, *C. moschata* and *C. maxima* x *C. moschata root stocks* was found very effective to control *Fusarium* wilt. Among the three rootstocks, the hybrid, *Cucurbita maxima* x *C. moschata* gave the highest yield in Greece (Vakalounakis, 1999). Several countries of the Philippines who stopped bitter gourd cultivation has returned to bitter gourd farming and it is being commercialized due to increased yield of grafted bitter gourd plants which reflected in farmers' income (FFTC Report, 2012).

Tamilselvi (2014) and Tamilselvi *et al.* (2016) studied the response of wild and cultivated cucurbitaceous rootstocks and bitter gourd scions against *Fusarium* wilt revealed that *Citrullus colocynthis*, *Cucumis metuliferus* and *Cucurbita moschata* rootstocks exhibited no symptom and manifested as resistant to *Fusarium* wilt and the least percent incidence of 21.62, 37.44 and 48.90 was observed in *Luffa cylindrica* followed by *Momordica charantia* var. *muricata* rootstock (23.58, 42.18 and 50.34) at 30, 45 and 60 days after inoculation. Seedlings of aforementioned species were include also harvested at 0, 7, 14, 21, 28 and 35 days after challenge inoculation and assayed for defense related enzymes activity. Significant increases in the activities of peroxidase (PO), polyphenol oxidase (PPO) and phenylalanine ammonia lyase (PAL) activity was observed in resistant rootstocks *viz.*, *C. colocynthis*, *C. metuliferus* and *C.moschata* followed by moderately resistant rootstocks *viz.*, *M. charantia* var. *muricata* and *L. cylindrica.*

Punithaveni (2015) carried out a study to identify suitable rootstocks with resistance *Fusarium* wilt *(Fusarium oxysporum)* from the wild and cultivated cucurbitaceous rootstocks for grafting with cucumber scions. The inoculation of wild and cultivated cucurbitaceous rootstocks with *Fusarium* wilt pathogen (*Fusarium oxysporum*) on 30, 45 and 60 DAP showed that colocynth *(Citrulus colocynthis)* and African horned cucumber *(Cucumis metuliferus)* exhibited no symptoms and manifested as resistant to *Fusarium* wilt. Further, other rootstocks *viz*., winter squash (*Cucurbita maxima*) and fig leaf gourd (*Cucurbita ficifolia*) also showed moderately resistant reaction under pot culture condition.

The biochemical constituents cucurbitaceous rootstocks and cucumber scions after challenge inoculation of *Fusarium oxysporum* showed that higher content of phenol, ortho- dihydroxy phenols and enzymes *viz*., peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase were observed in colocynth *(Citrulus colocynthis)* and African horned cucumber *(Cucumis metuliferus)* followed by winter squash (*Cucurbita maxima*) and fig leaf gourd

(*Cucurbita ficifolia*) rootstocks at 21 days after inoculation (DAI) under pot culture condition.

GRAFT COMPATIBILITY

Though the rootstock are resistance to biotic or abiotic factors, the success of grafting depends on the compatibility between the rootstocks and scions which decides the undergrowth and/or overgrowth of the scion, water and nutrient flow through the grafted union, fruit yield and quality (Davis *et al.,*2008). Moreover, the survival rate of grafted plants depends on compatibility between scion and rootstock, quality and age of seedlings, quality of the joined section, and post-grafting management (Hassell et al. 2008). Graft compatibility was determined by assessing the survival rate of the grafted plants after the regeneration of vascular bundles across the graft interface and vegetative growth of the scion. The series of structural events involved in graft compatibility between the scion and rootstocks that begins with ruptured cells at the graft interface collapsing to form a necrotic layer that disappears subsequently and living cells from both rootstock and scion then extend into the necrotic zone. A callus bridge of connecting parenchyma cells formed and new vascular cambium is differentiated and secondary xylem and phloem are produced by the reconstituted cambium, providing a vascular connection between rootstock and scion.

Graft incompatibility usually occurs at the time of vascular connections between rootstock and scion. Sometimes incompatibility may appear as late as at the fruiting stage when there is a high demand for nutrients and water by the scion. Hence, the rootstock/scion combinations should be carefully selected to avoid loss due to graft incompatibility. Sherly (2010) observed of highest grafting success between *S. torvum* and brinjal accessions than other species and brinjal scions which indicates their compatibility. Observation on highest survival rate of grafted plants using *Solanum torvum* rootstock is in agreement with the observations of Petron and Hoover (2014). Similarly, Dhivya (2014) reported higher success per cent among tomato scions and *Solanum torvum* rootstock.

Reyes (1990) reported that bitter gourd grafted onto sponge gourd recorded higher plant survival rate (87 per cent) than bitter gourd grafted onto bottle gourd (21 per cent). Similarly, Chen *et al*. (1998) reported that Luffa rootstock showed good compatibility with bitter gourd scions where 81.5 per cent seedlings were survived under field condition and grafted plants grew vigorously during the later stages of growth and produced good quality fruits. Davis *et al.* (2009) reported that bottle gourd (*Lagenaria siceraria*), pumpkin (*Cucurbita moschata)*, inter-specific pumpkin hybrids (*C. maxima* x *C. moschata*) and fig leaf gourd (*C. ficifolia*) are the most commonly used rootstocks for bitter gourd grafting. Tamilselvi and Pugalendhi (2017) carried out an experiment to determine the graft compatibility of bitter gourd scions (Palee F_1 and CO 1) with ten different cucurbitaceous rootstocks and noticed pumpkin (*Cucurbita moschata*) and sponge gourd (*Luffa cylindrica*) rootstocks are compatible rootstocks for grafting with bitter gourd scions. Compatibility among these graft combinations was also confirmed through anatomical observations at 7, 15 and 21 days after grafting.

Cucumber has few compatibility problems and adapts well to grafting (Hoyos, 2001). Oda *et al*. (2000) and Yetisir and Sari (2004) reported that grafting of cucumber seedlings onto *Cucurbita* spp. rootstocks recorded a higher survival rate. An attempt had been made by Thangamani and Pugalendhi (2015) to determine the graft compatibility of cucumber scions with cucurbitaceous rootstocks revealed that the rootstocks *viz., Cucurbita ficifolia, Cucurbita moschata, Cucurbita maxima, Lagenaria siceraria* and *Luffa cylindrica* were grafted onto two cucumber scions *viz.,* Green Long (cultivar) and NS 408 (hybrid) in 'Hole Insertion Grafting' method. The scions Green Long and NS 408 had higher graft success percentage of 70.10; 70.23 per cent in *C. ficifolia* and 71.32; 72.97 per cent in *C. moschata*, 64.54; 65.91 per cent in *C.maxima*, 65.32; 67.94 per cent in *L. siceraria* and 63.04; 63.91 per cent in *L. cylindrica* respectively.

INFLUENCE OF GRAFTING ON YIELD

Grafting is a popular and valuable technique among farmers because it increases the fruit yield and enhanced overall plant vigor through efficient and increased water and nutrients uptake during the growing season (Aloni *et al.* 2010, Lee *et al.* 2010). However, rootstock/scion combinations affect final size, yield and quality of fruits from grafted plants, both immediately postharvest and during prolonged storage. Similarly, Xu *et al*. (2005); Qi *et al*. (2006) and Wu *et al*. (2006) reported that grafting can increase yield since grafted plants are resistant to soil-borne disease, have strong root systems and increased photosynthesis. Many workers in different parts of the world have reported the influence of grafting on yield improvement. Salam *et al.* (2002) demonstrated 3.5 times higher yield in watermelon due to larger fruit size, more fruit per plant, and improved plant survival rates.

Similarly, Seong *et al*. (2003) observed 27% more marketable fruit per plant in cucumber plants grafted onto pumpkin rootstocks than self-rooted cucumber plants. Rouphael *et al.* (2008) reported that cucumber grafted onto commercial cucurbita rootstocks under copper toxicity recorded higher yield (8.4 kg/vine) than non grafted plants. Sherly

(2010) observed the highest fruit yield per plant, when COBH 2 grafted onto *S. torvum* rootstock compared to non-grafted plants. In addition, these graft combinations have longer crop duration (10-15 months), amenable for ratooning too. Similarly, Dhivya (2014) observed increased fruit set percentage, number of fruits, yield per plant, number of harvests and crop duration the graft combination TNAU tomato hybrid CO-3 on *S. torvum* followed by TNAU tomato hybrid CO-3 on *S. incanum* during both the seasons. Chen *et al*. (1998) observed 38.4 per cent higher fruit yield in grafted bitter gourd plants than that of non grafted plants besides fruit quality and nematode resistance. Hua *et al.* (2011) observed increased yield of 63.2 per cent by grafted bitter gourd plants than the self-rooted plant. Concomitant to these findings Tamilselvi and Pugalendhi (2015 and 2017) noticed increased fruit number (28.02 fruits) and fruit yield per vine (3.55 kg/vine) were observed in Palee F_1 scion grafted onto 'pumpkin (*Cucurbita moschata*)' rootstock than other graft combinations and non-grafted plants.

Punithaveni (2015) evaluated different cucumber graft combinations and cucumber scions under shade net and insect proof net house condition at the Department of Vegetable Crops, HC&RI, TNAU. The results revealed that the yield characters *viz*., fruit number per vine (25.88 and 29.88), fruit weight (445.50 and 482.58 g), fruit length (29.56 and 30.49 cm) and diameter (52.10 and 52.40 mm), fruit yield per vine (11.22 and 13.84 kg), total number of harvests (12.75 and 15.10) and crop duration (130.67 and 142.57 days) were noted to be the highest in NS 408 hybrid scion grafted onto winter squash rootstock. It was also observed that final root length (95.49 and 113.90 cm) and root fresh weight (117.05 and 122.46 g) under shade net and insect proof net house condition respectively

CONCLUSION

Grafting technique is a rapid alternative means to the moderately slow breeding methodology. In recent days, grafting limits the use of harmful soil disinfectants which minimizes the toxic residues in vegetables and environmental pollution. Hence, Grafting in vegetable crops may be useful for low-input, sustainable horticulture of the future. Moreover, advances have been made to expand adoption of techniques such as grafting robots to produce a large number of grafted plants in a short period which reduces the price of grafted seedlings. However, the range of commercial rootstocks is limited; hence further research needs to focus on the development of rootstocks by using unexplored wild relatives to mitigate unpredictable biotic and abiotic stresses.

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