R-2602
[1-8]

REVIEW ARTICLE Agricultural Reviews

Inevitable Role of Grafting in Improvement of Cucurbitaceous Crops: A Review

P. Karthiga[1], S. Senthilkumar[1], S. Srivignesh[1], S. Manivannan[1]

10.18805/ag.R-2602

ABSTRACT

Cucurbit grafting has grown in favour among vegetable gardeners all over the world. The approach was originally developed to prevent soil-borne diseases, which remain still very important in today's intensive agriculture. Important diseases that can be controlled by utilizing cucurbit rootstocks include fusarium and verticillium wilt, bacterial wilt, phytophthora and root-knot nematode. Demand for vegetables has been tremendously increasing around the world and due to the scarcity of arable land, persistent cultivation of vegetables being done under unfavourable soil and environmental stress conditions, especially in protected cultivation. Hence to lessen the production losses brought on by such abiotic and biotic stresses in cucurbits be to graft them onto rootstocks. Cucurbit grafting has also resulted in the production of organic and environmentally safer produce by reducing the intake of unfavourable pesticide residues. However, due to recent developments, this strategy now multifarious and used for a multitude of things. Increased usage of grafted seedlings will surely be encouraged by the development of versatile rootstocks, effective grafting tools and methods in numerous nations. The current review work highlights numerous studies on cucurbitaceous crop grafting carried out globally on issues including abiotic and biotic stresses, growth, yield and quality of cucurbitaceous crops.

Key words: Abiotic stress, Biotic stress, Cucurbits, Rootstocks.

The vegetables play a crucial role in ensuring food and nutritional security for the expanding global population. However, the production of vegetables hindered by various factors, including both biotic factors such as pest and disease incidence, as well as abiotic factors like environmental and soil stresses (Tirupathamma *et al*., 2019). Hence, farmers regularly forced to depend on agrochemicals to combat the damage caused by pests and diseases. The chemical pest management can be detrimental to the environment as well as costly and not always effective (Colla *et al*., 2010). The successful mitigation of these limitations has been achieved through the advancement of novel cultivars or hybrids and the establishment of standardized crop management protocols. Grafting, a time-honored technique, has been extensively utilized in the cultivation of various fruits for the purpose of disease and pest control. This practice involves the use of carefully chosen resistant rootstocks (Mudge *et al*., 2009). Grafting, a horticultural technique employed in the cultivation of fruit crops, has been a longstanding practice spanning several millennia. In recent years, there has been a growing interest in vegetable grafting among vegetable growers worldwide (Ashok Kumar and Sanket, 2017). By employing resistant rootstock, grafting now proven to be a quick, effective and alternative method for sustainable vegetable production by reducing the need for agrochemicals that combat abiotic stresses and ameliorate soil-borne issues. To fight the Fusarium wilt problem in the late 1920s in Japan, the first attempt at vegetable grafting was made in watermelon (*Citrullus lanatus*) with pumpkin (*Cucurbita moschata*) rootstock (Leonardi, 2017). Grafting has now become a common practice in vegetable crops all over the world. Currently, grafting procedures used to cultivate majority of cucurbits in greenhouse environments in Japan and Korea (Kumar *et al*., 2018). Even though there were many advantages in utilizing grafted plants, not all vegetables can be grafted since the success percentage of grafted plants depends on the genetic makeup, growth characters, anatomy and biochemical and physiological aspects of the species. The Cucurbits and solanaceous crops remain as the most commonly grafted vegetable crops around the world (Lee, 1994; Schwarz *et al*., 2010). The inter-graftability of cucurbitaceous vegetables including cucumber, watermelon, bitter gourd, muskmelon and other gourds has been used and there were other related graft-compatible wild and cultivated species that could be employed as rootstocks to alleviate biotic and abiotic stresses (Huang *et al*., 2014). Notable grafting methods include hole insertion grafting, tongue approach grafting, splice grafting and cleft grafting (Mohamed *et al*., 2014). Intra-and interspecific grafting, a widely observed

[1]Department of Horticulture, School of Life Sciences, Central University of Tamil Nadu, Thiruvarur-610 005, Tamil Nadu, India.

Corresponding Author: S. Senthilkumar, Department of Horticulture, School of Life Sciences, Central University of Tamil Nadu, Thiruvarur-610 005, Tamil Nadu, India.
Email: senthilkumar@cutn.ac.in

How to cite this article: Karthiga, P., Senthilkumar, S., Srivignesh, S. and Manivannan, S. (2023). Inevitable Role of Grafting in Improvement of Cucurbitaceous Crops: A Review. Agricultural Reviews. DOI: 10.18805/ag.R-2602

Submitted: 15-10-2022 **Accepted:** 09-11-2023 **Online:** 08-12-2023

phenomenon, stands prevalent among plant belonging to the Cucurbitaceae family. The potential for implementing high-throughput techniques through automation, either with operator assistance or complete robotic control, has been explored as a means to decrease the cost associated with grafted seedlings (Comba *et al*., 2016). This review delivers the information on role of grafting in improving cucurbitaceous crops.

Current status of vegetable grafting

Due to the greater preference and production of cucurbits and other grafted vegetables in East Asia, this region remain as a largest market for vegetable grafting. Watermelon grown through grafted transplants in Korea, Japan and China to varying degrees (99, 94 and 40% respectively). In case of solanaceous vegetables, about 60 and 65 per cent of tomatoes, eggplants and 10-14 per cent of peppers cultivated through grafted transplants. Grafted tomato transplants used in Netherlands for all soilless tomato production. Popularity of vegetable grafting raising rapidly everywhere especially in Eastern Europe, North and South America, India and Philippines. More than 1500 industrial nurseries in China produce grafted transplants. Vegetable transplants that have been grafted found increasingly traded internationally (Bie *et al*., 2017). Around the world, cucurbitaceous crops predominate in vegetable grafting. However, this technology remain infancy in India.

Potential rootstocks for different cucurbitaceous crops

The most frequently grafted cucurbitaceous crops includes watermelon, melon and cucumber. *Cucurbita* species, *Citrullus* species and bottle gourd can all be utilized as rootstocks for watermelon. The three most prevalent rootstocks for watermelons are bottle gourd, interspecific hybrids between *Cucurbita moschata*, *Cucurbita maxima* and wild watermelon (*C. lanatus* var. *citroides*) (Davis *et al*., 2008). Although there can be variation within a species, watermelon generally very compatible with all of these rootstocks. Melons can be grafted onto rootstocks from *Cucurbita* species, bottle gourds and *C. melo*. There are other examples of grafting melon onto wax gourds [*Benincasa hispida* (thumb.) Cogn.] and luffas [*Luffa cylindrical* (L.)] M. Roem. Each rootstock contains both advantageous and unfavourable traits (Edelstein *et al*., 2004). The most widely used Cucurbita spp. rootstock as an interspecific hybrid of *Cucurbita maxima* and *C. moschata*, which offers non-specific but effective defense against a variety of soil-borne pathogens as well as against several abiotic stresses. *Cucumis* spp., Cucurbita interspecific hybrids, *Cucurbita* spp., wax gourd, bottle gourd, fig leaf gourd (*C. ficifolia* Bouché) and luffa can all be effectively grafted with cucumber (Sakata *et al*., 2008). Fig leaf gourd has historically been the most popular rootstock for cucumbers because it has a strong affinity for the plant, greater cold tolerance and resistance to Fusarium wilt. The Cucurbita interspecific hybrids remain well-liked for cucumbers grown in the summer because they offer enduring Fusarium resistance and improved heat tolerance. In addition, Cucurbita interspecific hybrids also proven some cold tolerance (King *et al*., 2010).

Influence of cucurbit rootstocks to soil-borne biotic stresses

Grafting against verticillium wilt

In tomato and brinjal, grafting has been used frequently to tackle verticillium wilt, while cucurbits hardly employ it for this purpose. The main pathogen to be concerned about among all of these pathogen races is *V. dahliae*. All 33 of the examined cucurbit rootstocks exhibited some signs of *V. dahlia* colonisation. *Lagenaria siceraria* and *Cucurbita pepo* were among those that were discovered to be the most tolerant. It was discovered that watermelon and melon were both highly vulnerable (Paplomatas *et al*., 2000). Increased root vigour, biomass and concomitant increase in water and nutrient uptake are some of the mechanisms used by grafting to battle Verticillium in the contaminated soils (Bletsos *et al*., 2008). The impact of decreased infestation, according to Klosterman's findings, may be caused by the poor penetration of the inoculum and colonization into vascular tissue and even though the colonization does occur, it is a long process (Klosterman *et al*., 2009). A lesser amount of wilt may also be due to a pathogen's reduced colonization in the vascular tissue (Paplomatas *et al*., 2000). Another crucial aspect of root exudates is their ability to inhibit Verticillium growth in the rhizosphere of both susceptible and resistant rootstocks (Liu *et al*., 2009). "Crimson Sweet" watermelon grafted onto "Emphasis" and "Strongtoza" rootstocks grew more quickly and were more resistant to *V. dahliae* when compared to non-grafted plants (Buller *et al*., 2013). Devi *et al*. (2020) found that Verticillium wilt severity differed between grafted watermelon plants and non-grafted 'Secretariat' watermelon plants. Grafted watermelon plants had 3.5 times less disease than non-grafted ones. The research also found that Pelops (*L. siceraria*), Round (*B. hispida*), Super Shintoza and Tetsukabuto (*C. maxima* × *C. moschata* hybrids) all mitigated Verticillium wilt equally.

Grafting against fusarium wilt

Fusarium species can survive for years in soils by symptomless colonizing on multiple alternate hosts, hiding in soil particles, or *via* long-lasting survival mechanisms like chlamydospores. Therefore, it revealed that crop rotation remain ineffective in controlling Fusarium pathogens. Fusarium species can easily be reintroduced into cultivation regions on contaminated equipment, soil and plant tissue. They have a prodigious capacity to colonize polluted soils. However, grafting has been more effective in cucurbits than in solanaceous crops for treating Fusarium wilt. Interspecific or intergeneric grafting with non-host resistance, or exploiting host pathogen incompatibility, has proven to be a successful management strategy, especially in cucurbit crops. As a result, interspecific hybrids are frequently used in the instance of watermelon. In Japan, bottle gourd considered as the significant rootstock against this watermelon pathogen (Sugiyama *et al*., 2006). Because it found effective to all races of Fusarium and contributes towards stability of yield, the rootstock "Shintoza" recommended in Spain.

When rootstocks with improved yield and environmental stress tolerance were coupled with rootstocks resistant to *F. oxysporum* f. sp. *cucumerinum*, cucumber grafting became popular in Japan. Since the fig leaf gourd (*Cucurbita ficifolia*) exhibits good to outstanding resistance to fusarium wilt and has a tolerance to low temperature stress, it is frequently used as a rootstock for cucumbers during the winter production season. For cucumber production in the summer, ISHc 'Shintoza,' a rootstock with fusarium wilt resistance and heat tolerance, is favoured (Sugiyama *et al*., 2006).

Squash, interspecific hybrids and watermelons have all been widely employed for their robust root systems, resilience to severe temperatures and Fusarium resistance. When grown in Fusarium-infested soils, the rootstocks "Shintoza" and "Super Shintoza," a hybrid of *C. maxima* and *C. moschata*, gave watermelon tolerance. The rootstocks also boosted fruit size and yield in comparison to plants that weren't grafted. The "Super Shintoza" rootstocks among these also offer resistance to Verticillium wilt, lowering the occurrence of microsclerotia, maintaining the structure of *Verticillium* spp. and maintaining fruit output (Gaion *et al*., 2018). The watermelon scions grafted onto *C. maxima* × *C. moschata* 'Super Shintoza' and *C. lanatus* 'Robusta' demonstrated resistance to *Fusarium oxysporum* f. sp. *niveum* (Alvarez *et al*., 2015). Grafting bitter gourd onto cucurbitaceous rootstocks *viz*., *C. colocynthis*, *C. metuliferus* and *C. moschata* with high or moderate levels of these biochemical constituents suffered less for Fusarium wilt pathogen and these rootstocks served as the best rootstocks followed by *M. charantia* var. *muricata* and *L. cylindrica*.

Grafting against root-knot nematode

Commercial cucurbits have no known RKN resistance, therefore finding resistant rootstock has been a top focus (Cohen *et al*., 2007). Cucurbit root systems are consumed by root-knot nematodes, which produce galls, which are unnatural, knotty growths on the roots. It is challenging for the plant to get water and nutrients from the roots to the above-ground plant sections due to the galls, which can reach a height of one inch or more. Cucurbits grow galls that are bigger than those found in solanaceous plants. Nematode infestations cause cucurbit crops to often be stunted as a result. They have yellow leaves and are susceptible to wilting in warm weather, but the symptoms are not alleviated by irrigation. Compared to healthy plants, infected plants produce fewer leaves, flowers and fruits and the fruits are of lesser quality.

The incidence of *Meloidogyne incognita* race 3-induced galling was reduced in cantaloupes (*Cucumis melo* L.) grafted on rootstocks *C. moschata* and *C. metuliferus*, with the latter rootstock being regarded as moderately resistant (Pradhan *et al*., 2017). Strongtosa and Shintosa produced greater yields ranging from 260 to 280% than that of non-grafted plants. Grafting studies in cucumber were done to investigate the influence of several cucurbit rootstocks under the impact of root-knot nematode on growth and yield of cucumber (Al-Debei *et al*., 2011).

In order to find resistant rootstocks of cucurbitaceous species for grafting cucumbers against root-knot nematode, Punithaveni *et al*. (2015) did a study where, *Citrullus colocynthis* and *Cucumis metuliferus* were found to have resistant reactions with a root knot index (RKI) of 2. They were backed by a related screening study of cucurbitaceous species against root-knot nematode conducted by Thangamani *et al*. (2018) to assess their suitability as rootstocks in grafting. *Cucurbita moschata*, *Cucumis metuliferus*, *Citrullus colocynthis* and *Cucumis callosus* were found to be resistant having an RKI-2. Although root-knot nematode tolerance can be increased through grafting, it has been shown that several common rootstocks (including interspecific Cucurbita hybrids and Lagenaria gourds) are entirely vulnerable but are tolerant due to their large root systems (Giannakou and Karpouzas, 2003). Since these rootstocks may permit a buildup of nematodes that could potentially infect following crops, such tolerance should be handled with caution. Evidence suggests that some rootstocks have hereditary nematode resistance, which can be used to increase resistance (Davis *et al*., 2008).

Influence of cucurbit rootstocks to abiotic stresses

Cold/heat stress

Losses in production of vegetable can occur as result of temperature extremes as they retard the appearance of flowers and affects the timing of fruit ripening. Due to the related physiological changes in the grafted plant, grafting can be utilized to shield plants from temperature shock and improve their yield (Rivero *et al*., 2003). Grafting superior commercial cultivars onto chosen low-temperature tolerant rootstocks is seen to be a potential strategy for reducing the heat demand of vegetables as a quick and effective substitute for the often labourious breeding procedure (Schwarz *et al*., 2010). To speed up the planting date during cool weather, watermelon is grafted onto rootstocks of the Shintosa type (an interspecific squash hybrid, *Cucurbita maxima* × *C. moschata*). Fig leaf gourd (*Cucurbita ficifolia*) and bur cucumber (*Sicos angulatus* L.) are frequently utilised as rootstocks for cucumber in order to increase cold resistance. In comparison to a self-grafted cucumber, a cucumber scion grafted onto a squash rootstock (*Cucurbita moschata*) might endure unfavourable conditions. Luffa [*Luffa cylindrica* (L.)] rootstock-grafted cucumbers were able to tolerate heat stress (36/31°C) (Gaion *et al*., 2018). Inhibition of growth caused by cold stress was greatly ameliorated in gourds (*Lagenaria siceraria*) grafted onto watermelons, as manifested by physiological indices, such as much better growth parameters; much higher chlorophyll and proline contents; lower levels of ROS and lipid peroxidation; higher antioxidant enzyme activities, especially CAT and GPX; and higher expression levels of enzymes related to the Calvin cycle (Lu *et al*., 2021).

Drought stress

Drought, an abiotic stressor, holds significant implications for crop productivity and quality on a global scale. Grafting high-yielding genotypes onto rootstocks that may lessen the effects of water stress on the shoot, as seen in tree crops, might be one method to reduce output losses and enhance water use efficiency under drought (Satisha *et al*., 2007). Under moisture stress, mini-watermelons grafted onto a commercial rootstock (PS 1313: *Cucurbita maxima* × *Cucurbita moschata*) produced a 60 per cent higher marketable yield than ungrafted melons (Gaion *et al*., 2018). In cucumber, five drought stress tolerant genotypes (*i.e*., rootstock) and drought-sensitive genotype Luerans (*i.e*., a scion) were evaluated under water deficient conditions, which resulted in increased commercial productivity of cucumber and also increased the expression of defense related genes and increasing accumulation of GA_3 and activity of antioxidant enzymes (CAT and POD), chlorophyll content, Chlorophyll fluorescence, efficiency of photosystem II (PSII) and decreased the electrolyte leakage, ABA and MDA (Shehata *et al*., 2022).

Salt stress

Soil salinity affects up to 20% of irrigated agricultural land and about 7% of the world's land area (Shahid *et al*., 2018). Salinity has a deleterious impact on plant development and growth. Several approaches have been put up to mitigate the effects of salinity. A simple and effective method for increasing crop tolerance to salt stress is the adoption of resistant genotypes as the rootstocks. The ability of watermelon plants to tolerate salt increased dramatically when bottle gourd was used as a rootstock (Yang *et al*., 2013). The interspecific squash rootstock (*Cucurbita maxima* × *Cucurbita moschata* Duch.) increased salt tolerance, plant biomass and leaf area in the grafted muskmelon compared to non-grafted control plants, according to research by Orsini *et al*. (2013) in case of the muskmelon.

Other studies showed that in salty conditions, grafted plants of the 'Crimson Tide' watermelon on squash (*Cucurbita maxima*) and two bottle gourds (*Lagenaria siceraria* (Molina) Standl.) rootstocks grew more than ungrafted plants (Yetisir *et al*., 2010). When cultivated in salty conditions, melons that were grafted onto squash (*Cucurbita maxima* Duch. × *C. moschata* Duch.) produced more fruit. Increased cucumber salinity tolerance may result from grafting cucumber onto pumpkin (*C. moschata*). Studies have made significant advances in the use of grafting to boost cucumber salt tolerance (Xu *et al*., 2017). Lower Na concentration in the scion was obtained by grafting cucumber cv. Jinchun No. 2 onto "Chaojiquanwang" rootstock (*C. moschata*). Tolerance to salt in cucumber is increased by this rootstock's greater capacity for exclusion and retention of Na in roots, which lowers Na transport to the scion (Huang *et al*., 2014). The same is true for pumpkin rootstocks, which can increase resistance to both cold and salt stressors (Xu *et al*., 2017). Additionally, growers employ *C. moschata* rootstocks because they make it possible to produce cucumber fruits that are wax-free (bloomless). Customers favour this fruit because of its attractiveness and prolonged shelf life (King *et al*., 2010). Grafting done by using highly salt tolerant rootstocks of Luffa on cucumber increased the tolerance of cucumber to salinity and significantly improved quality and yield by reducing sodium transport to the shoot (Guo *et al*., 2023).

Flooding stress

Because they are extremely sensitive to flooding, many vegetable crops are negatively impacted by excessive moisture caused by unpredictably heavy rainfall and some of the vegetables are intolerant to flooded soil conditions throughout their growth and development (Singh *et al*., 2020). By modifying photosynthesis and the water potential, high soil moisture reduces the amount of oxygen in the roots of plants. Grafting has been shown to increase flooding tolerance in a variety of vegetable crops by numerous research groups (Bhatt *et al*., 2015). Chlorosis signs were seen in watermelon grafted onto the landrace *Lagenaria siceraria*, albeit they were less severe in grafted plants in flood circumstances (Singh *et al*., 2020). Hazardous pollutants, heavy metals and nutritional stress are examples of additional pressures (deficient nutrient availability, excessive nutrient availability). When cultivated in heavy metal-contaminated soils, watermelon cv. Arava grafted onto cucurbita rootstock displayed reduced levels of B, Zn, Sr, Mn, Cu, Ti, Cr, Ni and Cd. Interspecific hybrids (*C. maxima* × *C. moschata*) have been shown to increase resistance to cadmium, nickel and nitrate (Gao *et al*., 2015; Savvas *et al*., 2013). Additionally, Allevato *et al*. (2019) showed in a hydroponic experiment that the melon cultivar Proteo may be grafted onto two intraspecific (Dinero and Magnus) and three interspecific (RS841, Shintoza and Strongtosa) hybrids to lessen the negative effects of a heavy metal like arsenic. The interspecific hybrid RS841 was the most effective rootstock for maintaining crop productivity in the presence of heavy metals and was also able to lessen the amount of arsenic that transferred to the fruits.

Influence of cucurbit rootstocks on qualitative and quantitative characters

Grafting is a popular and valuable method among farmers since it raises the fruit output and improves overall plant vigour through effective and increased water and nutrient uptake during the growth season (Lee *et al*., 2010). Yield, quality and size of the fruits from grafted plants are indeed influenced by rootstock/scion combinations, both immediately following postharvest and throughout extended storage. Similar to this, Xu *et al*. (2006) and Wu *et al*. (2006)

stated that grafting technology can boost yield because grafted plants have strong root systems, higher photosynthesis and resistance to soil-borne disease. Many workers across the globe have noticed the impact of grafting on increased production. Cucumber cv Kalaam grafted onto *Lagenaria siceraria* rootstocks showed highly compatibility and also significant increase in vegetative growth, maximum fruit yield and quality of cucumber fruits than the other cucurbitaceous rootstocks like ridge gourd, bitter gourd and pumpkin (Noor *et al*., 2019). Similarly, grafted cucumber plants on pumpkin rootstocks had 27% more marketable fruit per plant than non-grafted cucumber plants, according to Seong *et al*. (2003). Cucumber grafted onto commercial cucurbita rootstocks under copper toxicity produced a higher yield (8.4 kg/vine) than non-grafted plants, according to Rouphael *et al*. (2008). Pugalendhi *et al*. (2019) found that grafted bitter gourd plants produced a yield that was higher than the self-rooted plant by 63.2%. Parallel to these findings, Tamilselvi and Pugalendhi (2017) and Tamilselvi *et al*. (2015) found that Palee F1 scion grafted onto “pumpkin (*Cucurbita moschata*)” rootstock produced more fruit (28.02 fruits) and more fruit per vine (3.55 kg/vine) than other graft combinations or non-grafted plants. The ‘RS841’ and ‘Shintoza Camelforce’ watermelon grafted on Lagenaria and *C. maxima* rootstocks, respectively, had fruits that were 24% and 27% firmer than ungrafted plants. (Yetisir *et al*., 2003) According to studies by Yetisir *et al*. (2003) and Proietti *et al*. (2008), fruits from grafted watermelon vines had a rind thickness that is 21 per cent and 17 per cent higher respectively. Even though this physical property improvement led to comparatively more waste during consumption, it also ensured better postharvest handling safety and injury prevention.

Challenges ahead

The labour and skills needed for the grafting process as well as the post-graft care of grafted seedlings for speedy healing for 7 to 10 days are the main issues with grafting.

The rural farmers may not have or understood correctly the proper knowledge of rootstock-scion compatibility, which is necessary.

Synchronization and good scion and rootstock germination rates, as well as higher success rate of grafts and stand establishment following transplant, are necessary for the successful production of grafted plants, however these conditions may not always be met (Sen *et al*., 2018).

For the grafts to successfully establish themselves, it is crucial to maintain ideal conditions for temperature, humidity and light intensity during the post-grafting stage, which is particularly challenging in open field conditions. For grafts to heal, a regulated environment is necessary.

Grafting can increase the danger of disease dissemination, particularly for infections in the nursery that are disseminated by seed. Heat stress and discomfort are issues that grafting workers in a greenhouse and growth chamber must deal with (Maurya *et al*., 2019).

A significant problem in large-scale manufacturing is ensuring a consistent and timely supply of promising rootstocks. Large-scale adoption is discouraged by the requirement to prepare or buy the seedlings every season. Expensive rootstock seeds, grafting tools, *etc.*, also contribute to a significant problem.

FUTURE PROSPECTS

The development of suitable rootstocks currently relies on trial and error and future rootstock breeding will not previously have used particular physiological factors to choose plants for breeding. Specific stress-tolerant rootstocks exhibit favourable responses through a variety of physiological and molecular processes, some of which are still poorly understood. In order to create a framework for the early detection of incompatible grafts for use in commerce, it is necessary to understand the functional physiology of grafting plants. For this technology to be used more effectively, more research is needed to understand many genetic and physiological components. Future studies should concentrate on identifying the crucial physiological processes that are derived from the roots and are highly linked with the desired rootstock properties. It is resistant to diseases like Phytophthora blight, Mosaic virus and Bacterial wilt. Working together, researchers, extension personnel and seed firms may effectively use this new technology to grow vegetables of the finest quality. For use on a commercial scale, grafting techniques must be refined and the healing environment should be standardized. Rootstock development, creation of acclimatization facilities and improvement of grafting robots must all be the subjects of future study. The cost of producing grafted seedlings in the future should be significantly lower.

CONCLUSION

Vegetable grafting, which has a variety of uses around the world, has the potential to help India’s vegetable industry overcome its challenges and increase farmer income by increasing crop production and decreasing the need to buy a lot of fertilizer, pest and disease control chemicals. For soil-borne diseases, grafting provides a quick alternative control technique. Although grafting can have an impact on a number of vegetable crop quality factors, it nevertheless works effectively in an organic and integrated crop production system. When used in association with growing knowledge of the biology, diversity and population dynamics of the pathogen, grafting will be beneficial. Vegetable seedlings are being produced on a large scale for commercial purposes at a rapid rate in a number of developed nations; as a result, grafted seedlings are now more widely available and used commercially. Additionally, developments in automated and robotic grafting might be advantageous for an environmentally friendly strategy.

Conflict of interest: None.

REFERENCES

Al-Debei, H.S., Makhadmeh, I., Abu-Al Ruz, I., Al-Abdallat, A.M., Ayad, J.Y. and Al Amin, N. (2011). Influence of different rootstocks on growth and yield of cucumber (*Cucumis sativus* L.) under the impact of soil-borne pathogens in Jordan. Journal of Food, Agriculture and Environment. 10(2): 343-349.

Allevato, E., Mauro, R.P., Stazi, S.R., Marabottini, R., Leonardi, C., Ierna, A. and Giuffrida, F. (2019). Arsenic accumulation in grafted melon plants: Role of rootstock in modulating root-to-shoot translocation and physiological response. Agronomy. 9(12): 828. https://doi.org/10.3390/agronomy 9120828.

Alvarez, H., Juan, C., Javier, Z., Cesar, A., Huitrón, R., María, F., Francisco, C. (2015). Influence of rootstocks on fusarium wilt, nematode infestation, yield and fruit quality in watermelon production. Ciência e Agrotecnologia. 39: 323-330.

Ashok Kumar, B. and Sanket, K. (2017). Grafting of vegetable crops as a tool to improve yield and tolerance against diseases-A review. International Journal of Agriculture Sciences. ISSN, 0975-3710.

Bhatt, R.M., Upreti, K.K., Divya, M.H., Bhat, S., Pavithra, C.B. and Sadashiva, A.T. (2015). Interspecific grafting to enhance physiological resilience to flooding stress in tomato (*Solanum lycopersicum* L.). Scientia Horticulturae. 182: 8-17.

Bie, Z.H.I.L.O.N.G., Nawaz, M.A., Huang, Y., Lee, J.M. and Colla, G.I.U.S.E.PP.E. (2017). Introduction of vegetable grafting. Vegetable Grafting, Principles and Practices. 1-21.

Bletsos, F.A. and Olympios, C.M. (2008). Rootstocks and grafting of tomatoes, peppers and eggplants for soil-borne disease resistance, improved yield and quality. The European Journal of Plant Science and Biotechnology. 2(1): 62-73.

Buller, S., Inglis, D. and Miles, C. (2013). Plant growth, fruit yield and quality and tolerance to verticillium wilt of grafted watermelon and tomato in field production in the Pacific Northwest. Hort Science. 48(8): 1003-1009.

Colla, G., Rouphael, Y., Leonardi, C. and Bie, Z. (2010). Role of grafting in vegetable crops grown under saline conditions. Scientia Horticulturae. 127(2): 147-155.

Comba, L., Gay, P. and Aimonino, D. R. (2016). Robot ensembles for grafting herbaceous crops. Biosystems Engineering. 146: 227-239.

Cohen, R., Burger, Y., Horev, C. and Koren, A. (2007). Introducing grafted cucurbits to modern agriculture: The Israeli experience. Plant Disease. 91(8): 916-923.

Davis, A.R., Perkins-Veazie, P., Hassell, R., Levi, A., King, S.R. and Zhang, X. (2008). Grafting effects on vegetable quality. Hort Science. 43(6): 1670-1672.

Devi, P., Perkins-Veazie, P. and Miles, C.A. (2020). Rootstock and plastic mulch effect on watermelon flowering and fruit maturity in a verticillium dahliae-infested field. Hort Science. 55(9): 1438-1445.

Edelstein, M., Burger, Y., Horev, C., Porat, A., Meir, A. and Cohen, R. (2004). Assessing the effect of genetic and anatomic variation of Cucurbita rootstocks on vigour, survival and yield of grafted melons. The Journal of Horticultural Science and Biotechnology. 79(3): 370-374.

Gao, Y., Tian, Y., Liang, X. and Gao, L. (2015). Effects of single-root-grafting, double-root-grafting and compost application on microbial properties of rhizosphere soils in Chinese protected cucumber (*Cucumis sativus* L.) production systems. Scientia Horticulturae. 186: 190-200.

Giannakou, I.O., Karpouzas, D.G. (2003). Alternatives to methyl bromide for root-knot nematode control. Pest Management Science. 59: 883-892.

Guo, Z., Qin, Y., Lv, J., Wang, X., Dong, H., Dong, X. and Piao, F. (2023). Luffa rootstock enhances salt tolerance and improves yield and quality of grafted cucumber plants by reducing sodium transport to the shoot. Environmental Pollution. 316: 120521. doi: 10.1016/j.envpol.2022.120521.

Gaion, L.A., Braz, L.T. and Carvalho, R.F. (2018). Grafting in vegetable crops: A great technique for agriculture. International Journal of Vegetable Science. 24(1): 85-102.

Huang, Y., Kong, Q.S., Chen, F. and Bie, Z.L. (2014). The History, Current Status and Future Prospects of Vegetable Grafting in China. In: I International Symposium on Vegetable Grafting. Acta Horticulturae. 1086(1086): 31-39. DOI: 10.17660/ActaHortic.2015.1086.2.

King, S.R., Davis, A.R., Zhang, X. and Crosby, K. (2010). Genetics, breeding and selection of rootstocks for Solanaceae and Cucurbitaceae. Scientia Horticulturae. 127(2): 106-111.

Klosterman, S.J., Atallah, Z.K., Vallad, G.E. and Subbarao, K.V. (2009). Diversity, pathogenicity and management of Verticillium species. Annual Review of Phytopathology. 47: 39-62.

Kumar, S., Bharti, N. and Saravaiya, S.N. (2018). Vegetable Grafting: A Surgical Approach to combat biotic and abiotic stresses-A review. Agricultural Reviews. 39(1): 1-11.

Lee, J. M. (1994). Cultivation of grafted vegetables I. Current status, grafting methods and benefits. Hort Science. 29(4): 235-239.

Lee, J.M., Kubota, C., Tsao, S.J., Bie, Z., Echevarria, P.H., Morra, L. and Oda, M. (2010). Current status of vegetable grafting: Diffusion, grafting techniques, automation. Scientia Horticulturae. 127(2): 93-105.

Leonardi, C.H.E.R.U.B.I.N.O., Kyriacou, M., Gisbert, C.A.R.MI. N.A., Oztekin, G.B., Mourão, I.S. A.B.E.L. and Rouphael, Y.O.U.S.S.E.F. (2017). Quality of Grafted Vegetables. Vegetable Grafting: Principles and Practices. [(Eds.) Colla, G., Pérez-Alfocea, F. and Schwarz, D.] CAB International, Oxfordshire, UK, 216-244.

Liu, N., Zhou, B., Zhao, X., Lu, B., Li, Y. and Hao, J. (2009). Grafting eggplant onto tomato rootstock to suppress *Verticillium dahliae* infection: The effect of root exudates. Hort Science. 44(7): 2058-2062.

Lu, K., Sun, J., Li, Q., Li, X. and Jin, S. (2021). Effect of cold stress on growth, physiological characteristics and calvin-cycle-related gene expression of grafted watermelon seedlings of different gourd rootstocks. Horticulturae. 7(10): 391. https://doi.org/10.3390/horticulturae7100391.

Maurya, D., Pandey, A.K., Kumar, V., Dubey, S. and Prakash, V. (2019). Grafting techniques in vegetable crops: A review. International Journal of Chemical Studies. 7(2): 1664-1672.

Mohamed, F.H., Abd El-Hamed, K.E., Elwan, M.W.M. and Hussien, M.N.E. (2014). Evaluation of different grafting methods and rootstocks in watermelon grown in Egypt. Scientia Horticulturae. 168: 145-150.

Mudge, K., Janick, J., Scofield, S. and Goldschmidt, E.E. (2009). A history of grafting. Horticultural Reviews. 35: DOI: 10.1002/9780470593776.ch9.

Noor, R.S., Wang, Z., Umair, M., Yaseen, M., Ameen, M., Rehman, S.U. and Sun, Y. (2019). Interactive effects of grafting techniques and scion-rootstocks combinations on vegetative growth, yield and quality of cucumber (*Cucumis sativus* L.). Agronomy. 9(6): 288. https://doi.org/10.3390/agronomy 9060288.

Orsini, F., Sanoubar, R., Oztekin, G. B., Kappel, N., Tepecik, M., Quacquarelli, C., Tuzel, Y., Bona, S. and Gianquinto, G. (2013). Improved stomatal regulation and ion partitioning boosts salt tolerance in grafted melon. Functional Plant Biology. 40(6): 628-636.

Paplomatas, E.J., Elena, K., Tsagkarakou, A. and Perdikaris, A. (2000). Control of Verticillium wilt of tomato and cucurbits through grafting of commercial varieties on resistant rootstocks. Acta Horticulturae. 579: 445-449.

Pradhan, S.R., Sahu, G.S., Tripathy, P., Dash, S.K., Mishra, B., Jena, R. and Sahoo, T.R. (2017). Vegetable grafting: A multidimentional approach for crop management in vegetables. International Journal of Current Microbiology and Applied Sciences. 6(10): 3332-3345.

Proietti, S., Rouphael, Y., Colla, G., Cardarelli, M., De Agazio, M., Zacchini, M., Moscatello, S. and Battistelli, A. (2008). Fruit quality of mini-watermelon as affected by grafting and irrigation regimes. Journal of the Science of Food and Agriculture. 88: 1107-1114.

Pugalendhi, L., Tamilselvi, N.A. and Thangamani, C. (2019). Vegetable grafting-a boon for soil-borne pest and disease management-A review. Madras Agricultural Journal. 106(10/12): 561-570.

Punithaveni, V., Jansirani, P. and Sivakumar, M. (2015). Screening of cucurbitaceous rootstocks and cucumber scions for root knot nematode resistance (*Meloidogyne incognita* Kofoid and White). Electronic Journal of Plant Breeding. 6(2): 486-492.

Noor, R.S., Wang, Z., Umair, M., Yaseen, M., Ameen, M., Rehman, S.U. and Sun, Y. (2019). Interactive effects of grafting techniques and scion-rootstocks combinations on vegetative growth, yield and quality of cucumber (*Cucumis sativus* L.). Agronomy. 9(6): 288. https://doi.org/10.3390/agronomy 9060288.

Rivero, R.M., Ruiz, J.M. and Romero, L. (2003). Can grafting in tomato plants strengthen resistance to thermal stress. Journal of the Science of Food and Agriculture. 83(13): 1315-1319.

Rouphael, Y., Cardarelli, M., Colla, G. and Rea, E. (2008). Yield, mineral composition, water relations and water use efficiency of grafted mini-watermelon plants under deficit irrigation. Hort Science. 43: 730-736.

Sugiyama, M., Sakata, Y. and Ohara, T. (2006). The history of melon and cucumber grafting in Japan. In XXVII International Horticultural Congress-IHC2006: International Symposium on Sustainability through Integrated and Organic 767 (pp. 217-228).

Satisha, J., Prakash, G.S., Bhatt, R.M., Sampath Kumar, P. (2007). Physiological mechanisms of water use efficiency in grape rootstocks under drought conditions. International Journal of Agricultural Research. 2: 159-164. DOI: 10.3923/ ijar.2007.159.164.

Savvas, D., Ntatsia, G. and Barouchas, P. (2013). Impact of grafting and rootstock genotype on cation uptake by Cucumber (*Cucumis sativus* L.) exposed to Cd or Ni stress. Scientia Horticulturae. 149: 86-96.

Schwarz, D., Rouphael, Y., Colla, G. and Venema, J.H. (2010). Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. Scientia Horticulturae. 127(2): 162-171.

Singh, H., Sethi, S., Kaushik, P. and Fulford, A. (2020). Grafting vegetables for mitigating environmental stresses under climate change: A review. Journal of Water and Climate Change. 11(4): 1784-1797.

Sen, A., Chatterjee, R., Bhaisare, P. and Subba, S. (2018). Grafting as an alternate tool for biotic and abiotic tolerance with improved growth and production of Solanaceous vegetables: Challenges and scopes in India. International Journal of Current Microbiology and Applied Sciences. 7(1): 121-35.

Seong, K.C., Moon, J.M., Lee, S.G., Kang, Y.G., Kim, K.Y. and Seo, H.D. (2003). Growth, lateral shoot development and fruit yield of white-spined cucumber (*Cucumis sativus* cv. Baekseong-3) as affected by grafting methods. Journal of Korean Society of Horticultural Science. 44: 478-482.

Shahid, S.A., Zaman, M. and Heng, L. (2018). Soil Salinity: Historical Perspectives and a World Overview of The Problem. In: Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques (pp. 43-53). Springer, Cham.

Shehata, S.A., Omar, H.S., Elfaidy, A.G., El-Sayed, S.S., Abuarab, M.E. and Abdeldaym, E.A. (2022). Grafting enhances drought tolerance by regulating stress-responsive gene expression and antioxidant enzyme activities in cucumbers. BMC Plant Biology. 22(1): 1-17.

Sakata, Y., Ohara, T., Sugiyama, M. (2008). The history of melon and cucumber grafting in Japan. Acta Horticult. 767: 217-228.

Tamilselvi, N.A., Pugalendhi, L. and Sivakumar, M. (2015). Response of cucurbitaceous rootstocks and bitter gourd scions against root knot nematode *Meloidogyne incognita* Kofoid and White. Annals of Plant and Soil Research. 17(Special issue): 175-177.

Tamilselvi, N.A. and Pugalendhi, L. (2017). Graft compatibility and anatomical studies of bitter gourd (*Momordica charantia* L.) scions with cucurbitaceous rootstocks. International Journal of Current Microbiology and Applied Sciences. 6(2): 1801-1810.

Tirupathamma, T.L., Ramana, C.V., Naidu, L. and Sasikala, K. (2019). Vegetable grafting: A multiple crop improvement methodology. Current Journal of Applied Science and Technology. 33(3): 1-10.

Thangamani, C., Pugalendhi, L. and Punithaveni, V. (2018). Screening wild and cultivated cucurbits against root knot nematode to exploit as rootstocks for grafting in cucumber. Journal of Horticultural Sciences. 13(1): 32-41.

Venema, J.H., Dijk, B.E., Bax, J.M., Van Hasselt, P.R. and Elzenga, J.T.M. (2008). Grafting tomato (*Solanum lycopersicum*) onto the rootstock of a high-altitude accession of *Solanum habrochaites* improves suboptimal-temperature tolerance. Environmental and Experimental Botany. 63(1-3): 359-367.

Wu, Y.F., Chen, Y. and Zhao, Y.J. (2006). Effect of pumpkin stocks on growth, development, yield and quality of grafted muskmelon. Fujian Journal of Agricultural Sciences. 21: 354-359.

Xu, C.Q., Li, T.L., Qi, H.Y. and Wang, H. (2006). Effects of grafting on development and sugar content of muskmelon fruit. Journal of Shenyang Agricultural University. 37: 378-381.

Xu, Y., Guo, S., Li, H., Sun, H., Lu, N., Shu, S. and Sun, J. (2017). Resistance of cucumber grafting rootstock pumpkin cultivars to chilling and salinity stresses. Horticultural Sciences and Technology. 35: 220-231.

Yang, Y., Lu, X., Yan, B., Li, B., Sun, J., Guo, S. and Tezuka, T. (2013). Bottle gourd rootstock-grafting affects nitrogen metabolism in NaCl-stressed watermelon leaves and enhances short-term salt tolerance. Journal of Plant Physiology. 170(7): 653-661.

Yetisir, H. and Sari, N. (2003). Effect of different rootstock on plant growth, yield and quality of watermelon. Australian Journal of Experimental Agriculture. 43: 1269-1274.

Yetisir, H. and Uygur, V. (2010). Responses of grafted watermelon onto different gourd species to salinity stress. Journal of Plant Nutrition. 33: 315-327.