Chapter 12
Improvement of Vegetables Through Grafting in Changing Climate Scenario

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Abstract Grafting in vegetables is an ancient technique to improve the yield through climate friendly practices. This technique was introduced in USA and become very popular in organic vegetables cultivation. Vegetable grafting is popular practice in many European and North American countries, Japan, Korea, and China. Because vegetable crops are so easy to grow, they are very sensitive to climate change. Drought, floods, and salt caused by temperature and precipitation shifts have severely impacted vegetable crop productivity. Vegetable crop cultivation is difficult to say the least in the face of a rapidly changing environment. Although grafting has traditionally been employed on woody and perennial fruit trees, it is increasingly being used to herbaceous plants like vegetables and flowers. In East Asia, grafting is used as a unique method for dealing with the many threats to intensive vegetable production. The genetic and physiological complexity of abiotic stress restricts the creation of tolerable cultivars at the commercial level. In addition, many vegetable crops lack resistant crossover suitable wild resistant sources, with the exception of a few. In this case, the surgical procedure of grafting a plant has been employed successfully to reduce a wide range of different environmental

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stress. In this chapter, we illustrate the efficacy of this plant propagation method through a review of research results on vegetable grafting.

Keywords Climate friendly · Abiotic stress · Grafting · Resistant sources · Vegetables

12.1 Introduction

Vegetable seedlings with grafts are a unique horticultural technique that has been used for a long time. In the latter half of the twentieth century, this method along with enhanced grafting procedures ideal for commercial production and productivity of grafted vegetable seedlings—was brought to Europe and other nations. Vegetable grafting is taking a vegetable plant's stem at the seedling stage and affixing it to the seedling's rootstock of another vegetable plant, such as a wild brinjal or a pumpkin. The grafted seedling is developed under regulated climatic circumstances once the attachment is accomplished, and then it may be planted in the field. In general, grafting onto certain rootstocks offers resistance to biotic and abiotic stress tolerance, crop development, yield, and quality, as well as nematodes and illnesses carried by the soil. Grafting is a useful tool to utilize in conjunction with more environmentally friendly crop production methods, such as lower rates and general usage of soil fumigants in many other nations. Especially the production of vegetables is sensitive to a range of abiotic environmental stresses, such drought, salt, floods and temperatures (Moretti et al. 2010). However, the insect pest and disease burden stated above might be compounded by an increase. However, a rise in mean warmth and humidity in a changeable climatic situation might worsen the Climate change may have a direct or indirect influence on food safety.

The grafting method was brought from Europe to North America. For greenhouse and organic farms, grafting techniques for fruits and vegetables are a desirable strategy. Grafting is a distinctive horticultural technique used for many years in East Asia on herbaceous seedlings to combat problems with biotic and abiotic stressors. The oldest written accounts of self-grafting to grow larger watermelon fruits date back to China in the fifth century and Korea in the seventeenth century. A watermelon farmer in Japan developed the first record of inter-specific grafting in watermelon using a squash rootstock (*Cucurbita moschata* Duch.) to boost productivity and prevent pests and illnesses. In order to produce grafted seedlings for commercial vegetable production in Japan in the 1930s, watermelon was grafted on *Lagenaria siceraria* (Mol.) Standl (Oda. 2002). Grafting of watermelons for drought tolerance is a potential strategy under limited water condition for taking higher yield as well as quality fruits (Adarsh et al. 2020). *Cucumis sativus* L. grafting was began in the late 1920s, but it wasn't successful until the 1960s (Sakata et al. 2008). In the 1950s (Oda. 1999), grafting was first used on eggplant (*Solanum melongena* L.), a Solanaceae plant, on scarlet eggplant (*Solanum integrifolium* Poir), and it was later commercialized on tomatoes (*Lycopersicon esculentum* Mill.) in the 1960s (Lee and Oda 2003). Conventional procedures for breeding which take time and advancement are gradual. In order to deal with different environmental stressors, grafting is necessary for a treatment based on the rootstock and scion compatibilities (Nilsen et al. 2014). Grafting is now commercially utilized in the vegetables such as tomato, eggplant, and cucurbits for control of soil borne diseases (Solankey et al., 2019). Grafting is a reciprocal procedure that is ecologically favourable, efficient, quick and integrative, affects both spring and rootstock. For watermelon this approach was originally used in Japan. The findings of the grafting were published in the first scientific research. The results of grafting of water melon plants to potatoes in the first scientific journal were reported to minimize fusarium fusion. In the 1920s, however, grafting was mostly considered a woody permanent fruit technique and was not employed until last time in cucurbits for the treatment of diseases of soil transmission, notably fusarium (Bhatt et al. 2015).

Many recognized researchers are currently employing this grafting approach to enhance the environmental stress tolerance in solanaceous and cucurbitaceous vegetables (Johnson et al. 2014). However, only tomatoes and potatoes are the most recent breeding technology and completely forgotten are other crops (Kato et al. 2001a). The importance of plant grafting for the control of environmental stressors, including floods, drought, heat and salinity, under a changing climate scenario will be discussed in this review paper.

12.2 Environmental Stress

The main limitations to the sustainable development of agricultural and horticultural products are the different environmental stresses, high temperatures, drought and flooding (because of irregular precipitation), and salt (Mittler. 2006). The intensity of this stress on plants varies on the stage of growth, kind and duration of stress exposure. Many researches describe the use of grafting procedures to enhance tolerance to a wide range of environmental stress on different vegetable crops, and we have compiled the key results in this chapter.

12.2.1 Flooding

Increasing flood tolerance has shown to be the use of numerous research organizations in various grafting vegetables. Tomato is a model of a flood-prone worldwide crop. Bhatt et al. (2015) used interspecies tomato greasing to improve flood tolerance. Four eggplant plants like BPLH-1, Neelkanth, Mattu Gulla, Arka Keshav have been grafted into Arka Rakshak for commercial tomatoes. Research has shown that the grateful returns of flooded and non-inundated circumstances were considerably influenced. The unexpected and self-grafted plant was murdered after five days of inundation. After five days of inundation, Arka Rakshak/Arka Keshav and BPLH-1 perished, but two combinations performed well. This study finds that eggplants withstand flooded terrain and may provide an enough radical fat material to increase the resistance to tomato flood. The World Vegetable Center (AVRDC) was also advised to increase flood tolerance for EG195 and EG203 eggplant additions to tomatoes (Black et al. 2003).

Tomato $F_{1's}$ (Arka Rakshak and Arka Samrat) in eggplant rootstock (IC-111056, IC-354557, IC-374873 and IC-2) have been found in recent research. Observations indicated that no leaf or plant withering symptoms and reduced chlorophyll decrease occur at all stages of plant growth. In contrast, following 96 hours of water stress, ungrafted plants had a 41–100 per cent decrease in chlorophyll levels and perished 4–7 days later. In 7–10 days after exposure, the flushing plants recovered entirely from flood stress. Thus, the water logging tolerance for grafting tomatoes increased for the aubergine rootstocks of IC-354557 and IC-111056 at 72–96 hours (Bahadur et al. 2015).

In addition, wild eggplant species are also employed in grease tomato rootstocks (Petran and Hoover 2014). Yetisir et al. (2006) showed that bitter melon plants grew on rootstocks of Luffa, in flooded circumstances, were more successful than ungrafted plants. The trade variety 'Crimson Tide' was also grafted in the watermelon to *Lagenaria siceraria* SKP (landrace), with chlorosis symptoms occurring both on grafted and ungrafted plants, but the symptoms were less pronounced in flooding plants.

However, non-grafted plants were less dry than grafted plants with high humidity; in addition, the fresh weight loss of ungrafted plants was around 180 per cent and of grafted plants was 50 per cent. In non-grafted and grafted plants respectively, dry weight was reduced by around 230 and 80 per cent. These results show the development of adventitious roots and aerenchyma tissue in grafted plants after 3 days, but for non-grafted plants under flood circumstances no such observations were recorded. Kato et al. (2001b) formulated a grafting trial in water-logged cucumber in accordance with research by Keatinge et al. (2014) and established that leaf chlorophyll content was increased by grafting on squash rootstocks. The rootstock suggested lately by AVRDC in East Asia for flood tolerance for tomatoes is VI045276, VI046103, VI034845, VI046104 and VI046101 for eggplants, and for rootstocks of East Asia is VI046378 (Peng et al. 2013). Rootstocks for vegetables and other economically significant crops can be placed in flood conditions. Table 12.1 provides other examples.

Table 12.1 Top-performing combinations of rootstock and scion in vegetables under induced flood stress

S. No.	Rootstock	Scion	References
1.	*S. melongena* cv. Arka Keshav	*S. lycopersicum* cv. Arka Rakshak	Bhatt et al. (2015)
2.	*S. melongena* cv. IC- 374873	*S. lycopersicum* cv. Arka Samrat	Bahadur et al. (2015)
3.	*C. maxima* x *C. moschata*	*C. sativus*	Kato et al. (2001a, b)
4.	*L. siceraria*	*C. lanatus*	Yetisir et al. (2006)

12.2.2 Drought

Drought is yet another significant challenge of water stress for sustainable worldwide vegetable production, caused by deficiencies in water supplies. Although breeding and biotechnology interventions led to new drought-tolerant crop types, the progress was mostly restricted to cereal crops. Certainly, climate change, affecting agricultural production, in particular the availability of vegetables and overall crop failures is greatly impacted by the availability of water. The lower irrigation water supply might be the explanation for decreased precipitation coupled with higher median air temperature. In drought circumstances, an upturn in evapotranspiration is also predicted as vegetables contain around 90% water (Thomas et al. 2011).

Water scarcity and drought stress are significant environmental stressors under the global climate change scenario (Schwarz et al. 2010). Grafting may thus be employed to reduce losses in production and to improve the efficiency of water usage (WEU) in a water shortage. The grafting of sensitive commercial cultivars on the rootstocks can do this by decreasing the effect of moisture stress on the shoot. In Europe, tomato hybrids, particularly *solanum* spp., and interspecific hybrids are common rootstocks for eggplants. Simile grafting on pumpkin (*Cucurbita moschata*), rootstocks, of watermelon (*Citrullus lanatus*) contributes to the water stress of watermelon shooting (King et al. 2010).

Tolerant plant grafts for vegetable plants were carried out to regulate or improve drought tolerance, in particular solanaceous and cucurbitaceous vegetables (Sanchez-Rodriguez et al. 2016). At genetic level, microRNAs (miRNAs) monitored plant growth and growth and reacted specifically to different environmental stresses. Li et al. (2016) reports that scion of squash grafted from the bottle siceraria or from the rootstock (*Cucurbita maxima* the *Cucurbita moschata*) caused a change of over 40 mil RNI expression, according to Li et al., 2016 in a spring graph of watermelon (*Citrullus lanatus*). In addition, in recent research studies, molecular processes were investigated by grafting cucumber plants on pumpkin rootstock (*Cuurebita moschata*) in 17 chosen miRNAs in the grafted plants under drought stress. As a consequence, mini-watermelon cv. Ingrid was ungrafted or grafted using a rootstock called ‘PS 1313’ (*Cucurbita maxima* + *Cucurbita moschata*) and findings showed that the yield, nutritional and fruit quality associated metrics of grafted plants are greater than those of non-grafted plants. In the case of gas exchange and leaf water relations no significant differences were seen between grafted and non-grafted plants. Although moisture stress sensitivity of grafted plants and ungrafted plants was equal, the greater marketable yields were reported with grafting. The findings of this study showed the benefits of rootstock ‘PS 1313.’ Under particular in drought circumstances, the usage of grafted rootstock plants was advised to alleviate drought stress. Another study comparing moisture stress-tolerant rootstocks for watermelon has found that wax gourds are a superior rootstock than dry gourds (Muneer et al. 2016). Other crucial physiological responses, such as changes in stomatal behaviour that have enhanced the WUE and

Table 12.2 Examples of high-performing pairings of rootstock and scion in plants under caused dry stress

S. No.	Rootstock	Scion	References
1.	*S. lycopersicum* L. (cv. Faridah)	*S. lycopersicum* L. (cv. Unifort)	Ibrahim et al. (2014)
2.	*S. lycopersicum* L. (cv. Jjak Kkung)	*S. lycopersicum* L. (cv. BHN 602)	Nilsen et al. (2014)
3.	*S. lycopersicum* L. (cv. Unifort)	*S. lycopersicum* L. (cv. Farida)	Wahb-Allah (2014)
4.	*C. annuum* (cv. Atlante)	*C. annuum* (cv. Herminio)	Lopez-Marin et al. (2013)
5.	*S. lycopersicum* (cv. Beaufort)	*S. lycopersicum* (cv. Amelia)	Chaudhari et al. (2017)
6.	*C. maxima* x *C. moschata*	*C. lanatus*	Rouphael et al. (2008)
7.	*C. annuum* L. (cv. Verset)	*C. annuum* L. (cv. Atlante)	Penella et al. (2014)
8.	*S. lycopersicum* (cv. Zarina)	*S. lycopersicum* (cv. Josefina)	Sanchez-Rodriguez et al. (2016)

photosynthetic activity have been recorded in the stress-prone environment, apart from those instances of the molecular physiological response of grassed vegetables to drought stress. For sweet pepper grafted on the rootstock of Creonte, the overall crop output and marketable fruit growth rose by 30 and 50 per cent correspondingly under the Mediterranean climate. In addition, the rootstock kept the photosynthetic leaf activity 30–60% higher and showed much greater WUE (10%). While, Amelia enhanced photosynthesis and stomach condition for tomato cultivar. In addition, the rootstock kept the photosynthetic leaf activity 30–60% higher and showed much greater WUE (10%). While enhanced photosynthesis and stomatal conduct for tomato cultivar Amelia were seen when Maxifort cultivar was utilized as a rootstock (Chaudhari et al. 2017). Thus, grafting onto the robust and tolerant and resistant rootstock, which are susceptible to drought, of commercial plants from plants in locations that are susceptible to water stress is a feasible method. The benefits of grafting in previous research were maintaining a high water and nutrient absorption capacity together with the larger WUE under drought. Table 12.2 provides further instances of research of vegetable grafting under severe stress.

12.2.3 Thermal Stress

Extreme temperatures can lead to loss of vegetable output by stimulating fusion and necrosis, delaying the development of truss and affecting the time of fruit maturing. Grafting can be utilized to protect plant against heat shock and to improve production performance in plants owing to the accompanying changes in physiology in the parent plant (Rivero et al. 2003). Plants are very susceptible to low as well as high temperatures. High temperatures are generally found in rainforests, whereas the temperatures or low temperatures of vegetables, particularly for tomato, squash, peat and water melon, occur in the winter, spring and fall seasons in temperate and subtropical areas. Due to high temperature the plant's physiological, morphological, molecular and biochemical response to change significantly affects on plant growth, development and economic yield of legume (Singh et al. 2021). In addition, cold stress has an effect on germination, plant growth and plant growth leading to a loss in economic returns (Venema et al. 2008). High temperatures, for example, in tomatoes cause considerable loss of agricultural output because of reduced fruit, small size of fruit and reduced quality of fruits. Similarly, the low temperature causes permanent malfunction, cell death and eventually plant death, depending upon the severity and duration of exposure. Temperature is also impacted by early fruit production and quality attributes. Species have been developed through breeding and biotechnology with increased thermal stress tolerance, but with little market success as such stressors are genetically complicated and plant specific. In vegetable crops, the genetic basis of environmental stresses tolerance such as heat, cold, drought, flood, salinity is necessity for development of superior biotype (Solankey et al. 2021). Therefore, grafting on chosen low−/high-temperature resistant rootstocks existing commercial elite varieties might be considered as a feasible plant multiplication strategy as a quick and efficient alternative. One of the best features for greenhouse vegetable production in winter or at an early spring is the low-temperature tolerance of the rootstock. Den Nijs (1980) conducted a low temperature grafting experiment with four advanced breeding lines and the rootstock of *Cucurbita ficifolia* in the Netherlands. This test showed that the survival, lifespan and fruit quality of grafted plants were excellent compared to those not grafted in low-temperature environments. Cucumber plants greased from the rootstock, *Cucurbita ficifolia*, increased transhexadecenoic Acid in phosphatidyl glyc. Horvath et al. (1983) continued this work by observing the increase in trans-hexadecenic acid in phosphatidylglycerol, which contributes to the low-temperature tolerance in plants in cucumber plants grafted onto *Cucurbita ficifolia* rootstock. In Morocco, *Cucurbita ficifolia* is also the favorite cucumber rootstock and is a great rootstock for low tolerance for soil temperature, particularly in winter spring production. During its development and growth, the grown tomato is very sensitive to the suboptimal and cold temperature. The grafting of high yielding commercial and sensitive cultivars on tolerant rootstock is regarded as a fast approach to enhance resistance to low-temperature tomato stress. In 1777, the *Solanum habrochaites* (LA) adhesives of the wild tomato were grafted by the tomato cultivar Moneymaker to examine the low temperature impact of Venema et al. (2008). The authors found the high relative growth rate of the shooting and the increased root mass ratio under the lowest temperatures in comparison with the self-sustaining and non-grafted plants to be present on the wild tomato rootstock. The results of this study therefore record the accession of the wild tomatoes *Solanum habrochaites* (LA) in 1777 as an additional rootstock in tomatoes as well as other solanaceous vegetables for regulating inadequate root zone temperature. Further research in tomatoes has also found the importance of the resistant rootstock in maintaining appropriate hydraulic and stomach behaviour. Moreover, the impacts in grafting compared to nongrafted plants are recognized to be far less than those in greater productivity of biomass.

The findings of this investigation indicated that grafted plants were used practically under extremely high temperature circumstances. In addition, the same study groups explained that thermal stress increased phenylalanine ammonia lyase (PAL) activity in the grafted and non-grafted tomato plants, increased total phenols and increased o-diphenols, decreased polyphenol oxidase (PPO) activities and goaiacol peroxidase (GPX) activity, and decreased dry weight. In comparison with non-grafted tomato plants, however, pressure impact was reduced in grafting (Lopez-Marin et al. 2013). Under addition to increased RuBisCO activity and more photosynthetically efficient performance of grafting plants in heat stress conditions can be ascribed to better. In the instance of pepper, the behaviour of non-grafted was tested. Under the case of pepper, tests were carried out on three rootstocks, Atlante, Create and Terrano, in shaded and non-shaded circumstances for the conduct of non grafted cultivar Herminio plants. Under both situations the grafted plants were performed better than not. In plant grafted onto the rootstock of Atlante, almost 40 percent more of the leaf area was registered as neutral for Atlante than other pairings. Grabing on Creonteeli had no significant influence on the biomass of the leaves. The total and marketable fruit yields of greased plants in non-shaded and shaded circumstances were nonetheless between 30 and 50 percent higher than that of non-grafted plants. Therefore, when greased to sweet pepper, the rootstock Creontemay is more efficient in resisting heat stress. Further investigations by Del Amor et al. (2008) and Colla et al. (2008) have also demonstrated highenetic yields of sweet pepper-grafted plants for the Mediterranean climate.

High day and night temperatures affect the setting of fruits for tomato growing and cause loss of output. A high-temperature stress-related study was carried out to test greased tomato plants under high temperature stress. ‘UC 82-B’ has been grafted with the heat-sensitive tomato plant ‘Summerset’ and with the eggplant cultivar ‘Black Beauty.’ ‘UC 82-B’ has been planted. The findings indicates that at 37/27 °C at late fruits, larger leaf area and low electrolytic leakage levels of non-greaser ‘UK 82-B’ displayed substantially higher chlorophyll fluorescence, but Abdelmageed & Gruda had no favourable effect on total yields than non-grafted ‘UC 82-B’. The number of tomato cellular proteins that have recently been shown by Muneer et al. (2016) has been 87. Further researches are presented in Table 12.3 which evaluates the application of vegetable grafting to control thermal stress.

12.2.4 Salinity Stress

Around 7% of the global surface and almost 20% of the arable land is soil salinity impacted (Shahid et al. 2018). Climate change encourages salinization and so the quantity of salt land under climate change scenarios is projected to rise. Salinity impacts output and development of plants negatively. A number of techniques have been developed to counteract the influence of salt and saline soils on vegetable crop yield. Many of the techniques for reclamation of salt soils are a temporary remedy and quite costly. The breeding of salt-tolerant was also studied for vegetables but

Table 12.3 Examples of high-level pairings of rootstock and scion in plants under heat stress

S. No.	Rootstock	Scion	References
1 .	*S. habrochaites* LA-1777	*S. Lycopersicum* cv. Moneymaker	Venema et al. (2008)
2.	*S. lycopersicum* cv. Summerset and *S. melongena* cv. Black beauty	*S. lycopersicum* cv. UC 82 B	Abdelmageed and Gruda (2009)
3.	*C. ficifolia* and *L. cylindrica* cv. Xiangfei	*C. sativus* cv. Jinyan no.-4	Li et al. (2016)
4.	*S. lycopersicum* cv. RX 335	*S. lycopersicum* cv. Tmknvf2	Rivero et al. (2003)
5.	*S. lycopersicum* cv. LA-1778	*S. Lycopersicum* cv. T-5	Bloom et al. (2004)
6.	*C. ficifolia*	*C. sativus* cv. Jinyan no.-4	Zhou et al. (2007)

Table 12.4 Examples of high-performance pairings of rootstock and scion in plants with induced salinity stress

S. No.	Rootstock	Scion	Reference
1.	*S. lycopersicum* x *S. habrochaites* Maxifort'	*S.lycopersicum* L. cv. Cuore di Bue	Di Gioia et al. (2013)
2.	*L. siceraria*	*C. lanatus* cv. Xiuli	Yang et al. (2013)
3.	*C. maxima* x *C. moschata*	*C. melo* L. cv. Brennus	Orsini et al. (2013)
4.	*C. moschata*	*C. sativus* L.	Zhen et al. (2011)
5.	a) *C. chinense* ECU-973, *C. baccatum* L. var. pendulum BOL- 58	*C. annuum*	Penella et al. (2014)
6.	*C. maxima*. X *C. moschata*. P-360 and PS-13132	(a) *C. melo* L. cv. Cyrano (b) *C. sativus* L. cv. Akito	Rouphael et al. (2012)

multiple cycles of plant breeding were necessary because of the complicated polygenic traits which trigger salt tolerance.

The adoption of resistant genotypes as rootstocks was considered a simple and effective method for enhancing the tolerance of the crop against salt stress. Research of salt tolerances for greased vegetable crops have examined throughout the last decade and most studies suggest that grafting is a highly effective technique to enhance salt tolerance. The salt tolerance has improved with interspecific, hybrid rootstock for grafted tomato plants. When bottle gourd rootstock is used for salinity tolerance for watermelon plants then the salinity tolerance can be increased many times. Orsini et al. (2013), reported that non-grafted control plants for interspecific squash rootstock, have an increased salinity tolerance, along with plant biomass and leafy regions (*Cucurbita maxima* of *Cucurbita moschata* Duch.). Salt tolerance in many vegetable crops by using grafting methods is presented in Table 12.4.

12.3 Conclusion

Summarizing, the scientific literature documented the grafting of genetically diverse crops to reduce environmental stress in a changing global climate. New studies are needed as a source of rootstock to evaluate and test different germplasm. However, the full potential of the grafting technique depends on a number of characteristics, such as the appropriate selection of scion and rootstock, location, communication between rootstock and scion, and reciprocal effects of root systems. Further research is needed in order to create automated grafting platforms that expand this technique to make it a key aspect of modern vegetable production. This alone allows the production of grafted plant material at reduced price for vegetable growers in modern simulation and automated grafting technologies. In addition, vegetable grafting is pursued in developed countries due to up-to-date farmers' understanding of the contemporary technology of vegetable manufacturing.

Plant grafting can help producers tackle climate change and overcome unsustainable production methods of vegetables that lead to soil degradation and the rapid loss of natural resources. Research is necessary in order to make this technique easier for farmers in every area of the world, requiring the development of greasing technologies that are suitable for steady, whole year round and inexpensive production of seedlings.

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