***Review Article***

**Vegetable Grafting- A Horticultural Tool for Mitigating Abiotic Stresses in Vegetable Crops under Changing Climate**

**ABSTRACT**

Vegetables are considered as protective food and play an important role in providing balance diet to the human beings. Vegetables being succulent in nature are susceptible to number of biotic and abiotic stresses. For successful cultivation of vegetables, the crops should be resilience to abiotic stress under changing climate. Traditional breeding methods involving large breeding cycles are time-consuming and progress slowly. Vegetable grafting, a plant surgical technique that is eco-friendly, rapid and efficient, is currently the best alternative approach to climate change-resilient plant production that addresses the abiotic stressors.

*Keywords*: grafting, stresses, vegetable, climate change, abiotic

**Introduction:**

India is second largest producer of vegetables in the world after China. The total area under vegetables 10.86 million ha and total production 200.45 million tonnes (Horticultural statistics at a glance, 2021). Over the past 5 years, the cultivable area and crop production of vegetables in India have increased drastically by 11.23% and 10.57%respectively, (Horticultural statistics at a glance, 2021). However, there is instability in production at national level (Bhuyan & Kotoky, 2023). Vegetable crops are extremely susceptible to climatic change. The varieties of many vegetables crops with higher yields have been developed or are now under development. Some cultivars, meanwhile, are unable to deliver this potential in fields despite having high yield values under controlled conditions. To overcome these issues, breeding tolerant cultivars is difficult, and a time-consuming approach. On the other hand, grafting technology has emerged out an alternative tool of slow breeding programs to alleviate various abiotic stresses effectively. Grafting has been practiced in fruit trees for a long time; however, its application in vegetables is relatively new. Vegetable grafting began in Japan in 1927 wherein watermelon was grafted on pumpkin to control Fusarium wilt disease. Commercial grafted vegetable production can be traced back between the late 1950s to the early 1960s in Japan and Korea. (Bahadur & Kumar, 2024). Grafting, a vegetative propagation process, joins rootstock and scion from two plants of the same or different species (Bayoumi *et al*., 2022). Rootstock is the underground plant component that becomes the root system, whereas scion is the aboveground part that becomes the shoot system of the scion plant (Dhar *et al*., 2023). The grafted plant combines the characteristics of two different plants. The rootstocks (lower part) used in grafting are usually close relatives or wilds (mostly within the genera) of the scion crop, and have tolerance for biotic (pathogens), abiotic stresses (environmental stress) and plant vigor, whereas the scion (upper part) has some peculiar qualitative and quantitative horticultural traits. Earlier, grafting technology was used mostly for tolerance to soil-borne diseases and nematodes (Rivard *et al*., 2010; Barrett *et al*., 2012), but in recent pasts, it has also been widely used to mitigate the adverse effects of several abiotic stresses such as salinity (Coban *et al*., 2020), thermal stress (Han et al., 2019), nutrient absorption and translocation (Savvas *et al*., 2017), heavy metals (Xie *et al*., 2020) and water deficit or drought (Zhang *et al*., 2019).

The objective of this paper is to systematically review contemporary research pertaining to the responses of grafted plants to adverse chemical soil conditions, encompassing nutrient deficiencies, toxic metal concentrations, water deficits and surpluses, as well as extreme pH levels. Additionally, it will scrutinize the agronomic, physiological, and biochemical mechanisms inherent in grafted plants that facilitate tolerance to these unfavorable soil conditions. Ultimately, the review will propose prospective research avenues aimed at further augmenting the role of grafting in vegetable production in the face of abiotic stresses.

**Abiotic stress tolerance**

Vegetable crops are sensitive to a variety of abiotic stresses such as drought, flood, salinity, and low and high temperatures, all of which have a significant impact on plant physiological and morphological growth, resulting in reduced yield. Grafting aids the vegetable crop in mitigating abiotic stresses and provides healthy mechanisms for crop protection.

**Drought Stress:**

In many parts of the world, water is swiftly turning into an economically scarce resource. Commercial vegetable production requires ongoing development of irrigation practices because to the rising rivalry for water among agricultural, industrial, and urban customers. Grafting high-yielding genotypes onto rootstocks that can lessen the effects of water stress on the shoot is one strategy to decrease production losses and enhance water usage efficiency during drought circumstances (Satisha *et al*., 2007). When grown under conditions of deficit watering, mini-watermelons that were grafted onto a commercial rootstock (PS 1313 Cucurbita maxima × Cucurbita moschata) demonstrated a more than 60% higher marketable yield than un-grafted melons (Rouphael *et al*., 2008). A higher N, K, and Mg concentration in the leaves, as well as increased CO2 absorption, were indicators of improved water and nutrient uptake, which contributed to the higher marketable output observed with grafting. In another study conducted on tomatoes, it was reported that grafting improved drought tolerance by enhancing photosynthetic capacity and also reduced the ROS accumulation (Zhang *et al*., 2019).

**Flood or Water lodging stress:**

Flooding stress can negatively impact plant growth and development, but plants have a number of ways to adapt it, and several agricultural practices are also followed to tackle it, and one practice among them is grafting. The mechanism of grafting and flooding stress is not well-known; limited studies are reported. For example, the scion region of watermelon was grafted with the rootstock of bottle gourd in loam soil, which has the capacity to enhance the flood tolerance (Maurya *et al*., 2019). The grafting of cucumber scion part with the squash rootstock region has shown an increase in the chlorophyll content against flooding stress in a previous study (Kato *et al*., 2001); whereas in another report (Yetı¸sır *et al*., 2003), the watermelon cv. Crimson Tide scion plant was grafted with the rootstock of *Lagenaria siceraria* SKP (Landrace), and it has shown a decrease in chlorophyll content, which is noticed in rare conditions. The scion part of tomato plant was used to graft with the brinjal accessions EG195 and E203, which has further resulted in the flood tolerance in a previous study. The scion region of the pepper plant was grafted with chili accessions “PP0237-7502,” “PP0242-62,” and “Lee B,” which has resulted in flooding tolerance (Ashok Kumar & Sanket, 2017).

**Heat Stress:**

Elevated temperatures can significantly influence vegetable cultivation, especially in hot (semi) arid regions and in lowland tropical areas during the hot-wet and hot dry seasons. For instance, Solanaceous vegetables may be unable to thrive at temperatures exceeding 35°C, whereas Cucurbitaceous vegetables exhibit a lesser degree of susceptibility. The adverse effects of high temperatures encompass stunted growth, diminished photosynthetic activity, increased respiration rates, a shift in nutrient allocation towards reproductive organs, osmotic and oxidative stresses, reduced absorption of water and ions, and cellular desiccation. Grafting onto resistant rootstocks, namely brinjal, has been suggested as a potential solution to the issue of flooding in tomatoes. Bahadur *et al*. (2016) proved that waterlogging tolerance in tomatoes for durations of 4 and 6 days, respectively, by using distinct brinjal rootstocks. According to Mauro *et al*. (2020), it was observed that the grafting of tomato (cv. 'Dreamer') onto interspecific rootstock 'Maxifort' and 'Beaufort' (*S. lycopersicum x S. habrochaites*) resulted in improved photosynthesis, root biomass, and growth performance. This improvement was attributed to the buffering effect of root hypoxia under low root zone oxygen conditions (2–3 mg L-1for 30 days).

**Cold Stress:**

Low temperature is one of the most common abiotic stresses that reduce the productivity of crops (Duan *et al*., 2012), and about 25% of the entire area of the world’s land are affected with cold stress (Peel *et al*., 2007). Incase of vegetable cultivation the tropical and subtropical plants suffer more to the low temperature condition. It was observed that grafting of cucurbits with cucumber scion having *Cucurbita ficifolia* and *Sicos angulatus* L. has shown an improvement in vegetative growth and yield against low temperature stress condition (Zhou *et al*., 2007). In another study (Shibuya *et al*., 2007), it is stated that there was a tolerance towards low temperature stress under sub-optimal temperature, when the cucumber scion was grafted onto the squash rootstock (*C. moschata* Duch). The watermelon plant was used as a scion to perform grafting with the inter-specific squash hybrid (*C. maxima* × *C. moschata*), this has resulted in improvement of propagating duration by cold period (Davis *et al*., 2008). In case of tomato, rootstocks of the high-altitude accession LA 1777 (*Solanum habrochaites* syn. *S. hirsutum*), KNVF (the interspecific hybrid of *S. lycopersicum*× *S. habrochaites*), and back-crossed progeny of S*. habrochaites* LA 1778 × *S. lycopersicum* cv. T5 are able to alleviate low root-temperature stress for different scion cultivars of tomato (Bloom *et al*., 2004; Venema *et al*., 2008).

**Salinity Stress:**

Salinity is the most serious abiotic stress and poses a great threat to agricultural productivity. Globally, about one-third of irrigated land is affected with salinity stress and, it is anticipated that by 2050, more than 50% of the world’s cultivated land will be affected by soil salinity (Roșca *et al*., 2023). Salinity adversely impacts plant growth and overall development, for instance, in tomato plants, elevated salinity levels result in diminished plant height attributed to shortened internodes and inhibited leaflet growth (Najla *et al*., 2009). A number of solutions have been put up to lessen the detrimental effects of salinization and the utilization of salty soils for the production of vegetable crops. Last ten years Studies on the salt tolerance of grafted vegetable crops have been conducted, and most research have discovered that the most effective technique to improve salt tolerance is by grafting. (Colla *et al*., 2010). It was reported that grafting of pepper cultivar "Adige" onto the salt-tolerant rootstock "A 25," which resulted in a 75% increase in yield and a 31% reduction in fruit damage (Penella *et al*., 2016). Grafted plants typically sustain improved leaf water status. Grafting tomato ("Ikram") onto potato rootstock ("Charlotte") demonstrated potential for salinity tolerance levels reaching 5.0 dS/m, resulting in an enhancement of water productivity by 56.8% (Parthasarathi *et al*., 2021). Watermelon plants were able to tolerate salt more than a few times better, while using bottle gourd as a rootstock (Yang *et al*., 2013). The interspecific hybrid of pumpkin and squash which was first described by (Orsini *et al*., 2013), increased plant biomass and leaf area as well as tolerance to stress induced due to salinity in grafted plants of muskmelon when compared to non-grafted ones.

**Heavy metal stress**

Heavy metal contamination in agricultural soil poses an increasingly major risk to the environment, human health, intact plant growth, and output (Hong-Bo *et al*., 2010). While some heavy metals can be hazardous to plants even at very low concentrations, others can build up in plant tissues to a certain point without causing any obvious symptoms or a decrease in yield (Verkleij *et al*., 2009). Industrial waste, reclaimed wastewater, and soil amendments from diverse sources are only a few of the factors that bring toxic non-nutrient heavy metals like cadmium, arsenic, lead, and mercury to agricultural ecosystems (Gupta *et al*., 2010). Several studies on metal toxicities in plants have been carried out, but very limited studies are reported on grafting and toxic metals. According to Arao *et al*., 2008, cadmium concentrations in the eggplant (*S. melongena*) were grafted onto *Solanum torvum*; the leaves and stem have shown a reduced level of Cd concentrations (67%–73%). In another study (Edelstein & Ben-Hur, 2007), it was noticed that when the melon plants (cv. arava-galia type) were grafted on to the rootstock of cucurbita plant (TZ-148), there was a reduction in boron(B), zinc (Zn), strontium (Sr), manganese (Mn), copper (Cu), titanium(Ti), chromium (Cr), nickel (Ni), and cadmium (Cd) compared to the non-grafted plants. The lower quantities of heavy metals and trace elements in fruits were mostly attributed to variations in the root system features between the two plant species. However, more study is required to clarify the mechanisms that prevent heavy metals from moving from the root to the shoot in specific rootstock/scion combinations.

**Conclusion:**

In today’s changing climate abiotic stresses are the major limiting factors for vegetable production. It caused reduced photosynthetic activity, less development of root, reduced water and nutrient absorption which resulted in stunted growth with reduced or no yield. Grafting is an efficient rapid alternative tool to the relatively slow breeding methodology for enhancing environmental-stress tolerance in tomatoes. The use of appropriate tolerant rootstocks improves crop growth, yield and quality in vegetable crops which confer resistance against abiotic stresses. Graft compatibility is a key factor in the success of grafting so future studies should be focused on this aspect.

**References:**

Arao, T., Takeda, H., & Nishihara, E. (2008). Reduction of cadmium trans-location from roots to shoots in eggplant (Solanum melongena) by grafting onto *Solanum torvum* rootstock. *Soil Science and Plant Nutrition*, 54(4): 555–559.

Ashok Kumar, B., & Sanket, K. (2017). Grafting of vegetable crops as a tool to improve yield and tolerance against diseases—A review. *International Journal of Agriculture Sciences*, 9(13): 4050–4056.

Bahadur, A., & Kumar, R. (2024). Grafting in Tomato for Improving Abiotic Stress Tolerance, Yield and Quality Traits. *Vegetable Science*, 51: 22-33.

Bahadur, Anant, K. K. Jangid, Amit K. Singh, Umesh Singh, K. K. Rai, Manish K. Singh, Nagendra Rai, P. M. Singh, A. B. Rai, and B. Singh (2016). Tomato genotypes grafted on eggplant: Physiological and biochemical tolerance under waterlogged condition. *Vegetable Science*, 43(2), 208-215.

Barrett, C. E., Zhao, X., & Hodges, A. W. (2012). Cost benefit analysis of using grafted transplants for root-knot nematode management in organic heirloom tomato production. *Hort Technology*, 22(2): 252-257.

Bayoumi, Y., Shalaby, T., Abdalla, Z. F., Shedeed, S. H., Abdelbaset, N., El-Ramady, H., & Prokisch, J. (2022). Grafting of vegetable crops in the era of nanotechnology: A photographic mini review. Environment, *Biodiversity and Soil Security*, 6 (2022):133–148.

Bhuyan, D., & Kotoky, A. (2023). Instability in production and productivity of horticultural crops in Assam. *Indian Journal of Agricultural Research*, 57 (1): 123–127.

Bloom, A. J., Zwieniecki, M. A., Passioura, J. B., Randall, L. B., Holbrook, N. M., & St. Clair, D. A. (2004). Water relations under root chilling in a sensitive and tolerant tomato species. *Plant, Cell & Environment*, 27(8), 971-979.

Coban, A., Akhoundnejad, Y., Dere, S., & Dasgan, H. Y. (2020). Impact of salt-tolerant rootstock on the enhancement of sensitive tomato plant responses to salinity. *Hort. Science*, 55(1): 35-39.

Colla, G., Suarez, C. M. C., Cardarelli, M., & Rouphael, Y. (2010). Improving nitrogen use efficiency in melon by grafting. *Hort. Science*, *45*(4), 559-565.

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

Dhar, S., Borauh, P., & Gogoi, S. (2023). Importance of rootstocks in cucurbitaceous vegetables: A review. *The Pharma Innovation*, 12 (6): 1709–1714.

Duan, M., Feng, H. L., Wang, L. Y., Li, D., & Meng, Q. W. (2012). Overexpression of thylakoidal ascorbate peroxidase shows enhanced resistance to chilling stress in tomato. *Journal of Plant Physiology*, 169(9): 867-877.

Edelstein, M. and Ben, H. M. (2007). Preventing contamination of supply chains by using grafted plants under irrigation with marginal water. In: Wilson, J. (Ed.), *Proceedings of the International Symposium on Water Resources Management*. Honolulu, Hawaii, USA, 150–154.

Gupta, N., Khan, D. K. and Santra, S. C. (2010). Determination of public health hazard potential of wastewater reuse in crop production. World Review of Science, Technology and Sustainable Development, 7: 328–340.

Han, M., Cao, B., Liu, S., & Xu, K. (2018). Effects of rootstock and scion interaction on chilling tolerance of grafted tomato seedlings. *Acta Horticulturae Sinica*, 45(2): 279-288.

Hong-Bo, S., Li-Ye, C., Cheng-Jiang, R., Hua, L., Dong-Gang, G., & Wei-Xiang, L. (2010). Understanding molecular mechanisms for improving phytoremediation of heavy metal-contaminated soils. *Critical reviews in biotechnology*, 30(1): 23-30.

Horticultural statistics at a glance (2021). Department of Agriculture and Farmer Welfare, Govt. of India, https://agriwelfare.gov.in/en/PublicationReports.

Kato, C., Ohshima, N., Kamada, H., & Satoh, S. (2001). Enhancement of the inhibitory activity for greening in xylem sap of squash root with waterlogging. *Plant Physiology and Biochemistry*, 39(6), 513-519.

Mauro, R. P., Agnello, M., Distefano, M., Sabatino, L., San Bautista Primo, A., Leonardi, C., & Giuffrida, F. (2020). Chlorophyll fluorescence, photosynthesis and growth of tomato plants as affected by long-term oxygen root zone deprivation and grafting. *Agronomy*, 10(1): 137.

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.

Najla, S., Vercambre, G., Pages, L., Grasselly, D., Gautier, H., & Genard, M. (2009). Tomato plant architecture as affected by salinity: descriptive analysis and integration in a 3-D simulation model. *Botany, 87*(10): 893-904.

Orsini, A. (2013). Multi-forum non-state actors: Navigating the regime complexes for forestry and genetic resources. *Global Environmental Politics*, 13(3): 34-55.

Parthasarathi, T., Ephrath, J. E., & Lazarovitch, N. (2021). Grafting of tomato (*Solanum lycopersicum* L.) onto potato (*Solanum tuberosum* L.) to improve salinity tolerance. *Scientia Horticulturae*, 282: 110050.

Peel, M.C., Finlayson, B.L., & McMahon, T.A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences*, 11: 1633-1644.

Penella, C., Landi, M., Guidi, L., Nebauer, S.G., Pellegrini, E., San Bautista, A., Remorini, D., Nali, C., López-Galarza, S. and Calatayud, A. (2016). Salt-tolerant rootstock increases yield of pepper under salinity through maintenance of photosynthetic performance and sinks strength. *Journal of plant physiology*, 193: 1-11.

Rivard, C. L., O’Connell, S., Peet, M. M., & Louws, F. J. (2010). Grafting tomato with interspecific rootstock to manage diseases caused by *Sclerotium rolfsii* and southern root-knot nematode. *Plant Disease*, 94 (8): 1015-1021.

Roșca, M., Mihalache, G., & Stoleru, V. (2023). Tomato responses to salinity stress: From morphological traits to genetic changes. *Frontiers in plant science*, 14: 1118383.

Rouphael, Y., Cardarelli, M., Colla, G., & Rea, E. (2008). Yield, mineral composition, water relations, and water use efficiency of grafted mini-watermelon plants under deficit irrigation. *Hort. Science*, 43(3), 730-736.

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

Savvas, D., Öztekin, G. B., Tepecik, M., Ropokis, A., Tüzel, Y., Ntatsi, G., & Schwarz, D. (2017). Impact of grafting and rootstock on nutrient-to-water uptake ratios during the first month after planting of hydroponically grown tomato. *Journal of Horticultural Science and Biotechnology*, 92(3): 294-302.

Shibuya, T., Tokuda, A., Terakura, R., Shimizu-Maruo, K., Sugiwaki H., Kitaya, Y., & Kiyota, M. (2007). Short-term bottom heat treatment during low air temperature storage improves rooting in squash (Cucurbita moschata Duch.) cuttings used for rootstock of cucumber (*Cucumis sativus* L.). *Journal of Japanese Society of Horticultural Science*, 76(2): 139–143.

Venema, J. H., Dijk, B. E., Bax, J. M., van Hasselt, P. R., & 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.

Verkleij, J. A. C., Golan-Goldhirsh, A., Antosiewisz, D. M., Schwitzguébel, J. P. and Schröder, P. (2009). Dualities in plant tolerance to pollutants and their uptake and translocation to the upper plant parts. *Environmental and Experimental Botany*, 67: 10–22.

Xie, Y., Tan, H., Sun, G., Li, H., Liang, D., Xia, H., ... & Tang, Y. (2020). Grafting alleviates cadmium toxicity and reduces its absorption by tomato. *Journal of Soil Science and Plant Nutrition*, 20: 2222-2229.

Yang, Y., Lu, X., Yan, B., Li, B., Sun, J., Guo, S., & 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.

Yetı¸sır, H., Sari, N., & Yücel, S. (2003). Rootstock resistance to Fusarium wilt and effect on watermelon fruit yield and quality. *Phytoparasitica*, 31: 163–169.

Zhang, Z., Cao, B., Gao, S., & Xu, K. (2019). Grafting improves tomato drought tolerance through enhancing photosynthetic capacity and reducing ROS accumulation. *Protoplasma*, 256: 1013-1024.

Zhou, Y., Huang, L., Zhang, Y., Shi, K., Yu, J., & Nogués, S. (2007). Chill-induced decrease in capacity of RuBP carboxylation and associated H2O2 accumulation in cucumber leaves are alleviated by grafting onto fig leaf gourd. **Annals of Botany**, 100(4): 839–848.