MITIGATE THE IMPACT OF VARIOUS ABIOTIC STRESS BY USING GRAFTING IN TOMATO (SOLANUM LYCOPERSICUM L.) AND OTHER VEGETABLES: A COMPREHENSIVE REVIEW

ABSTRACT

Grafting technology has developed as a promising alternative to slow traditional breeding methods for boosting abiotic stressor resistance, soil pathogen tolerance, and fruit vegetable output and quality. Tomato, cucumbers, watermelons, eggplants, muskmelonand sweet papers have been grafted commercially to increase plant tolerance to factors such as salt, drought, waterlogging, the heavy metal toxicity, extreme temperatures, and variations in vegetable crop yield and quality. The goal of this study was to evaluate the research on the effect of grafting in reducing abiotic stressors and increasing vegetable crop production and quality. At different phases of culture, abiotic and biotic stressors harm tomato (*Solanum lycopersicum* L.), a significant vegetable crop globally. Drought, salt, floods, severe temperatures, and heavy metals may alter plant morphology, physiology, and biochemistry, affecting crop development, production, and quality. Grafting technology is an excellent alternative to delayed breeding operations to reduce biotic and abiotic stressors. Grafted tomatoes have higher osmolytes, antioxidant enzymes, photosynthesis, which improves plant growth and fruit harvests and makes them more tolerant to abiotic challenges. Additionally, tomato grafting on proper rootstocks enhances fruit nutritional value, including lycopene, β-carotene, ascorbic acid, and proteins. This information may help researchers and producers improve vegetable quality, especially under abiotic stress.

Keywords: abiotic stressor resistance, Grafting technology,crop yield,plant morphology,

1. INTRODUCTION

Through the process of grafting, plant parts are joined together to establish vascular continuity, enabling the resultant genetically composite organism to carry out the same functions as a single plant. Nevertheless, there have been documented instances of spontaneous grafts occurring across distinct families (Warschefsky *et al*., 2016). The use of resistant rootstock via vegetable grafting emerged as a strategy to address soil transmitted illnesses, commencing in the 1920s. Grafted vegetables were first cultivated on a large area in Japan and Korea.

Vegetables provide a substantial component of a nutritious dietary regimen, serving as a valuable reservoir of dietary fiber, antioxidants, protein, carbohydrates, vitamins and minerals. The agricultural development worldwide is often hindered by several abiotic variables, such as drought, floods, soil salinity, hot or cold temperatures, oxidative stress, and heavy metal toxicity (Fu *et al*., 2022). Depletion of water supplies, forest clearing, and unintentional climate change increase the potential for plants to face various abiotic stressors. The worldwide output of vegetables is significantly limited by increasing temperatures, decreasing supply of irrigation water, floods, and salt (Coskun, 2023). The reduction in agricultural output by 50% can be attributed to various abiotic stresses, including water-related factors such as drought, flooding, and hypoxia, temperature variations such as heat, cold, chilling, and freezing, chemical exposures such as mineral deficiency or excess, heavy metal pollutants, pesticides, and gaseous toxins, radiation exposure such as UV and ionizing radiation, as well as mechanical factors like wind, soil erosion, and submergence. The majority of watermelon seedlings in countries such as Korea, Greece, Japan, Spain, Turkey and Italy are grafted. The use of grafted plants is seeing a growing trend in many vegetable cultivations worldwide, including tomato, eggplant, sweet pepper, cucumber, and muskmelons. According to Fu *et al*. (2022), the process of grafting in vegetables has been seen to improve several aspects of plant vigor, harvesting time, yield, and fruit quality (Tsaballa *et al*., 2013). Today, we use the practice of grafting to reduce soil-borne pathogen infections and increase resistance to abiotic stresses.**(see Figure 1).**

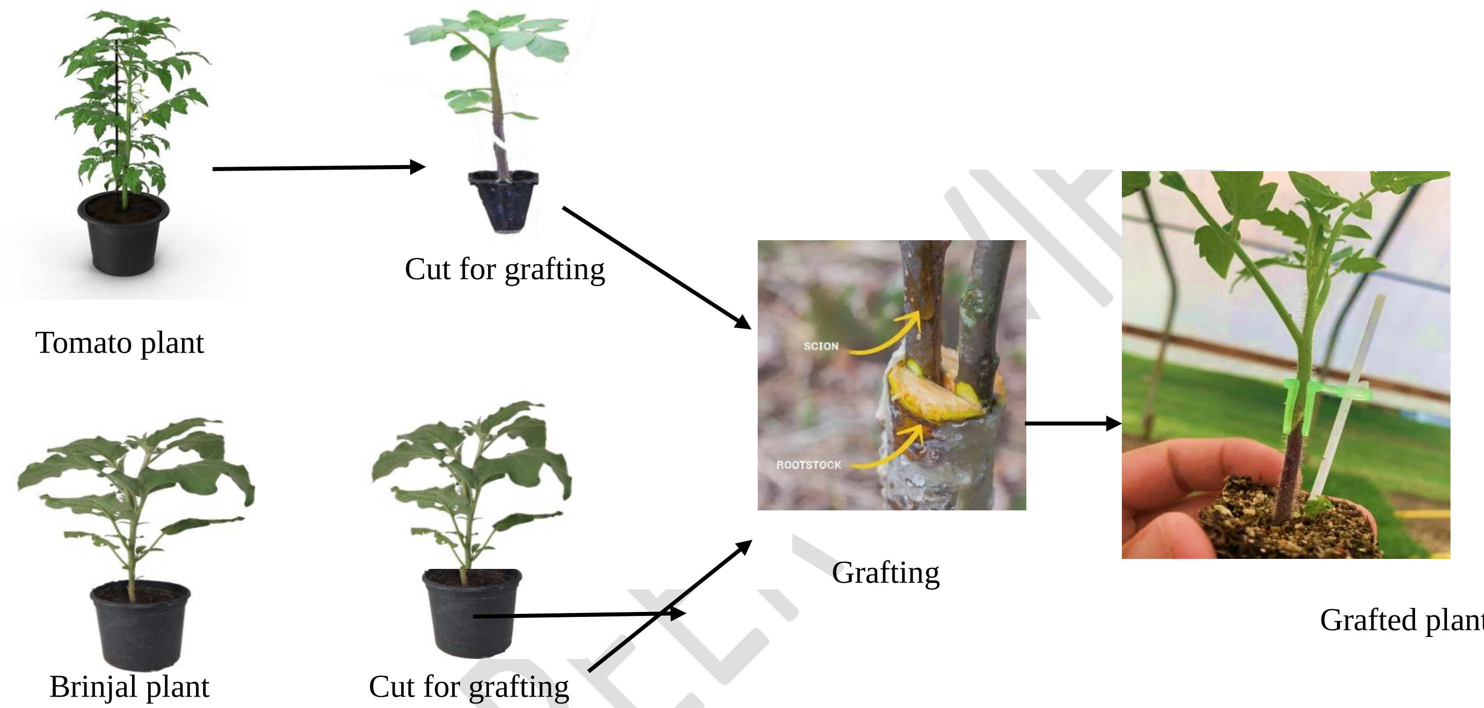

Figure 1. Grafting of tomato on brinjal plant.

According to FAOSTAT (2019), tomato (Solanum lycopersicum L.) is a significant fruit or vegetable crop, ranking second only to potato. According to FAOSTAT (2019), tomato consumption is mostly connected with India, China, North Africa, the Middle East, and Brazil. The per capita tomato consumption in these regions ranges from 61.9 to 198.9 kg. The tomato fruitis belongingSolanaceae family, which encompasses other commercially significant crops like the potato, pepper, and eggplant.

Tomatoes provide several bioactive components that contribute to overall health and may be readily included into a well-rounded dietary regimen (Martú *et al*., 2016). While there is a wide range of functional meals available to meet these needs, it is worth mentioning that consuming fruits and vegetables is more efficient for achieving this goal (Viuda-Martos *et al*., 2014). Tomatoes possess a range of health-promoting components, such as vitamins, carotenoids, and phenolic compounds, which contribute significantly to their nutritional significance (Liu *et al*., 2016). According to Raiola *et al*. (2014), the spectrum of physiological activities shown by these bioactive chemicals include antiallergenic, antibacterial, antiinflammatory, vasodilatory, antithrombotic, cardio-protective, and antioxidant actions.

ABIOTIC STRESS IN TOMATO

Vegetable crops exhibit sensitivity to a range of abiotic stressors, such as drought, flood, salt, and extreme temperatures. These stresses have a profound impact on the physiology and development of plants, ultimately resulting in a decrease in output**see figure 2.**

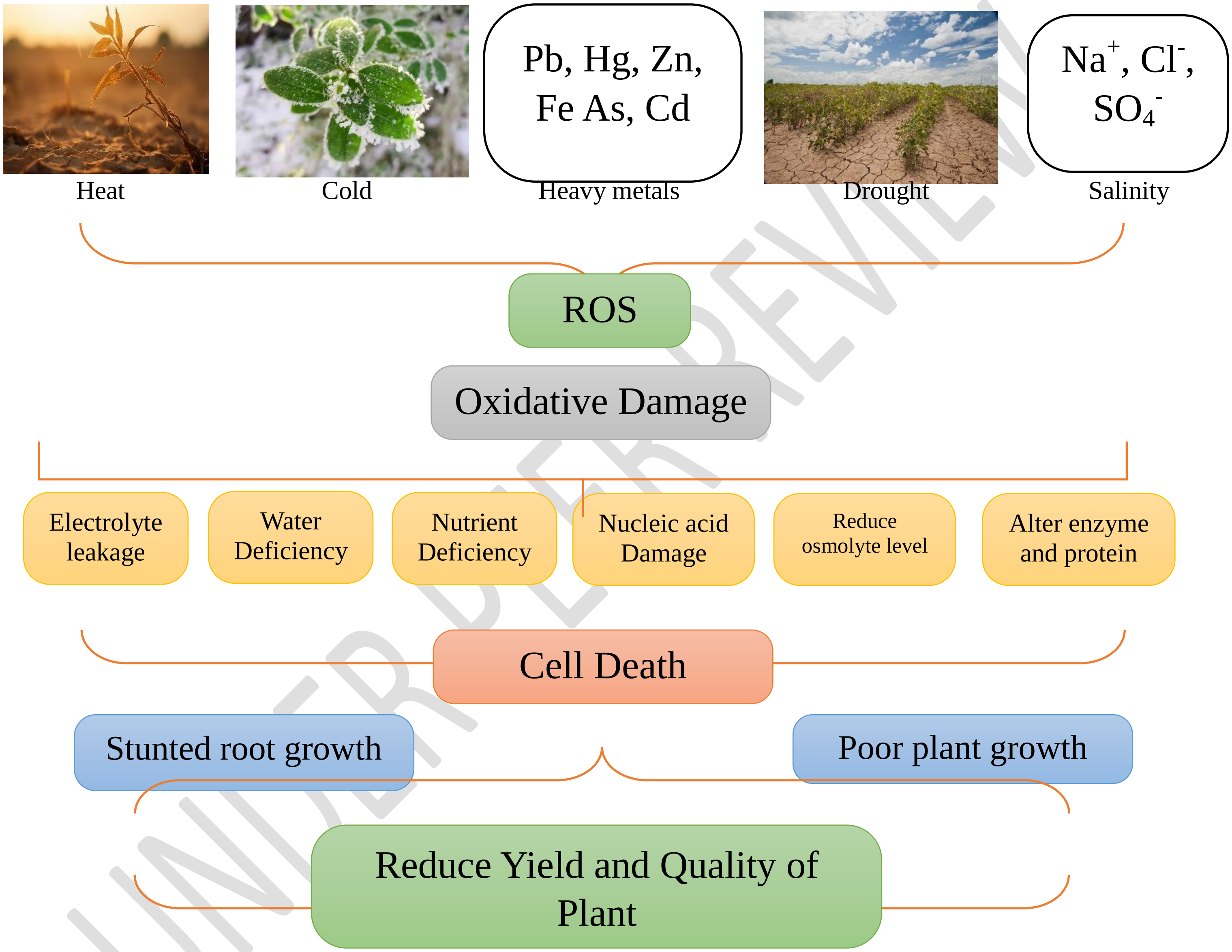

Figure 2. Different abiotic stresses affect plant growth, physiology, and production.

Temperature stress:

Temperature is one of the most important environmental factors that significantly affects tomato production. Tomato plants are able to flourish in a broad range of temperatures, fruit set and production are severely restricted when the maximum temperatures (during the day) are higher than 32 degrees Celsius and the lowest temperatures (during the night) are lower than 21 degrees Celsius. According to Jones (2007), the optimal range of temperatures for plant development, fruit set, and yield in tomatoes is between 21 and 29.5 degrees Celsius during the day and between 18.5 and 21 degrees Celsius during the night of the plant.

COLD STRESS:

Low temperature is a prevalent abiotic stressor that diminishes agricultural yield (Duan *et al*., 2012), impacting around 25% of the global land area (Peel *et al*., 2007). According to Ronga *et al*. (2018), tomatoes are classified as cold-sensitive vegetables, since their growth and development are significantly impacted when exposed to temperatures below 12°C. According to Cao *et al*. (2015), tomato fruit may experience chilling harm when subjected to temperatures above 10°C for a duration of 14 days or temperatures below 5°C for about one week. The development rate and photosynthesis are reduced, and the emergence of truss and fruit growth are delayed when exposed to low-temperature or sub-optimal temperatures above the chilling temperature. Plants may experience cold stress damage during a timeframe of 48 - 72 hours after exposure to stress (Atayee and Noori, 2020).

WATERLOGGING STRESS:

Flooding or waterlogging, which results from the slow movement of gaseous substances in water and the consumption of oxygen by microbes and plant roots, causes oxygen deprivation in plants. Grafting onto resistant rootstocks, namely brinjal, has been suggested as a potential solution to the issue of flooding in tomatoes. Bahadur *et al*. (2016) and Bhatt *et al*. (2015) 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^{-1} for 30 days). **Figure 3** demonstrates a favorable transformation in vegetable crops as a result of grafting.

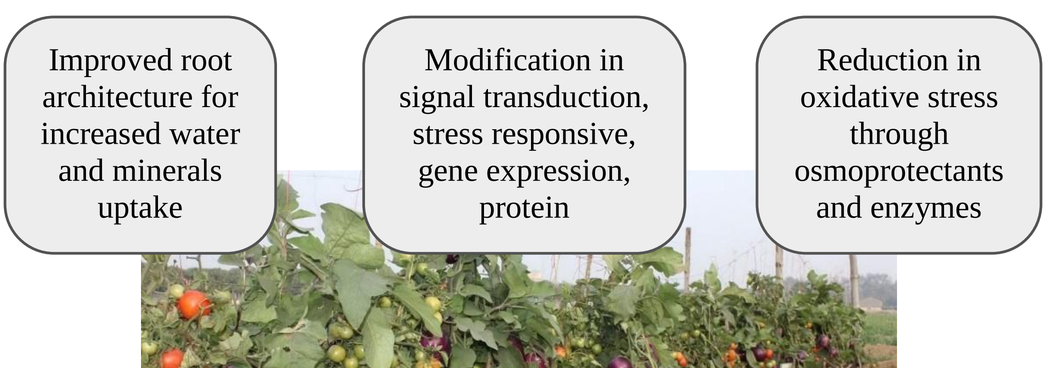

Figure 3. Beneficial impact of grafting in vegetables

According to Bahadur *et al*. (2015) grafted watermelon and tomato plants have been shown to have increased adventitious roots and parenchyma production, which is linked to their ability to tolerate waterlogging (Bahadur *et al*., 2016). The use of promising rootstocks for grafting is widely recognized as a viable strategy for minimizing the adverse impacts of floods in various vegetable crops. For example, Bhatt *et al*. (2015) shown that tomato plants can tolerate waterlogging or flooding for a duration of 4-6 days by using eggplant as a rootstock (Kato *et al*., 2001). According to Haghighi and Khosravi (2022), the grafting of cucumber into 'Ferro' and 'Cobalt' resulted in a notable enhancement of flooding stressin cucumber. Grafting has the potential to enhance the tolerance of bitter melon to waterlogging stress (Peng *et al*., 2020). This improvement is achieved through the upregulation of anaerobic respiration enzymes, namely pyruvate dehydrogenaseinboth adventitious and taproots. Additionally, grafting also leads to the expansion of the aerenchyma in the adventitious roots of bitter melon. In contrast, the non-grafted plants experienced a reduction in Fv/Fm ranging from 39.6% to 41% and a reduction in CCI ranging from 41% to 100% at 96 hours after exposure to waterlogging stress. In addition, Bahadur *et al*. (2016) have reported that the physiological, biochemical, and yield parameters, exhibited minimal impact on tomato plants subjected to waterlogging conditions for a duration of up to 96 hours when grafted onto eggplant rootstocks. Grafting research conducted at the World Vegetable Centre in Taiwan found that wild varieties of chili can withstand floods in sweet pepper plants in hot-humid conditions, resulting in enhancedproduction (Palada & Wu, 2008).

SALINITY STRESS:

The presence of salinity is a significant abiotic stressor that poses a substantial risk to agricultural output. Salinity stress is seen in around one-third of irrigated land worldwide, and projections indicate that by the year 2050, over 50% of the world's cultivated area would experience the adverse effects of soil salinity (Roșca *et al*., 2023). Salinity arises as a consequence of an inordinate buildup of salts (namely Na^+, Cl^-, and SO_4^-) within the soil or irrigation water. In addition, an excessive number of salts may lead to ion toxicity and an imbalance in nutrients, including potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}), by disrupting their absorption and/or transportation to the shoots (Sholi, 2012).

HEAVY METAL STRESS:

Agricultural soil contaminated with heavy metals poses risks to human health, the environment, and plant development. Many different sources, including industrial runoff, reclaimed wastewater, and soil amendments, have introduced heavy metals including cadmium, arsenic, lead, mercury, and nickel into agricultural environments. It is possible that soil levels of NO_3, SO_4, $H_2PO_4^-$, K^+, Ca^{2+}, Mg^{2+}, and metallic micronutrients (such as Cu) may become abnormally high due to these sources. Limited copper transmission to tomato leaves and roots was noted by Savvas *et al*. (2009) when the tomato variety 'Belladona' was grafted onto the He-Man rootstock (*Solanum lycopersicum* × S. *habrochaites*).

DROUGHT STRESS:

With less water available and more people demanding it, drought stress is becoming worse. Seventy percent of the world's fresh water consumption is attributable to agriculture, and that number is projected to climb sharply in the years ahead (Boretti and Rosa, 2015). Drought stress levels determine the extent to which drought reduces crop yields. As shown for barley under field circumstances, crop loss due to severe drought might be entire in the absence of irrigation (Samarah *et al*., 2009). Results from field experiments were included in a meta-study that found that when water was decreased by around 40%, yields dropped by about 21% in wheat and 39% in maize (Daryanto *et al*., 2016). Drought in Europe is expected to reduce wheat and maize yields by 10% (Webber *et al*., 2018).

When comparing species based on their drought resistance, it is important to keep in mind that, similar to other abiotic stressors, drought-induced yield loss differs between cultivars (Mickky *et al*., 2020). In addition, water scarcity reduces crop quality; for instance, rapeseed seeds have been shown to have less oil when grown in drought (Hussain *et al*., 2018). The stage of development at which a plant is when drought strikes is an important consideration in determining yield loss. According to Dufková *et al*. (2022), plants are more susceptible to drought while they are in the reproductive stage. Consequently, according to Wiegmann *et al*. (2019), improving the timing of plant growth might lead to improved yields. According to Farooq *et al*. (2016), traits including grain filling, flower output, seed composition, and lifespan are all negatively impacted by prolonged exposure to drought stress during the reproductive period.

Reduced fruit set in tomatoes and chillis, tomato and cabbage splitting, root crop nitrate toxicity, watermelon bitterness, and cucumbers with crooked fruits are some notable impacts of drought stress. According to Padilla *et al*. (2023), one way to decrease output losses and boost water use efficiency (WUE) during drought is to graft high-yielding vegetable cultivars onto rootstocks that may mitigate the effects of water stress on the shoot. The effects of water stress on the development and output of many vegetable cropshave been extensively studied (Djidonou *et al*., 2013). During drought stress circumstances, interspecific grafting of cucumber plants led to higher plant heightand also a notable decrease in leaf lipid peroxidation content (Coskun, 2023). In order to alleviate drought stress in plants, rootstock mediated phytohormone synthesis is also crucial **(see table 1)**.

Table 1. The aims of using grafting in vegetables by using different rootstock.

Plant	Rootstock	Aims	References

Tomato	*Solanum lycopersicum*x *S. habrochaites* interspecific hybrid	Able to withstand bacterial, Fusarium, root knot, verticillium, corky root, floods, drought, salt, temperature, longer fruiting, greater yield, and fruit quality.	(Awu *et al*., 2023)
Eggplant	*Solanum torvum*and *S. integrifolium*	This includes plant vigor, yields, nutritional composition, and resistance to bacterial, verticillium, and Fusarium wilts.	(Consentino *et al*., 2022)
Watermelon	*Cucurbitamaxima* x *Cucurbita moschata*	Strong roots, Fusarium wilt tolerance, physiological abnormalities, low and high temperature, B. hispida for many diseases tolerance	(Pal *et al*., 2020)
Cucumber	*Cucurbita ficifolia* (fig-leaf gourd)	Robust root system, resistance to water stress, phytophthora, low and high temperatures, and nematodes	Zhen *et al*., 2023
Muskmelon	*Cucumis melo, Cucumis metuliferus*	Fruit quality, Phytophthora infections, a robust root system, and high soil moisture	(Chawda, 2021)

2. QUALITY AND YIELD PARAMETER:

The freshness, texture, flavor and health-related compounds of a vegetable fruit are some of the criteria for determining its quality. Heavy metals, pesticides, and nitrates are some of the undesirable compounds that should be minimized. It is well-known that grafting may alter the nutritional value, taste, and physical characteristics of vegetables, particularly the amounts of minerals, vitamin C, and carotenoids (Rouphael *et al*., 2010). Because research on the impact of grafting on quality characteristics is mixed, selecting the right rootstock/scion combination is essential for optimal fruit quality. It has been noted that watermelon grafting results in subpar fruit quality, such as lower levels of soluble solids, more yellowish bands in the flesh, bland flavor, uneven texture (due to the presence of more fibers), and less firmness (Lee & Oda, 2003).Grafting is a powerful method for improving the nutritional value and bio-fortification of vegetables

3. CONCLUSION:

Significant physiological and biochemical processes such as reduced photosynthetic activity, altered metabolism and enzymatic activity, thermal injury to the tissues, reduced pollination and fruit set, etc. are significantly impacted by abiotic stresses such as low and high temperatures, drought, salinity flooding, heavy metals, and so on, which in turn significantly reduce tomato yield and quality. When compared to the time-consuming process of breeding tomatoes to be more resistant to environmental stress, grafting is a clear winner. Soil and weather circumstances that aren't ideal are common for many vegetable crops that are in the Cucurbitaceous and Solanaceous families. Grafting is a potential method for improving plant production in Cucurbitaceous and Solanaceous vegetables when contact with different types of abiotic stress, including drought, salt, waterlogging, sub- or supra-optimal temperature, heavy metals, and soil-borne pathogens. This can lead to higher yields and improved quality traits. This method might become a game-changer in the future for increasing vegetable yields, especially in the face of abiotic stressors, because to its many advantages. To boost tomato crop growth, production, and quality while conferring resistance to abiotic stressors, suitable tolerant rootstocks should be used. Future research should concentrate on graft compatibility as it is an important component of successful grafting.

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