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Vegetable Grafting: A novel approach for tolerance against environmental stresses

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Abstract
Vegetables are susceptible to various environmental stresses both biotic as well as abiotic factors due to the changing environment. The position of vegetables for human health cannot be understated, and they are the most significant source of nourishment in our diet. The majority of vegetable crops are frequently subjected to a variety of environmental conditions, such as salt, drought, alkalinity, and heavy metals, which severely hamper growth and development and result in significant production losses. The yield potential of horticulture crops cannot be increased solely through breeding because this would increase the sustainability of high input production methods and inevitably widen the yield gap under unfavourable conditions. To lessen production losses brought on by unfavourable climatic changes grafting could act as one way. Grafting is the fastest, most effective, and environmentally friendly plant surgery procedure. The tolerance of grafted plants to unfavourable climatic circumstances can therefore be influenced by both the scion and the rootstock because it is an integrable reciprocal process. With the help of this review, we are able to defend the effectiveness of grafting plant propagation techniques as a way to lessen the effects of abiotic pressures on the development and production of horticultural crops.

Keywords: Abiotic stress, biotic stress, environment grafting and rootstock

Introduction

There are numerous biotic and abiotic elements that affect the growth and yield of vegetable crops grown in greenhouses and open fields (Rouphael *et al.*, 2018) [40]. Several enhanced characteristics of grafted plants have been linked to capability of grafting to raise vegetable crop's resistance to biotic and abiotic stresses, including: (1) stronger root system equipment; (2) increased absorption of nutrients and water; (3) enhanced water relations and photosynthetic efficiency; (4) enhanced antioxidant protection; (5) additional hormonal signalling; and (6) motion of mRNAs, short RNAs, and proteins over great distances (Albacete *et al.*, 2015; Warschefsky *et al.*, 2016; Kumar *et al.*, 2017) [3, 4, 50]. These mechanisms affect the functioning of both the shoot and the root, and the interdependence of the variables involved (the rootstock, scion, and environment) conceals specific donation to phenotypic alteration (Warschefsky *et al.*, 2016) [50]. In hydroponics, where there is a considerable risk of the rapid spread of noxious diseases once they are infected, grafted seedlings are highly preferred (Adarsh *et al.*, 2020) [2]. Breeding attempts are hampered by the need to combine desired features with numerous stresses while avoiding unwanted combinatorial or pleiotropic effects (Rouphael *et al.*, 2018) [40]. Advances in grafting, a surgical substitute for breeding that couples two independent genotypes chosen separately for favourable root and shoot features, have made it easier to select desirable qualities for herbaceous annual crops (Albacete *et al.*, 2015; Koevoets *et al.*, 2016) [3, 4]. The main cause as for crop failure or total loss is environmental stress caused by a shifting solar cycle. Extreme temperatures, droughts, and salinity are the main environmental pressures that limit the production of agricultural and horticultural crops on a sustainable basis. The severity of the stress on plants depends on its nature, duration, and growth stage. Numerous studies have been done on the application of grafting method to various vegetable crops to boost their liberality to a wide range of environmental conditions. (Singh *et al.*, 2020). Grafting high yielding genotypes onto chosen rootstocks in vegetable crops could be a potential technique for an abiotic stress.

Flooding

While growing and developing, several crops are sensitive of flooded soil conditions, and many vegetable crops are badly impacted by excessive moisture brought on by unexpectedly heavy rains because of the higher sensitivity to flooding

(Liao and Lin, 1996; Kato *et al.*, 2001) [27, 22, 23, 24]. Because of the high moisture content, plant roots contain less oxygen, which alters photosynthesis and water potential. Numerous research teams have demonstrated that grafting increases flooding tolerance in a range of crops (Bhatt *et al.*, 2015) [7]. One globally consumed vegetable which is vulnerable to flooding is tomato (Petran and Hoover, 2014) [35]. Interspecific tomato grafting was utilised by Bhatt et al. (2015) [7] to increase flooding tolerance. Arka Rakshak was grafted on different brinjal rootstocks which includes Neelkanth, Arka Keshav, Mattu Gulla and BPLH-1. The findings demonstrated that grafting had a considerable impact on yield in both wet and dry situations. Non-grafted and self-grafted plants perished after 5 days of flooding, but two combinations namely Arka Keshav and Arka Rakshak/BPLH-1—performed superior. Both the egg plant's capacity to tolerate flooded soil conditions and its potential to serve as a good grafting rootstock to increase tomatoes' capacity to withstand flooding are asserted. In Taiwan, H7996 and brinjal rootstock (EG203) had the greatest degree of opposition to the widest variety of strains examined (Lin *et al.*, 2008) [28]. Significant examples given by different researchers with relation to various vegetable rootstocks and their characteristics performing best under flooding stress are mentioned in Table 1.

Fig 1: Seedling of Tomato under flood stress.

Table 1: Examples of different vegetable rootstocks and their characteristics performing best under flooding stress.

Sr. No.	Rootstocks	Cultivars	Major characteristics	References
1.	*Lagenaria siceraria*	*Citrullus lanatus* (Crimson Tide)	Under flooded conditions, adventitious roots and arenchyma tissue both develop, and chlorophyll loss is decreased.	Yetisir *et al.*, 2006
2.	An interspecific cross between *Cucurbita maxima* Duch. × *Cucurbita moschata* Duch. (Shintosha-ichigou)	Kaga-aonagafushinari cultivar of *Cucumis sativus* L.	Induces the biosynthesis of ethylene, which reduces degradation of chlorophyll	Kato *et al.*, 2001a, 2001b [22, 23, 24]
3.	*Solanum melongena* cultivar Mattu Gulla, Arka Neelkanth (IIHR), Arka Keshav (IIHR) and BPLH1	(Arka Rakshak) a variety of tomato from IIHR, Bangalore	Photosynthetic rate and chlorophyll fluorescence decline less. CO2 concentration and stomatal conductance	Bhatt *et al.*, 2015 [7]
4.	*Luffa cylindrica Roem*	*Momordica charanthia* cultivar New Known You	Rate of Photosynthesis, degree of stomatal opening, evaporation of water through aerial parts, and RuBisCo activity all decreased slightly.	Liao & Lin, 1996 [27]

Thermal stress

Plants that grow vegetables are extremely sensitive to both high and low temperatures. Tropical environments typically experience high temperatures during the growing season, while temperate and subtropical environments experience chilling or low temperatures during the winter, spring, and autumn seasons. This is particularly problematic for the production of vegetables like tomatoes, squash, cucumbers, and others. Low temperatures can also affect how seeds sprout, seedlings develop, and plants mature, which lowers the profit (Venema *et al.*, 2008) [48]. For instance, because high temperatures promote fewer fruit sets, smaller fruits, and lower fruit quality, they drastically impair tomato crop yield. Whereas, when the temperature is below optimum levels or low it leads to everlasting malfunction, cell bereavement, and ultimately plant demise determined by the extent and exposure time. Temperature has an impact on early fruit output and quality traits. Since these stresses are genetically complex and plant-specific, efforts to generate cultivars with improved thermal stress resistance utilising breeding and various biotechnological methods have met with very little commercial success. Therefore, grafting premium commercial cultivars that are currently available onto chosen high or low temperature resistant rootstocks could be seen as a useful method of plant multiplication that is quick and effective.

In the Netherlands, Den Nijs performed a grafting experiment using *Cucurbita ficifolia* as the rootstock and four advanced breeding lines to manage low temperatures. The experiment shown that grafted plants outperformed non-grafted plants in terms of survival, lifespan, and fruit quality at low temperatures. Horvath *et al.*, continued on the aforementioned study in 1983 and concluded that the plants of cucumber grafted on rootstock of *C. ficifolia* boosted the trans-hexadecenoic acid in phosphatidyl glycerol that assist plants tolerate low temperatures. Throughout all phases of growth and development, the cultivated tomato plant is extremely delicate to suboptimal in addition to cold temperatures. One rapid strategy to increase tomato tolerance to cold stress is to graft high yielding commercial cultivars that are vulnerable onto rootstock that is tolerant. To investigate how cold temperatures affected the wild tomato *Solanum habrochaites* accession, the tomato cultivar Moneymaker was grafted onto it (LA) 1777. (Venema *et al.*, 2008) [48]. Studies were done on the behaviour of cultivar Herminio plants that were not grafted and those that were grafted on rootstocks namely Atlante, Create, and Terrano in shaded as well as un-shaded situations. In both situations, grafted plants outperformed non-grafted ones. Plants grafted onto Atlante root stock had around 40% higher leaf area than the other pairings, but the results were neutral for Atlante. There was no discernible impact of grafting into Creonteeli on leaf biomass grafted plants. (Del Amor *et al.*, 2008) [16] Suggested that when the rootstock Creontemay is grafted to sweet pepper, then it is capable of resisting thermal stress.

Fig 2: Effect of cold stress in Capsicum.

Table 2: Examples of different vegetable rootstocks and their characteristics performing best under thermal stress.

Sr No.	Rootstocks	Cultivars	Major characteristics	References
1.	Tomato (Summerset) and Brinjal (Black Beauty)	Tomato (UC 82-B)	Greater the leaf area, greater will be the leaf fresh and dry weight Pollen grains per flower	Abdelmageed and Gruda, 2009 [1]
2.	*Solanum habrochaites* (line LA1777)	Tomato (Moneymaker)	Root mass ratio is enhanced A higher concentration of total leaf carbon	Venema *et al.*, 2008 [48]
3.	*Cucurbita ficifolia Bouche* (Fig leaf Guard)	*Cucumis sativus* L. (Jinyan No. 4)	Carboxylation activity RuBisCO activity are reduced less, resulting in higher carbon dioxide assimilation.	Zhou *et al.*, 2007 [54]
4.	*Solanum lycopersicum* (RX-335)	Tomato (Tmknvf2)	Enhanced the PAL activity. It has decreased PPO as well as GPX activity. Reduction in dry weight content.	Rivero *et al.*, 2003 [37]
5.	LA 1778 accession of *Solanum lycopersicum*	Tomato	In grafted plants, root hydraulic conductance and stomatal conductance were preserved.	Bloom *et al.*, 2004 [8]

Drought

Another significant issue with water stress that affects sustainable vegetable production globally is drought, which happens when there is a water shortage. Despite some novel drought-tolerant crop types emerging as a result of breeding and biotechnological treatments, these developments have largely only applied to cereal crops (Potop *et al.*, 2012) [36]. Environmental abnormalities unquestionably have a considerable impact on water availability, which in turn affects crop output, particularly in case of vegetable crops, and complete failure of the crops are typical. The decreasing amount of irrigation water may be due to less precipitation and an increase in mean air temperature. Vegetables contain 90% water, hence a rise in evapotranspiration under drought circumstances would also be anticipated (Brown *et al.*, 1997; Thomas *et al.*, 2007). Environmental stressors like water scarcity and drought stress will be crucial in the case of global climate change (Schwarz *et al.*, 2010). Thus, grafting could help us to lower yield deprivation and enhance the water usage effectiveness (WUE). Commercial cultivars with high yields that are susceptible to water stress could be grafted onto rootstocks that can minimise the effects of water stress on the shoot to do this efficiently. In Europe, interspecific hybrids and Solanum spp. are common rootstocks for eggplant hybrids. Water stress on the watermelon shoots is also lessened by grafting watermelon on pumpkin rootstocks (Davis *et al.*, 2008; King *et al.*, 2010) [15, 25]. Grafting scions onto rootstock that shows tolerance towards various stresses has been used in vegetable crops, belonging to Solanaceae and Cucurbitaceae families, to regulate or improve drought tolerance (Sanchez-Rodriguez *et al.*, 2016) [43]. To obtain grafted plants in various combinations, Sanchez-Rodriguez and Ruiz experimented with tomato using a drought-tolerant cultivar and a drought sensitive cultivar (Liu *et al.*, 2016) [29]. The findings of this study revealed that fruits from grafted and non-grafted plants under drought stress have different levels of antioxidant enzymes. According to research on cucumber, grafting increased WUE via influencing the ABA production pathway, which in turn increased plant growth and yield (Sakata *et al.*, 2007) [41]. After being grafted onto relatively tolerant rootstocks, sensitive pepper plants, osmotic manipulations took place according to the water stress level (Penella *et al.*, 2014) [34]. An experiment conducted at the same time revealed that in the grafted tomato plants, due to the effective production of micro and macronutrients, plant vigour has increased in turn raised economic yield (Ibrahim *et al.*, 2014) [21]. Table 3. represents the different vegetable rootstocks that are compatible to various scions performing best under drought stress.

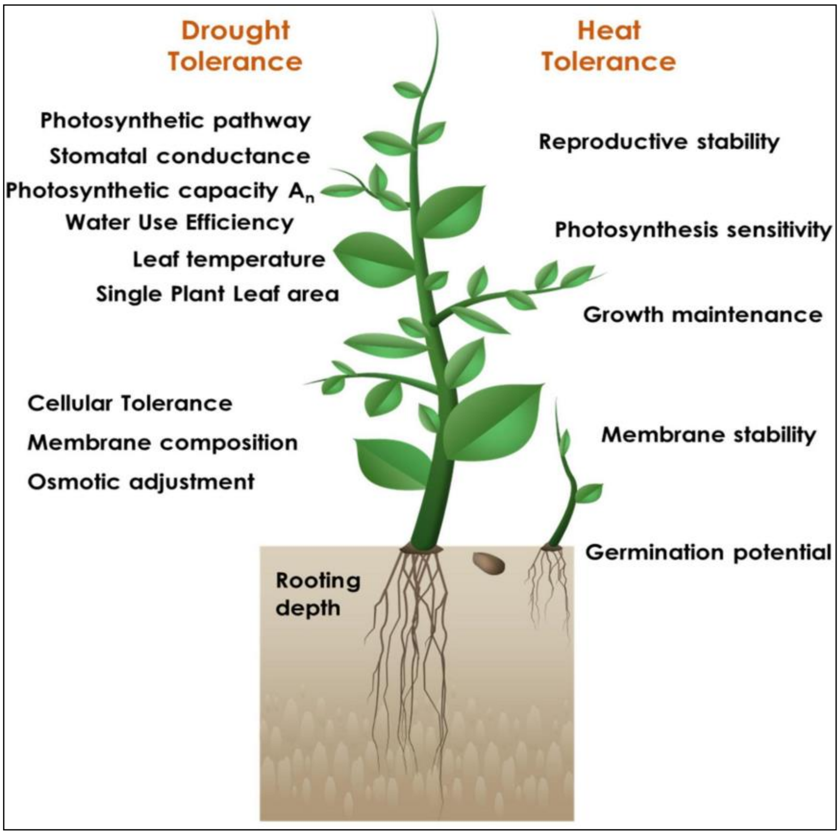

Fig 3: Physiological-trait based screening for identification of drought and heat stress tolerant stresses.

Table 3: Examples of different vegetable rootstocks and their characteristics performing best under drought stress

Sr. No.	Rootstocks	Cultivars	Major characteristics	References
1.	Tomato (Beaufort and Maxifort)	Tomato (Amelia)	Photosynthesis and stomatal conduction were found to be improved.	Chaudhari *et al.*, 2017 [10]
2.	Capsicum (*Capsicum annum*) rootstock named Terrano/Atlante/Creonte	Capsicum (Herminio)	A higher rate of photosynthesis, higher relative moisture (leaf), more LAI (Leaf Area Index), and the preservation of a high ratio of vegetative to reproductive components	Lopez-Marin *et al.*, 2017 [30]
3.	Tomato (Unifort)	Tomato (Farida)	In grafted plants elevation in yield, WUE and growth was observed.	Wahb-Allah, 2014 [21, 49]
4.	Tomato (Zarina)	Tomato (Josefina)	Radicle is improved and intensify utility of micronutrients *viz.* Copper, Nitrogen, Phosphorus, and Potassium.	Sanchez-Rodriguez *et al.*, 2014 [42]
5.	Tomato (Beufort)	Tomato (M28)	A higher rate of photosynthesis, more consistent (LAI) is observed and the least amount of a decrease in chlorophyll b content.	Altunlu & Gul, 2012 [5]
6.	Tomato (Jjak Kkung)	Tomato (BHN 602)	It enhanced the photosynthetic activity and aboveground growth is reduced.	Nilsen *et al.*, 2014 [32]
7.	PS 1313 hybrid between *C. maxima Duchesne* × *C. moschata Duchesne*	Watermelon	Increase in uptake of nutrients (Mg, N, and K), and water and also in CO2 assimilation	Rouphael *et al.*, 2008 [38]
8.	Sweet pepper (Verset)	PI-15225 ECU-973 and Atlante accessions of sweet pepper	An efficient lowering of osmotic potential was perceived, followed by the optimal function of photosynthesis in water scarcity circumstances.	Penella *et al.*, 2014 [34]
9.	*Solanum lycopersicum* (Faridah)	Tomato (Unifort)	With the grafting there is production of more robust vegetables with excessive fruit quality (enhanced Vit. C, TSS and total sugar amounts)	Ibrahim *et al.*, 2014 [21]

Salinity

Soil salinity affects around 7% of the world's land surface and about 20% of irrigated arable land (Shahid *et al.*, 2018) [45]. Climate change encourages salinization; hence it has been anticipated that, in climate change scenarios, there will be an increase in the amount of salt land (Srivastava and Kumar, 2015) [46]. Salinity adversely affects the growth and also the development of plants. 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. Many of the techniques created to recover salty soils are only band-aid solutions that are costly to implement (Machado and Serralheiro, 2017) [31]. The development of vegetable crops that are salt-tolerant, has also been investigated, although this needs numerous cycles of plant breeding due to the complicated polygenic characteristic that induces salt tolerance (Ashraf *et al.*, 2008) [6]. Crop tolerance to salt stress was thought to be improved through the adoption of resistant genotypes as the rootstocks (Koevoets *et al.*, 2016) [26]. Studies on the salt tolerance of grafted vegetable crops have been conducted over the past ten years, and most research have discovered that the most effective technique to improve salt tolerance is by grafting. (Colla *et al.*, 2010) [13, 44]. There is improvement in grafted tomato plants against salt tolerance because of Interspecific hybrid rootstock (Di Gioia *et al.*, 2013) [18]. Watermelon plants were able to tolerate salt more than a few times better, while using bottle gourd as a rootstock (Yang *et al.*, 2013) [51]. The interspecific hybrid of pumpkin and squash which was first described by (Orsini *et al.*, 2013) [55], 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.

Table 4: Examples of different vegetable rootstocks and their characteristics performing best under salinity stress:

Sr. No.	Rootstocks	Cultivars	Major characteristics	References
1.	*Lagenaria siceraria* Standl. Nunhems Zaden,	Watermelon	There is an increase in dry matter, total soluble solids, and sugar content.	Colla *et al.*, 2006 [11]
2.	Fig leaf gourd	Cucumber plant cv. Jinchun No.2	The scion dry weight, soluble sugar content, and micronutrient content of grafted plants were all significantly higher.	Huang *et al.*, 2010 [38]
3.	*Cucurbita* hybrid rootstocks PS 1313	*Cucumis sativus* (Akito)	Higher nutritional value, higher net assimilation rate, and higher chlorophyll content (SPAD index).	Colla *et al.*, 2012 [14]
4.	*Cucurbita* hybrid (P360 and PS13132)	*Cucurbita melo* L. Cyrano *Cucumis sativus* Akito	The leaf area index is reduced less in grafted plants. In grafted individuals' salinity has a smaller effect on net photosynthetic rate and stomatal conductance.	Rouphael *et al.*, (2012) [14, 39]
5.	Interspecific cross between (*Solanum lycopersicum* × *S. habrochaites*)	Tomato (*Cuore di bue*)	Juice content of fruits has increased	Di Gioia *et al.*, 2013 [18]
6.	Cucumber (*Cucumis sativus* L.) (Affyne)	*Cucumis sativus* L. (Ekron)	A rise in photochemical activity. Less chlorophyll concentration reduction (SPAD index)	Colla *et al.*, 2013 [12]
7.	Pumpkin	*Cucumis sativus* L. (Jinchun No. 2)	Peroxidase, Glutathione reductase, ascorbate, and Dehydroascorbate reductase were shown to have relatively enhanced activity in the chloroplasts of plants that had undergone grafting.	Zhen *et al.*, 2011 [53]
8.	Interspecific cross between (*C. maxima* × *C. moschata*) RS841 improved	*Cucumis melo* L.	increased biomass as well as (LAI) in plants improved stomatal control when exposed to salt stress	Orshini *et al.*, 2013
9.	(*Lagenaria siceraria* Standl.)	(*Citrullus lanatus*) cv. Xiuli	Rise in biomass overall	Yang *et al.*, 2013 [51]

Conclusions and future thrust

In conclusion, the scientific literature has highlighted grafting of cutting and rootstalk in hereditarily diverse vegetable crops, as a promising technique for decreasing environmental stressors anticipated under a scenario of changing global climate. To analyse and evaluate elite diversified germplasm as a source of the viable root stock, a new study should be carried out. The placement, communication between the scion and rootstock, and reciprocal action of the shoot and root systems are just a few of the factors that must be considered in order for the grafting process to be fully effective. More research be compelled to develop grafting techniques that speeds up this method in order for grafting to become a significant component of the production of modern vegetable crops. Vegetable farmers won't be able to employ grafted plant material more economically unless modern simulation and automated grafting techniques for doing so. Vegetable grafting is also used in industrialised nations due to farmer's updated understanding of contemporary vegetable production techniques. By using vegetable grafting, farmers may combat climate change and put an end to unsustainable vegetable production methods that degrade the soil and use up natural resources quickly. In the future, grafting technology development research will be necessary to produce seedlings in a stable, profitable, and year-round way, making this technique more available to farmers everywhere.

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