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Vegetable grafting: A new milestone for mitigating global climate change

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Abstract
Climate change has significant devastating effect on abiotic stress in vegetable production. Vegetable cropping systems must have high resilience to climate change, so that production practices can achieve economic profitability and environmental sustainability. Different abiotic stress including flooding, drought and extreme temperatures have drastic effect towards vegetable crop production leading to reduced yield potential of vegetable crops are photoperiod reduction, water availability and poor vernalization leading to total crop failures. Recent researches infer that adaptation to counteract environmental stresses and improving the tolerance can be possible through alteration of the root system through grafting over selected vigorous rootstocks. Some of the successful achievements include grafting of Bitter melon (*Momordia charanthia*) cv. New Known on rootstock of Luffa (*Luffa cylindria* Roem) cv. Cylinder leading to flooding tolerant genotype. Similarly, drought resistance have been achieved by grafting Tomato (*Solanum lycopersicum*) cv. M28 scion with Tomato (*Solanum lycopersicum*) cv. Beaufort rootstock. Besides there are evidences of mitigating thermal stress through grafting of Cucumber (*Cucumis sativus*) cv. Jinyan No. 4 scion with Figleaf Guard (*Cucurbita ficifolia*) and Luffa (*Luffa cylindrica*) cv. Xiangfei rootstock. Salinity tolerance has also been achieved by grafting Cucumber (*Cucumis sativus* L.) cv. Jinchun No. 2 scion with Pumpkin (*Cucurbita moschata* Duch.) cv. Chaojiquanwang rootstock. Therefore in this context, vegetable grafting has been reported to be highly efficient, eco-friendly plant surgical technique for development of climate resilience crop production in order to combat with different abiotic stress.

Keywords: abiotic stress, grafting, resilience, vegetables

Introduction
The worldwide drastic climate change represents the devastating abiotic stress impact on crop and health of human beings (Costello *et al.*, 2009) [4]. This has been given a profuse global priority because of its adverse effect on agricultural practices (Olesen & Bindi, 2002; Baer & Risbey, 2008) [9, 2]. Globally, it has been reported that approximately 50% deterioration of crop yield as well as drastic crop failures have been caused by these environmental stressors. The global change in climatic conditions has a significant effect on vegetable crops because of their susceptibility to different environmental conditions. Therefore, it can be inferred that the global climatic variations are likely to have drastic effects on vegetable production anatomically, biochemically, physiologically and morphologically.

A successful grafting technique is dependent upon the compatibility of scion and rootstock. In order to mitigate different environmental stress, susceptible scions are grafted over resistant rootstocks.(Altunlu & Gul, 2012**;** Nilsen *et al.*, 2014) [8]. Grafting is an eco- friendly, successful, fast and surgical process in which either of the rootstock and scion has considerable impact on the transformed plant (Sakata *et al.*, 2007). In Japan, this approach was initially applied in watermelon. (He *et al.*, 2009) [6]. Recently, it has been reported that scientists around the globe are applying this technique, for increasing the resistance to abiotic stresses in cucurbitaceous and solanaceous vegetables thereby improving qualitatively as well as quantitatively.

Grafting and environmental stress
Environmental stress, due to changing worldwide climate can be considered as the principle reason for failure of crop production. The different limiting factors for successful production of vegetable crops including profuse temperature variations, sudden flooding and drought due to irregular rainfalls and salinity are various environmental stressors (Mittler, 2006) [7].

The intensity of these abiotic stresses on plants is based upon the different phenological stage, type of stress as well as period of stress exposure (Crawford, 1982) [5].

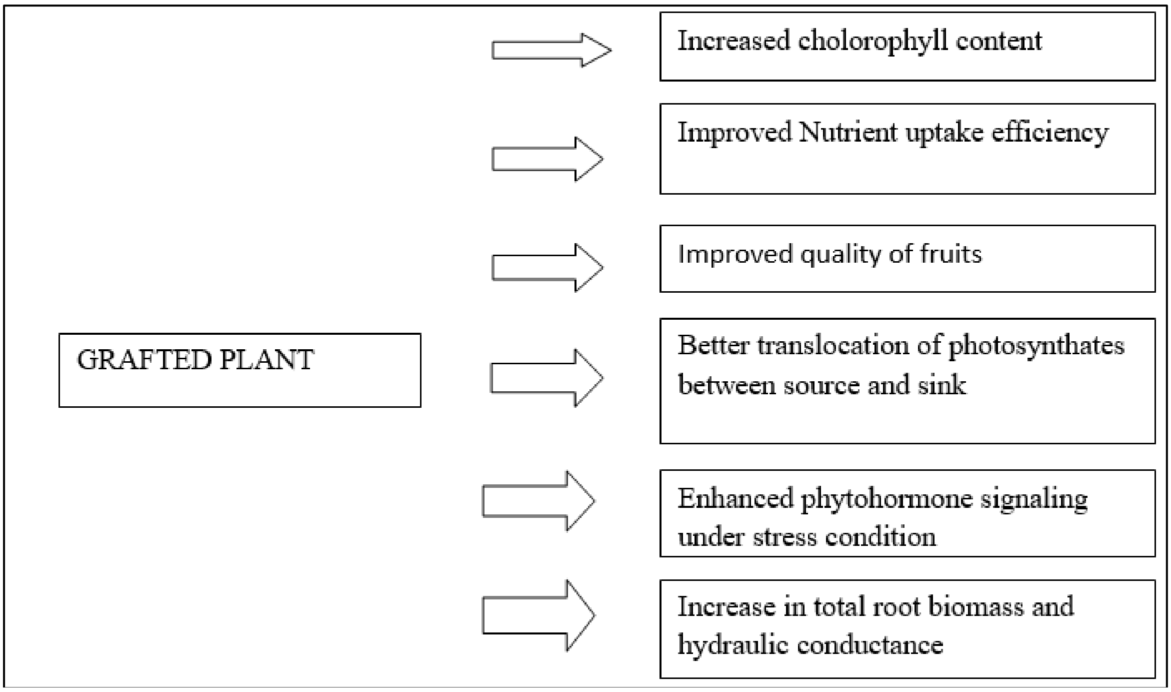

Fig 1: Properties of grafted plant mitigating stress tolerance

Unpredictable heavy rainfall and excessive moisture adversely affect many vegetable crops and their production due to their high susceptibility to flooding. However, it has been reported that some vegetables show intolerance to flooded soil conditions during their different phenological stages of growth and development. Presence of excessive soil moisture in leads to reduced concentration of available oxygen in the root rhizosphere of plants by alteration of the rate of photosynthesis. It has been reported that grafting has been applied to improve the flooding tolerance character in various vegetable crops. A detailed illustration of vegetable grafting for flooding tolerance has been mentioned in Table below.

Table 1: Vegetable grafting for flooding tolerance

Rootstock	Scion	Key improved characteristics
Luffa (*Luffa cylindria* Roem) cv. Cylinder	Bitter melon (*Momordia charanthia*) cv. New Known You	Slight reduction in photosynthetic rate, stomatal movement, rate of transpiration and the activity of RuBisCO
Lagenaria siceraria	Watermelon (*Citrullus lanatus* (thunb.) Matsum and Nakai) cv. Crimson Tide	Under flooded conditions, chlorophyll loss has been reduced. Besides, there has been the formation of aerenchyma tissue and adventitious roots.
Eggplant (*Solanum melongena*) cv. Arka Neelkanth, Mattu Gulla, BPLH1 and Arka Keshav	Tomato (*Solanum lycopersicum*) cv. Arka Rakshak	The declination of photosynthetic rate has been reduced. Enhanced stomatal conductance and CO_2 concentration. Physiological adaptation has been improved along with better fruit yield.
Eggplant (*Solanum melongena*) cv. IC-354557, IC-111056, IC-374873, CHBR-2	Tomato (*Solanum lycopersicum*) Hybrid line cv. Arka Rakshak, Arka Samrat	Reports infer comparatively lesser reduction in chlorophyll fluorescence yield and chlorophyll content.

The water limiting conditions leading to tremendous worldwide drought has been proved to be highly detrimental for sustainable vegetable production. The reduced level of available irrigation water is basically due to reduced rates of precipitation along with increased mean air temperature. Under drought conditions, there are chances of enhanced rates of evapotranspiration in vegetables being rich in water content. Therefore, during periods of acute water scarcity, vegetable grafting has been reported to be a potential tool for increasing the water use efficiency (WUE) of the plants. The effect of water stress on the shoot can be reduced by grafting drought sensitive scions with drought tolerant rootstocks. A detailed illustration of vegetable grafting for mitigating drought sress has been mentioned in Table below.

Table 2: Vegetable grafting for mitigating drought stress (Chaudhari *et al*., 2017)

Rootstock	Scion	Key improved characteristics
Tomato (*Solanum lycopersicum*) cv. Beaufort	Tomato (*Solanum lycopersicum*) cv.M28	The total proline and carotenoid content has been relatively increased. Reduction in chlorophyll b concentration has been decreased. There has been increase in total biomass content.
Tomato (*Solanum lycopersicum*) cv. Zarina	Tomato (*Solanum lycopersicum*) cv. Josefina	Improved uptake of nutrients including Fe, Cu, N, P and K has been due to development of better radicular system.
Tomato (*Solanum lycopersicum* L.) cv. Faridah	Tomato (*Solanum lycopersicum* L.) cv. Unifort	Plant vigor and fruit quality has been improved with increased concentration of vitamin C, total soluble salts and total sugar.
Tomato (*Solanum lycopersicum* L.) cv. Unifort	Tomato (*Solanum lycopersicum* L.) cv. Farida	Grafting has lead to Increase in WUE, growth and yield potential among the plants
Tomato (*Solanum lycopersicum*) cv. Beaufort and cv. Maxifort	Tomato (*Solanum lycopersicum*) cv. Amelia	Stomatal conductance and photosynthesis rates have been improved.

High levels of temperature variation results in reduction in vegetable production by promoting wilt and necrosis, reduction in the rate of appearance of truss and influencing the timing of fruit ripening. Vegetable grafting can be a potential tool for protection of plants from heat shock. Reports prove that vegetable crops are highly susceptible to extreme temperatures. Extreme-temperature is a major stressor for production of vegetables especially for those belonging to family solanaceae and cucurbitaceae. Low temperatures affect rate of seed germination, growth of seedling as well as development of plant resulting in economic yield loss. Grafting of elite scions on temperature resistant rootstocks can prove to be a viable plant propagation technique. A detailed illustration of vegetable grafting for mitigating thermal stress has been mentioned in Table below.

Table 3: Vegetable grafting for mitigating thermal stress (Li *et al*., 2014)

Rootstock	Scion	Key improved characteristics
Tomato (*Solanum lycopersicum*) cv. RX-335	Tomato (*Solanum lycopersicum*) cv. Tmknvf2	Enhanced activity of Phenylalanine Ammonia Lyase. Decreased Polyphenol Oxidase and Glutathione Peroxidase activity. Decrease in dry weight. Increase in concentration of total phenols and odiphenols
Tomato (*Solanum lycopersicum*) cv. Summerset and Eggplant (*Solanum melongena*) cv. Black Beauty	Tomato (*Solanum lycopersicum*) cv. UC 82-B	Increased area of leaves, enhanced leaf dry and fresh weight Higher fluorescence of chlorophyll pigment, Increased number of pollen grains/flower
Figleaf Guard (*Cucurbita ficifolia*) and Luffa (*Luffa cylindrica*) cv. Xiangfei	Cucumber (*Cucumis sativus*) cv. Jinyan No. 4	Adequate biomass production and CO2 assimilation capacity Reduced peroxidation in lipid and protein oxidation

The soil salinity has been reported to affect approximately 7% of global area as well as approximately 20% of cultivated irrigated land.Plant growth and production is adversely affected by salinity stress. For the development of salt tolerant plants, tolerant rootstocks have been successfully and efficiently grafted with the susceptible scions. (Colla *et al*., 2010). Reports infer the successful interspecific hybridization of tomato rootstocks with susceptible scions through grafting technique has improved the salt tolerance character. A detailed illustration of vegetable grafting for mitigating salinity stress has been mentioned in Table below.

Table 4: Vegetable grafting for mitigating salinity stress

Rootstock	Scion	Key improved characteristics
Cucurbita hybrid rootstocks (*Cucurbita maxima* Duch. X *Cucurbita moschata* Duch.) ‘P360’ and ‘PS13132’	a) Melon (*Cucumis melo* L.) cv. Cyrano b) Cucumber (*Cucumis sativus* L.) cv. Akito	1. In grafted plants, reduction in leaf area index has been comparatively less. 2. Smaller effect of salinity on the in grafted plants, there has been comparatively lesser effect of salinity on the stomatal conductance and net photosynthetic rate.
Cucumber (*Cucumis sativus* L.) cv. Affyne	Cucumber (*Cucumis sativus* L.) cv. Ekron	1. The PSII photochemical activity has been enhanced. 2. The SPAD index deduction has been reduced. Besides the enzymatic activity of Glutathione Peroxidase enzyme was increased thereby leading to enhanced concentration of antioxidants. This further develops the stress tolerance character among the grafted genotypes.
Pumpkin (*Cucurbita moschata* Duch.) cv. Chaojiquanwang	Cucumber (*Cucumis sativus* L.) cv. Jinchun No. 2	Increase in enzymatic activities of ascorbate peroxidase, dehydroascorbate reductase and glutathione reductase were reported in the chloroplasts of grafted plants thereby improving the Hydrogen Peroxidase scavenging capacity. Increased transpiration rates and net Carbon Dioxide assimilation in the grafted plants.

Capsicum baccatum L. var. pendulum 'BOL-58'	Pepper (*Capsicum annum*) cv. Adige	Negative effect on the nitrate reductase activity, lipid peroxidation and photosynthetic ratehas been reduced.

Conclusion and future prospects

Further research should be conducted for the evaluation and testing of elite diverse germplasm as a source of the viable rootstock. However, grafting compatibility depends upon many factors. These include suitable rootstock and scion selection, grafting location and climate as well as reciprocal effect of root and shoot system. Vegetable grafting is a successful alternative approach to conventional and transgenic breeding for improving genotypes by compilation of qualitative and quantitative traits.

Vegetable grafting is an advanced strategy for development of climate resilience by preventing soil degradation as well as depletion of natural resources thereby promoting sustainable vegetable production. More emphasis has to be given towards utilizing this technique on a mass scale especially among the farming community so as to promote a sustainable, economical and year round vegetable production.

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