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Grafting of Vegetable Crops Improve Diseases Control, Salt and Drought Strees Tolerance and Nutrients, Water Use Efficiency (Article Review)

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Abstract

Grafting is a technique used in plants to obtain economic benefits. Grafting increases nutrient uptake and utilization efficiency in vegetables also reduced the negative effects of the pathogens on disease index. Selected rootstocks of the same species or close relatives are utilized in grafting. Rootstocks absorb more water and nutrients than self-rooted plants and transport these water and nutrients to the aboveground scion. Nutrients uptake is regulated by a complex communication mechanism between the scion and rootstock. Sugars, hormones, as long-distance signaling molecules and regulate nutrient uptake and ion homeostasis by affecting the activity of nutrients transporters. Grafting applications have expanded mainly in Solanaceous crops and cucurbits, which are commonly grown in arid and semi-arid areas characterized by long drought periods. The current review gives an overview of the recent scientific literature on root-shoot interaction and rootstock-driven alteration of growth, yield, and fruit quality in grafted vegetable plants under drought stress. Further, we elucidate the drought resistance mechanisms of grafted vegetables at the morpho-physiological, biochemical, and molecular levels. Information will improve the development of nutrient-efficient rootstocks. Water scarcity in arid and semi-arid regions represents a serious problem for agriculture management. Thus, effective irrigation strategies are essential for crop productivity and quality in addition to conserving water. A proper irrigation management is essential for improving the quantity and quality of vegetative crop grown under limited water conditions.

Keywords: grafting, rootstock, scion, WUE, NUE, disease, drought control

Introduction

Grafting is currently practiced worldwide on many high-value cucurbitaceous and solanaceous crops such as watermelon Citrullus lanatus and melon (*Cucumis melo* L.), cucumber (*Cucumis sativus* L.), tomato (*Solanum lycopersicum* L.), eggplant (*S. melongena* L.), and pepper (*Capsicum annuum* L.) for both open-field production and protected culture (Lee *et al*., 2010; Nawaz *et al*., 2016) [38, 49].Vegetable grafting has proven to be an innovative and effective technique for controlling soil borne diseases such as fusarium wilt (caused by *Fusarium oxysporum*), verticillium wilt (caused by *Verticillium dahliae*), southern blight (caused by *Sclerotium rolfsii*), and bacterial wilt (caused by *Ralstonia solanacearum*) (McAvoy *et al*., 2012; Rivard and Louws, 2008; Rivard *et al*., 2010, 2012) [45, 43, 62] as well as root-knot nematodes (*Meloidogyne* spp.) (Barrett *et al*., 2012; Bausher, 2009; Lo´pez-Pe´rez *et al*., 2006; Guan and Xin, 2012) [9, 10, 42, 30]. Grafting with certain rootstocks has also been shown to improve plant tolerance to abiotic stresses such as high salt and low temperature (Schwarz *et al*., 2010; Kumr *et al*., 2017) [72].

Previous studies have demonstrated that in addition to disease management, plant vigor and yield often increase as a result of grafting with vigorous rootstocks. In the case of tomato production, grafted plants can increase marketable yield by 20**%** to 62% over non-grafted plants, depending on scion–rootstock combinations and production conditions **(**Di Gioia *et al*., 2010; cf *et al*., 2018, 2019) [17].

The improved productivity of grafted plants has been attributed by some studies to the intrinsic vigor of the rootstock and the scion–rootstock interaction, which in turn exerts positive influence on plant nutrient and water absorption, N assimilation, and photosynthetic processes (Aloni *et al*., 2010; Lee *et al*., 2010; Stegemann and Bock;2009) [4, 38, 75]. Given the physiological and phenotypic modifications caused by grafting with selected, vigorous rootstocks ,it is likely that irrigation and fertilization management for maximizing crop yield may differ between grafted vs. non-grafted vegetable production. In addition to these commercially important benefits, grafting increases nutrient uptake and utilization efficiency in a number of plant species (Schwarz *et al*., 2013; Huang *et al*., 2013b; Esmaeili *et al*., 2015) [73, 32, 20]. The world's nutrient resources are finite (Venema *et al*., 2011) [76] and thus require justified utilization; moreover, inorganic fertilizers are expensive. Scientists are working to modify the root architecture of cereal crops (monocots) to enhance nutrient uptake and utilization efficiency (*et al*., 2015; Rogers and Benfey, 2015; Wissuwa *et al*., 2016) [63, 78]. Rootstock grafting is used as an alternative for horticultural crops; appropriate and compatible rootstocks are utilized to improve water and nutrient acquisition and nutrient utilization efficiency (Gregory *et al*., 2013; Albacete *et al*., 2015a, b; Ropokis *et al*., 2018, 2019) [29, 1, 2, 64, 65]. Nutrient efficiency is a general term that refers to the capacity of a plant to acquire and use nutrients. It is measured by plant dry weight produced per unit of nutrient supplied (g DW/g nutrient supplied).

This parameter includes nutrient uptake efficiency and nutrient use efficiency (Gerendás *et al*., 2008; Ceylan *et al*.,

2018) [26, 13]. Although other efficiency indicators, such as nutrient harvest index, nutrient influx rate, and nutrient partitioning, have been proposed (Rengel and Damon, 2008) [61], measurement of plant growth and harvestable yield per unit input of applied fertilizer remains reliable (Venema *et al.*, 2011; Santa-Maria *et al.*, 2015) [76, 70]. In addition to these commercially important benefits, grafting increases nutrient uptake and utilization efficiency in a number of plant species (2015a, b; Lee *et al.*, 2010; Schwarz *et al.*, 2013; Huang *et al.*, 2013b; Esmaeili *et al.*, 2015; Garcia-Bañuelos *et al.*, 2017) [38, 73, 32, 20, 25].

The world's nutrient resources are finite (Venema *et al.*, 2011) [76] and thus require justified utilization; moreover, inorganic fertilizers are expensive. Scientists are working to modify the root architecture of cereal crops (monocots) to enhance nutrient uptake and utilization efficiency (Meister *et al.*, 2014; Rogers and Benfey, 2015; Wissuwa *et al.*, 2016) [63, 78]. Rootstock grafting is used as an alternative for horticultural crops; appropriate and compatible rootstocks are utilized to improve water and nutrient acquisition and nutrient utilization efficiency (Gregory *et al.*, 2013; Albacete *et al.*, 2015a, b; Ceylan *et al.*, 2018) [29, 1, 2, 13]. Nutrient efficiency is a general term that refers to the capacity of a plant to acquire and use nutrients. It is measured by plant dry weight produced per unit of nutrient supplied (g DW/g nutrient supplied). This parameter includes nutrient uptake efficiency and nutrient use efficiency (Nawaz *et al.*, 2016, 2018) [49, 50]. Although other efficiency indicators, such as nutrient harvest index, nutrient influx rate, and nutrient partitioning, have been proposed (Rengel and Damon, 2008) [61].

Nowadays, water scarcity in arid and semi-arid regions represents a serious problem for agriculture management. Thus, effective irrigation strategies are essential for crop productivity and quality in addition to conserving water water (Al-Taey, *et al.*, 2018; AL-Taey and Majid 2108; Burhan and AL-Taey, 2018).) [56, 57, 58]. A proper irrigation management is essential for improving the quantity and quality of tomato crop grown under limited water irrigation conditions (Ibrahim *et al.*, 2014, Al-Taey and AL-Musawi, 2019) [33].

Several reviews have been conducted on grafting improve nutrients, water use efficiency, selection of rootstocks, biotic and abiotic stresses, pathogens (Schwarz *et al.*, 2013; Edelstein *et al.*, 2016; Kumar *et al.*, 2017) [73, 37], other important approaches are presented diseases control, salt and drought streets tolerance; these approaches can be combined with grafting to further enhance nutrient uptake, utilization efficiency and water use efficiency.

Root System Architecure and Ion Uptake

In cereal crops, modification of the root architecture is a popular means to enhance ion uptake, accumulation, and utilization efficiency, and this means has been discussed in several reviews (Meister *et al.*, 2014; Rogers and Benfey, 2015; Wissuwa *et al.*, 2016; Ceylan *et al.*, 2018) [63, 78, 13]. Nutrient uptake and utilization in horticultural crops are enhanced by selecting appropriate rootstocks. Rootstocks play a vital role in manipulating the nutrient status of the scions by directly affecting ion uptake and transport (Amiri *et al.*, 2014). The ion concentration in the roots and shoots of grafted grapevines depends on rootstock genotype (Lecourt *et al.*, 2015). The selected rootstocks have a vigorous root system, i.e., large main roots, many lateral roots and root hair, large total root length, and root surface area. These roots absorb a large amount of water and nutrients by exploring wide and deep soil volumes (Pérez-Alfocea, 2015). According to a report, the root dry weight of watermelon grafted onto Jingxinzhen No. 4 pumpkin (*C. moschata* Duch.) is 2.24 times that of self-rooted plants (Huang *et al.*, 2013b) [32], and the K uptake efficiency of grafted plants is 2.02 times that of self-rooted plants. Similarly, the root dry weight of a rose cultivar (*Rosa* "BAIore") is thrice that of a poorly performing cultivar *Rosa* "Frontenac" under stress conditions (Harp *et al.*, 2015). Therefore, this vigorous root system of rootstock can capture and transport a large amount of nutrients to the above ground scion. Vigorous rootstocks have high levels of sugars, amino acids, and enzymes and secrete organic acids in the soil, which are important in nutrient mobilization and affect nutrient availability and uptake (Jaitz *et al.*, 2011; Khorassani *et al.*, 2011; Dam and Bouwmeester, 2016). Jiménez *et al.* (2011) reported that high concentrations of root sucrose, total organic and amino acids, and phosphoenolpyruvate carboxylase activity in the roots of *Prunus* rootstocks subjected to iron deficiency promote root growth and trigger iron uptake. Similarly, under iron-deficient conditions, the roots of *Malus* species secrete acids, reduce the pH of rhizosphere, and significantly increase the activities of root ferric chelate reductase (FCR), thereby leading to increased ferrous uptake (Zha *et al.*, 2014).

Diseases Control

Improved resistances to many soilborne fungal, oomycete, bacterial, and nematode pathogens have been reported in grafted *solanaceous* and cucurbitaceous crops. Moreover, certain foliar fungal and viral diseases were suppressed when susceptible scions were grafted onto specific rootstocks (Louws *et al.*, 2010) [43]. Soilborne fungal and oomycete diseases. The earliest reported use of vegetable grafting for disease control was for management of fusarium wilt in cucurbits (Sakata *et al.*, 2005; Guan and Xin, 2012) [30]. Commonly used cucurbitaceous rootstocks are non-hosts to most formae speciales of *F. oxysporum*, and thus grafting has been successfully used to control fusarium wilt in cucurbit production (Louws *et al.*, 2010) [43]. Verticillium wilt, primarily caused by *Verticillium dahliae*, is another vascular wilt diseasethat often affects Solanaceae and Cucurbitaceae. Studies with plants grafted onto commercial rootstocks and subjected to infection with *V. dahliae* indicated that both scions and rootstocks contributed to disease resistance of the grafted combinations in watermelons, melons (*Cucumis melo* L.), cucumbers (*Cucumis sativus* L.), and tomatoes (*Solanum lycopersicum* L.) (Paplomatas *et al.*, 2002) [55]. Monosporascus sudden wilt, caused by Monosporascus cannonballus, is an important soilborne disease of melon and watermelon in hot and semiarid areas.

Grafting scions of susceptible melon cultivars onto *C. maxima* Duch. and *C. maxima* × *C. moschata* rootstocks improved resistance of melon (Edelstein *et al.*, 1999) [19] although Cucurbita is normally regarded as a host for *M. cannonballus* (Mertely *et al.*, 1993) [46]. However, the improved resistance and better yield with grafted plants was inconsistent. The variable results might be attributed to differences in rootstock–scion combinations and growing conditions. Phytophthora blight, caused by *Phytophthora* *capsici*, is regarded as one of the most destructive diseases in production of cucurbits. In *P. capsici*-infested fields, yields of cucumbers grafted on bottle gourd [*Lagenaria siceraria* (Mol.) Standl.], *C. moschata* Duch., and wax gourd [*Benincasa hispida* (Thunb.) Cogn.] rootstocks were significantly increased and vegetative growth was more vigorous (Wang *et al.*, 2004) [77]. Watermelons grafted onto selected bottle gourd rootstocks also exhibited resistance to *P. capsici* (Kousik and Thies, 2010) [36]. Corky root disease caused by *Pyrenochaeta lycopersici* is a severe problem for Solanaceae. Tomatoes grafted onto 'Beaufort' rootstocks (*S. lycopersicum* × *S. habrochaites* S. Knapp & D.M. Spooner) had lower disease incidence, higher yield, and larger fruit (Hasna *et al.*, 2009) [31]. Similar results were also found in grafted eggplants (*S. melongena* L.) (Iouannou, 2001). Soilborne bacterial diseases. Tomato bacterial wilt, caused by *Ralstonia solanacearum*, is one of the most destructive diseases of tomato. Resistance to bacterial wilt in tomatoes is a quantitative trait and is closely associated with small fruit size (Louws *et al.*, 2010) [43].

Salt and Drought Strees Tolerance

Soil salinity influences horticultural productivity and plant growth. Approximately 7% of the world's land area and 20% of the irrigated land are affected by soil salinity (Ferreira-Silva *et al.*, 2010) [23]. There are 2 ×10 7 hm 2 of salt wasteland and 6.67 ×10 6 hm 2 of saline land in China, accounting for approximately 25% of arable land (Xing *et al.*, 2015) [79]. Improper fertilizer and water man- agement also exacerbate salinization, and the amount of saline land increases each year (Forni *et al.*, 2017) [24]. To reduce the impact of salinity on agricultural productiv- ity and to facilitate the development and utilization of saline soil, several strategies have been proposed and used in the past decades. Reclamation of saline soil and correction of soil salin- ity are fundamental strategies in agriculture; however, these are temporary and relatively expensive (Dasgan *et al.*, 2002) [16]. Breed- ing resistant genotypes have also been considered as means for improving salt tolerance in horticultural crops, but it is labori- ous and complex due to the polygenic nature of salt resistance (Ashraf and Foolad, 2007) [7]. The application of some plant growth regulators, including humic acid (Ouni *et al.*, 2014) [52], brassinolide (Yuan *et al.*, 2015) [83], polyamine (Gong *et al.*, 2014a) [27], and mela- tonin (Liu *et al.*, 2015) [41], has been utilized to improve salt tolerance in crops, and several growth regulator-based commodities have been manufactured and used in agricultural systems. However, the prolonged effects of these substances have yet to be evaluated. Based on these challenges, the use of resistant geno-types as rootstock is considered a simple and effective method for improving crop tolerance to salt stress (Gong *et al.*, 2014b) [28]. Recent studies have examined the response of grafted horti-cultural crops to salt stress and have demonstrated that graft-ing is a valid strategy for improving salt tolerance in horticultural crops, including cucumber (Zhen *et al.*, 2010) [84], tomato (Fan *et al.*, 2011) [22], pepper (Penella *et al.*, 2013) and potato (Etehadnin *et al.*, 2010. [21] Previous studies have demon-strated that higher photosynthetic capacity, carbon assimilation rates, proline, sugar, betaine accumulation, antioxidant capacity, and lower accumulation of Na^+ and/or Cl^- in the leaves constitute possible explanations for grafting-induced salt tolerance (Ferreira-Silva *et al.*, 2010) [23]. These results indicate that the utilization of rootstocks with high salinity tolerance can result in highly salt stress-resistant scion plants. Watermelon is a popular but salt sensitive crop that constantly experiences salt stress. K^+ deficiency, decreased photosynthesis, excess reactive oxygen species (ROS), and Na^+ accumulation under salt stress have resulted in metabolic disturbance and growth inhibition. To alleviate productivity losses due to salt stress, watermelon scions have been grafted onto rootstocks with high salt stress tolerance. However, salt resistance conferred by the rootstock in watermelon species depends on complex physiological interactions that remain unclear.

Drought depresses plant growth due to decreased cellular water potential and stomatal conductance, inhibition of photosynthesis, and enhanced reactive oxygen species (ROS) accumulation. This causes heavy and economically relevant yield losses (Altunlu and Gul, 2012; Liu *et al.*, 2014) [5, 40]. Thus, it is a considerable challenge to develop scientific strategies for minimizing yield losses under drought conditions (Cantero-Navarro *et al.*, 2016) [12], to increase water use efficiency (WUE) of crops. WUE is defined as the ratio of the CO_2 assimilation rate and transpiration rate (instantaneous WUE), or the ratio of crop yield over the applied water (yield WUE). Grafting has demonstrated its potential in alleviating abiotic factors such as drought stress in different fruiting vegetables belonging to the *Solanaceae* and *Cucurbitaceae* families (Schwarz *et al.*, 2010) [72]. emerged as a potential tool to quickly enhance the efficiency of modern vegetable cultivars for wider adaptability or resistance to different stresses when these are grafted onto resistant rootstocks for specific stresses (Rouphael *et al.*, 2016; Kumar *et al.*, 2017) [37].

Nutrients Use Effeciency

It is well established that water stress decreases the plant ionome by restricting uptake and translocation of mineral nutrients owing to restricted transpiration rate and reduced active transport and membrane permeability (Sánchez-Rodríguez *et al.*, 2013, 2014) [68, 69]. Many rootstocks are capable of increasing the uptake and translocation of nutrients (Savvas *et al.*, 2010). The increased fruit yield and yield WUE in grafted mini-watermelon plants under full and deficit irrigation regimes was partly due to the rootstock-mediated increased nutrient status of plants (i.e., N, K, and Mg; Rouphael *et al.*, 2008) [66]**.** Accumulation of macro and micronutrients (N, P, K, Fe, and Cu) in susceptible tomato scion "Josefina" increased when grafted onto drought-tolerant "Zarina" rootstocks (Sánchez-Rodríguez *et al.*, 2014) [69]. Working with similar plants, Sánchez-Rodríguez *et al.* (2013) [68] concluded that drought-tolerant rootstock could improve absorption, upward transfer, and accumulation of NO^{3-} in tomato scion, thus stimulating nitrate reductase NR activity and NO^{3-} assimilation. Consequently, improved growth of grafted plants under moderate water stress was noted. Penella *et al.* (2014b) [58] also observed that the NR activity in leaves of pepper plants increased when grafted onto tolerant rootstocks. The increase of nutrient uptake in drought resistance grafting combinations can be related to the considerable soil exploration resulting from the deep and vigorous root system, and the enhanced root exudation of organic acids into the soil, which contribute to the release of nutrients (e.g., P and Fe) more efficiently in the rhizosphere (Colla *et al.*, 2010a) [14]. However, it may also be possible that rootstocks enhance nutrient transporters in the plasma membrane, thus increasing the capacity of grafted plants to take up nutrients. Was partly due to the rootstock-mediated increased nutrient status of plants (i.e., N, K, and Mg; Rouphael *et al.*, 2008) [66].

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In plant growth, N is the most important essential element **,** which also has greater complexity within the potential physiological processes in which it is involved. However, it may also be possible that rootstocks enhance nutrient transporters in the plasma membrane, thus increasing the capacity of grafted plants to take up nutrients. In plant growth, N is the most important essential element **,**which also has greater complexity within the potential physiological processes in which it is involved. However **,** several studies carried out around the world and in different environments, have shown that between 50 and 70% of the total N applied to the soil, is lost as a result of runoff **,** denitrification, volatilization and leaching (Montemurro and Diacono, 2016; Ropokis *et al.*, 2018, 2019) [64, 65]. This macroelement, is considered a potential environmental contaminant, and therefore **,**the efficiency NUE of its rational use, is fundamental for agricultural sustainability and natural environmental conservation (Yasuor *et al.*, 2013; Mascleaux-Daubresse *et al.*, 2010) [81, 44]. Care in the application of nitrogen fertilizers in crops, has become a priority in recent years, due to the worrying increase in nitrate NO^{3-} N concentrations in groundwater, which have been associated with the excessive application of these Fertilizers in agriculture (Yasuor *et al.*, 2013; Garcia-Bañuelos *et al.*, 2017) [81, 25].

Water Use Effeciency

Increased WUE of grafted plants relative to non-grafted or self-grafted plants is often related to increases in net CO_2 assimilation rate, or reduced transpiration rate, or both (Khah *et al.*, 2011) [35]. In luffa rootstock-grafted cucumber, increased instantaneous WUE over self-grafted cucumber was due to a higher CO_2 assimilation rate and lower transpiration rate in comparison to self-grafted plants under drought stress (Liu *et al.*, 2016) [39]. Apart from stomatal movement, rootstock-induced changes in stomatal development also affects water conservation in grafted cucumber, as reduced transpiration relates to lower stomatal density in grafted plants (Liu *et al.*, 2016) [39]. Compared to self-rooted mini watermelon, the higher yield and yield WUE in grafted plants was due to their higher net CO_2 assimilation rate, along with their efficiency in acquiring more water (high crop evapotranspiration) and nutrients from soil (Rouphael *et al.*, 2008) [66]. Grafting has the potential to be as a strategy to increase the tolerance of plants to promote water use efficiency WUE (Öztekin *et al.*, 2007) [53].

Grafted tomato plants under a moderate water level (80% ETc) resulted in 16.7% saving in irrigation water, with only slight reduction in yield (0.7-1.3%). Therefore, it can be concluded that grafting is beneficial alternative method for tomato production and conserving water under greenhouse conditions (Ibrahim *et al.*, 2014) [33]. While found Al-Harbi *et al.* (2018) [When grafting of tomato increasing water stress. Between the two tested cultivars, Durinta showed more vigorous growth than Valouro. Plant growth, proline, Ca^{+2} and K^{+} concentrations, fruit yield, and TYWUE were higher in grafted plants than in non-grafted plants. Adverse effect of high water stress (50% ETc) was evident in the non-grafted plants, particularly in Valouro. A positive effect of grafting was observed when Beaufort was used as the rootstock. Durinta grafted onto Beaufort (DB) under moderate irrigation regime (75% ETc) exhibited water savings (25%). The water consumption and the water use efficiency were negatively affected by the LT regime, however the temperature effect interacted with the rootstock/scion combination (Ropokis *et al.*, 2019) [65].

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