Chapter

Perspective Chapter: Rootstock-Scion Interaction Effect on Improving Salt Tolerance in Fruit Trees

Ahlem Zrig, Safia Belhadj, Taieb Tounekti, Habib Khemira and Salma Yousif Sidahmed Elsheikh

Abstract

Salt stress is a sever threat to global agriculture. Improving salt tolerance is a problematic task due to the large number of characteristics involved. Graft technique is a potential substitute to breeding and interesting practices to salt tolerance since it unites a scion and rootstock of two genotypes. Increased salinity tolerance in fruit trees will alter water relations, disrupt ionic balance, which can harm plant tissues and thus limit plant productivity. Therefore, the ability of fruit trees to resist salinity varies by species, although it is mostly determined by the type of their root systems. In this regard, the selection of salt-tolerant rootstocks can help maintain productivity under salinity. Several physiological and biochemical changes are attributed to the favorable response of grafting exerted by tolerant rootstocks or scion-rootstock interactions on yield and fruit attributes of plants in saline environments. Rootstocks provide grafted plants different salt tolerance mechanisms including the accumulation of compatible solutes and enhancing the antioxidant mechanisms in scion. The importance of grafting, strategies for selecting appropriate rootstocks, scion-rootstock interaction for growth and the tolerance mechanisms used by plants to avoid the effects of salt stress, are all discussed in this review. Grafting's potential challenges are also discussed.

Keywords: grafting, rootstocks, scion, salinity, glycophyte

1. Introduction

Environmental stress causes a variety of physiological stress reactions in plants, which can change the chemical composition of crops and, as a result, the quality of harvested goods and linked to the quantity and quality of agricultural seeds and food. The most significant of all environmental stresses is salinity, which affects the plant growth and barricades plants from reaching their genetic potential [1]. Salinity occurs when salts accumulate excessively in the water [2]. High salinity affects about 20% of planted native land and 33% of watered farming lands all around the world, and these regions are growing at a pace of 10% each year. Salinity is expected to affect 50% of all arable land by 2050, according to estimates [3]. Salts in the soil are essential for the growth of plant [3]. However, excess of salt can lead to ion toxicity and osmotic stress and interfere with soil nutrient balance [4] affecting plant growth and physiological functions. Salt stress impairs a plant's capacity for photosynthesis and chlorophyll production, which frequently results in a decrease in PSII activity, an obstruction to electron transport, a restriction on carbon assimilation, and peroxidation or dissociation of the thylakoid membrane [5]. Plant roots are characterized by high developmental plasticity, facilitating adaptation to adverse environments [6]. Because there is less cell development in the root elongation zone, the root responds to salt stress by inhibiting root growth [5]. The most actively developing part of the root tip, the meristematic zone, which is a key component of the architecture of the root system, undergoes modifications as a result of saline stress in order for roots to adapt [7]. Therefore, rootstocks are also commonly employed in current wood fruit crop cultivation because of their capacity to adapt a cultivar to a variety of environmental conditions and cultural methods [8, 9]. Rootstocks, on the other hand, can alter scion performance by decreasing plant vigor and allowing the production of high-density orchards [10]. Several breeding initiatives around the world are working on improving rootstocks for fruit trees. It has been reported that the most important factor limiting the cultivation of fruit trees such as peach, almond, plum, cherry, olive, and grape is their special ecological requirements. Aside from the high lime rate of the soil, various diseases also hamper the cultivation of fruit tree species. As a result, in many Mediterranean regions, rootstock is needed to overcome these limitations while growing stone fruits. Therefore, interspecific hybridization is widely used in rootstock breeding programs to expand the genetic base and allow the introduction of genes not found in the breeding population [11]. Because they are tolerant of lime-induced Fe chlorosis and graft-compatible with peach cultivars, almond peach hybrids are widely used as rootstocks for peach trees in Mediterranean countries [12]. They are robust and suitable for use in poor and dry soils [13]. New varieties resistant to biotic stressors, including root-knot nematodes (Meloidogyne spp.) and replanting conditions, have also been produced [14, 15]. Rootstock/scion interactions are widely known to produce a range of properties that transform the overall performance of the combination and have important economic implications and are referred to as rootstock/scion relationships [16]. However, the mechanisms behind these connections are complicated and poorly understood. Soil salinity affects fruit tree species in particular. For instance, peach [17] and almond tree [18] shoot growth is inhibited by relatively low NaCl concentrations (25 mM) in the soil solution. Stress-tolerant crops must be produced through the selection and breeding of cultivars capable of providing commercial yields in saline or drought conditions to reduce the detrimental effects of these stresses [18]. Unfortunately, due to the genetic complexity of abiotic stress tolerance, this is a challenging task [19]. As a result, various cultural opportunities were scrutinized. In this regard, grafting has been used in crops production in the world to improve plant tolerance to abiotic stress by grafting best cultivars (as scion) onto more resistant genotypes (as rootstocks) [20]. Grafting is distinguished as a crucial process to adapt the plant vigor and extend the crops [8, 21]. The most important factor that affects the adaptability of fruit tree to soil stress is the scion-rootstock combination [22]. The combination of rootstock/scion has the potential to produce a plant with characteristics that neither component would have if grown independently. Indeed the rootstocks can provide many characteristics that do not appear in the scion, such as resistance to pests and diseases in the soil [23, 24], improved nutrient uptake, and better tolerance to high saline [25, 26]. The rootstock vigor can also improve the whole plant vigor, increase fruit quality, and alter fruit ripening period [27]. Grafting can also lengthen the harvesting season [13] and extend the life of the crop after harvest [28]. Based on recent studies in this subject, in this article, we will give an overview of the potential of the grafting method to improve the salt tolerance of fruit trees. The physiological and biochemical elements of the rootstock–scion relationship in fruit trees will be explored, as well as the mechanisms involved in the salt tolerance of grafted plants and the influence of the rootstock on the main physiological and biochemical processes of the scion, in order to boost the tolerance of trees grown under saline conditions.

2. The effect of salinity on fruit trees species

Soil salinity is a global issue endangering land productivity and one of the most important environmental concerns limiting plant production in arid and semiarid areas [16]. Salinity alters water relations, disrupt ionic balance, and produces reactive oxygen species (ROS) that can harm plant tissues and thus limit plant productivity. Salinity also causes osmotic and oxidative stress in plant tissues [29, 30] and affects growth, development [31], and the rate of plant less survival [32, 33].

The most sensitive horticultural crops to high salinity were fruit trees [34], Fruit crops are somewhat affected by salinity levels, and once salt concentrations exceed the threshold, their growth rate drops faster than most crops [35]. In fact, salt stress disrupts many metabolic activities in most glycophyte plants, impairing vital cellular function. Many fruit trees, on the other hand, have evolved systems to withstand salt stress and can thus thrive in saline soils [36]. The ability of fruit trees to resist salinity varies by species, although it is mostly determined by the type of their root systems [22]. The ability of most glycophyte plants, such as fruit trees, to exclude or retain potentially harmful ions, determines their salt tolerance. Different species or root types have different adaptation methods for salt stress. The overall concentration of soluble salts in the soil solution, or its osmotic potential, is linked to reduction in growth and yield [32]. For example, shoot growth of peach [37] and almond [5] is affected by low doses (25 mM NaCl) of salt in the soil solution. Zrig et al. [38] revealed that the sweet almond tree cannot tolerate a concentration higher than 75 mM NaCl. Under this lethal concentration, the total dry weight and shoot extension of almond cv Mazzetto decreased while the root/shoot ratio increased. The ratio root/shoot was a state of homeostasis and is independent of root salinity. In this regard, at high salinity level, many plants allow the big part of biomass to roots to maintain a better uptake of water and therefore reach to optimum autoregulation. In pistachio species (P. *atlantica* and Pistacia lentiscus), the growth, the number of leaves, and the fresh biomass of a 3-month-old plantlets decreased significantly with 10 gL^{-1} of NaCl. The leaf browning rate also increased [34]. Furthermore, several studies have been conducted to determine the effects of varying salt levels on the yield of mature plum trees (*Prunus salicina*, cv Santa Rosa) [39]. At 4 dm/S, plum vegetative development appeared more sensitive, and the same treatment caused significant leaf damage [35]. Excessive doses of salt in soil reduce significantly the performance of fast-growing plants of *Prunus* species [40]. Salt load control systems at the whole plant level strongly integrate growth rates and plant shape [41]. Furthermore, high salinity disturbs the osmotic adjustment and leaf water relations [42, 43]. Stone fruit crops (*Prunus* spp., for instance) such as apricot, cherry, nectarine, almond, peach, and plum are the world's seventh-largest crop producers. Stone fruit trees are sensitive to salinity, particularly to chloride, and irrigation with saline water can significantly reduce yields [44, 45]. The main ions causing problems are Cl^-, SO_4^{2-}, HCO_3^-, Na^+, Ca^{2+}, Mg^{2+}, NO_3^-, and K^+, although in several fields B is concerned [46]. In general, during the seed germination stage, the plants were moderately salt-tolerant, but during the young seedling stage, they become more sensitive and progressively more tolerant as they get older through the reproductive stage [47]. Furthermore, most stone fruit trees are sensitive to salt stressors, and their production gradually decreases at salt concentrations above 1.5 dSm^{-1}, reaching 50% of normal production at 4 dSm^{-1} [48].

Plants are affected by salt stress in various ways, including ionic diseases, osmotic stress, and nutritional imbalances. Overproduction of reactive oxygen species (ROS) such as singlet oxygen (O_2), superoxide anion (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radical (OH) is a common feature of these effects, which are highly reactive and toxic and cause damage to proteins, lipids, carbohydrates, and DNA, leading to oxidative stress [49]. Salt stress closes stomata, lowering the CO_2/O_2 ratio inside leaf tissues and preventing CO_2 fixation. Plant antioxidant enzymes work together to prevent uncontrolled oxidation cascades and protect plant cells from oxidative damage by scavenging ROS [50].

The processes of salinity sensing and signal transduction within the plant are not well understood, which is exacerbated by the restricted investigation done on this topic for fruit trees [51]. According to several authors [52, 53], plants respond to high levels of salt by activating a signaling network and a comprehensive reaction that involves the synthesis of a variety of chemicals that maintain cellular homeostasis. When the plants sense high levels of salt, primary and secondary metabolites will be activated to provide adequate osmotic balance. This is the cleanest approach for plants to adapt to salt stress. In almond leaves, when the electrical conductivity of irrigation water exceeds 3 $dS\ m^{-1}$, Ranjbarfordoei et al. [44] found that the total chlorophyll content and fluorescence parameters are negatively affected. *In vitro* cultivated “Gisela 6” cherry and exposed to various salt concentrations also showed increased malondialdehyde content as well as expression of SOD, ascorbate peroxidase, catalase, and glutathione reductase. Milosevic et Milošević [54] found that the Myrobalan plum (*Prunus cerasifera* Ehrh.) is one of the most tolerant to salinity and B (reduced salt uptake in the root), while the peach “Nemared” (*Prunus persica* (L.) Batsch) is one of the most sensitive (high salt content in the stem).

Traditional breeding programs have attempted to improve crop salt tolerance, but with limited success due to the trait’s complexity [55]. The adoption of resistant rootstocks is a technique to avoid or reduce production losses caused by salinity. In this regard, scion/rootstock pairings with a modest growth response have been demonstrated to have a greater ability to exclude Na^+ and Cl^- from the shoot [56].

3. Effect of the rootstock on the salt tolerance of grafted plants

Plant development and structure can be influenced by the complex interactions between scion and rootstock. Rootstocks provide grafted plants with more favorable tolerance against several environmental stresses (both abiotic and biotic); therefore, one of the most important steps in starting a new plantation is choosing a good rootstock, achieving outstanding tree performance in various ecological zones. In fruit trees, rootstocks have been used to boost fruit yield, flavor, and quality while improving nutrient uptake, transport, and resistance to a variety of environmental challenges. The rootstocks had an impact on the physiological characteristics of the grafted plants, as well as other elements of growth and development [49]. Therefore, using grafting techniques to choose a salt-tolerant root system as rootstock can support plants become more salt-tolerant (**Table 1**). The root system of the rootstock replaces the scions during grafting. If the rootstock is chosen correctly, this method will improve nutrition and water uptake, increase carbon and nitrogen metabolism, and increase the salt tolerance of plants [63, 64]. Depending on the intrinsic qualities of the scion, rootstock, and their functional linkages, as well as the severity of salt stress, the persuasive response of grafting on plant growth and production characteristics may differ under salty environments. A number of studies have suggested that grafting can help plants cope with the negative effects of salt stress. Therefore, the rootstock's involvement in determining the tree's performance under saline conditions is essential [65]. Physical characteristics of the root system, such as lateral and vertical development, lead to increased or reduced uptake of water and minerals, which is one of the reasons for the widespread use of rootstocks to overcome salinity. In order to increase detection of better sources of tolerance in the rootstock selection process, it is crucial to determine which type of test offers the best response in a commercial orchard (**Figure 1**).

3.1 Growth and yield

Rootstocks alter the size and shape of trees by reducing internodes, altering branch angles, and altering dates and rates of active growth [49]. The rootstock's response to salinity was related to improved growth under saline circumstances. Several fascinating research studies on Prunus rootstocks, for example, have indicated that via grafting, the rootstock's degree of tolerance is transmitted to the scion variety. In fact, several studies have shown that grafting onto salt-tolerant rootstock can reduce more effectively the negative effects of salt on scion growth. For example, shoot extension and leaf dry weight of almond cv. Mazzetto grafted on Garnem (GN15), which considered as more salt tolerance, were found to be higher to those grafted on GF677 [43]. Accordingly, it appears that grafting onto specific rootstocks can successfully

Species	Rootstocks genotypes	References
Almond	GN15 (*Prunus dulcis* (Mill.) D.A. Webb × (*Prunus persica* (L.)	[57]
Pistachio	*Akbari, 'Ahmad-Aghai' and 'UCB-1*	[34]
Plum	'Mariana 2624 and Adesoto 101'	[58]
Cherry	CAB 6P' (*Prunus cerasus* L.) and Colt' (*Prunus avium* (L.) L. × *Prunus pseudocerasus* Lindl.)	[59]
Apricots	*Prunus microcarpa*	[60]
Olive	Arvanitolia and Lefkolia	[61]
Citrus	Shaker and Cleopatra mandarin	[62]

Table 1.
Different genotypes of rootstocks of different trees. They are used as most salt-tolerant rootstocks.

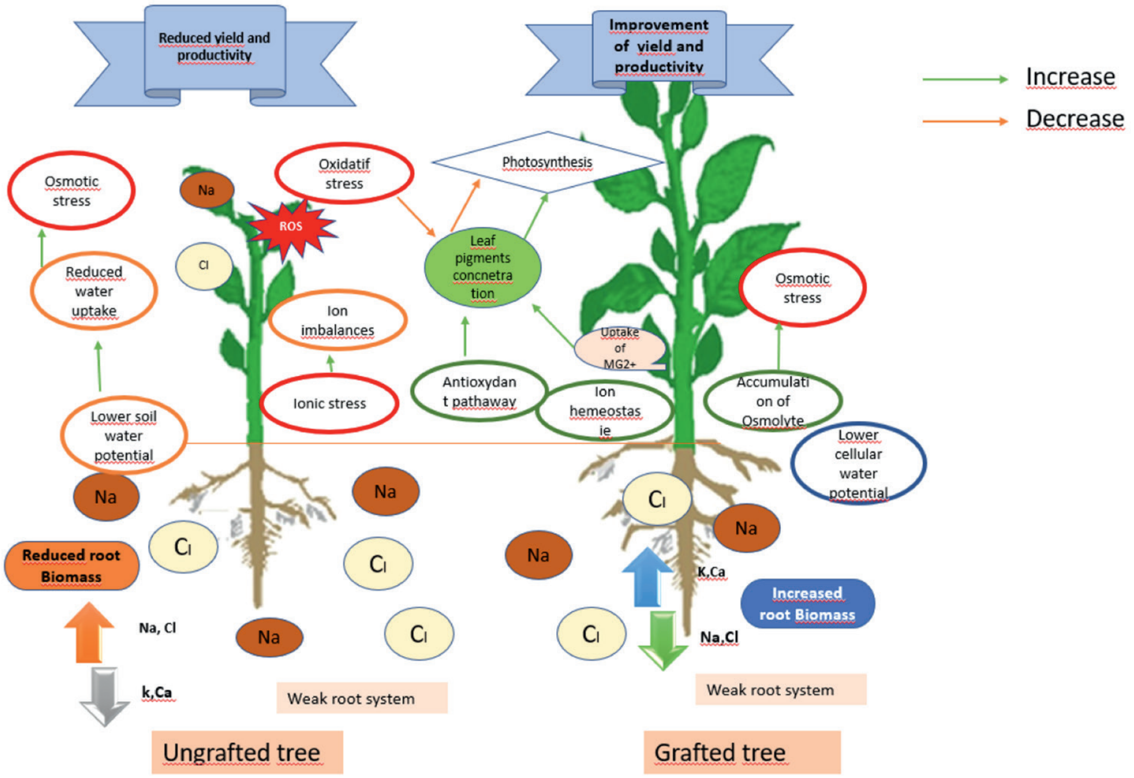

Figure 1.
Potential beneficial effects of rootstocks on trees in saline soil conditions, summarized from the literature. Salinity reduces root biomass because it prevents cell proliferation, which lowers the overall biomass yield (left). Grafting improves roots vaporosity by modifying root architecture and increased nutrient uptake (right). In ungrafted tree, Na^+ and Cl^- accumulation generates competition for nutrient uptake and transport. This results in imbalance of the ionic composition of plant and affects plant's physiological traits (left). In grafted tree, rootstock could improve nutrient uptake and maintenance of ionic homeostasis (right). The high uptake of Na^+ and Cl^- caused by an increase in salt content (left). In grafted tree, the accumulation of osmolytes consequently improves plant's water status (right). In ungrafted tree, increasing salinity causes oxidative stress due to imbalance in reactive oxygen species generation and quenching activities of antioxidants (left). In grafted plants, the oxidative stress was reduced under salt stress (right). Salt stress causes a decline in photosynthesis by decreasing chlorophyll concentration (left). The vigor rootstock has positive effect on photosynthesis under salt stress (right).

minimize the negative effects of salt on the scion; this is consistent with previous observations on various plant species [5]. Similarly, Massai et al. [37] found that peach cv. Armaking grafted onto GF677 inhibited whole plant and lateral root growth more than the Arm/Mrs. combination. This indicated that the first combination was more sensitive to NaCl than the second. Aras and Eşitken [66] studied the responses of cherry plants grafted onto two distinct rootstocks (CAB6P, MaxMa 14, and Mazzard Rootstocks) to short-term salt. This study found that 0900 Ziraat grafted onto MaxMa 14 had the largest decreases in rootstock and shoot diameter by 14 and 14.2%, respectively, while 0900/Mazzard had the smallest decreases in rootstock and shoot diameter by 9.2 and 11%, respectively. Cherry (*Prunus cerasus*) rootstocks can considerably alter the scion's tolerance to salinity, according to Ertuka et al. [67]. Kucukymuk et al. [68] confirmed that sweet cherry trees with the 0900/mazzard combination were more vulnerable to salinity increases than plants with the 0900/mahaleb combination. Further research has shown that when "GF-677" and "Mr.S. 2/5" rootstocks were grafted with peach and exposed to varying NaCl concentrations (0–120 mM), the "GF-677" showed improved sensitivity in terms of growth and net CO_2 assimilation [41].

3.2 Root system architecture

The rootstock's root system characteristics are often the most important criterion for increasing salt tolerance in grafted plants; therefore, the most significant factor for enhancing salt tolerance may be a healthy root system [69]. The root is the first organ to deal with salt excess in soil, due to its activities of searching for and moving water, nutrients, and ions, and it can play a key role in defining plant sensitivity or tolerance to salt stress. Under salt stress, a decline in root growth was observed in woody fruit trees with different levels of salt tolerance. Accordingly, the loss was linked to a decrease in root respiration, which is susceptible to high salinity in soils [70]. Root respiration is also a major source of carbohydrates [71], and it is classified into two types: "maintenance respiration," which includes the preservation of existing tissue, and "growth respiration," which involves the production of new tissue [72]. Maintaining a root respiration is important for producing energy and coping with adverse environments like salinity. Because of the significant requirement for ATP to maintain transport activities across concentration gradients, a higher percentage of root respiration was found to be dedicated to scion maintenance in plants under salt stress. For example, a healthy root system produced more cytokinins and utilized xylem sap to transport water to the shoot system, thereby increasing plant development and yield [73]. Furthermore, root hydraulic conductivity can control plant growth by controlling the water supply to the aboveground plant components [67]. The mechanism, however, is still unknown. Because roots are the primary organ exposed to salt stress, salt-induced suppression of root development is extremely clear. Salt stress, for example, slowed root growth in ungrafted plants, whereas the rate of root dry mass loss was lower in grafted Kinnow mandarin [69] and Pistachio [74]. According to recent study, the first defense under salinity takes place in the root system and apoplastic barrier differentiation contribute to salinity response [35]. The exodermis and the endodermis serve as two apoplastic barriers contributing to protection against abiotic stress, such salinity, by regulating the uptake and transport of water and ions from the soil. An anatomical analysis of suberin in almonds roots revealed that the most salt tolerance rootstock exhibits a strinking increase of suberine deposition at both exodermal and endodermal cells under salinity stress [35]. Furthermore, the lignin deposition, particularly at the Casparian strip, is also critical for the regulation of solute transport at apoplastic barriers [75].

3.3 Gas exchange attributes

The first signs of salt stress in glycophytes are the decrease in leaf development, which seems to be driven by a decrease in stomatal conductance [76]. The stomatal closure reduces the assimilation rate of CO_2 in both grafted and non-grafted salt-treated plants by impairing CO_2 diffusion into the leaves as a result of mesophyll conductance impairment. Photosynthesis is blocked by salt stress because it suppresses the electron transport chain leading to photoinhibition, which leads to a decline in plant growth [57]. Earlier findings have demonstrated that grafting onto salt-tolerant rootstocks can enhance photosynthetic efficiency by preserving chloroplast composition and reducing oxidative damage, which ultimately leads to a delay in photoinhibition rate [32]. The photosynthetic rate (A), stomatal conductance (gs), and transpiration of many prunus rootstocks, such as almond, were all impacted by salinity [77]. It is worth noting that the grafting can modify the photosynthetic performance depending on the scion-rootstocks combinations. Several works reported that the grafting on salt-tolerant rootstocks reduced the salt effect on gas exchanges of scion. In fact, research on almond rootstocks found that after 4 weeks of NaCl treatment, A, gs, and rate of transpiration rate (E) were all lower in all grafting combinations compared to control. Mazzetto/GF677 reliably showed the ultimate reductions. By supporting stomatal conductance, the leaves of Mazzetto/Garnem plants were able to lessen the harm of photosynthetic apparatus. In peach trees, Massai et al. [37] showed that the severe reduction in net assimilation rates was observed in Arm/Mrs. compared to Arm/GF during the first 2 weeks of stress imposition. Besides, these reductions in net assimilation rate seemed to be mainly limited by CO2 diffusion into the leaves during the first 15 days of salt stress. A greater decrease in stomatal conductance was obvious in salt-treated Arm/GF leaves, clearly resulting from salt-induced water stress. Goharrizi et al. [29] examined the photosynthetic activity of three Iranian cultivars of pistachio grafted on four rootstocks and found that trees grown on Sarakhs and *P. atlantica* rootstocks had the highest photosynthetic rates. Sharma et al. [78] recorded higher leaf chlorophyll content in Non Pareil almond and bitter almond rootstock combination than on wild peach rootstock, although wild peach rootstock had higher leaf photosynthesis.

3.4 Mineral content

Fruit species, such as prunus or citrus, are categorized as glycophyte plants because they are salinity sensitive on a scale ranging from moderate to severely salt sensitive. Ion transporters' activities are affected by rootstocks, which alter ion intake and transfer to the scion. Rootstocks promote the acquisition of vital elements while reducing salt uptake and transport (e.g., Na^+ and Cl^-) under saline conditions by exclusion or retention of ions. It is thought that effective rootstocks will be able to limit salt ion uptake and their transit to the shoot, hence slowing or preventing hazardous salt ion accumulation in the leaves [79].

The ability of rootstocks to minimize toxicity of Na^+ and/or Cl^- by exclusion and/or reduction of Cl- uptake by the roots, and replacement or substitution of total K^+ by total Na^+ in the foliage, is related to increased salt tolerance by grafting [80, 81]. The rootstocks minimize Na^+ and Cl^- loading and transport to the scion while enhancing K, Ca, and Mg^{2+} ion intake and allowing for low energy osmotic potentials [82]. The salt sensitivity of fruit tree is related to the sensitivity of the leaves to chloride, while the rootstock salt tolerance is related to the rootstock's ability to exclude chloride and protect the scion leaves [26]. The physical characteristics of the root system, such as lateral and vertical development, which results in increased or reduced uptake of water and minerals, have been attributed to the rootstock's influence on the concentration of certain minerals in the aerial parts of the plant; this is one of the reasons for the widespread use of rootstocks to overcome salinity [83]. Other research has shown that increased salt tolerance in grafted plants is related to increased K^+, Ca^{2+}, or Mg^{2+} translocation to the leaves [53]. The rootstock's ability to minimize damaging ion uptake and transport over time is thought to influence shoot growth [84]. According to Zrig et al. (2016) [85], Mazzetto/Garnem had lower Na + content in the aerial sections than Mazzetto/GF677. The greater shoot extension and leaf biomass of Mazzetto/Garnem found in this study can be explained, at least in part, by such an exclusion mechanism. In this regard, scion/rootstock pairings with a modest growth response have been shown to have a greater ability to exclude Na^+ and Cl^- from the shoot. The ability to stock Na^+ and Cl^- in the cell vacuole and excrete salts outside of the leaf cells via specialized organs is a crucial determinant for salt tolerance in glycophytes [86]. Massai et al. [87] showed that a gradient in Na^+ and Cl^- concentration (tissue water molar basis) was observed in leaves of various age of Arm/GF plants, since basal leaves of 120 mM salt-treated plants had a $Na^+ + Cl^-$ concentration 2.1 and 3.4 times higher than that of medial or apical leaves, respectively. On the contrary, the concentration of $Na^+ + Cl^-$ did not differ between leaves of different age of both 80 and 120 mM salt-treated Arm/MrS plants. According to Küçükyumuk et al. [68], when increasing salinity of the irrigation solution, leaves of sweet cherry trees grafted onto mazzard rootstock suffered more than sweet cherry trees grafted onto mahaleb. Na^+ and Cl^- ions can build up in high concentrations in leaves, causing leaf burn in trees grafted with mahaleb.

Rootstocks protect scion shoots from salt damage primarily by reducing ionic stress and, to a lesser extent, by enhancing K^+, Ca^{2+}, and Mg^{2+} translocation to the shoots and leaves, according to studies, but they have minimal role in reducing osmotic stress [88]. Exclusion or restricted uptake by the roots is used to reduce Na^+ and/or Cl^- translocation to the shoot system. According to Pérez-Alfocea et al. [89], plants use their inherent potential to exclude Na^+ and/or Cl^- from shoots by preserving energy consumption in the root system from risky ion efflux.

Aside from osmotic balancing and root exclusion or restricted root-to-shoot transfer of the harmful ion (i.e., Na^+), plants use ion buildup and subsequent partitioning among plant organs or compartmentalization in cellular organs such as vacuoles to reduce salt toxicity. The grafted plants were able to maintain favorable K^+/Na^+, Ca^{2+}/Na^+, and Mg^{2+}/Na^+ ratios in actively growing leaves [77].

By reducing Na^+ toxicity, rootstocks have been proven to restore plant salt tolerance. According to several studies, the increased salt tolerance of grafted plants such as prunus cultivars is due to a decrease in the accumulation of Na + and/or Cl^- in the shoots of the plant [77]. Other research has shown that increased salt tolerance in grafted plants is associated with better transfer of K^+, Ca^{2+}, or Mg^{2+} to the leaves [53]. A 19-year-old commercial Japanese plum (*P. salicina* Lindl. var. salicina) orchard grafted onto "Marianna 2624" rootstock and received varying amounts of a mixture of NaCl and $CaCl_2$ ranging from 0 to 28 mM. This study found that woody tissues accumulated a lot of Na^+ and Cl^-, while the leaves accumulated a lot of Cl^-, leading to leaf lesions. They found that woody tissue can presumably retain the flow of Na^+ to the leaves (which was not observed in young trees). Chlorides have the greatest damaging influence at the leaf level, lowering net photosynthesis, total carbohydrates, chlorophyll content, and leaf area, according to the second part of the invitation [9]. The ability to keep the rate of buildup of harmful ions (Na^+/Cl^-) as close to physiological homeostatic capacity as possible disturbs the plant's response to salinity. Martinez-Rodriguez et al. [84] state that these characteristics can be transmitted to a more salt-sensitive cultivar by using tolerant genotypes as rootstocks [84]. Despite the fact that ionic homeostasis is mandatory for plant persistence, tissue ion concentration is not a reliable measure of salt tolerance [90, 91].

Different amounts of NaCl and $CaCl_2$ mixture from 0 to 28 mM were administered to a 19-year-old commercial orchard of Japanese plum (*P. salicina*) grafted on the rootstock "Marianna 2624" [92]. These researchers found that woody tissues stored a lot of Na^+ and Cl^-, while leaves mainly accumulated Cl^-, leading to leaf lesions. They found also that woody tissue can apparently retain the movement of Na^+ to the leaves (which was not observed in young trees). The same authors observed that the most negative impact was caused by chlorides at leaf level, decreasing net photosynthesis, total carbohydrates, chlorophyll content, and leaf area [92].

3.5 Water relations

Under normal conditions, grafted plants frequently show improved mineral and water uptake compared to non-grafted plants due to improved root vigor of the rootstock [81]. The plasticity in hydraulic properties in a crop species may be offered through increasing resistance along the pathway of water transport in the plant, and this is central to the maintenance of an adequate water supply to the foliage. In glycophyte plants, which include most crops, high salt content in the medium has a well-known influence on plant growth. First, the saline soil's osmotic potential decreased considerably, resulting in a loss in root water uptake ability. Osmotic stress impacts root and leaf growth as well as stomatal conductance and photosynthetic rate. Water relations in the rootstock-scion system have been explored with a focus on increasing plant adaptability to stressful situations. Zrig et al. [38] showed a decline of the relative water content (RWC) similarly in two Mazzetto/GF677 and Mazzetto/GN15 combinations. On the other hand, Massia et al. [37] reported that the greatest reductions in relative growth rate (RGR) observed in salt-treated Arm/GF as compared to Arm/MrS plants. Nevertheless, at the lowest NaCl doses (25 mM), the water potential dropped significantly, especially in Mazzetto/GF677. Compared to GF677, plants grafted onto Garnem consistently had higher leaf water potential, indicating that Mazzetto/Garnem had higher turgor potential. Salinity affected RWC values in 0900/mazzard trees more than 0900/mahaleb trees, according to a study on sweet cherry [68]. Rootstocks give grafted plants a stronger and wider root system, which allows them to absorb more minerals and water than non-grafted plants [57].

4. Some mechanisms of salt tolerance in grafted plants

Salt tolerance mechanisms have been shown to be transported from rootstock to scion [93]. In fact, several mechanisms of salt tolerances have been observed in the rootstock (**Figure 1**), after grafting it has been observed in the scion. While, in some varieties their salt tolerance was different between scion and rootstocks, this may be due to the interaction between the scion and the rootstock through the graft association. Through their roots, plants were evolved different mechanisms of salt tolerance such as exclusion of salts, accumulation of salts for osmotic adjustment, and activation of antioxidative system.

4.1 Accumulation of compatible solutes

To maintain turgor and water intake for growth, plants must keep their internal water potential below that of the soil. This requires an increase in cell osmotic concentration, either by inorganic ion uptake or by the manufacture of metabolically suitable solutes such as sucrose and proline [32]. Osmoregulation is further facilitated by cytosolic compatible solutes, which impede water outflow to the apoplast and vacuole [2]. In this regard, Zrig et al. (2016) [38] showed that Mazzetto/GN15 had higher concentrations of polyamine, proline, and total soluble sugar (TSS) in their leaves than those of Mazzetto/GF677. This highest accumulation of compatible solute was observed in GN15 rootstocks more than on GF677 rootstocks [5, 38]. These results suggest that the rootstock Garnem enhanced the accumulation of those osmolytes in the leaves of the scion (Mazzetto) to be more tolerant to salinity. Still in almond tree, Zrig et al. [38] testified that GN15 rootstocks accumulated anthocyanin in their leaves, and that these polyphenols were reinforced under salt stress. These anthocyanin productions were observed in leaves of Mazzetto grafted onto Garnem (GN15) also under normal conditions; thereafter, the anthocyanin content was sharply increased under a high level of salinity. According to this earlier study, rootstocks induce the anthocyanin biosynthesis in scion leaves to effectively contribute to osmoprotection under salt stress. Thus, the lower salt-tolerant plants Mazzetto grafted onto GF677 rootstocks showed novel production of polyphenols and polyamines to contribute to osmoregulation [43].

4.2 Antioxidant mechanisms

Photosynthesis can be reduced by a reduction in photochemical activity under salt stress, regardless of stomatal conductance [17]. Several abiotic stressors have been shown to decrease Chla+b content and photochemical efficiency of photosystem II (PSII), still these effects can be improved by grafting. In fact, it was demonstrated that the total chlorophyll contents were reduced in the leaves of Mazzetto grafted on GF677; however, it remained unchanged in the plants grafted on Garnem [38]. Accordingly, the rootstock appears to have influenced the rate of Chl turnover or biosynthesis in scion leaves. Similarly, Aras and Eşitken [66] showed that the lesser decrease of cholrophyll pigment is related to the salt tolerance of rootstocks. In fact, in this study on cherry trees, the plants (0900) grafted on Mazzard displayed the lowest decline in chlorophyll content by 7% under salinity compared to those grafted onto CAB 6P and MaxMa 14. Such effect could be due to its ability to maintain higher chlorophyll levels or its ability to block chlorophyllase activity, which causes chlorophyll degradation [66]. Plants also have the ability to scavenge or detoxify ROS produced by salinity to safeguard photosynthesis and prevent the breakdown of cholorophyll pigments. In grafted crops, such antioxidants have been used as indicators for salinity tolerance. Accordingly, an effective antioxidant system is a key determinant of increased salt tolerance of grafted plants. This is accomplished by increasing the activity of antioxidant enzymes and the amount of non-enzymatic antioxidants in the plant. Under NaCl stress, non-enzymatic antioxidant activity was found to be considerably higher in the leaves of grafted eggplant seedlings than in self-rooted seedlings [94]. There has been less research on the antioxidant system in the roots of grafted plants under salt stress than in the leaves. Non-enzymatic antioxidants are higher in sweet almonds grafted on salt-tolerant rootstocks than in sweet almonds grafted onto salt-sensitive rootstocks. Indeed, research on sweet almond cv. Mazzetto found that Mazzetto/Garnem leaves had higher carotenoid/Chl and anthocyanin/Chl ratios than Mazzetto/GF677 foliage. These findings suggest that the light-harvesting antenna and photosystems are protected by more effective antioxidant mechanisms. Carotenoids protect chlorophylls from oxidative damage by scavenging two ROS, singlet molecular oxygen and peroxyl radicals, in addition to their role as light-harvesting pigments that aid in photosynthesis [95]. These results show that Garnem rootstock improved the antioxidation capacity of Mazzetto cells. Mazzetto/Garnem leaves had higher anthocyanin concentrations and anthocyanin/Chl ratios than in Mazzetto/GF677 leaves, even in control plants. The leaves of the scion seem to adopt some of the rootstock's characteristics; for example, the red-leafed Garnem contains more anthocyanins in its tissues than in green-leafed GF677 [38]. The mechanism of this influence is unknown, but growth regulators such as auxin may play a role. Several studies have established the impact of rootstock on the biochemical composition of the scion of several species, including almond [96] and grapevine [63]. The photo-protective importance of anthocyanins against photo-oxidation during salinity stress was highlighted by Zrig et al. [43] in Garnem rootstock, overall antioxidant activity was favorably related to carotenoid and anthocyanin concentrations rather than polyamines. Mazzetto/Garnem plants appear to exhibit the most efficient photoprotective mechanism, which require carotenoids and anthocyanins, as well as more osmoprotectants in the form of proline and soluble sugars. Mazzetto/antioxidant GF677's effect appears to be mostly due to polyphenols and spermidine, both of which were abundant in its leaves.

5. Impact of scion/rootstock reciprocal effects

Rootstock-scion have the capacity to influence tree physiology in several ways, as the relationships between rootstocks and scions are both vast and complex. The scion assimilates the carbohydrates and translocates them, along with the hormones, to the root system. While the root system can also provide hormones for the scion, as well as water and nutrients absorbed from the soil [97]. Numerous research studies have been done to better understand how rootstock and scion interact to produce traits such as modest tree stature and precocity. Further studies have described a main effect of the rootstock and its proficiency to exhibit consistency of growth to the scion, while the scion showed influence in determining tree weight. Physiological research on rootstock-scion interactions revealed a complex relationship that differed depending on the rootstock and scion varieties used [23]. Despite the fact that scion genotype has a dominant effect on most agronomic variables, rootstock-scion-environment interactions introduce new sources of genotypic and phenotypic diversity into the crop. Hydraulic and chemical impulses pass through the xylem and phloem to cause these interactions. Although maximizing crop productivity requires the leaves to obtain an appropriate supply of water and mineral nutrients from the root system via the xylem, integrated plasticity also requires long-distance communication, in which tiny organic molecules play an important role [1]. The xylem and phloem, two plant vascular systems, conduct cross talk between the above and below graft components under normal conditions. Under salt stress, plants accumulate many osmoregulators such as amino acids, carbohydrate, organic acids, and enhance mineral uptake, all these compounds abound in phloem sap, which includes both organic and inorganic components. In a grafted tree, a reciprocal bond between scion and roots develops, in which a progression of reciprocated adjustment develops in the forced connection between two genotypes. Furthermore, the qualities of a scion or rootstock can only be determined in conjunction with the characteristics of other scions/rootstocks. Therefore, the required characteristics of either the scion or the rootstock (e.g., salinity tolerance) should come first when selecting a rootstock-scion combination, followed by a careful selection of a compatible partner [94].

6. Conclusion

The global climate change makes the crop production very vulnerable. In addition, climate change was linked to the increase in temperatures, and fluctuating rainfall patterns cause a significant rise in soil salt, leading to a decline in the production of fruit trees given their sensitivity to this abiotic stressor. In this regard, grafting has been described by several studies as a practice to improve tolerance to a variety of environmental conditions. Indeed, rootstock and scion interaction is effective in reducing stress factors and producing a healthier plant ideotype. Moreover, the trait of salt tolerance of rootstock was transfer to the aerial part (scion). In fact, the scion could adopt several mechanisms including antioxidant activities to tolerate the salinity. Furthermore, progeny assessment requires an understanding of the mechanisms underlying responses to abiotic stressors. The establishment of a network of assessment sites lets for more information on the performance and salt tolerance mechanism of each rootstock in each season, and which, when combined with the specific tests, leads to a detailed characterization of each genotype, making it easier to select the most appropriate rootstock for each producer's conditions.

Replace the entirety of this text with the main body of your chapter. The body is where the author explains experiments, presents and interprets data of one's research. Authors are free to decide how the main body will be structured. However, you are required to have at least one heading. Please ensure that either British or American English is used consistently in your chapter. Future research should concentrate on understanding the molecular interactions between and within cells that contribute to the salt stress response. With more candidate genes for salinity tolerance being discovered and widely used, genetic engineering has already proven to be an effective method for creating plants that can withstand salty environments. Through interspecific crosses, new sources of variation within the species must be sought. This requires a diverse array of resources that will provide breeders with new options for breaking down resistance and/or tolerance barriers to pests and diseases.

Conflict of interest

"The authors declare no conflict of interest."

Author details

Ahlem Zrig[1,2]*, Safia Belhadj[3], Taieb Tounekti[4,5], Habib Khemira[4]
and Salma Yousif Sidahmed Elsheikh[6]

1 Higher Institute of Preparatory Studies in Biology and Geology, University of Carthage, Tunisia

2 Laboratory of Engineering Processes and Industrial Systems, Chemical Engineering Department, National School of Engineers of Gabes, University of Gabes, Tunisia

3 Ziane Achour University of Djelfa, Route de Moudjebara, Djelfa, Algeria

4 Jazan University, Centre for Environmental Research and Studies, Jazan, Saudi Arabia

5 Faculty of sciences of Gafsa, University of Gafsa, Campus Universitaire Sidi Ahmed Zarroug, Gafsa, Tunisia

6 College of Science, Department of Biological Science, Northern Boarder University, Arar

*Address all correspondence to: ahlem18zrig@yahoo.fr

References

[1] Schwarz D, Rouphael Y, Colla G, Venema JH. Grafting as a tool to improve tolerance of vegetables to abiotic stresses: Thermal stress, water stress and organic pollutants. Scientia Horticulture (Amsterdam) [Internet]. Elsevier Bacterial vaginosis. 2010;**127**:162-171. Available from: DOI: 10./j.scienta.2010.09.016

[2] Parida AK, Das AB. Salt tolerance and salinity effects on plants: A review. Ecotoxicology and Environmental Safety. 2005;**60**:324-349

[3] Wang CM, Zhang JL, Liu XS, Li Z, Wu GQ, Cai JY, et al. Puccinellia tenuiflora maintains a low Na+ level under salinity by limiting unidirectional Na+ influx resulting in a high selectivity for K+ over Na+. Plant, Cell & Environment. 2009;**32**:486-496

[4] Gupta B, Huang B. Mechanism of salinity tolerance in plants: Physiological, biochemical, and molecular characterization. International Journal of Genomics. 2014;**24**:12-22

[5] Takahashi M, Shigeto J, Sakamoto A, Morikawa H. Selective nitration of PsbO1, PsbO2, and PsbP1 decreases PSII oxygen evolution and photochemical efficiency in intact leaves of Arabidopsis. Plant Signaling and Behavior. [Internet]. Taylor & Francis; 2017;**12**:1-5. Available from:. DOI: 10.1080/15592324.2017.1376157

[6] Liu Z, Bie Z, Huang Y, Zhen A, Niu M, Lei B. Rootstocks improve cucumber photosynthesis through nitrogen metabolism regulation under salt stress. Acta Physiologiae Plantarum. 2013;**35**:2259-2267

[7] Julkowska MM, Koevoets IT, Mol S, Hoefsloot H, Feron R, Tester MA, et al. Genetic components of root architecture remodeling in response to salt stress. Plant Cell. 2017;**29**:3198-3213

[8] Allevato E, Mauro RP, Stazi SR, Marabottini R, Leonardi C, Ierna A, et al. Arsenic accumulation in grafted melon plants: Role of rootstock in modulating root-to-shoot translocation and physiological response. Agronomy. 2019;**9**:2-18

[9] Gainza F, Opazo I, Guajardo V, Meza P, Ortiz M, Pinochet J, et al. Rootstock breeding in prunus species: Ongoing efforts and new challenges. Chilean Journal of Agricultural Research. 2015;**75**:6-16

[10] Rouphael Y, Kyriacou MC. Enhancing quality of fresh vegetables through salinity eustress and biofortification applications facilitated by soilless cultivation. Frontiers in Plant Science. 2018;**9**:1-6

[11] Velasco D, Hough J, Aradhya M, Ross-Ibarra J. Evolutionary genomics of peach and almond domestication: G3 Genes, Genomes. Genetics. 2016;**6**:3985-3993

[12] Socias i Company R, Rubio-Cabetas MJ, Alonso JM, Kodad O, Gómez Aparisi J. An overview of almond cultivars and rootstocks: Challenges and perspectives. Options Méditerranéennes Séries A Mediterrean Seminaire. 2010;**214**:205-214

[13] Baumgartner K, Fujiyoshi P, Ledbetter C, Duncan R, Kluepfel DA. Screening almond rootstocks for sources of resistance to Armillaria root disease. HortScience. 2018;**53**:4-8

[14] Felipe AJ. “Felinem”, “Garnem”, and “Monegro” almond x peach

hybrid rootstocks. HortScience. 2009;**44**:196-197

[15] Mestre L, Reig G, Betrán JA, Pinochet J, Moreno MÁ. Influence of peach-almond hybrids and plum-based rootstocks on mineral nutrition and yield characteristics of "Big Top" nectarine in replant and heavy-calcareous soil conditions. Horticultural Science. [Internet]. Amsterdam: Elsevier B.V.; 2015;**192**:475-481. DOI: 10.1016/j.scienta.2015.05.020

[16] Bastam N, Baninasab B, Ghobadi C. Improving salt tolerance by exogenous application of salicylic acid in seedlings of pistachio. Plant Growth Regulation. 2013;**69**:275-284

[17] Tattini M, Guidi L, Morassi-Bonzi L, Pinelli P, Remorini D, Degl'Innocenti E, et al. On the role of flavonoids in the integrated mechanisms of response of *Ligustrum vulgare* and *Phillyrea latifolia* to high solar radiation. New Phytologist. 2005;**167**:457-470

[18] Cuartero J, Bolarín MC, Asíns MJ, Moreno V. Increasing salt tolerance in the tomato. Journal of Experimental Botany. 2006;**10**:1045-1058

[19] Iqbal M, Ashraf M. Presowing seed treatment with cytokinins and its effect on growth, photosynthetic rate, ionic levels and yield of two wheat cultivars differing in salt tolerance. 2005;**47**:1315-1325

[20] Öztekin G, Tüzel Y, Gül A, Tüzel IH. Effects of grafting in saline conditions. Acta Horticulturae. 2007;**761**:349-355

[21] Colla G, Rouphael Y, Leonardi C, Bie Z. Role of grafting in vegetable crops grown under saline conditions. Scientia Horticulturae [Internet]. Amsterdam: Elsevier B.V.; 2010;**127**:147-155. DOI: 10.1016/j.scienta.2010.08.004

[22] Alves FO. Rootstock 3 scion interactions on Theobroma cacao resistance to witches' broom: Photosynthetic, nutritional and antioxidant metabolism responses. 2016;**28**:3-10

[23] Gregory PJ, Atkinson CJ, Bengough AG, Else MA, Fernández-Fernández F, Harrison RJ, et al. Contributions of roots and rootstocks to sustainable, intensified crop production. Journal of Experimental Botany. 2013;**64**:1209-1222

[24] Louws FJ, Rivard CL, Kubota C. Grafting fruiting vegetables to manage soilborne pathogens, foliar pathogens, arthropods and weeds. Horticultural Science [Internet]. Amsterdam: Elsevier B.V.; 2010;**127**:127-146. DOI: 10.1016/j.scienta.2010.09.023

[25] Nawaz MA, Imtiaz M, Kong Q, Cheng F, Ahmed W, Huang Y, et al. Grafting: A technique to modify ion accumulation in horticultural crops. Frontiers in Plant Science. 2016;**7**:1-15

[26] Wahb-Allah MA. Effectiveness of grafting for the improvement of salinity and drought tolerance in tomato (*solarium lycopersicon* L.). Asian. Journal of Crop Science. 2014;**25**:112-122

[27] Rouphael Y, Kyriacou MC, Colla G. Vegetable grafting: A toolbox for securing yield stability under multiple stress conditions. Frontiers in Plant Science. 2018;**8**:10-13

[28] Zhao X, Guo Y, Huber DJ, Lee J. Grafting effects on postharvest ripening and quality of 1-methylcyclopropene-treated muskmelon fruit. Horticultural Science [Internet]. Amsterdam: Elsevier B.V.; 2011;**130**:581-587. DOI: 10.1016/j.scienta.2011.08.010

[29] Jamshidi Goharrizi K, Baghizadeh A, Kalantar M, Fatehi F. Combined effects

of salinity and drought on physiological and biochemical characteristics of pistachio rootstocks. Horticultural Science [Internet]. Amsterdam: Elsevier B.V.; 2020;**261**:108970. DOI: 10.1016/j.scienta.2019.108970

[30] Isayenkov SV, FJM M. Plant salinity stress: Many unanswered questions remain. Frontiers in Plant Science. 2019;**10**:30-41

[31] Tavallali V, Karimi S. Methyl jasmonate enhances salt tolerance of almond rootstocks by regulating endogenous phytohormones, antioxidant activity and gas-exchange. The. Journal of Plant Physiology [Internet]. Elsevier; 2019;**234-235**:98-105. DOI: 10.1016/j.jplph.2019.02.001

[32] Munns R. Comparative physiology of salt and water stress. Plant, Cell & Environment. 2002;**25**:239-250

[33] Ouhaddach M, El-Yacoubi H, Douaik A, Hmouni D, Rochdi A. Réponse à la salinité de quelques paramètres physiologiques et biochimiques du Blé (*Triticum aestivum* L.) au stade montaison. Journal of Materials and Environmental. Science. 2016;**7**:3084-3099

[34] Abidine MKZ, Belhadj Safia LS, Abdelhamid B. Influence DU NACL sur quelques parametres morpho-physiologiques et biochimiques de jeunes plantules de deux influence of nacl on some morpho-physiological and biochemical parameters on young seedlings of two spontaneous species of *Pistacia Genus* P Le. 2020;**10**:2129-2140

[35] Shao Y, Cheng Y, Pang H, Chang M, He F, Wang M, et al. Investigation of salt tolerance mechanisms across a root developmental gradient in Almond rootstocks. Frontiers in Plant Science. 2021;**11**:15-22

[36] Patel MK, Kumar M, Li W, Luo Y, Burritt DJ, Alkan N, et al. Enhancing salt tolerance of plants: From metabolic reprogramming to exogenous chemical treatments and molecular approaches. Cell. 2020;**9**:1-26

[37] Massai R, Remorini D, Tattini M, Plant S, Legnose S, Coltivazioni S, et al. Gas exchange, water relations and osmotic adjustment in two scion/rootstock combinations of Prunus under various salinity concentrations. Stable. 2016;259:153-162. Available from: http://www.jstor.org/stable/24124369 Your use of the JSTOR archive indicates your acceptance of the Te

[38] Zrig A, Ben Mohamed H, Tounekti T, Ennajeh M, Valero D, Khemira H. A comparative study of salt tolerance of three almond rootstocks: Contribution of organic and inorganic solutes to osmotic adjustment. Journal of Agricultural Science and Technology. Tarbiat Modares University; 2015;**17**:675-689

[39] Sidorova T, Miroshnichenko D, Kirov I, Pushin A, Dolgov S. Effect of grafting on viral resistance of non-transgenic plum scion combined with transgenic PPV-resistant rootstock. Frontiers in Plant Science. 2021;**12**:1-14

[40] Toro G, Pimentel P, Salvatierra A. Effective categorization of tolerance to salt stress through clustering prunus rootstocks according to their physiological performances. Horticulturae. 2021;**7**:12-19

[41] Munns R. Genes and salt tolerance: Bringing them together. New Phytologist. 2005;**25**:645-663

[42] Yang S, Zu Y, Li B, Bi Y, Jia L, He Y, et al. Response and intraspecific differences in nitrogen metabolism of alfalfa (*Medicago sativa* L.) under

cadmium stress. Chemosphere. 2019;**220**:69-76

[43] Zrig A, Ben MH, Tounekti T, Ahmed SO, Khemira H. Differential responses of antioxidant enzymes in salt-stressed almond tree grown under sun and shade conditions. Journal of Plant Science and Research. 2015;**2**:117-127

[44] Ranjbarfordoei A, Samson R, Van Damme P. Chlorophyll fluorescence performance of sweet almond [*Prunus dulcis* (Miller) D. Webb] in response to salinity stress induced by NaCl. Photosynthetica. 2006;**44**:513-522

[45] Zrig A, Ferreira JFS, Hamouda F, Tounekti T, Selim S, Al Jaouni S, et al. The impact of foliar fertilizers on growth and biochemical responses of *Thymus vulgaris* to salinity stress. Arid Land Research and Management[Internet]. Taylor & Francis; 2019;**10**:1-24 Available from: https://www.tandfonline.com/doi/full/10.1080/15324982.2018.1551817

[46] Bernstein N, Meiri A, Zilberstaine M. Root growth of avocado is more sensitive to salinity than shoot growth. The Journal of the American Society for Horticultural Science. 2004;**129**:188-192

[47] Ghada S, Shimaa F. Evaluation of salinity tolerance on new selected almond×peach hybrid rootstocks. Arab Universities Journal of Agricultural Sciences. 2021;**10**:10-20

[48] Dejampour J. Evaluation of salt tolerance in almond [*Prunus dulcis* (L.) Batsch] rootstocks. African Journal Biotechnology. 2012;**11**:11907-11912

[49] Alam A, Ullah H, Attia A, Datta A. Effects of salinity stress on growth, mineral nutrient accumulation and biochemical parameters of seedlings of three citrus rootstocks. International Journal of Fruit Science[Internet]. Taylor & Francis; 2020;**20**:786-804. DOI: 10.1080/15538362.2019.1674762

[50] Talhouni M, Sönmez K, Kiran S, Beyaz R, Yildiz M, Kuşvuran Ş, et al. Comparison of salinity effects on grafted and non-grafted eggplants in terms of ion accumulation, MDA content and antioxidative enzyme activities. Advances in Horticultural Science. 2019;**33**:87-95

[51] Hasegawa PM, Bressan RA, Zhu J-K, Bohnert HJ. Plant cellular and molecular and molecular responses to high salinity. Annual Review of Plant Physiology and Plant Molecular Biology. 2000;**51**:463-499

[52] Shulaev V, Cortes D, Miller G, Mittler R. Metabolomics for plant stress response. Physiology Plant. 2008;**132**:199-208

[53] Zhu JK. Plant salt tolerance. Trends. Plant Science. 2001;**23**:66-71

[54] Milošević N, Milošević T. Seasonal changes and content of sodium in main organs of European plum trees (*Prunus domestica* L.), fruit size and yield as affected by rootstocks on acidic soil. Semina: Ciencias Agrarias. 2012;**33**:605-620

[55] Flowers TJ. Improving crop salt tolerance. Journal of Experimental Botany. 2004;**15**:307-319

[56] Bahrami V, Imani A, Piri S. Evaluation of almond' cultivars growth characteristics under salinity stress. Journal of Novel Applied Sciences. 2015;**87**:1227-1229

[57] Tortosa I, Douthe C, Pou A, Balda P, Hernandez-Montes E, Toro G, et al. Variability in water use efficiency of grapevine tempranillo clones and stability over years at field conditions. Agronomy. 2019;**9**:1-11

[58] Andreu P, Arbeloa A, Lorente P, Marín JA. Early detection of salt stress tolerance of prunus rootstocks by excised root culture. HortScience. 2011;**46**:80-85

[59] Papadakis IE, Veneti G, Chatzissavvidis C, Therios I. Physiological and Growth Responses of Sour Cherry (Prunus cerasus L.) Plants Subjected to Short-Term Salinity Stress. 2018

[60] Larsen SU, Bailly C, Côme D, Corbineau F. Use of the hydrothermal time model to analyse interacting effects of water and temperature on germination of three grass species. Seed Science Research. 2004;**14**:35-50

[61] Asimakopoulou G, Karnaouri A, Staikos S, Stefanidis SD, Kalogiannis KG, Lappas AA, et al. Production of omega-3 fatty acids from the microalga crypthecodinium cohnii by utilizing both pentose and hexose sugars from agricultural residues. Fermentation. 2021;**7**

[62] Shafieizargar A, Awang Y, Ajamgard F, Juraimi AS, Othman R, Ahmadi AK. Assessing five citrus rootstocks for NaCl salinity tolerance using mineral concentrations, proline and relative water contents as indicators. Asian Journal Plant Science. 2015;**14**:20-26

[63] Sanwal SK, Mann A, Kumar A, Kesh H, Kaur G, Rai AK, et al. Salt tolerant eggplant rootstocks modulate sodium partitioning in tomato scion and improve performance under saline conditions. Agriculture. 2022;**12**

[64] Shahid MA, Balal RM, Khan N, Zotarelli L, Liu G, Ghazanfar MU, et al. Ploidy level of citrus rootstocks affects the carbon and nitrogen metabolism in the leaves of Chromium-stressed Kinnow mandarin plants. Environmental and Experimental Botany[Internet]. Elsevier B.V.; 2018;**149**:70-80. DOI: 10.1016/j.envexpbot.2018.02.010

[65] Grieve C, Grattan S. Mineral nutrient acquisition and response by plants grown in saline environments. Open Journal of Forestry. 1999;**203**:29-35

[66] Aras S, Eşitken A. Responses of cherry plant grafted onto CAB-6P, MaxMa 14 and mazzard rootstocks to short term salinity. Journal of Agricultural Studies. 2019;**7**:29

[67] Erturk U, Sivritepe N, Yerlikaya C, Bor M. Responses of the cherry rootstock to salinity in vitro. Biologia Plantarum. 2007;**10**:2-6

[68] Küçükyumuk C, Yildiz H, Küçükyumuk Z, Ünlükara A. Responses of "0900 Ziraat" sweet cherry variety grafted on different rootstocks to salt stress. Notulae Botanicae Horti Agrobotanici Cluj-Napoca. 2015;**43**:214-221

[69] Sinha AK, AbdElgawad H, Zinta G, Dasan AF, Rasoloniriana R, Asard H, et al. Nutritional status as the key modulator of antioxidant responses induced by high environmental ammonia and salinity stress in European sea bass (*Dicentrarchus labrax*). PLoS One. 2015;**10**:1-29

[70] Jacoby RP, Taylor NL, Millar AH. The role of mitochondrial respiration in salinity tolerance. Trends in Plant Science[Internet]. Elsevier Ltd; 2011;**16**:614-623. DOI: 10.1016/j.tplants.2011.08.002

[71] Rachmilevitch S, Lambers H, Huang B. Root respiratory characteristics associated with plant adaptation to high soil temperature for geothermal and turf-type Agrostis species. Journal of Experimental Botany. 2006;**57**:623-631

[72] Meloni DA, Oliva MA, Martinez CA, Cambraia J. Photosynthesis and activity of superoxide dismutase, peroxidase and glutathione reductase in cotton under salt

stress. Environmental and Experimental Botany. 2003;**49**:69-76

[73] Grace JK, Sharma KL, Seshadri KV, Ranganayakulu C, Subramanyam KV, Raj GB, et al. Evaluation of sweet orange (*Citrus sinensis* L. Osbeck) cv. sathgudi budded on five rootstocks for differential behavior in relation to nutrient utilization in alfisol. Communications in Soil Science and Plant Analysis. 2012;**43**:985-1014

[74] Raoufi A, Rahemi M, Salehi H, Javanshah A. Selecting high performance rootstocks for pistachio cultivars under salinity stress based on their morpho-physiological characteristics. International Journal of Fruit Science[Internet]. Taylor & Francis; 2020;**20**:S29-S47. DOI: 10.1080/15538362.2019.1701616

[75] Naseer S, Lee Y, Lapierre C, Franke R, Nawrath C, Geldner N. Casparian strip diffusion barrier in arabidopsis is made of a lignin polymer without suberin. Proceedings of the National Academy of Sciences. USA. 2012;**109**:10101-10106

[76] Omamt EN, Hammes PS, Robbertse PJ. Differences in salinity tolerance for growth and water-use efficiency in some amaranth (*Amaranthus* spp.) genotypes. New Zealand Journal of Crop and Horticultural Science. 2006;**34**:11-22

[77] Zrig A, Tounekti T, Vadel AM, Ben Mohamed H, Valero D, Serrano M, et al. Possible involvement of polyphenols and polyamines in salt tolerance of almond rootstocks. Plant Physiology and Biochemistry. 2011;**49**:1313-1322

[78] Sharma RM, Dubey AK, Awasthi OP. Physiology of grapefruit (*Citrus paradisi* Macf.) cultivars as affected by rootstock. The Journal of Horticultural Science and Biotechnology. 2015;**90**:325-331

[79] Zrig A, Ben Mohamed H, Tounekti T, Khemira H, Serrano M, Valero D, et al. Effect of rootstock on salinity tolerance of sweet almond (cv. Mazzetto). South African Journal of Botany. Elsevier; 2016;**102**:50-59

[80] Estañ MT, Martinez-Rodriguez MM, Perez-Alfocea F, Flowers TJ, Bolarin MC. Grafting raises the salt tolerance of tomato through limiting the transport of sodium and chloride to the shoot. Journal of Experimental Botany. 2005;**56**:703-712

[81] Martínez-Ballesta MC, Alcaraz-López C, Muries B, Mota-CadenasC, CarvajalM. Physiological aspects of rootstock-scion interactions. Scientia Horticulturae Amsterdam. 2010;**127**:112-118

[82] Prior N. North Dakota State University. Grad Study Criminology and Criminal Justice. 2020;**5**:212-213

[83] Lee JM, Kubota C, Tsao SJ, Bie Z, Echevarria PH, Morra L, et al. Current status of vegetable grafting: Diffusion, grafting techniques, automation. Scientia Horticulturae [Internet]. Amsterdam: Elsevier B.V.; 2010;**127**:93-105. DOI: 10.1016/j.scienta.2010.08.003

[84] Martinez-Rodriguez MM, Estañ MT, Moyano E, Garcia-Abellan JO, Flores FB, Campos JF, et al. The effectiveness of grafting to improve salt tolerance in tomato when an "excluder" genotype is used as scion. Environmental and Experimental Botany. 2008;**63**:392-401

[85] Zrig A, AbdElgawad H, Touneckti T, Ben Mohamed H, Hamouda F, Khemira H. Potassium and calcium improve salt tolerance of *Thymus vulgaris* by activating the antioxidant systems. Scientia Horticulturae. Amsterdam. 2021;**277**

[86] Tounekti T, Vadel AM, Oñate M, Khemira H, Munné-Bosch S.

Salt-induced oxidative stress in rosemary plants: Damage or protection? Environmental and Experimental Botany. 2011;**71**:298-305

[87] Massai R, Remorini D, Tattini M. Gas exchange, water relations and osmotic adjustment in two scion/rootstock combinations of prunus under various salinity concentrations. Plant and Soil. 2004;**259**:153-162

[88] Fullana-Pericàs M, Conesa M, Pérez-Alfocea F, Galmés J. The influence of grafting on crops' photosynthetic performance. Plant Science[Internet]. Elsevier; 2019:110250. DOI: 10.1016/j.plantsci.2019.110250

[89] Pérez-Alfocea F, Albacete A, Ghanem ME, Dodd IC. Hormonal regulation of sourcesink relations to maintain crop productivity under salinity: A case study of root-to-shoot signalling in tomato. Functional Plant Biology. 2010;**37**:592-603

[90] Villalta I. Genetic analysis of Na^+ and K^+ concentrations in leaf and stem as physiological components of salt tolerance in Tomato Genetic analysis of Na^+ and K^+ concentrations in leaf and stem. 2008

[91] Rajendran K, Tester M, Roy SJ. Quantifying the three main components of salinity tolerance in cereals. Plant, Cell & Environment. 2009;**23**:237-249. DOI: 10.1111/j.1365-3040.2008.01916.x

[92] Ziska LH, DeJong TM, Hoffman GF, Mead RM. Sodium and chloride distribution in salt-stressed Prunus salicina, a deciduous tree species. Tree Physiology. 1991;**8**:47-57

[93] Mauro RP, Pérez-Alfocea F, Cookson SJ, Ollat N, Vitale A. Editorial: Physiological and molecular aspects of plant rootstock-scion interactions. Frontiers in Plant Science. 2022;**13**:1-5

[94] Lu X, Liu W, Wang T, Zhang J, Li X, Zhang W. Systemic long-distance signaling and communication between rootstock and scion in grafted vegetables. Frontiers in Plant Science. 2020;**11**:1-11

[95] Stahl-Biskup E, Saez F. Thyme the genus thymus. Med Aromat Plants–Industrial Profiles, 24. 2002;**15**(xii):330

[96] Zrig A, Ferreira JFS, Serrano M, ValeroD,TounektiT,KhemiraH.Polyamines and other secondary metabolites of green-leaf and red-leaf almond rootstocks trigger in response to salinity. Pakistan Journal of Botany. 2018;**50**:245-250

[97] Ofosu M, Emmanuel BG, Khalilia WM, Yahaya MS, Salisi MS, Md. Isa NM, et al. Recent Research Advances in Biology. 2020;**4**