Citrus Response to Salinity

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Summary

Citrus is among the most salt sensitive of horticulture crops. Growth and yield of citrus are seriously limited by salinity in many areas worldwide. Salt damage usually manifests as trees physiological disturbances and growth reduction. Factor affecting citrus response to salinity included salinity levels for onset and rate of yield decline in mature trees. The salinity is concerned with the regulation of chloride and sodium concentration in the leaves, stems and roots. The factors underlying changes in leaf gas exchanges parameters, reduction in growth and foliage damage at increasing salinity levels depended on scion-rootstock combination. Foliage damage as leaf burn and defoliation associated with accumulation of excess toxic levels of sodium and chloride in leaf cells. However, this problem can be minimized by using rootstocks that restrict the uptake of these ions. Genetic transformation methods have been applied in citrus to improvement salt-tolerance mechanism.

Introduction

Salinisation of agriculture land is occurring throughout the world especially in regions where water irrigation has high salt concentration and water evaporates rapidly from the surface soil. Citrus is grown commercially in over fifty countries and ranks first in world production of fruit crops. Salinity is already an important problem in citrus production and is threatened by increase salinity due to the use poor quality irrigation water (García *et al*., 2002).

Citrus are among the most salt sensitive of horticulture crops (Mass, 1990). However, the ability of citrus trees tolerance to salinity varies among different species in these genera and depends on the rootstocks (Maas, 1993). High concentrations of chloride and/or sodium in the

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leaves of citrus trees have been frequently related to disturbances in nutrition, gas exchange and water relation (Ruiz et al., 1999). Citrus commonly grown in regions where the salinity of irrigation water is relatively low, typically < 0.5dSm-1, it is also growing in the regions where the salinity of irrigation water is significantly higher e.g. 1.4 dSm-1 (Bielorai et al., 1978). Depending on soil type, method of irrigation and frequency of irrigation, the soil solution salinity might also increase several fold between irrigations (Marschner, 1995). Tree growth and fruit yield of citrus species are impaired at soil salinity of about 2 dSm-1 soil saturation extract without the concomitant expression of leaf symptoms (Bingham et al., 1974; Cerdá et al., 1990). Continual improvement of rootstock and scion will be necessary to sustain irrigated citrus in increasingly salinity environments. Screening technique to reliably predict the performance of scion rootstock combination as mature trees under salinity conditions and identify good donor of salt tolerance for rootstock breeding programs (García et al., 2002).The greater rootstock salt tolerance such as Rangpur lime and Cleopatra mandarin, is associated with their capacity to limit the accumulation of Cl- in leaves. Other rootstocks, like trifoliate orange, demonstrated a capacity to restrict Na+ transport to the shoot at low salinity. A high concentration of salts in root zone substantially decreases leaf water potential and photosynthesis (Bañuls et al., 1997). Plant physiology responses to stress are modulated by hormones such as abscisic acid (ABA), ethylene. Citrus plant rapidly response to water deficit or salinity by increasing endogenous ABA level (Gómez-Cadenas et al., 1996, 1998). In salinity citrus leaves, the increase in chloride levels has been correlated with the accumulation of 1-aminocyclopropane-1-carboxilic acid (ACC) and its subsequent oxidation to ethylene (Gómez-Cadenas et al., 1998). The capacity of citrus trees tolerate salinity varies among different species and depends upon the rootstocks. García- Agustin and Primo-Millo (1992 and 1995) reported that mutagenesis technique have shown some promise for induction of salt resistance in citrus. Another approach is the isolation and transference of genes directly implicated in salt tolerance mechanisms. The over expression of HAL2 genes were demonstrated to improve growth and yeast under salt stress (Gaxiola, 1992; Gläser et al., 1993). The research have successfully transformed plant of Carrizo citrange via Agrobacterium tumefaciens with the halotolerance gene HAL2, originally isolated from yeast and implicated in salt tolerance mechanisms. In an attempt to improve the behavior of this important genotype under salt stress (Cervera et al., 2000).

This paper reviewed these research reports to summarize the state of understanding about the response and tolerance of citrus trees to salinity.

Salinity effect on citrus

I. Growth and yield

The critical salinity level (where plants are adversely affected) varies with the buffering capacity of the soil (soil type, organic matter) climatic conditions and the soil moisture statutes (Boman and Solver, 2002). Salt damage induced symptoms such as reduced root growth, decreased flowering, small leaf size and impaired shoot growth are often difficult to assess. Leaf injury result from the accumulation of toxic ion chloride and sodium from salt induced nutritional deficiencies (Bernstein, 1965; Boman and Solver, 2002). As salinity increased the leaf size will be decrease, begin to shed and thinning of the canopy (Syvertsen et al., 1988; Lloyd and Howie, 1989a). The relationship between salinity and yield may be expressed negative linear response function at salinity above a critical threshold (Maas and Hoffman, 1977). The research reported that reduction in fruit yield occur without excessive accumulation of Cl^{-} or Na+ and without any apparent toxicity symptoms indicate that the dominant effect in osmotic (Bigham et al., 1974; Bielorai et al., 1978, 1988; Levy et al., 1979; Cerda et al., 1990; Dasberg et al., 1991). Lemon trees on Citrus Macrophylla rootstock, orange trees were reduced fruit yield with applied water salinity. The reduction due to a decrease in number of fruit per tree (Bielorai et al., 1978; Dasberg et al., 1991; García- Sánchez et al., 2003). The increase of lemon fruit yield was observed by increasing the quantity of water. Salinity and among of water apply affected fruit quality (Gracia- Sánchez et al., 2003).

II. Rootstock varieties and scion –rootstock combination

The performance of citrus rootstock have been evaluated using rootstock seedlings and grafted plants. One way of improving the salt tolerance of citrus is to graft scions onto salt tolerance rootstocks. Rootstocks differ in their salinity tolerance as estimated by the ability to inhibit the accumulation of Cl^{-} and /or Na+ in leaf of the scion (Storey and Walker, 1999). Salt tolerance in citrus is intimately linked to rootstock characteristics (Levy et al. 1999; Levy and Syvertsen, 2003; Moya et al., 2003). Story and Walker (1999) compiled the numerous studies have reported in which large number of rootstock, hybrid and scion have been screened (Peynado and Young, 1969; Wutscher et al., 1974; Ream and Furr, 1976; Peynado and Sluis, 1979; Grieve and Walker, 1983; Sykes, 1985a, 1985b; Gallasch and Dalton, 1989; Chen, 1992). The results of several earlier studies and ranked the rootstocks in order of their relative elemental concentrations (Embleton et al., 1973; Wutscher et al., 1974; Ream and Furr, 1976; Creda et al., 1977; Joolka and Singh, 1979; Peynado and Sluis, 1979; Grieve and Walker, 1983; Walker et al., 1983; Behboudian et al., 1986; Syvertsen et al., 1988; Vardi et al., 1988; Banuls et al., 1990; Zekri, 1991). Maas (1993) noted that there is considerable diversity in salt resistance within the citrus genus and between closely related species but there are also examples of consistencies in the ranking of rootstock. Screening large number of scion- rootstock combinations for yield in a range of environment, although a desirable goal is not feasible. Since then, there is a need for a screening technique to reliably predict the performance of scion-rootstock combinations as a mature tree under saline conditions and identify good donors of salt tolerance by Cleopatra mandarin when used as rootstock for citrus rootstock breeding program (García et al., 2002).

III. Effect of different salt

Several studies indicated that the concentration of Ca^{2+} in the soil solution is an important factor controlling the severity of specific ion toxicities (Maas, 1993). Zekri and Parson (1990a) were studied on four months old sour orange seedling growth in NaCl on the addition of $CaSO_4$ ameliorated the some effects of salinity in citrus. Similar results was reported by Bañuls et al., (1991) supplement Ca^{2+} as $CaSO_4$ and $Ca(NO_3)_2$ to saline root solution partially reversed growth inhibition and reduced defoliation of two years old Navel orange scion. The addition of Ca^{2+} greatly reduced the transport of Na^+ and Cl^- to the leaves of scions budded to either Cleopatra mandarin or Troyer citrange rootstocks. Calcium uptake by leaves increased concomitantly with increasing Ca^{2+} concentrations in the external solution (Maas, 1993). Bañuls et al. (1997) studied on growth and gas exchange of Valencia orange scion grafted on Cleopatra mandarin or Poncirus trifoliate rootstock which expose to different salts NaCl, KCl and $NaNO_3$. The result showed that both chloride salts caused a similar reduction in photosynthesis and stomata conductance, whereas $NaNO_3$ had no detectable effects on these parameters. Salem and El-Khorieby (1989) found that different types of salts applied in concentrations reduced growth of four rootstocks in the order NaCl>KCl>$CaCl_2$. Potassium nitrate supplementation improved the performance of salinity plants base on the increase in total biomass and significant reduction in leaf abscission. In addition, increasing leaves nitrogen, chlorophyll concentrations and photosynthesis of salt- treated Navelina orange grafted into either Carrizo citrange, Citrus macrophylla or Cleopatra mandarin (Iglesias et al., 2004). Cerezo et al. (1999) and Tyerman and Skerrett (1999) indicated that chloride was reduced in the nitrate-supplemented trees through an antagonism between chloride and nitrate uptake at the fibrous root–soil interface.

IV. Sodium and Chloride accumulation

Under saline conditions, growth of Citrus species may be reduced as a result of the accumulation of Na^+ or Cl^- or both. Various differences among Citrus species in their ability to regulate root uptake and transport of Na^+ and Cl^- from roots to shoots have been reported (Grieve and Walker, 1983; Behboudian et al., 1986; Storey and Walker, 1987; Storey 1995, Storey and Walker, 1999). The accumulation of Na+ and Cl^{-} in leaves may be influence by rootstock, scion or both depending on the scion-rootstock combination (Storey and Walker 1999). Grafting of lemon scion varieties on sour orange and Citrus macrophylla produced variable effects of leaf Na+ and Cl^{-} concentrations (Nieves et al., 1992). Maas (1993) reported that chloride was accumulated sooner and much higher concentrations in leaves than sodium. The relative capability of rough lemon and sweet orange rootstocks to exclude Cl^{-} from the scion showed the contradictory. Grieve and Walker (1983) indicated that rough lemon accumulated Cl^{-} more readily than sweet orange, whereas Cooper (1962) indicated in contrast. Levy and Shalhevet (1990) reported that sour orange was much more effective than rough lemon in excluding Cl^{-} from leaves of mature 'Marsh Seedless' grapefruit and 'Washington' navel orange trees. Ranked the best Cl^{-} excluders as Sunki mandarin, grape-fruit, Cleopatra mandarin, Chinese Box orange and Rangpur lime. The same author ranked the best Na+ excluders as sour orange, Cleopatra mandarin, Rusk citrange, rough lemon and Rangpur lime. Walker and Douglas (1983) reported a limit to the accumulation of Cl^{-} in the root that was independent of NaCl concentration in three self-rooted plants (Citrus reticulate var., Citrus karma Raf., Citrus media L.) that had differing Cl^{-} accumulation rates in the leaves. However, Bañuls et al. (1990) observed that the upper limit of root Cl^{-} concentration differed for each scion-rootstock combination assayed. Scions on Cleopatra mandarin accumulated less Cl– in their leaves than did scions on Troyer citrange. In addition, leaf Cl^{-} levels in Clementine scions were lower than in Navel orange when both were grafted on the same rootstock, whereas sodium concentration was lower in scions on Troyer citrange than in Cleopatra mamdarin (Bañuls and Primo-Millo, 1995). Fernández-Ballester (2003) indicated the genotypic differences among rootstocks, root capacity for Cl^{-} accumulation also depends on the scion-rootstock combination. It is also closely related to juice Cl^{-} as 'Marsh Seedless' grapefruit and 'Washington' navel orange scions on three rootstocks (Levy and Shalhevet, 1990) and with yield of 'Marsh Seedless' grapefruit grafted on rough lemon rootstock (Levy et al., 1992).

Photosynthesis

Several studies have determined the effect of salt stress on water relations and gas exchange of citrus plants. Under high concentration of Na+ and Cl^{-} in citrus leaves also caused substantial reductions in CO2 assimilation rate and stomata conductance. (Walker et al., 1982; Behboudian et al., 1986; Lloyd et al., 1990; Banuls and Primo-Millo, 1995; Banuls et al., 1997; Gómez-Cadenas et al., 1998; García-Sánchez et al., 2002). Lloyd et al. (1987b) examined the effects of salinity on the relationship between CO2 assimilation and stomata conductance and concluded that the reduction in CO2 assimilation also due to direct biochemical inhibition of photosynthesis capacity. The factors responsible for the different effects of salinity on photosynthesis in citrus are complex. Plant response varies with season, tree and leaf age, various soil and environmental condition (Syvertsen et al., 1988). The reductions in leaf gas exchange of citrus influenced by rootstock (Lloyd et al., 1987b; 1990) and the scion(Behboudian et al., 1986; Lloyd et al., 1990; Bañuls and Primo-Millo, 1995; García-Sánchez et al., 2002).

Hormones

Several of physiological effects are modulated by hormonal intermediates, such as abscisic acid (Zeevaart and Creelman, 1998) or ethylene (Gómez-Cadenas et al., 1996). However, hormonal signals are likely to be secondary responses caused by primary effects of salinity are osmotic and accumulation of toxic ions (Munns, 1993).

Salinity promotes senescence of plant tissue by increasing the production of ethylene (Kefu et al., 1991; Zhao et al., 1992). ABA is known to play an important role in the efficiency of water use in plants under environment stresses. Citrus plants rapidly response to a water deficit or salinity by increasing endogenous ABA levels. In addition, ethylene modulates leaf abscission in citrus plants under salt stress (Gómez-Cadenas et al., 1996, 1998).The effect of ABA treatment on citrus response to salinity was studies by Gómez-Cadenas et al. (2003) using grafted citrus plants Salustiana scion on Carrizo citrange rootstock growth in the salt stress. It is shown that ABA regularly added to the watering solution reduces the damaging effects that a high NaCl concentration causes in citrus plants. The salt induced defoliation was delayed by ABA treatment probably through mechanism that slow down plant metabolism, chloride uptake and accumulation in leaves, that is initial reduction of stomata aperture and transpiration. ABA appears to improve tolerance to salinity in citrus. In salinity citrus leaves, the increase in chloride levels has been correlated with the accumulation of 1- amonocyclopropane-1 carboxylic acid (ACC) and it subsequent oxidation to ethylene (Bar et al., 1998)

Introduction of salt tolerance

I. In vitro mutagenesis

Mutagenesis techniques have shown some promise for induction of salt tolerance in citrus (Storey and Walker, 1999). Since the nucellar tissue readily undergoes embryogenesis when culture in vitro with suitable medium (Button and Bornman 1971, Kochba et al., 1972). Garcia-Agustin and Primo-Millo (1995) using unfertilized ovule of Troyer citrange treated with a mutagen to induce genetic variability. Screening for salt tolerance was accomplished on complete plant regenerated from ovule culture, the selected plant grown well, less leaf damage and lower concentration of Cl^{-} and Na+ in leaves than original clone.

II. Gene transformation

Increasing interest has been shown in stress- induced changes in gene expression and gene production. The majority of studies have been conducted on NaCl adapted cultured cells (Ben-Hayyim et al., 1989, 1993; Naot et al., 1995), with a focus on genes encoding proteins that increase in salt-adapted cells (Ben-Hayyim et al., 1993). This study approach is yet to be translated into increased resistance of whole citrus plants in either the glasshouse or field. The capacity of citrus trees to tolerance salinity varies among different species and depends upon the rootstock. Carrizo citrange is nowadays the most extensively used citrus rootstock due to its general good agronomic behavior. Genetic transformation of Carrizo citrange was attempted by Moore et al. (1992) and Gutiérrez et al. (1997), but difficulties with rooting of transgenic plants. Currently, the study have successfully transformed plants of Carrizo cirange via Agrobacterium tumefaciens with the halotolerance HAL2, originally isolated from yeast and implicated in salt tolerance mechanism (Cervera et al., 2000).

Conclusion

The salt tolerant of citrus plants is associated with the restriction of Na+ or Cl^{-} transport from the root to shoot. This exclusion trait for both Na+ and Cl^{-} is heritable (Sykes, 1992), suggesting that breeding and selection for Cl^{-} and Na+ excluding genotypes will continue to be a potential rewarding area of research. Improve understanding of membrane transporter system for Na+, Cl^{-} and salinity impacts on citrus growth regulator levels and effects on growth. With the recent advent of gene transformation technologies for citrus, the way is open to manipulate citrus salt tolerance by insertion of specific tolerance genes. The immediate challenge, However, is to further understand the primary physiological processes involved in uptake and root to shoot transport of Na+ and Cl^{-} (Storey and Walker,1999).

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柑桔之鹽害反應

阮 一 月[1)]

關鍵字:柑桔、鹽害、砧木、氯、鈉、生理

摘要：柑桔是對鹽分敏感的園藝作物之一，在世界上有許多地區之柑桔生長及產量因鹽害而受到嚴重的限制。一般柑桔發生鹽害時常出現生理失調及生長遲緩的現象，其受害程度及降低之產量與鹽分濃度高低有關。植體的根、莖及葉內鹽害之發生與 Na^+及 Cl^-的調節及水分變化有關，利用適當接穗及砧木組合，可減緩鹽害所造成葉片氣體交換係數之改變、葉片生長遲緩及葉傷等現象。而葉傷的症狀，如葉燒及落葉之原因為葉片細胞累積過量的 Na^+及 Cl^-。不過該問題可藉由砧木的應用而限制離子之吸收加以改善，目前已有利用基因轉殖的方法促進柑桔對鹽害之忍受機制。

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