The effects of salt stress on ornamental plants: a review

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Abbreviations

Dry weight (DW)

Electrical conductivity (EC)

Fresh weight (FW)

Light emitting diode (LED)

Pour Through (PT)

Abstract

Ornamental horticultural production is closely associated with a high water consumption and yet the availability of freshwater is reducing. The irrigation of ornamental plants with saline water may be an alternative, but an improvement in knowledge of the effects on salinity on species used as ornamentals is essential. At high salinities, plants exhibit a reduction of growth parameters such as biomass or leaf area related to osmotic and ionic effects of salinity. Growth under saline conditions leads to uptake of Na^+ and Cl^- by plants, which can result in a nutritional imbalance due to the antagonism between nutrients and saline ions with possible effects on the foliage. Salinity can affect water relations in plants and photosynthetic capacity by stomatal limitations. These negative effects can be counteracted by the plants through the accumulation of compatible solutes or osmolytes and the activation of antioxidant machinery. Nevertheless, the performance of these mechanisms is sometimes not enough to avoid damage to the appearance of the plant and in consequence the saleability of an ornamental species. In this review recommendations for the establishment of new culture methods for nursery growers are made; these include exogenous application of nutrients and osmolytes, enrichment with CO_2, and shading treatments, in order to mitigate the damage caused by salt stress to ornamental plants.

Keywords: Antioxidant responses, biomass, nutritional balance, osmolytes, photosynthetic parameters, water relations.

1. Introduction

Ornamental plants have an important place within the horticultural industry as they are used in gardening, landscaping, and as cut flowers. The total turnover for all aspects of floriculture is estimated to be more than 300 billion USD and cut flowers make up about one-third of the global value of the ornamental plants market (Azadi et al., 2016). Currently, the main constraint to ornamental plant production is water consumption: it has been estimated that 100-350 kg of water are needed to produce 1 kg of plant dry matter, although this can vary with species and variety, cultivation system and plant growing season (Fornes et al., 2007). Growers have, over decades, used high quality water to irrigate ornamental plants because of their high economic value. Nowadays the increase in population and agricultural production together with the diminishing sources of fresh water continue to intensify competition for good water

(Carter and Grieve, 2010). As a consequence, the use of saline water could be considered an advisable source for the irrigation of ornamental plants since in floriculture the products are not consumed.

Ornamental plants can be grown under field conditions and sold on as bare-rooted plants or potted in containers filled with substrates such as peat moss, coconut fibre or different kinds of mixtures with other materials (Reid and Jiang, 2012). The selection of how plants are grown, whether under field conditions or in containers, will be influenced by the salinity in the soil and the irrigation water available. There are different causes of salinity in the soil and water. In the case of the soil, the main causes are long-term natural accumulation of salts, deposition of sea-salt carried by wind and rain and anthropogenic activities that disrupt the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration) (Singh, 2015). For the salinization of water, the main causes are overexploitation of ground-waters, percolation of salts into the aquifers and seawater intrusion in aquifers (Payen et al., 2016).

Soils are considered saline when they have an EC of 4 dS m^{-1} or higher, which can be particularly problematic if the increased EC is the result of NaCl (Ghassemi et al., 1995). Soil salinities of 50 mM NaCl (6 dS m^{-1}) are considered moderately saline, whereas salinities greater than or equal to 150 mM NaCl (18 dS m^{-1}) are considered highly saline by Cassaniti et al. (2013). They classified waters as slightly brackish with an EC which ranges from 0.6 to 1.5 dS m^{-1}, brackish with an EC from 1.5 to 3.0 dS m^{-1}, moderately saline from 3 to 8 dS m^{-1}, saline from 8 to 15 dS m^{-1} and highly saline from 15 to 45 dS m^{-1}.

Plant growth response under saline conditions presents two phases. In the first phase (osmotic phase), there is a growth reduction which starts immediately after exposure of the roots to salt. This effect is associated with an osmotic impediment to water uptake and consequent changes in water relations at a cellular level. The second phase (ionic phase) results when old leaves are not able to compartmentalize sufficient Na^+ and Cl^- concentrations to prevent effects on photosynthesis and consequently old leaves die (Munns and Tester, 2008). However, plants differ considerably in the concentration of salt that brings about these changes and species have been divided into halophytes and glycophytes; the former can tolerate high concentrations of salt between 80 and 200 mM NaCl) while the latter are susceptible (see Flowers and Colmer, 2015).

The effect of saline irrigation on ornamental plants has been investigated to a much lesser extent than other crops because ornamentals are normally irrigated with high quality water. Nevertheless, there are many papers on the effects of the saline stress in ornamental plants, describing the effects on one or more species (e.g. Valdes et al., 2015 a; Garcia-Caparros et al., 2016) as well as comprehensive reviews (Niu and Cabrera, 2010 a; Cassaniti et al., 2013). In this review we update information on the effects of salinity on ornamental plants with material covering the last ten years, tabulating effects on growth, nutritional status, water relations, photosynthetic parameters, osmolytes accumulation and antioxidant activity, with the aim of allowing the grower to make rational choices of plants and culture methods.

2. The effects of salt stress on ornamental plants

2.1. Growth (biomass, leaf area and number of flowers)

Plant growth is affected by salinity as a result of the disruption of physiological processes such as: 1) disturbed photosynthesis, 2) disturbed osmoregulation, 3) down-regulation of aerial growth following a long distance signal, and 4) disturbance in mineral supply to the aerial part (Negrao et al., 2017).

Ornamental plants subjected to salt stress exhibit a decrease in fresh weight (FW) and dry weight (DW), especially in the aerial part, a reduction in total leaf area and plant height and a reduction of the number and quality of flowers, which has been recorded in previous reviews (Quist et al., 1999; Kucukahmetler, 2002) and can be seen in the updated references in Table 1. The decrease in FW or DW is mainly due to a reduction in the number of leaves or the formation of smaller and fewer leaves and reduced plant height as reported by Acosta-Motos et al. (2017 a). This reduction of FW and DW under saline conditions can be used for the classification of ornamental species according to the degree of salt tolerance, essential information for the nursery grower in order to choose which species is the most suitable for the soil and water available. Species that are very sensitive to salinity include *Impatiens walleriana*, *Zinnia angustifolia* and *Viola tricolor* with a high biomass decrease (90%), while *Chamaerops humilis* and *Washingtonia robusta* can be grown with electrical conductivity of irrigation water from 2 to 8 dS m^{-1} (see Table 1).

For ornamental plants, exposure to saline conditions can involve not only a decrease in plant weight, but also a consequent reduction of plant height (Zhang and Shi, 2013). Nevertheless, this reduction in size could be an advantage from the grower's point of view since consumers often require short, compact plants with good keeping quality and ornamental value, but taking into account that the consumer should continue with the irrigation with salt water in order to maintain the reduction in size. Furthermore, smaller plants require less space in expensive production facilities, are easier to handle, have reduced transportation costs and advantages for retailers (Lutken et al., 2012). Nevertheless, the use of salt has not yet been used as a technique to manage plant size.

A typical response to salt stress described in papers is a reduction in total leaf area. The reduction in leaf area, a consequence of changes in cell wall properties, cell water relations and a reduction in photosynthetic rate (Munns and Tester, 2008), has been recorded (see Table 1) for *Paulownia* sp. (Ivanova et al., 2014), *Callistemon laevis* (Alvarez and Sanchez-Blanco, 2015) and *Euonymus japonicus* (Gomez-Bellot et al., 2013). A reduction of leaf area due to the salt stress could be beneficial for nursery growers, especially when they want to produce compact plants without the use of plant growth regulators.

In floricultural crops, under salt stress there can be a reduction of the number and quality of flowers as was reported in previous literature (Wahome et al., 2000; Shillo et al., 2002). This effect can be related to an alteration of the concentration of hormones directly involved in flowering such as abscisic and jasmonic acids (Rogers, 2013). The reduction of number and quality of flowers can result in a decrease of sales for floricultural crops which is not acceptable to growers. Therefore, one possible solution to mitigate these effects could be the foliar application of hormones, following the recommendations given in a comprehensive review on post-harvest biology and technology in potted plants by Reid and Jiang (2012). To date, there is only information about the foliar application of these hormones under non-saline conditions. For instance, Jahanbazi et al. (2014) reported that the exogenous application of jasmonic acid in rose resulted in an increase of number of flower and quality. Raviz et al. (2016) reported the same effects in gerbera fumigated with methyl jasmonate.

2.2. Nutritional balance

Salt stress can affect the nutritional status of a plant through a complex net of interactions, including a decrease of nutrient uptake and/or transport from root to shoot

(Munns and Tester, 2008). As can be seen in Table 2, ornamental plants grown under saline conditions exhibited a decrease of N, P, K and Ca concentration in leaves related to antagonisms with Cl and Na and an increase in Na and Cl concentration in leaves.

Under salt stress conditions, nitrogen uptake is often disrupted mainly due to the antagonism between Cl^- and NO_3^- (Munns and Gilliham, 2015). Salinity stress also reduces P availability because of the antagonism between Cl^- and $H_2PO_4^-$ as reported by Parihar et al. (2015). Reduced uptake of phosphorus under salt stress can also be a consequence of the strong influence of sorption processes that control the concentration of phosphorus in the soil and low solubility of Ca-P minerals (Marschner, 2011). The inhibition of K^+ uptake in plant occurs primarily due to the physical and chemical similarities between K^+ and Na^+ and the tendency of the latter to compete with K^+ for major binding sites, including control of enzymatic activity that occurs at unfavourable cytosolic K^+/Na^+ ratios (Adams and Shin, 2014; Benito et al., 2014). With respect to Ca, the decrease in uptake is due to the to the antagonistic effect between Ca^{2+} and Na^+ ions, which affects membrane properties, due to displacement of membrane-associated Ca^{2+} by Na^+, leading to dissolution of membrane integrity and selectivity (Kopittke, 2012).

In plants subjected to saline conditions, there is an increase of toxic elements such as Na and Cl in leaves that can result in visual damage like tip and marginal burn, with negative influences on decorative value (Cassaniti et al., 2009). The typical symptoms of Na^+ accumulation are leaf burn, scorch and dead tissue along the leaf margins, which first occur in the oldest leaves. As the severity increases, the drying progresses towards the leaf centre until the entire tissue is dead. Injury due to Cl^- toxicity, however, typically, starts at the extreme leaf tip of older leaves and progresses from the tip back as the severity increases (Cassaniti et al., 2013).

The fact that water uptake by plants and relative exclusion of Na^+ and Cl^- from the transpiration stream can concentrate ions in the substrate leads to such aesthetic damage in ornamental plants, so one possible solution for the displacement of these ions is through the adjustment of the irrigation according to the electrical conductivity of the substrate as reported by Valdes et al. (2015 b). The estimation of the electrical conductivity in the substrate can be performed through three different methods: the pour-through (PT) method, the saturated media extract, and the 1:2 water:substrate (v/v) suspension test (1:2) (Camberato et al., 2009). The first method (PT) is a widely accepted practice amongst nursery growers. This method is a bulk solution displacement, simple, rapid, non-destructive, and cost effective means of monitoring EC and nutrient availability in substrates (Torres et al., 2010).

It is important to note that although growers supply standard nutrient solutions for an adequate growth of ornamental plants, it is common to see nutritional deficiencies of N, P, K and Ca in salt-affected plants (Table 2) as a consequence of the antagonisms between nutrient and Na and Cl uptake. A shortage of nutrient reduces the visual appearance and the quality in plants, thus decreasing their saleability. One culture method that could be implemented by nursery growers is the application of macronutrients via foliar spray, since the process of uptake via the leaves and the distribution of nutrients in the plant organs is enhanced compared with fertigation, resulting in a higher growth and better visual appearance as reported Kashif et al. (2014) in *Dahlia hybrida*.

2.3. Water relations

Plant-water relations explain the behaviour of plants in terms of how they control the hydration of their cells, which is essential in physiological and metabolic processes that determine the quantity and quality of plant growth (Acosta-Motos et al., 2017 a). One of the main problems for plants growing under saline conditions is the low water potential in the soil solution due to the increase of solute concentration in the root zone, therefore in order to ensure the water flow plants should adjust osmotically, decreasing their water and osmotic potentials (Cassaniti et al., 2013).

Water potential and osmotic potential of plants become more negative with an increase in salinity. Leaf water potential and osmotic potential decline depending on the osmotic potential of the rooting medium and the mode of stress imposition (Parihar et al., 2015). Consequently, it might be expected that ornamental plants grown under salt stress will show a decrease of water and osmotic and potential, but the reality is that each species behaves differently (Table 3). For instance, *Narcissus* sp., *Rose* sp. and *Salvia hispanica* exhibited no variation of leaf osmotic potential under saline conditions while *Teuchrium chamaedrys* showed an increase of leaf osmotic potential; the rest of the species in Table 3 showed a decline of leaf osmotic potential. These results can be related to the different degrees of salt tolerance and the time of salt exposure of each species since the methodology used was the same in all experiments (Scholander pressure chamber). Any change in water relations in ornamental plants can result in an appearance of drought stress and a decrease of growth thus there is a reduction in the saleability of plants with these symptoms. From the nursery grower’s point of view, the different trends between species can be solved with an irrigation-schedule based on the evapotranspiration demands of each species under saline conditions in order to improve their quality. Nevertheless, the applicability of this evapotranspiration-based irrigation scheduling is difficult for growers, since it requires an exhaustive study over several years. For instance, in an experiment conducted on *Forsythia intermedia*, *Photinia fraseri*, *Prunus laurocerasus* L. and *Viburnum tinus* L. during the summer of four consecutive years (2007–2010), Incrocci et al. (2014) determined the evapotranspiration irrigation scheduling of these species according to the type of container used for the growth. Carmassi et al. (2013) determined the rate of evapotranspiration of *Gerbera jamesonii* grown under greenhouse conditions in a Mediterranean climate. Such experiments need to be carried out under saline conditions if this methodology is to be applied to the use of brackish water, in evapotranspiration-based irrigation.

2.4. Photosynthetic parameters

The response of photosynthesis to salinity stress is highly complex because this abiotic stress affects photosynthesis both in the short and long term. In the short term, salinity can affect photosynthesis by stomatal limitations, leading to a decrease in carbon assimilation. In the long term, salt stress can also affect the photosynthetic process due to salt accumulation in young leaves and decreases in chlorophyll and carotenoid concentrations (Acosta-Motos et al., 2017 a).

2.4.1. Chlorophyll content

Chlorophyll a, chlorophyll b and carotenoids are the main photosynthetic pigments and they play important role in photosynthesis (Hagemman and Bauwe, 2016). Chlorophyll a functions as primary electron donor and chlorophyll b is consider the primary accessory pigment for light harvesting and energy transfer (Li and Chen, 2015).

It is well-known that chlorophyll content in plants correlates directly to the healthiness of plant (Barry, 2009). A decrease in chlorophyll concentration under salt stress is a commonly reported phenomenon used as a sensitive indicator of the cellular metabolic state. This decrease may be related to membrane deterioration (Silveira and Carvalho, 2016). Nevertheless, it is also possible to find that under salt stress, plants show an increase of chlorophyll concentration that can be due to an increase in the number of chloroplast per unit area of leaf in the stressed plant leaves as reported by Chaum and Kirdmanee (2009). For instance, in an experiment conducted on *Eugenia myrtifolia* grown in pots filled with a mixture of coconut fibre, sphagnum peat and Perlite (8:7:1) and irrigated with increasing NaCl concentrations, Acosta-Motos et al. (2015) reported an increase in total chlorophyll concentration compared to the control treatment.

A decrease of chlorophyll concentration in ornamental plants under saline conditions has been recorded by many researchers (Table 4). This negative effect results in the yellowing of leaves affecting the visual appearance and thus the sale value of these ornamental species. One possible technique to counteract these negative effects could be the use of shading since under low-light conditions, plants exhibit an increase of chlorophyll concentration (Ashraf and Harris, 2013). Pires et al. (2011) carried out an experiment with *Passiflora* cvs. grown under different light intensities and reported that one of the main effects of shading was an increase of chlorophyll concentration in these varieties. Lugassi-Ben-Hamo et al. (2010) reported the same effects in *Eustoma grandiflorum* grown under 67% or 88% reduction in light intensity through shading. Nevertheless, it is necessary to point out that these shading experiments were conducted with plants grown under non-saline conditions, so need to be repeated with saline irrigation.

The establishment of different shading regimes could be expensive, so another cheaper possibility to increase the chlorophyll concentration in leaves in these species is through the foliar application of magnesium, since its concentration is essential to the generation of chlorophyll. For instance, in an experiment conducted on *Epipremnum aureum*, Metwally et al. (2015) reported an increase of chlorophyll concentration in plants treated with magnesium sulphate as foliar fertilizer. The results of foliar application of Mg^{2+} in ornamental plants has not been tested in the presence of salinity, but might be particularly effective given the competition in uptake of nutrients by Na^+ (and Cl^-) mentioned above. Therefore, as for the use of shading already mentioned, it would be necessary to study the effects of foliar application of Mg^{2+} in species where salinity has a particularly detrimental effect on the appearance.

2.4.2. Photosystem efficiency

Chlorophyll fluorescence is a valuable tool to monitor the physiological status of plants under different abiotic stresses like salinity. Under saline conditions, there is a general decrease in PSII efficiency and photochemical quenching parameters (Fv/Fm) and an increase in non-photochemical quenching parameters (Acosta-Motos et al., 2017 a). The Fv/Fm ratio is an important ratio for the determination of the maximum quantum efficiency of PSII and the level of tolerance or sensitivity of a plant to stress (Zhao et al., 2015). Decrease in Fv/Fm is a clear indication that PSII was affected by salt and photoinhibition was occurring. In healthy leaves, Fv/Fm value is usually close to 0.8 in most plant species, therefore a lower value indicates that a proportion of PSII reaction centres is damaged or inactivated, a phenomenon, termed as photoinhibition, commonly observed in plants under stress (Kalaji et al., 2016). Non-photochemical quenching (NPQ) is a photoprotective mechanism in photosynthesis which protects the components of PSII by dissipating excess energy as heat when plants were exposed to stress (Ruban, 2016).

Few papers have analysed the effect of salinity on chlorophyll fluorescence in ornamental plants. From the general responses of plants to salinity, the most common trend in chlorophyll fluorescence would be predicted to be a decrease of PSII efficiency and photochemical quenching parameters (Fv/Fm) and an increase in non-photochemical quenching parameters as has been previously reported (Jimenez et al., 1997) in an experiment conducted in roses. However, there is a great variability in the effects of salinity on the chlorophyll fluorescence in ornamental plants (Table 5), but the response of each species is related to its degree of salt tolerance, confirming that chlorophyll fluorescence is a good indicator of which species to grow with saline water. The changes in chlorophyll fluorescence in ornamental plants involves a reduction of the photosynthetic capacity in leaves causing physiological changes that result in a loss of sale capacity for the growers. These negative effects could be mitigated through the use of light-emitting diode (LED) lamps at different wavelengths according to the requirement of each species. In an experiment carried out under non-saline conditions with different ornamental species such as *Impatiens walleriana*, *Petunia hybrida*, *Tagetes patula* and *Salvia splendens,* Wollaeger and Runkle (2013) reported that under red light conditions (600-700 nm), these species exhibited an improvement in the photosynthetic efficiency. Bergstrand and Schussler (2012) also reported that supplementary lighting, supplied by white LED and red/blue LED improved the photosynthesis in *Euphorbia pulcherrima*. Such experiments now need to be carried out under saline conditions.

2.4.3. Net photosynthesis and stomatal conductance

It is assumed that under saline conditions, plants suffer a decrease of net photosynthesis and stomatal conductance. The reduction in photosynthetic rate in plants under salt stress may be due to several factors: a) dehydration of cell membranes, which reduces their permeability to CO_2, b) salt toxicity, c) reduction of CO_2 supply because of hydroactive closure of stomata, d) enhanced senescence induced by salinity and e) changes of enzyme activity induced by changes in cytoplasmic structure (Gururani et al., 2015). Under salt stress there is a reduction in stomatal conductance which restricts the availability of CO_2 for carboxylation reactions. Moreover, this stomatal closure minimizes loss of water through transpiration and this affects light-harvesting and energy-conversion systems thus leading to alteration in chloroplast activity (Chaves et al., 2011).

The recent literature suggests ornamental plants subjected to saline conditions exhibited a decrease of net photosynthesis and stomatal conductance (Table 6). The consequence of these changes in photosynthesis is a reduction of saleable plants, therefore the enrichment of atmospheric CO_2 for ornamental plants with a high profitability could be an appropriate technology to overcome the negative effects of salinity. However, although a common practice in commercial horticulture, the establishment of this technique is expensive. Zhang et al. (2012) and Xu et al. (2014) conducted experiments on *Gerbera jamesonni* and *Impatiens hawkeri* and reported that the enrichment of CO_2 at levels of 800 $\mu mol \cdot mol^{-1}$ resulted in a growth increase of these species. These studies were not, however, conducted under saline conditions so that it would be necessary to investigate the interaction of salinity and enrichment of CO_2 on the growth of ornamentals.

2.5. Osmolytes

Under salt stress, plants accumulate low-molecular-mass compounds termed compatible solutes to adjust the osmotic potential of the cytoplasm because they do not interfere with normal biochemical reactions (Fahad et al., 2015). Nevertheless, the production of sufficient osmotica is metabolically expensive, potentially limiting plant growth by consuming significant quantities of carbon that could otherwise be used for growth (Flowers and Colmer, 2015).

Compatible solutes include compounds such as proline, sugars, glycine-betaine and other related quaternary ammonium compounds (Szabados and Savoure, 2010;

Slama et al., 2015), but due to the lack of information on the effects of salt stress on the accumulation of solutes in ornamental plants, we will focus on two of them: proline and soluble sugars.

The main roles of proline under salt stress include osmotic adjustment, protection of enzymes and membranes, as well as acting as a reservoir of energy and nitrogen for utilization (Amini et al., 2015). The accumulation of proline is a well-known adaptive mechanism in plants against salt stress conditions. It has also been suggested that proline accumulation can serve as a selection criterion for the salt tolerance because the increase in proline content was positively correlated to the level of salt tolerance (Kaur and Asthir, 2015).

Proline accumulation under salt stress can be explained by the higher inhibitory rate of proline dehydrogenase and proline oxidase (Kaur and Asthir, 2015). Nevertheless, it is also possible to find a depletion in the accumulation of proline in plants due to its rapid breakdown upon relief of stress. The breakdown products provide reducing agents that support mitochondrial oxidative phosphorylation and generation of ATP for recovery from stress and repairing stress-induced damage (Fichman et al., 2015). For instance, plants of *Catharantheus roseus* irrigated with salt solutions from 0 to 250 mM NaCl during 21 days showed a decline of proline concentration in leaves, which may be due to its breakdown to reduce the effect of salt stress (Chang et al., 2014).

In the recent literature on the effect of salt stress on ornamental plants it is clear that they commonly increase the proline concentration in leaves (Table 7), suggesting that the exogenous application of this osmolyte could be a useful tool for nursery growers to produce plants of better quality using saline irrigation water. Cirillo et al. (2015) and Zheng et al. (2015) carried out experiments with ornamental plants grown under different levels of salinity and reported that the exogenous application of proline resulted in an improvement of the salinity tolerance in these species. This relatively simple procedure could be evaluated for other ornamentals.

As far as soluble sugars are concerned, it is assumed that under saline stress there is an increase of concentration of soluble sugars in plants as sugars play a central role in osmoprotection, osmotic adjustment, carbon storage and radical scavenging under salt stress (Sami et al., 2016). The increase of soluble sugars under salt stress may be related to a decrease of sucrose phosphate synthase activity and a decrease of starch phosphorylase activity as reported by Ruan (2014). The increase of soluble sugars under increasing NaCl concentration in ornamental plants has been recorded only by a few researchers (Table 7). In previous literature there are reports of the value of exogenous application of soluble sugars in order to improve the postharvest longevity of, for instance, cut flowers: Ahmad et al. (2013) and Arrom and Munne-Bosch et al. (2012) carried out experiments with *Rosa hybrida* and *Eustoma grandiflorum*, respectively, where they reported that the application of sucrose resulted in an improvement of post-harvest longevity of cut flowers. However, there are no reports on the use of exogenous soluble sugars to increase the salt tolerance in ornamental plants. Nevertheless, we suggest that nursery growers might evaluate the exogenous application of soluble sugars in ornamental plants as a possible tool for the improvement of the salinity tolerance, as occurs with the exogenous application of proline. It is necessary to point out that the use of this technique can result in growth increase of pathogens and attraction of insects, therefore additional measures should be considered.

2.6. Antioxidant responses

Under saline conditions, one of the common responses of plants is the accelerated generation of reactive oxygen species (ROS), which include the superoxide radical ($O_2^{\bullet -}$), singlet oxygen ($^1O_2$), hydroxyl radical ($OH^{\bullet}$) and hydrogen peroxide (H_2O_2), all of which are cytotoxic to plants (De Gara and Foyer, 2017). The main sources of ROS generation in the cell are mitochondria, chloroplasts and peroxisomes (Pucciarello and Perata, 2017). These reactive oxygen species are involved in different process such as the DNA damage, lipid peroxidation and protein oxidation (Mittler, 2017).

In order to overcome the negative effects of ROS at the cellular level, plants show a mechanism of scavenging of these species through the antioxidative machinery composed by enzymatic and non-enzymatic components such as superoxide dismutase (SOD), ascorbate peroxidase (APX), peroxidase (POX) and catalase (CAT) (Sewelam et al., 2016). In the recent literature, there are a few references to the effect of salt stress on the antioxidant activity in ornamental plants (Table 8). These publications report an increase in the antioxidant machinery. As a consequence of oxidative stress due to the exposure to saline conditions, plants suffer serious injuries which can depreciate their economic value. Nevertheless, these injuries can be mitigated through the exogenous application of antioxidant compounds via foliar sprays, resulting in the use of this technique as an advisable tool for nursery growers. Hashish et al. (2015) conducted an experiment on gladiolus plants grown under saline conditions and reported that the foliar application with glutathione (100 and 200 ppm) resulted in an enhancement of salt tolerance in this species. In a similar vein, Badawy et al. (2015) showed an increase in yield and physiological enhancement of *Celosia argentea* sprayed with increasing concentrations of α-tocopherol (from 200 to 600 ppm).

3. Conclusions

Salt stress involves a growth reduction, nutritional imbalances, changes in water relations and photosynthesis and physiological changes that reduce the visual quality of ornamental plants and as a consequence their saleability. Nevertheless, the high water consumption associated with growing ornamental plants in a world with decreasing fresh water availability suggests the use of saline waters by nursery growers for the production these plants. where brackish water is used, the establishment of new culture methods by nursery growers is advocated, methods such as irrigation based on the water demands of each species, the exogenous application of nutrients and osmolytes, shading and the enrichment of CO_2, all of which might mitigate damage caused by the salinity and at the same time improve the visual quality and the profitability of growing these ornamental species.

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Table 1. Effects of salt stress on growth parameters in different ornamental species.

Botanical family	Species	Salt threshold	Observations	References
Plantaginaceae Solanaceae	*Antirrhinum majus* *Petunia hybrida*	0-80 mM NaCl, 5 wks	DW reduction of 50-70%	Villarino and Mattson (2011)
Begoniaceae Onagraceae Lamiaceae Asteraceae Apocynaceae Verbenaceae Geraniaceae	*Begonia hiemalis* *Fuchsia hybrida* *Solenostemon scutellarioides* *Tagetes patula* *Catharanthus roseus* *Verbena hybrida* *Pelargonium hortorum*	0-80 mM NaCl, 5 wks	DW reduction of 70-90%	Villarino and Mattson (2011)
Balsaminaceae Eupohorbiaceae Lamiaceae	*Impatiens walleriana* *Euphorbia hybrida* *Salvia splendens*	0-80 mM NaCl, 5 wks	DW reduction >90%	Villarino and Mattson (2011)
Asteraceae Violaceae	*Zinnia angustifolia* *Viola tricolor*	0-80 mM NaCl, 5 wks	100% mortality	Villarino and Mattson (2011)
Arecaceae	*Chamaerops humilis*	2-8 dS m^{-1}, 2 years	Total biomass decrease of 38%	Simon et al. (2010)
Arecaceae	*Washingtonia robusta*	2-8 dS m^{-1}, 2 years	Total biomass decrease of 48%	Simon et al. (2010)
Asparagaceae	*Hyacinthus orientalis*	0-600 mM NaCl, 15 d	Plant fresh weight reduction	Koksal et al. (2014)
Adoxaceae	*Viburnum lucidum*	0-200 mM NaCl, 3 months	Roots, stems and shoots dry weight reduction	Sifola et al. (2017)
Lamiaceae	*Lavandula angustifolia*	0-100 mM NaCl, 21 d	Plant dry weight reduction	Cordovilla et al. (2014)
Lamiaceae	*Salvia hispanica*	0.3-60 mM NaCl, 80 d	Plant fresh and dry weight reduction	Raimondi et al. (2017)
Asteraceae	*Stevia rebaudiana*	0.4-12 dS m^{-1}, 1 year	Plant fresh and dry weight reduction	Reis et al. (2015)
Asteraceae	*Tagetes erecta* *Tagetes patula*	2-10 dS m^{-1}, 16 d	Plant height reduction	Valdez-Aguilar et al. (2009)
Eupohorbiaceae	*Euphorbia pulcherrima*	0.5-1.2 g NaCl L^{-1}, 4 months	Plant height reduction	Gent et al. (2016)
Paulowniaceae	*Paulownia sp.*	50-200 mM NaCl, 58 d	Leaf area reduction	Ivanova et al. (2014)
Myrtaceae	*Callistemon laevis*	0.8-4 dS m^{-1}, 10 months	Leaf area reduction	Alvarez and Sanchez-Blanco (2015)
Celastraceae	*Euonymus japonicus*	0.9-4 dS m^{-1}, 20 wks	Leaf area reduction	Gomez-Bellot et al. (2013)

Iridaceae	*Freesia* sp.	1.5-6 dS m^{-1}, 7 months	Flower number reduction	Aydinsakir et al. (2010)
Rosaceae	*Rosa hybrida*	1.5-8.0 dS m^{-1}, 2 months	Flower yield reduction	Cai et al. (2014)

Table 2. Effects of salt stress on nutrient concentrations in leaves in different ornamental species.

Botanical family	Species	Salt threshold	Nutrients						References
			N	**P**	**K**	**Ca**	**Na**	**Cl**	
Scrophulariaceae	*Antirrhinum majus*	2.5-14 dS m^{-1}, 2 months		↓	↓		↑	↑	Carter and Grieve (2008)
Ericaceae	*Arbutus unedo*	0.85-9.45 dS m^{-1}, 16 wks			↓	↓	↑		Navarro et al. (2008)
Buxaceae	*Buxus sempervirens*	0-250 mM NaCl, 5 months					↑	↑	Caser et al. (2013)
Buxaceae	*Buxus microphylla*	0.6-8 dS m^{-1}, 6 months			↓		↑	↑	Valdez-Aguilar et al. (2011)
Arecaceae	*Chamaerops humilis*	2-8 dS m^{-1}, 2 years	↓	↓	↓		↑	↑	Simon et al. (2013)
Asteraceae	*Cichorium spinosum*	2-12 dS m^{-1}, 56 d			↓		↑	↑	Ntatsi et al. (2017)
Caryophyllaceae	*Diantus caryophyllus*	1-6 dS m^{-1}, 3 months	↓	↓	↓	↓	↑	↑	Navarro et al. (2012)
Escalloniaceae	*Escalonia exoniensis*	0.6-8 dS m^{-1}, 6 months			↓		↑	↑	Valdez-Aguilar et al. (2011)
Malvaceae	*Hibiscus rosa sinensis*	0.6-8 dS m^{-1}, 6 months					↑	↑	Valdez-Aguilar et al. (2011)
Cupressaceae	*Juniperus chilensis*	0.6-8 dS m^{-1}, 6 months					↑		Valdez-Aguilar et al. (2011)
Brassicaceae	*Matthiola incana*	2.5-14 dS m^{-1}, 2 months			↓	↓	↑	↑	Grieve et al. (2006)
Asteraceae	*Osteospermum hybrida*	1.5-5 dS m^{-1}, 14 wks			↓		↑	↑	Valdes et al. (2015 a)
Rosaceae	*Raphiolepis indica*	0.6-8 dS m^{-1}, 6 months			↓		↑	↑	Valdez-Aguilar et al. (2011)
Rosaceae	*Rosa hybrida*	1.4-6.4 dS m^{-1}, 7 wks			↓	↓	↑	↑	Niu et al. (2013)
Asteraceae	*Tagetes erecta*	0-200 mM NaCl, 25 d			↓		↑		Koksal et al. (2016)
Arecaceae	*Washingtonia robusta*	2-8 dS m^{-1}, 2 years	↓	↓	↓	↓			Simon et al. (2013)

Table 3. Effects of salt stress on leaf water relations in different ornamental species.

Botanical family	Species	Salt threshold	Observations	References
Asteraceae Lamiaceae Lamiaceae	*Achillea millefolium* *Agastache cana* *Salvia coccinea*	0.8-4 dS m^{-1}**,** 70 d	Decline of leaf osmotic potential	Niu and Rodriguez (2006a)
Ericaceae	*Arbutus unedo*	0-105 mM NaCl, 16 wks	Decline of leaf water and osmotic potential	Navarro et al. (2007)
Aizoaceae	*Delosperma cooperi*	0.8-12 dS m^{-1}, 11wks	Decline of leaf osmotic potential	Niu and Rodriguez (2006b)
Celastraceae	*Euonymus japonicus*	1.8-9 dS m^{-1}, 5 months	Decline of leaf water potential	Miralles et al. (2012)
Asteraceae	*Gaillardia aristata*	0.8-4 dS m^{-1}, 3 months	Decline of leaf osmotic potential	Niu et al. (2007)
Asteraceae	*Gerbera hybrida*	1.5-3 dS m^{-1}, 6 months	Decline of leaf water potential	Valdes et al. (2014 a)
Amaryllidaceae	*Narcissus sp.*	0-300 mM NaCl, 4 months	No variation in leaf osmotic potential	Veatch-Blohm et al. (2014)
Onagraceae Lamiaceae Asteraceae	*Oenothera elata* *Salvia farinacea* *Zinnia grandiflora*	1.50-7.30 dS m^{-1}, 45 d	Decline of leaf osmotic potential	Niu et al. (2012a)
Lamiaceae	*Phlomis purpurea*	1-4 dS m^{-1}, 26 wks	Decline of leaf osmotic potential	Alvarez et al. (2012 a)
Rosaceae	*Rose sp.*	1.6-9.0 dS m^{-1}, 15 wks	No variations of leaf osmotic potential	Niu et al. (2008)
Lamiaceae	*Salvia hispanica*	0.3-60 mM NaCl, 80 d	No variations of leaf water and osmotic potential	Raimondi et al. (2017)
Lamiaceae	*Teucrium chamaedrys*	0.8-12 dS m^{-1}, 11 wks	Increase of leaf osmotic potential	Niu and Rodriguez (2006 b)
Asteraceae	*Zinnia marylandica*	1.40-8.20 dS m^{-1}, 4 wks	Decline of leaf osmotic potential	Niu et al. (2012b)

Table 4. Effects of salt stress on pigments concentration in different ornamental species.

Botanical family	Species	Salt threshold	Observations	References
Fabaceae	*Acacia cultriformis*	0-15 g NaCl/L, 6 wks	Decrease of total chlorophyll concentration	Vernieri et al. (2010)
Myrtaceae	*Callistemon citrinus*			
Apocynaceae	*Carissa edulis microphylla*			
Onagraceae	*Gaura lindheimeri*			
Oleaceae	*Jasminum sambac*			
Lamiaceae	*Westringia fruticosa*			
Rosaceae	*Alchemilla mollis*	0-400 mM NaCl, 21 d	Decrease of total chlorophyll concentration	Eom et al. (2007)
Lamiaceae	*Nepeta faassenii*			
Polemoniaceae	*Phlox subulata*			
Asteraceae	*Solidago cutleri*			
Lamiaceae	*Thymus praecox*			
Apocynaceae	*Catharanthus roseus*	0-100 mM NaCl, 90 d	Decrease of chlorophyll a and b and total chlorophyll concentration	Jaleel et al. (2008)
Asteraceae	*Chrysanthemum morifolium*	2-16.9 dS m^{-1}, 60 d	Decrease of total chlorophyll concentration	Lee and van Iersel (2008)
Solanaceae	*Petunia hybrida*	0-125 mM NaCl, 1 month	Decrease of chlorophyll a and b concentration	Arun et al. (2016)
Asparagaceae	*Polianthes tuberosa*	0.7-4.3 dS m^{-1}, 47 d	Decrease of total chlorophyll concentration	Bahadoran and Salehi (2015)
Geraniaceae	*Pelargonium hortorum*	0-3 g/L NaCl, 3 months	Decrease of chlorophyll a and b concentration	Bres et al. (2016)
Asteraceae	*Stevia rebaudiana*	0-90 mM NaCl, 25 d	Decrease of chlorophyll a and b and total chlorophyll concentration	Cantabella et al. (2017)

Table 5. Effects of salt stress on fluorescence parameters in different ornamental species.

Botanical family	Species	Salt threshold	Observations	References
Celastraceae	*Euonymus japonicus*	1.8-9.0 dS m^{-1}, 6 months	Decrease of photosystem II efficiency and no variations of maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Miralles et al. (2016)
Moraceae	*Ficus benjamina*	1-5 dS m^{-1}, 5 months	No variation of photosystem II efficiency and decrease of maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Valdes et al. (2012)
Verbenaceae	*Lantana camara*	2-5 dS m^{-1}, 5 months	Decrease of photosystem II efficiency, maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Bañon et al. (2011)
Lythraceae	*Lawsonia inermis*	0-150 mM NaCl, 2 months	Decrease of photosystem II efficiency, maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Fernandez-Garcia et al. (2014)
Myrtaceae	*Metrosideros excelsa*	2-6 dS m^{-1}, 6 months	No variations of photosystem II efficiency, maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Bañon et al. (2012)
Lamiaceae	*Phlomis purpurea*	1-4 dS m^{-1}, 26 wks	No variations of maximum quantum yield of PSII (Fv/Fm)	Alvarez et al. (2012 b)
Polygalaceae	*Polygala myrtifolia*	2-5 dS m^{-1}, 5 months	No variations of photosystem II efficiency, maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Bañon et al. (2011)
Rosaceae	*Rosa hybrida*	1.5-8.0 dS m^{-1}, 2 months	Decrease of maximum quantum yield of PSII (Fv/Fm)	Cai et al. (2014)
Adoxaceae	*Viburnum lauristinus*	2-6 dS m^{-1}, 6 months	Decrease of photosystem II efficiency and no variations of maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Bañon et al. (2012)
Adoxaceae	*Viburnum odoratissimum*	0-60 mM NaCl, 4 months	No variations of photosystem II efficiency, maximum quantum yield of PSII (Fv/Fm) and non-photoquemical quenching (NPQ)	Cacini et al. (2013)

Table 6. References to a decrease of net photosynthesis and stomatal conductance in different ornamental species.

Botanical family	Species	Salt threshold	References
Myrtaceae	*Callistemon laevis*	0.8-4 dS m^{-1}, 10 months	Alvarez and Sanchez-Blanco (2015)
Myrtaceae	*Callistemon citrinus*	0.8-4 dS m^{-1}, 13 months	Alvarez and Sanchez-Blanco (2014)
Myrtaceae	*Eugenia myrtifolia*	0.3-12 dS m^{-1}, 30 d	Acosta-Motos et al. (2015)
Celastraceae	*Euonymus japonicus*	0.9-4 dS m^{-1}, 20 wks	Gomez-Bellot et al. (2013)
Euphorbiaceae	*Euphorbia pulcherrima*	1.5-4.5 dS m^{-1}, 2 months	Valdes et al. (2014 b)
Myrtaceae	*Myrtus communis*	0.8-8 dS m^{-1}, 2 months	Acosta-Motos et al. (2014)
Geraniaceae	*Pelargonium hortorum*	1.6-6.5 dS m^{-1}, 3 months	Valdes et al. (2015 b)
Fabaceae	*Sophora secundiflora*	0-6 dS m^{-1}, 6 months	Niu et al. (2010)
Adoxaceae	*Viburnum tinus*	0.9-4 dS m^{-1}, 6 months	Gomez-Bellot et al. (2015)

Table 7. Changes in proline and concentration of soluble sugars in leaves of different ornamental species.

Botanical family	Species	Salt threshold	Observations	References
Asteraceae	*Calendula officinalis*	50-100 mM NaCl, 36 d	Increase of proline concentration	Lacramioara et al. (2015)
Myrtaceae	*Eugenia myrtifolia*	0.3-12 dS m^{-1}, 30 d	Increase of proline concentration	Acosta-Motos et al. (2015)
Asteraceae	*Gerbera jamesonii*	0-40 mM NaCl, 6 months	Increase of proline concentration	Don et al. (2010)
Iridaceae	*Iris hexagona*	0-100 mM NaCl, 5 months	Increase of proline concentration	Wang et al. (2008)
Asparagaceae	*Polianthes tuberosa*	0.7-4.3 dS m^{-1}, 47 d	Increase of proline concentration	Bahadoran and Salehi (2015)
Geraniaceae	*Pelargonium hortorum*	0-3 g L^{-1} NaCl, 3 months	Increase of proline concentration	Bres et al. (2016)
Lamiaceae	*Rosmarinus officinalis*	0-150 mM NaCl, 4 wks	Increase of proline concentration	Tounekti et al. (2011)
Lamiaceae	*Lavandula multifida*	10-200 mM NaCl, 60 d	Increase of soluble sugars concentration	García-Caparrós et al. (2017)
Apocynaceae	*Cataranthus roseus*	50-200 mM NaCl, 4 months	Increase of soluble sugars concentration	Elfeky et al. (2007)
Boraginaceae	*Echium amoenum*	0-12 dS m^{-1}, 6 wks	Increase of soluble sugars concentration	Ramezani et al. (2011)

Table 8. Effects of salt stress on the antioxidant activity in different ornamental species.

Botanical family	Species	Salt threshold	Observations	References
Simaroubaceae	*Ailanthus altissima*	0-300 mM NaCl, 2 d	Increase of SOD and CAT activity	Filippou et al. (2014)
Asteraceae	*Calendula officinalis*	50-100 mM NaCl, 36 d	Increase of SOD, POX and CAT activity	Lacramioara et al. (2015)
Apocynaceae	*Catharanthus roseus*	0-100 mM NaCl, 2 months	Increase of SOD, POX and CAT activity	Misra and Gupta (2006)
Apocynaceae	*Catharanthus roseus*	0-100 mM NaCl, 90 d	Increase of APX activity and decrease of SOD, POX and CAT activity	Jaleel et al. (2007)
Myrtaceae	*Myrtus communis*	0.8-8 dS m^{-1}, 2 months	Decrease of APX activity and increase of SOD and POX activity	Acosta-Motos et al. (2014)
Solanaceae	*Petunia hybrida*	0-125 mM NaCl, 1 month	Decrease of CAT and POX activity	Arun et al. (2016)
Myrtaceae	*Eugenia myrtifolia*	0.9-7 dS m^{-1}, 23 wks	Decrease of APX activity and increase of SOD, POX and CAT activity	Acosta-Motos et al. (2017 b)
Apocynaceae	*Nerium oleander*	0-800 mM NaCl, 30 d	Increase of SOD, CAT and APX activity	Kumar et al. (2017)
Asteraceae	*Stevia rebaudiana*	0-90 mM NaCl, 25 d	Decrease of APX activity and increase of SOD, POX and CAT activity	Cantabella et al. (2017)