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GROWTH, EVAPOTRANSPIRATION AND MINERAL CONTENT OF GERBERA UNDER COMBINED SALINITY AND EXCESS BORON

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ABSTRACT

Gerbera is a very important plant widely grown for cut flowers. To check the influence of salinity and boron excess in nutrient solution, nine treatments as factorial combination of three sodium chloride (NaCl) (1, 15 and 30 mM) and three boron (B) (0.1, 1 and 2 mM) concentrations in the nutrient solution were applied during the gerbera cultivation. The effects of experimental treatments on gerbera growth, flowering and the interaction in morphological and nutritional aspects were tested. The formation of leaves, stems and flowers, flower dry mass and evapotranspiration (ET) were more negatively affected when plants were irrigated with 2 mM B than with 0.1 mM B concentration. High levels of boron (1 and 2 Mm) in nutrient solution resulted in leaf chlorosis and necrosis. The severity of leaf burn was correlated with leaf B content. Salinity acted as a protector against boron content in leaves and flowers at 1 Mm B. However, at the 2 Mm B in nutrient solution, leaf B accumulation was not reduced by the presence of NaCl but also increased with the increased levels of salinity. The external levels of boron used in this study, which were found to be the highest in the literature, and the high sensitivity of gerbera to boron, suggested that boron acted as the dominant factor. Lower external boron concentrations would be needed to establish to what extent salinity would be able to mitigate the negative effects of boron.

Keywords: boron toxicity; NaCl; nutrient uptake; ornamental plants; cut flowers

INTRODUCTION

In many areas of the world, increasing shortage of water resources has led to the use of low quality water for crop irrigation, specially reclaimed wastewater and brackish water (Shani & Dudley 2001). These waters sources are generally characterized by high salinity and concentrations of toxic elements like boron (B), which can negatively affect crop growth and yield. In fact, although boron is an essential micronutrient for plants (Brown et al. 2002), its excess may result in a decrease in plant growth and crop yield (Nasim et al. 2015; Zafar-ul-Hye et al. 2016), eventually having a lethal effect (Reid et al. 2004).

On many plants, the typical symptoms of excess B are represented by leaf chlorosis, which generally evolves in necrosis starting from the tips and margins of older leaves (Sonmez et al. 2009; Landi et al. 2013a, b). As a consequence of these symptoms, reductions of leaf growth, transpiration and photosynthesis have been observed in many plants irrigated with B concentrations around 6–20 $mg \cdot dm^{-3}$ (Alpaslan & Gunes 2001; Bañón et al. 2012b; Landi et al. 2012). Thus, in ornamental crops, B excess in the growing medium or in the

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irrigation water may also affect plant quality and commercial value (Bañón et al. 2012a).

As described above, boron is frequently associated with high salinity, and generally, it is found in arid regions with saline soils and saline irrigation water (Ben-Gal & Shani 2002). Salinity reduces crop growth and production in sensitive species as a consequence of negative effects on biomass, mineral content, water relations and carbon assimilation (Läuchli & Grattan 2007).

Many studies have been conducted on the interaction between salinity and B toxicity in horticultural and ornamental species (Yermiyahu et al. 2008; Smith et al. 2010; Alpaslan & Gunes 2001; Carmassi et al. 2013a; Bañón et al. 2012b). Some of these studies concluded that the effects of excess B are mitigated when the plants are grown under conditions of moderate salinity because salinity reduces plant transpiration and water uptake due to an osmotic effect (Ben-Gal & Shani 2002; Yermiyahu et al. 2008).

Gerbera is one of the most important greenhouse ornamental crops grown for cut flowers (Vidalie 2007). Several studies have been conducted on the response of this species to salinity stress (Paradiso et al. 2003; Akat et al. 2009; Ganege Don et al. 2010; Carmassi et al. 2013b). Gerbera has been classified as moderately sensitive to salinity (Sonneveld et al. 1999). The maximum salinity without yield reduction in substrate-grown gerbera is 1.5–2.8 $dS \cdot m^{-1}$. However, plant response to salinity depends on cultivar and growing conditions (Carmassi et al. 2013b). No studies have been conducted in relation to the interaction between salinity and B excess in gerbera. Jeong et al. (2009) reported that in gerbera leaf, the symptoms of B toxicity appeared with concentrations about 395.4 $mg \cdot kg^{-1}$ DW.

In view of the above, the objective of this study was to determine whether salinity may influence the response of gerbera (*Gerbera jamesonii Bolus* ex Hook. f.) plants to excess B. The plant response, in terms of plant growth, mineral ions, evapotranspiration (ET) and leaf toxicity symptoms were evaluated in plants growing in pots and irrigated with nutrient solution containing different concentration of sodium chloride (NaCl) and B.

MATERIAL AND METHODS

Plant material and growth conditions

On 4 May 2012, gerbera plants (*Gerbera jamesonii Bolus* ex Hook. f., cv 'Forsa') at full blooming were taken from a local nursery, in 1.5 dm^3 pots (diameter 17 cm, height 14.8 cm) filled with growing medium contained with a peat substrate and perlite 7:3 (v/v). The experiment was conducted between 4 May and 14 July 2012 in a glasshouse equipped with auto-mated side and roof windows (with insect screens) and heating system; ventilation and minimum temperatures were 27 °C and 15 °C, respectively, at the University of Pisa (Pisa, Italy, latitude 43°43'N, longitude 10°23' E). The pots were placed in the glasshouse with a crop density of six plants per m^2. The glasshouse was covered with black plastic net (30% shading rate). Plants were irrigated with the following nutrient solution (stock solution) concentration: $N\text{-}NO_3$ 10 mM, $N\text{-}NH_4$ 1 mM, P 1 mM, K 5 mM, Ca 3 mM, Mg 1.51 mM, $S\text{-}SO_4$ 1.76 mM, Cl 0.50 mM, Fe 45 μM, Cu 2.4 μM, Zn 2.3 μM, Mn 7.3 μM and 0.1 μM. The pH of nutrient solution in the tank was adjusted to 5.5–6.0 using sodium bicarbonate or sulfuric acid and the electrical conductivity (EC) ranged between 1.5 and 1.7 $dS\ m^{-1}$. Gerbera plants were irrigated manually from the top every one or two days, depending on weather conditions. During the application of experimental solutions with NaCl and B at different levels, a large volume of nutrient solution (1 dm^3 per pot) was applied at each irrigation event to obtain EC of drainage water similar to the EC of irrigation solution. The measurement was verified after every irrigation, ensured that the B concentration in the root zone remained very close to the nominal concentration.

On 10 May 2012, one week after planting, nine irrigation treatments were imposed resulting from a factorial combination of three NaCl (1, 15 and 30 mM) and three B (H_3BO_3) (0.1, 1 and 2 mM) concentrations in the nutrient solution. For this purpose, nine small tanks were also placed in the glasshouse, each of which was identified with each irrigation treatment. Each tank was filled with the stock solution plus the corresponding combination of

NaCl and B concentrations. There were twelve plants in each experimental treatment.

Measurements

At the beginning of the experiment, all flowers were detached from the plants at planting in order to assess the effect of salinity and B levels on flower production. The pH and EC from the drainage nutrient solution was daily measured from each treatment, with a Hanna HI 9813 portable pH/Conductivity Meter in the laboratory (Hanna Instruments, Guipúzcoa, Spain). Daily rate of evapotranspiration (ET) ($g \cdot plant^{-1}\ day^{-1}$) was determined every day using a Sartorius Cubis electronic MSA balance (Sartorius, Goettingen, Germany). All pots with plants were weighed daily before and after each irrigation, when drainage stopped.

At the end of the experiment, on July 14, leaf area, leaf number, number of flowers and length peduncle was measured. Leaf area was determined with a Tamaya Planix digital planimeter. Different organs of sampled plants were collected for dry mass determination of leaves, flowers (stem and capitulum) and roots. They were immediately washed with tap water, rinsed in distilled water and oven-dried at 80 °C until constant weight.

The occurrence of B toxicity symptoms (chlorotic and/or necrotic patches at the margins and tips) was also determined at the end of the experiment. The leaves of each sampled plant were photographed with a digital camera and images were processed using Image Tool for Windows (version 3.0; Microsoft, Pullman, WA) to determine the percent ratio of injured area on total area.

At the end of the experiment, dry samples of different plant organs were digested with a mixture of nitric and perchloric acid (HNO_3 : $HClO_4$, 5 : 2 v/v) at 230 °C. Potassium and Na were determined by flame photometry (Flame Photometer 230 VAC 50 60 Hz). The concentrations of Ca, Mg, Cu, Fe, Zn and Mn in the wet digested samples were quantified by atomic absorption spectrophotometry (Varian Model Spectra-AA240 FS, Australia). Phosphorus and B were determined colorimetrically with the molybdate method (Olsen & Sommers 1982) and the azomethine-H method (Page et al. 1982), respectively. Nitrate content of plant samples extracted with distilled water was determined colorimetrically using the salicylic acid method (Cataldo et al. 1975). Total nitrogen (N) was determined with an analyzer Flash EA 1112 Series Thermo (ThermoFisher Scientific, Waltham, USA), which treated samples in an oxidation reactor at 900 °C. The content of organic nitrogen was determined as the difference between total N and N-NO_3. For each parameter measured, four replicates per treatment were used (each replicate consisting of two plants).

The results were analyzed statistically using a completely randomized block design with two factors (B and NaCl) at three levels of each parameter. One-way and two-way analysis of variance (ANOVA) was performed using Stat-graphics Plus 5.1 (Manugistic, Rockville, MD). Ratios and percentages were subjected to an arcsine square-root transformation before statistical analysis to ensure homogeneity of variance. Treatment means were separated with Duncan's Multiple Range Test ($p \leq 0.05$).

RESULTS

Sodium chloride applied at three levels did not affect plant growth and ET significantly (Table 1). In contrast, B concentration in nutrient solution influenced flower formation, leaf area, flower dry mass, stem length and daily ET, which were significantly reduced at 2 mM of B with respect to the control concentration at 0.1 mM B (Table 1).

The typical symptoms of B toxicity on gerbera leaves (i.e., leaf chlorosis and necrosis) were observed at 1.0 and 2.0 mM (Fig. 1) regardless of the NaCl concentration; the severity of leaf damage increased with the B concentration in the nutrient solution. In our study, these symptoms were visible on the oldest leaves (i.e., those that had developed before the beginning of the experiment) of the plants grown at 2 mM B within a few days from the start of treatment; afterwards, they rapidly expanded to the whole plant.

Salinity and B levels did not significantly influence the foliar content of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu (data not shown). In addition, the results from leaf B and Na content did not differ

significantly between the old and new leaves; therefore, the data reported in the following figures concern the whole set of leaves remaining on the plants at the end of the experiment. Leaf B content increased with B concentration in the nutrient solution (Table 2; Fig. 2A), while regardless of the concentration of B in the nutrient solution, leaf B content slightly decreased at the highest level of Na in the nutrient solution (Table 2). The interaction showed that at 30 mM NaCl and 1 mM B in the nutrient solution, B content in leaves was lower than at 1 or 15 mM NaCl in nutrient solution (Fig. 2A). Nevertheless, at 2 mM B in the nutrient solution, the highest B contents in leaves were found at 15 and 30 mM NaCl (Fig. 2A).

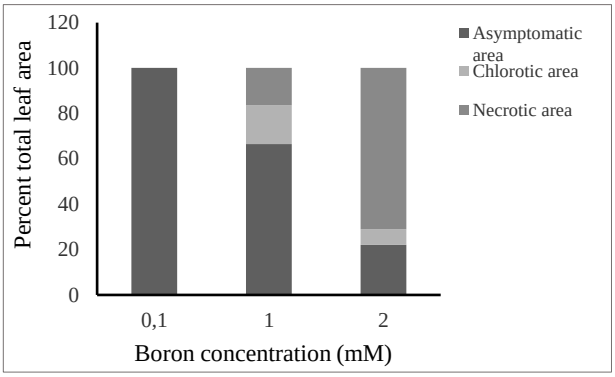

Fig. 1. The severity of leaf chlorosis and necrosis in gerbera plants grown in pot with different boron concentrations in the nutrient solution. The differences among B treatments as regard the damaged area were significantly different at 5% level. Mean values (n = 8)

Table 1. Effect of different boron (B) and sodium (Na) concentration in the nutrient solution on growth and evapotranspiration (ET) in gerbera plants (n = 8)

Treatment		Flower production ($n.\cdot plant^{-1}$)	Plant leaf area ($cm^2\cdot plant^{-1}$)	Leaf dry mass ($g\cdot plant^{-1}$)	Flower dry mass ($g\cdot plant^{-1}$)	Stem length (cm)	Daily ET ($g\cdot plant^{-1}\cdot d^{-1}$)
B	Na						
0	1	3.58 ± 0.42ab	1141.0 ± 106.2ab	4.88 ± 0.43	10.45 ± 0.65a	35.3 ± 0.8a	86.9 ± 1.1a
0	15	3.33 ± 0.00ab	1331.2 ± 86.6a	4.46 ± 0.66	9.23 ± 0.88ab	35.5 ± 0.6a	82.0 ± 0.4ab
0	30	4.00 ± 0.17a	1220.1 ± 94.2a	4.61 ± 0.55	9.98 ± 1.29ab	34.0 ± 1.3ab	80.6 ± 4.8ab
B	Na						
1	1	3.42 ± 0.08ab	955.4 ± 154.3ab	3.70 ± 0.61	7.53 ± 0.76abc	34.8 ± 1.1a	82.8 ± 4.8ab
1	15	3.67 ± 0.00ab	1144.8 ± 119.1ab	3.95 ± 0.40	7.00 ± 0.92bcd	34.5 ± 0.6a	83.0 ± 2.2ab
1	30	3.83 ± 0.33a	1233.34 ± 121.85a	4.40 ± 0.55	8.03 ± 1.41abc	34.0 ± 1.1ab	86.8 ± 3.5a
B	Na						
2	1	3.17 ± 0.33ab	762.10 ± 58.94b	3.35 ± 0.53	5.63 ± 0.69cd	31.3 ± 1.4b	76.4 ± 0.5b
2	15	2.17 ± 0.00c	756.7 ± 37.5b	3.95 ± 0.57	4.28 ± 0.73d	30.3 ± 1.3b	73.3 ± 1.5b
2	30	2.83 ± 0.33bc	803.8 ± 57.7b	3.48 ± 0.48	5.15 ± 0.94cd	30.8 ± 1.4b	75.4 ± 2.3b
B		**	***	ns	***	***	*
Na		ns	ns	ns	ns	ns	ns
Na×B		ns	ns	ns	ns	ns	ns

*** indicate the level of significance at $p \leq 0.001$, according to Duncan's multiple range test

Table 2. Effect of different boron (B) and sodium (Na) concentration in the nutrient solution on boron and sodium content in leaves, flowers, and roots

Mineral concentration		B (mM)			Na (mM)			Significance		
($mg\cdot kg^{-1}$ DW)		0.1	1	2	1	15	30	B	Na	B × Na
Leaves	Boron	127.3	879.7	1475.7	784.6	900.2	797.9	***	***	***
	Sodium	8482.0	6936.0	9602.0	1180	9310	14530	***	***	***
Flowers	Boron	64.13	141.97	384.92	200.16	195.5	195.26	***	ns	***
	Sodium	6788	6822	6920	1290.0	7360	11880	ns	***	ns
Roots	Boron	74.38	131	226.87	130.06	150.7	151.46	***	ns	***
	Sodium	14840	14320	13840	7800	16940	18260	ns	***	ns

*** indicate the level of significance at $p \leq 0.001$, according to Duncan's multiple range test

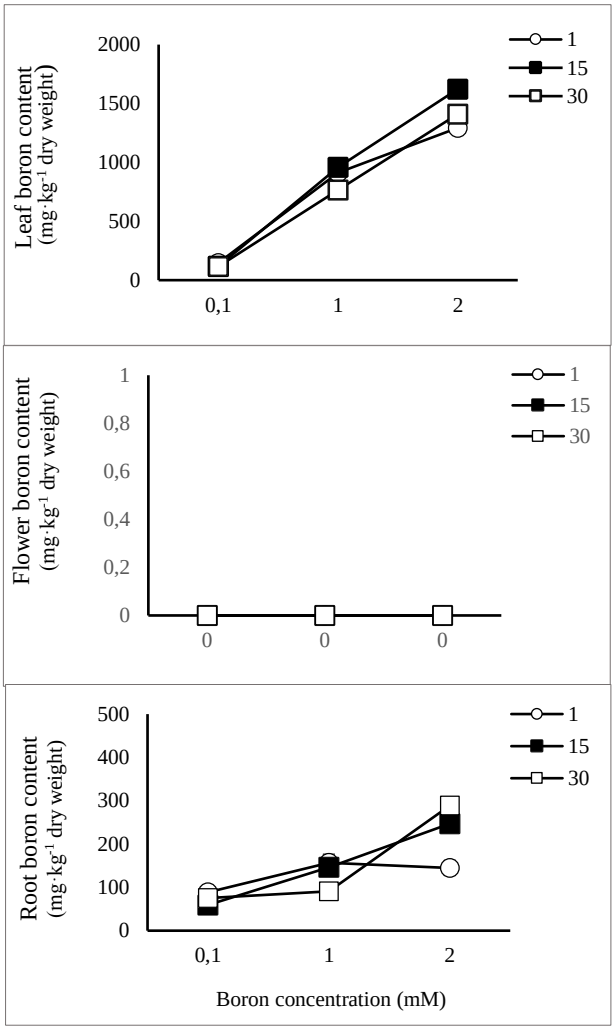

Fig. 2. Boron concentration in leaves (A), flowers (B) and roots (C) of gerbera plants grown in pot with different B and NaCl concentrations in the nutrient solution. Asterisks indicate statistically significant differences by Duncan 0.05 test. The vertical bars indicate standard errors (n = 8)

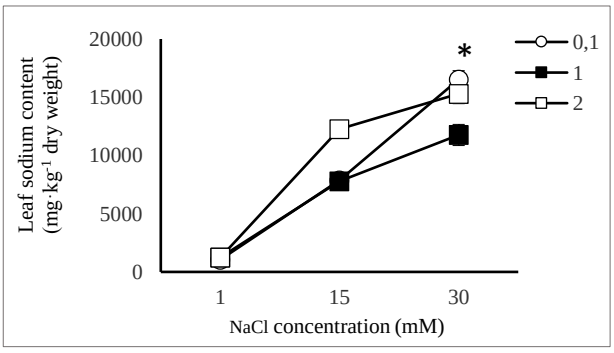

Fig.3. Leaf sodium (Na) concentration in gerbera plants grown in pot with different B and NaCl concentrations in the nutrient solution. Asterisks indicate statistically significant differences by Duncan 0.05 test. The vertical bars indicate standard errors (n = 8)

Increasing B level also enhanced B accumulation in flower and root tissues although to a lesser extent compared with the leaves (Table 2). In addition, regardless of the concentration of B in the nutrient solution, the presence of NaCl in the nutrient solution did not significantly affect the accumulation of B in the flower and in the roots. Nevertheless, as regards to B concentration in flowers, the interaction between both factors showed that at 1 mM B in nutrient solution, the highest level of NaCl (30 mM) prevented the accumulation of B in flowers, while at 2 mM B in nutrient solution the highest level of NaCl had the opposite effect (Fig. 2B). The interaction between both factors for the root boron content showed a similar trend to the flower boron content, although less marked (Fig. 2C). On the other hand, the Na accumulation in flowers and roots increased as NaCl increased in the nutrient solution, while any statistical differences were observed in Na accumulation in the same tissues by the effect of boron in the nutrient solution (Table 2).

The leaf Na content also raised as Na level increased in the nutrient solution (Table 2), while the effect of B in the nutrient solution diminished the Na concentration at 1 mM B in the nutrient solution (Table 2). There was also an interaction between both factors. Leaf sodium content in-creased as NaCl concentration in nutrient solution was higher. Nevertheless, sodium accumulation in leaves tissues was significantly reduced when the plants were grown at 1.0 mM B and 30 mM NaCl, while the opposite was observed in the plants irrigated at 2 mM B level and 15 mM NaCl (Fig. 3).

DISCUSSION

In our study, gerbera plants tolerated NaCl salinity up to 30 mM, while they were quite sensitive to excess B. Concentration of 1.0 and 2.0 mM B in the nutrient solution rapidly induced the typical symptoms of B toxicity, and, in general, growth was inhibited significantly at the highest B level. Similar results were observed in tomato plants with excess B (Carmassi et al. 2013a); in this species, in spite of leaf burn, the reduction of leaf area was not enough to result in a decrease of photosynthesis. In our case,

as a consequence of a reduction in the leaf area, ET was reduced.

In plants grown at high B concentration in the root zone, the reduction of the photosynthetic leaf area caused by leaf burn, reduced the overall photosynthetic rate and dry matter accumulation (Landi et al. 2013a, b; Simón et al. 2013).

In gerbera plants, the reduction of leaf area induced by 2 mM B was a result of an inhibition of leaf expansion and not of leaf formation, since the number of leaves showed no statistical differences. Similar results were observed by Jeong et al. (2009). In these plants, reduced leaf area was associated with a greater reduction of ET with respect to the plants grown with lower B concentration in the irrigation water. In contrast to leaf expansion and flower production, root growth was not affected by B level. In fact, excess B may affect differently each organ of the plant (Bañón et al. 2012a). In some species, such as *Capsicum annuum* L., *Laurustinus tinus* and *Jatropha curcas*, the root system is more sensitive to B toxicity than the aerial organs (Yermiyahu et al. 2008; Bañón et al. 2012b; Simón et al. 2013). While in others, such as *Hordeum vulgare* L. cv schooner, *Triticum* spp. cv. 'Kenya farmer', *Metrosideros excelsa*, shoots are more sensitive to B toxicity than roots (Nable 1988; Bañón et al. 2012b).

Once absorbed, B is transported to the shoot in the xylem driven by transpiration flux and tends to accumulate especially where leaf veins terminate, at the leaf edges. These tissues indeed display the most severe symptoms of B toxicity (Shelp et al. 1995). In other species that produce phloem-mobile B-polyol complexes (Brown & Shelp 1997), B is uniformly distributed within the plant or even at a higher concentration in young tissues than in mature leaves (Camacho-Cristóbal et al. 2008). In gerbera plants exposed to high B concentration in the nutrient solution, chlorosis and necrosis were observed first on the oldest leaves due to a higher B content in old than in young leaves at the first steps (Wimmer et al. 2015). This suggests that in gerbera, B was translocated via the xylem from the root to the leaves (Shelp et al. 1995). However, the symptoms appeared rapidly in all the leaves.

Leaf concentration of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu were not affected by experimental treatments and they were in accordance with the normal range reported for gerbera (Mills & Jones 1996). Nevertheless, the severity of the damage expressed as a percentage of necrotic leaf area, increased with the concentration of B in the nutrient solution, in agreement with those reported by other authors (Smith et al. 2010, Bañon et al. 2012b; Carmassi et al. 2013a; Landi et al. 2013b). Leaf damage induced by excess B was not attenuated by high salinity of the nutrient solution. At 1 mM B in the nutrient solution, only the highest salinity level (30 mm NaCl) reduced the B concentration in leaves. However, at the highest B level in the nutrient solution (2 mM B), the presence of high levels of NaCl in nutrient solution (15 and 30 mM NaCl) favored the leaf B accumulation (Farooq et al. 2015). These results are in contrast with previous findings in other crops (Edelstein et al. 2005; Yermiyahu et al. 2007; Smith et al. 2010; Bañon et al. 2012a, b). In our study, higher B concentrations were used than those applied by other authors (e.g., Ben-Gal & Shani 2002; Edelstein et al. 2005; Yermiyahu et al. 2007) with values that do not exceed 0.7 mM of boron (Yermiyahu et al. 2007). Evapotranspiration rate was unaffected by salinity and it was reduced only at the highest B concentration, contrary to what Bañón et al. (2012a) found in geranium plants. These conditions stimulated the uptake of B and prevented the ameliorating effect of NaCl, which depends on the reduction of root water uptake, at least partially (Wimmer & Goldbach 2012).

Boron was less accumulated in flowers and roots than in leaves. As regards gerbera flowers, salinity exerted a protective action against B, but only for relatively moderate concentrations (1 mM B). At concentrations of 2 mM B, in fact, the presence of a high concentration of NaCl favored the accumulation of B in flowers. The B amount in roots was linked to the B amount in nutrient solution, and therefore, this confirms that these plants do not have the ability to exclude the absorption of B in small quantities, unlike tolerant plants. Nevertheless, the roots accumulated much less B than leaf tissues in agreement with other authors (Kaur et al. 2006;

Carmassi et al. 2013a), probably due to boron being passively transported through the transpiration stream and tending to accumulate in the vegetative tissues.

Notably, B level influenced leaf accumulation of Na since 1 mM B in the nutrient solution reduced the accumulation of Na with respect to the control, whereas a B concentration of 2 mM had the opposite effect. Other previous studies on wheat, pepper and geranium showed that leaf Na content decreased in the presence of boron (Holloway & Alston 1992; Grieve & Poss 2000; Bañón et al. 2012a). Some of them hypothesized that the decreased leaf Na accumulation was due to the reduction in rooting density caused by the B treatments. However, in our experiment, root growth was not affected by boron toxicity. Therefore, other different mechanisms were involved. The accumulation of NaCl and B within the plants may depend on the competition between both elements for uptake by the roots (Bañón et al. 2012b) and/or for transport within the plant (Grattan & Grieve 1999), which in turn depend on the degree of tolerance of the species under consideration (Alpaslan & Gunes 2001).

As the relationship between B content in nutrient solution and salinity was complex (Bastías et al. 2010), several hypotheses are established. Many authors suggest that in the presence of multiple stressors, when the effect of one stress factor on plant response is particularly strong, the influence of the second stressor will be minor (Shani et al. 2005; Grieve et al. 2010).

CONCLUSIONS

In our case, B content in the nutrient solution might be the dominant stress factor due to the high external concentration and the sensitivity of gerbera plants to boron. Only at moderate concentration of B in nutrient solution (1 Mm B), salinity was able to mitigate the boron accumulation in leaves and flowers. In our conditions, salinity and boron had a synergistic effect on leaves, flowers and roots at the highest B external concentration (2 mM), since at the highest B external concentration, the highest NaCl external concentration enhanced the B concentration in these tissues. Therefore, the explanation for our results may lie in the range of salinities and external B concentrations used, the composition of the irrigation waters, and/or the tolerance degree of the crop species used in the study. Due to the high external boron concentration in brackish water sources used for horticultural purposes and the fact that there are no previous studies on this subject in gerbera, lower external boron concentrations would be needed to apply for these plants. This would help to establish to what extent salinity would be able to mitigate the negative effects of boron.

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