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Effect of NaCl salinity on growth, pigment and mineral element contents, and gas exchange of broad bean and pea plants

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Abstract

Increasing salinity of growth medium induced a reduction in growth and transpiration rate. The concentrations of chlorophylls and carotenoids were increased in most cases in broad bean leaves while in pea plants they remained more or less unchanged with the rise of salinization up to 80 mM NaCl. Thereabove a significant decrease in these contents was observed. A stimulation of the net photosynthetic rate of pea was observed at the lowest levels of NaCl but at the highest levels inhibitory effect was recorded. In broad bean all salinization levels inhibited photosynthetic activity, but dark respiration of both plant species was stimulated. The content of Na^+ in the roots and shoots of both species increased at increasing salinity. In broad bean, Ca^{2+} concentration in shoots and K^+ and Ca^{2+} contents of roots increased at increasing salinization, while in pea plants, the content of K^+ and Ca^{2+} was almost unaffected by salinity. Salinity induced an increase in the content of these ions in pea roots. Mg^{2+} content in shoots and roots of both broad bean and pea decreased at increasing salinity except in roots of pea, where it was generally increased.

Introduction

Salinity has an adverse effect in the growth rate of plants and consequently their final yield (*e.g.* Hsiao *et al.* 1976, Babalola and Fawusi 1980, Imamul-Huq and Larher 1983, Pandey *et al.* 1984, Bejaoui 1985). Plants vary, however, in their ability to cope with salinity. For crop plants, differences in salt resistance exist not only among different genera and species, but even within a species which may on the whole be considered salt sensitive (Epstein 1972, Mass and Hoffman 1977, Epstein *et al.* 1989 and Kalaji and Nalborczyk 1991). These observations support two arguments: (a) crop plants can be adapted to saline environments, (b) intraspecies variation can be exploited to investigate the nature of salt resistance or sensitivity (Epstein *et al.* 1980, Kalaji and Nalborczyk 1991). It is the second of these claims that is addressed in the current study. The variation in plant response and need to select some economic

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plants for cultivation in saline soils, necessitates testing their ability to tolerate salinity and adapting to possible changes in their physiological activities under salinization treatment.

The aim of this study was to investigate the influence of NaCl on growth, pigment contents, net photosynthetic, dark respiration and transpiration rates, and mineral composition in broad bean (*Vicia faba L.*, cv. Bunyard's Exhibition) and pea (*Pisum sativum L.* cv. Progress No. 9) grown under different salinities.

Materials and methods

1 kg of soil composed of mixed sieved air-dried clay and sand (2:1 by volume) was put in a polyethylene bag which was introduced into a plastic pot (10 cm in diameter and 13.5 cm high). Perforated plastic tubes (1.2 cm in diameter and 15.7 cm long) were inserted into the soil to help the distribution of water and nutrient solution. The seeds were soil sown and vigorous and uniform seedlings were subjected to the desired salinity (0, 40, 80, 120 and 160 mM NaCl) that was further kept by daily irrigation. At the end of the experimental period (40 d), fresh and dry matter yields of roots and shoots were determined by drying in an aerated oven at 70 °C until constant dry mass.

Transpiration rate was measured under 25 °C as described by Bozcuk (1975). The contents of chlorophylls *a* and *b* and carotenoids were determined spectrophotometrically (Metzner *et al.* 1965). Net photosynthetic rate (oxygen evolution) and dark respiration rate (oxygen consumption) were determined manometrically using disks (diameter 16 mm) of leaf tissue exposed at 25 °C, irradiance of 5.9 W m^{-2} (40 W *GEF* lamps) using the Warburg buffer No. 2961 type VL 85 (Umbreit *et al.* 1959). Sodium and potassium were determined by flame photometer method (Williams and Twine 1960), calcium and magnesium by the versene titration method (Schwarzenbach and Biedermann 1948).

Results

The most striking feature of these investigations is the tolerance of pea and broad bean used to relatively low salinity. The critical concentration for broad bean was 40 mM NaCl and for pea 80 mM NaCl during the vegetative growth. The tested broad bean cultivar was more susceptible to water stress induced by salinity than the pea cultivar.

The mentioned salinity levels did not affect the production of fresh and dry matter, but above these levels they decreased sharply with the rise of salinity (Table 1). The reduction was much lower in pea than in broad bean.

The concentration of chlorophylls and carotenoids in broad bean and of carotenoids in pea increased with salinization up to 80 mM NaCl, thereabove concentrations of all photosynthetic pigments were significantly decreased as compared with control (Table 2).

NaCl concentrations of 40 and 80 mM stimulated net photosynthetic rate of pea but at higher concentrations a significant decrease was recorded. In broad bean all salinization levels induced a significant decrease in the photosynthetic activity (Table 2).

Table 1. Effect of different NaCl concentrations on transpiration rate [kg(H_2O) m^{-2} d^{-1}] and fresh and dry matter [g $plant^{-1}$] of broad bean and pea. * Significant (P = 0.05) and ** highly significant (P = 0.01) differences as compared with control.

Treatment NaCl [mM]	Transpiration rate [kg(H_2O) m^{-2} d^{-1}]	Fresh matter [g $plant^{-1}$] root	shoot	Dry matter [g $plant^{-1}$] root	shoot
Broad bean					
0 (control)	1.84	6.41	7.56	0.69	0.98
40	1.69	6.34	7.60	0.69	0.98
80	1.56**	3.58**	5.20**	0.41**	0.68**
120	1.04**	1.82**	3.23**	0.28**	0.42**
160	0.98**	1.53**	2.39**	0.26**	0.37**
L.S.D. at 5 %	0.14	0.30	0.22	0.12	0.07
L.S.D. at 1 %	0.22	0.46	0.33	0.18	0.11
Pea					
0 (control)	3.20	1.43	4.45	0.41	0.62
40	3.22	1.37	4.43	0.39	0.61
80	3.11	1.39	4.33	0.39	0.55
120	1.70**	1.26*	3.28**	0.31**	0.43**
160	1.21**	1.01**	3.16**	0.22**	0.41**
L.S.D. at 5 %	0.17	0.14	0.29	0.04	0.09
L.S.D. at 1 %	0.27	0.22	0.46	0.07	0.15

The contents of sodium in shoots and roots of both plants generally increased with increasing salinity (Table 3). The concentration of potassium in broad bean shoots decreased significantly with the rise of NaCl salinization; this reduction was more obvious at the moderate and high salinities. On the contrary, the roots exhibited a marked and progressive increase in potassium content with increasing salinity. The amount of K^+ in broad bean roots subjected to the highest salinity was about 4-fold that of the control plants. In pea, the K^+ content of shoots and roots remained more or less unchanged at all investigated salinities, except in roots at 120 and 160 mM NaCl, when potassium concentration increased significantly. There was a marked and progressive increase in the accumulation of calcium in shoots and roots of broad bean plants with increasing salinity, while in pea shoots salinity did not induce significant changes in the content of calcium remained except at the highest level (160 mM) when Ca^{2+} content was significantly decreased. In roots, the concentration of Ca^{2+} more or less unchanged up to 80 mM NaCl, thereabove the concentration was significantly increased. All salinization levels induced a significant reduction in the concentration of Mg^{2+} in shoots of broad bean and pea plants; an opposite situation was found in broad bean roots at 40 mM NaCl and in pea roots at all salinization levels (Table 3).

Table 2. Effect of different NaCl concentrations on the contents of chlorophylls (Chl) and carotenoids (Car) [g kg^{-1} (d.m.)], net photosynthetic (P_N) and dark respiration (R_D) rates [μmol (O_2) kg^{-1} (d.m.) s^{-1}] of broad bean and pea. * Significant (P = 0.05) and ** highly significant (P = 0.01) differences as compared with control.

NaCl [mM]	Chl *a* [g kg^{-1}(d.m.)]	Chl *b*	Car	P_N [μmol(O_2) kg^{-1}(d.m.) s^{-1}]	R_D
Broad bean					
0 (control)	6.78	2.89	2.21	1093.6	51.5
40	7.67**	2.99	2.85**	1069.4*	51.5
80	7.74**	2.98	2.63**	170.0**	113.3**
120	5.84**	2.15**	2.39	73.5**	94.5**
160	5.67**	2.11**	2.12	48.8**	83.9**
L.S.D. at 5 %	0.56	0.22	0.21	19.2	3.2
L.S.D. at 1 %	0.86	0.33	0.31	29.0	4.9
Pea					
0 (control)	11.10	9.47	0.99	229.6	55.6
40	11.14	9.06	1.82**	291.1*	141.9**
80	11.10	9.00	1.55**	288.7*	189.8**
120	5.37**	4.67**	0.91	163.5**	205.7**
160	4.62**	3.77**	0.61*	126.3**	333.4**
L.S.D. at 5 %	0.59	0.89	0.28	40.7	27.3
L.S.D. at 1 %	0.93	1.39	0.45	63.9	42.7

Discussion

With the rise of NaCl concentration over 80 mM, the growth and transpiration of the tested cultivars were greatly reduced. The inhibitory effects of salinity on plant growth was also reported by *e.g.* Patil *et al.* (1984) and Jeschke and Wolf (1988). In the present investigation, a considerable reduction in the contents of photosynthetic pigments and photosynthetic activity was induced by relatively high salinity levels. This inhibitory effect is in agreement with that reported by Carter and Myers (1963), Shimose (1973), Heikal (1975), Ahmed *et al.* (1980), El-Tayeb (1986) and Kalaji and Nalborczyk (1991). The reduction in pigment biosynthesis due to salt stress could be attributed to structural changes in photosynthetic apparatus. Strogonov *et al.* (1970) mentioned that salinity may affect the forces binding the pigment-protein-lipid complex in chloroplast structure. Various levels of NaCl had a stimulatory effect on dark respiration of both plant species. The increase in respiration seems to be linked to the suppression of growth (Pandey and Divate 1976), eventually due to the contrasting response of different respiratory processes to salt stress (Schwartz and

Gale 1981). An increase in respiration may be even a characteristic of salt tolerance (Schwartz and Gale 1981).

Table 3. The distribution of some mineral elements [g kg^{-1} (d.m.)] in broad bean and pea as affected by salt stress. * Significant (P = 0.05) and ** highly significant (P = 0.01) differences as compared with control.

Treatment NaCl [mM]	Shoot Na	K	Ca	Mg	Root Na	K	Ca	Mg
Broad bean								
0 (control)	21.00	22.55	10.40	5.19	26.30	7.40	10.30	7.02**
40	29.39**	22.05	11.60**	3.39**	30.00*	8.90*	10.40	8.58**
80	50.93**	19.94**	13.60**	3.06**	35.10**	19.10**	11.70**	4.68**
120	68.86**	16.49**	16.30**	2.82**	44.90**	22.90**	12.20**	4.44**
160	75.95**	16.25**	17.70**	4.32**	58.20**	25.10**	12.50**	4.44**
L.S.D. at 5 %	1.46	1.45	0.44	0.38	3.53	1.00	0.61	0.43
L.S.D. at 1 %	2.21	2.19	0.67	0.58	5.35	1.51	0.93	0.65
Pea								
0 (control)	31.85	27.99	37.85	11.70	36.70	24.10	26.80	8.22
40	37.60**	29.00	39.95	9.00**	43.80**	24.30	26.20	8.82
80	43.70**	26.80	38.90	8.10**	46.70**	25.20	25.00	9.24
120	55.90**	27.00	36.65	7.00**	70.80**	34.90**	36.40**	9.90**
160	69.10**	26.50	33.90*	5.20**	74.90**	42.00**	35.60**	12.20**
L.S.D. at 5 %	0.91	1.67	2.77	0.46	1.58	1.42	2.00	0.77
L.S.D. at 1 %	1.42	2.61	4.35	0.72	2.49	2.24	3.14	1.21

The increase in sodium accumulation with the rise of salinization is in accordance with that obtained in other crop plants (Heikal *et al.* 1979, Coughlan and Wyn Jones 1980). However, the extent of sodium accumulation varied among the two plant species as well as in the roots and shoots. In this respect, the shoots of broad bean plants accumulated, generally, more sodium than the roots, while an opposite event was obtained in pea. Lahaye and Epstein (1969) found in many glycophytes relatively small amounts of sodium in the aerial parts, while most of it was retained in roots. Accordingly, plants differ in their strategy towards Na accumulation under salinity roots and shoots of both broad bean and pea contained appreciable amounts of K^+, Ca^{2+} and Mg^{2+} under the relatively low salinity, which indicated their partial resistance to low salt stress. The contents of Ca^{2+} and Mg^{2+} were apparently low, especially in broad bean, as compared with the high contents of Na^+ and K^+. Reed *et al.* (1981) suggested that the distribution of both divalent cations is passive, or it requires active efflux to produce the observed low values for intracellular concentrations. Moreover, especially the highest levels of NaCl stimulated the accumulation of K^+ and Ca^{2+} in roots of both species. This suggested that the osmoregulatory role of both cations was increasing tissue water content which in turn might play a role in salt tolerance of these plants (Shaddad 1990). Hedge and Joshi (1974) and Janardan *et al.* (1976), in rice and cotton found that the content of K^+ was higher in salt tolerant than sensitive cultivars and recommended it as a suitable selection criterion for salt tolerance.

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