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Sensitivity of Sesame to Various Salts[1]

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ABSTRACT

Plants tolerate widely varying proportions of salts in the root media but nutritional imbalances and specific ion toxicities may occur if one salt predominates under saline conditions.

The relative sensitivity of sesame (*Sesamum indicum* L.) to various ions and the nature of the specific ion toxicities were studied in water culture experiments. At 0.10 MPa osmotic pressure, $NaNO_3$, NaCl, Na_2SO_4, and $CaCl_2$ reduced the yield (shoot + pods) of sesame by about 15, 26, 33, and 65%, respectively. At 0.20 MPa, $Ca(NO_3)_2$ was more injurious than NaCl or any combination of the two salts.

Chemical analyses indicated that sesame roots did not accumulate Cl, Na, and Ca readily, since the accumulation factors for these ions were near or less than 1. However, leaves accumulated these ions to a considerable extent. Leaf Na concentrations of 162 μmol/g fresh wt were associated with necrosis but no evidence of Cl toxicity was noted. Calcium-induced necrosis seemed indirect, possibly a consequence of decreased Mg concentration. Ion concentration gradients indicated a specific accumulation of Na in the stem. This retention was greater, and less Na reached the leaves, when the anion was Cl than when it was SO_4, a difference that may explain the greater sensitivity of sesame to Na_2SO_4 than to NaCl.

The high sensitivity of sesame to single-salt salination emphasizes the importance of using salt mixtures in salt tolerance studies. At extreme Na-Ca ratios, ionic imbalance predominates and growth suppression exceeds that due to osmotic stress.

***Additional index words:* *Sesamum indicum* L., Specific ion effects, Leaf injury, Mineral composition.**

SESAME (*Sesamum indicum* L.) is an important oil crop cultivated in many semiarid regions where saline soils are prevalent. The few published reports indicate that sesame is very salt sensitive and resembles beans (*Phaseolus vulgaris* L.) in its response to Na (Yousif et al., 1972a, b; Cerda et al., 1977).

The present investigation was undertaken to determine the relative sensitivity of sesame to different salts and the nature of specific ion injuries.

MATERIALS AND METHODS

Plant Culture. Seeds of sesame (cv. 'Long-pod') were germinated in vermiculite moistened with dilute (1:10) Hoagland's solution No. 1 (Hoagland and Arnon, 1950) modified by reducing the orthophosphate concentration to 0.02 m*M* and by supplying Fe as the chelate, diethylene-triaminepentaacetate (Sequestrene 330). When seedlings were about 10 cm tall, they were transferred to 15-liter polyethylene pots containing a 1:2 dilution of Hoagland's solution with 0.1 m*M* orthophosphate. Culture solutions were renewed weekly or adjusted to the initial concentration and the pH was maintained between 5.5 and 6.5. They were salinized when plants were 2 to 4 weeks old depending on the experiment. The excess salt was added in two equal increments, 24 hours apart, at the beginning of the dark period. Some experiments were conducted in a growth chamber at 25 C with a 16-hour/day photoperiod and irradiation intensity of 58 W/m^2 at the plant top; other experiments were in the greenhouse with a day-night temperature range of 30 to 18 C and a natural light regime of about 12 hours/day. Treatments were replicated with two to four pots each with a maximum of three plants in each pot. Fresh and oven-dry weights (70 C) of plant parts were measured at the early fruiting stage.

Chemical Analyses. Dry plant tissues were digested in a 3:1 concentrated nitric-perchloric acid mixture (1 g sample/10 ml). The clear digest was diluted to the desired concentration and analyzed for cations by atomic absorption spectrophotometry and for sulfate by the gravimetric procedure described by Shaw (1959). For Cl analysis, dry tissues were extracted overnight with 0.1 *M* HNO_3 in 1.7 *M* acetic acid (200 mg sample/100 ml) and Cl was measured by coulometric-amperometric titration (Cotlove, 1963). Chemical analyses of leaves with leaf burn and necrosis were performed only on non-necrotic portions.

RESULTS

Sensitivity of Sesame to Specific Ions. Salinization with $NaNO_3$, NaCl, Na_2SO_4, or $CaCl_2$ at 0.10 MPa OP (osmotic pressure calculated, 1 megaPascal = 10 bars) reduced sesame yields (shoot + pods) by about 15, 26, 33, and 65%, respectively (Table 1). Except for $NaNO_3$ which seemed to stimulate root growth, the saline treatments decreased root and top growth similarly. At isosmotic potentials, Na_2SO_4 inhibited growth significantly more than NaCl, but $CaCl_2$ was the most injurious; it caused leaf necrosis within 12 days, sooner than any of the other salts. However, analysis of the necrotic leaves did not indicate excessive concentrations of either Cl or Ca. The Cl concentrations of non-necrotic portions of injured second and third leaves (0.10 MPa $CaCl_2$) were 133 and 116 μmole/g fresh wt, respectively (Table 2). These values were about one-half those of normal appearing leaves on 0.20 MPa NaCl-treated plants. The Ca concentrations were no higher than those in control leaves, 192 as compared with 200 μmole/g fresh wt (Leaf 2). Although the toxic effects of the $CaCl_2$ treatment increased with time, the concentrations of Cl and Ca in necrotic leaves remained below those of uninjured

Table 1. Effect of different salts on growth of 55-day-old sesame plants (41 days after salination). Top weights are means ± standard errors of four to eight plants.

Treatment	Osmotic pressure of added salt	Top		Roots	
		Mean dry weight	Growth decrease	Mean dry weight	Growth decrease
	MPa	g/plant	%	g/plant	%
Control		6.62 ± 0.43		2.04	
$NaNO_3$ (21 m*M*)	0.10	5.65 ± 0.17	14.6	2.23	−9.4
NaCl (21 m*M*)	0.10	4.88 ± 0.27	26.3	1.86	8.8
Na_2SO_4 (15 m*M*)	0.10	4.42 ± 0.36	33.2	1.74	14.6
$CaCl_2$ (15 m*M*)	0.10	2.32 ± 0.29	64.9	0.60	70.6
NaCl (31.5 m*M*)	0.15	4.64 ± 0.11	29.9	1.46	28.4
Na_2SO_4 (22.5 m*M*)	0.15	3.24 ± 0.19	51.0	1.21	40.7
NaCl (42 m*M*)	0.20	2.71 ± 0.49	59.1	0.90	55.9
Na_2SO_4 (31.5 m*M*)	0.20	1.69 ± 0.18	74.5	0.67	67.2

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Table 2. The effect of NaCl, Na_2SO_4, and $CaCl_2$ salinity on leaf injury and ion concentrations in leaves and roots of 55-day-old plants (41 days after salination).

Treatment (OP)	Plant part	Leaf appearance	K	Na	Ca	Mg	Cl	SO_4
			μmole/g fresh wt					
Control	1st Leaf	Normal	88	0.3	236	39.5	4.7	‡
	2nd Leaf	Normal	88	0.3	200	33.8	2.1	‡
	Roots		50	1.4	3.2	7.8	0.6	‡
NaCl (0.20 MPa)	2nd Leaf†	Normal	24	63	94	21.7	225	‡
	3rd Leaf	Normal	32	41	118	27.5	218	‡
	Roots		15	39	2.2	4.9	16.4	‡
Na_2SO_4 (0.20 MPa)	2nd Leaf†	Severely necrotic	53	162	76	19.0	16.4	8.2
	3rd Leaf	Normal	52	105	70	24.5	16.6	8.3
	Roots		7	34	1.6	1.3	2.4	‡
$CaCl_2$ (0.10 MPa)	2nd Leaf†	Severely necrotic	52	0.6	192	7.9	133	‡
	3rd Leaf	Necrotic	48	0.2	184	6.0	116	‡
	Roots		44	1.6	3.1	4.4	59	‡

† Leaf 1 had developed severe necrosis and abscised. ‡ Not analyzed.

NaCl-treated and control leaves, respectively. Thus, necrosis was due to factors other than high concentrations of Ca and Cl in the leaves. It may have been due to the low Mg concentration (Table 2).

In the case of Na_2SO_4-induced necrosis, the only significant difference in ionic composition was that of Na. Sodium accumulation in the leaves was much greater from the Na_2SO_4 than from the NaCl treatment. Despite the higher Na accumulation, K uptake was decreased less by Na_2SO_4 than by NaCl. The necrotic leaves of Na_2SO_4-stressed plants had higher Na concentrations than normal-appearing leaves on the same plant, 162 as compared with 105 μmole/g fresh wt (Table 2). The sulfate concentrations, however, were very low in both normal and necrotic leaves.

Neither Na, Ca, nor Cl accumulated to any appreciable degree in roots since the concentrations of these ions in the roots were near or below those in the treatment solutions (Table 2). The K and Mg concentrations in the root were considerably reduced by salinity, particularly by Na_2SO_4.

Specific Effects of Ca and Cl. Since $CaCl_2$ was the most injurious salt, it was desirable to discriminate between injury caused by Ca and that caused by Cl. We accomplished this by varying the ratios of $Ca(NO_3)_2$ and NaCl at a constant OP of 0.20 MPa. The plants were harvested before maturity, thus pod weights are those for immature pods. Figure 1 shows that $Ca(NO_3)_2$ suppressed growth more than NaCl or any combination of the two salts used in this experiment. Root and pod growth was little affected by 0.20 MPa of salt when the Ca:Na OP ratios were 1 or less, but at higher ratios growth was greatly reduced. Roots and pods seemed even more sensitive to Ca than were shoots. Since nitrate was the least detrimental of the three anions tested (Table 1), the poor growth of plants at 0.20 MPa of $Ca(NO_3)_2$ presumably resulted from the presence of high Ca concentrations. As NaCl replaced the $Ca(NO_3)_2$, growth suppression and leaf necrosis decreased, as did the leaf Ca concentrations (Table 3). The decrease in leaf Ca was especially evident for the third and fourth leaves. The leaf K concentrations also decreased as the Ca:Na ratio decreased.

The data in Table 3 also show that Na, unlike K, was accumulated in the lower leaves to relatively high levels before it accumulated in the tops. This concentration gradient was also present in the stem (Fig. 2). At 0.20 MPa NaCl, Na accumulated mainly in the

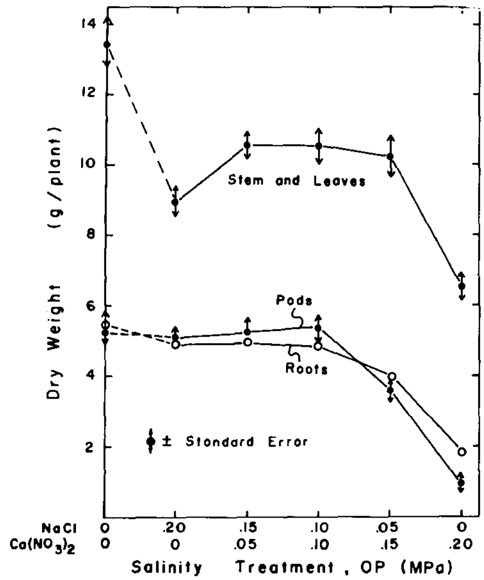

Fig. 1. The effect of varying ratios of NaCl and $Ca(NO_3)_2$ at 0.20 MPa osmotic pressure on the growth of 75-day-old sesame plants.

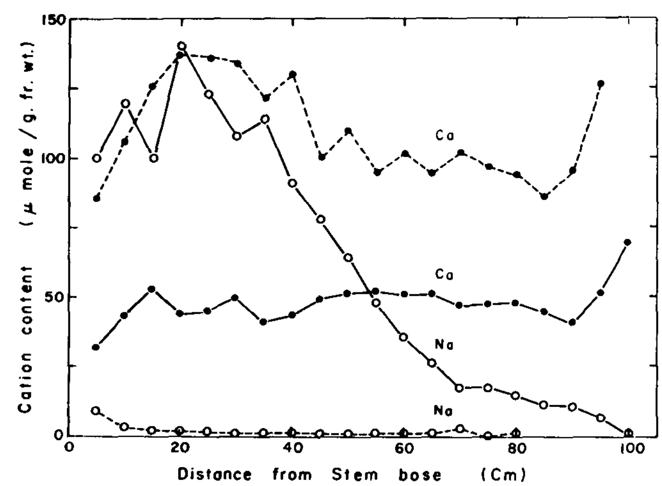

Fig. 2. Sodium and Ca concentrations in 5-cm stem sections of 75-day-old sesame plants 46 days after salination with 0.20 MPa NaCl (——) or 0.15 MPa $Ca(NO_3)_2$ + 0.05 MPa NaCl (— — — —).

Table 3. The effect of various combinations of $Ca(NO_3)_2$ and NaCl on the leaf concentrations of K, Na, Ca, and Cl of 60-day-old sesame plants (31 days after salination).

Treatment (osmotic pressure)	Leaf position	K	Na	Ca	Cl
		μmole/g fresh wt			
Control	2	87	0.19	203	‡
	3	116	0.12	112	‡
	Top	94	0.09	56	‡
NaCl (0.20 MPa)	2	21	82.1	154	125
	3	71	48.3	120	100
	Top	82	0.72	76	43
NaCl (0.15 MPa) + $Ca(NO_3)_2$ (0.05 MPa)	2	26	33.6	280	106
	3	64	15.1	186	92
	Top	82	0.84	86	28
NaCl (0.10 MPa) + $Ca(NO_3)_2$ (0.10 MPa)	2	56	5.9	325	71
	3	83	0.95	219	59
	Top	84	0.30	92	18
NaCl (0.05 MPa) + $Ca(NO_3)_2$ (0.15 MPa)	3†	84	0.34	272	31
	4	93	0.19	216	27
	Top	84	0.19	98	11
$Ca(NO_3)_2$ (0.20 MPa)	4†	90	0.11	266	1
	5	80	0.23	230	1
	Top	78	0	132	1

† Leaf was necrotic and all lower leaves had abscised following necrosis. Leaf 1 had senesced in all treatments. ‡ Not analyzed.

lower stem and decreased markedly in the upper portion. This Na accumulation did not occur in the NaCl-$Ca(NO_3)_2$ treatment. Sodium levels were negligible in both the leaves and stems where Ca was the predominant ion. The Ca and Cl concentrations were also highest in the lower leaves (Table 3) but no such concentration gradient was apparent in the stem (Fig. 2; Cl data not shown).

DISCUSSION

The sensitivity of sesame to NaCl reported here agreed with earlier data (Yousif et al., 1972a, b; Cerda et al., 1977). However, NaCl suppressed the top growth at early fruiting stage less than Na_2SO_4 and much less than $CaCl_2$ (Table 1). The greater sensitivity of sesame to $CaCl_2$ than to NaCl (Table 1) resembles that reported for beans (Bernstein, 1964, 1975). The greater sensitivity to Ca than to Na and the severe Ca-induced necrosis of lower leaves did not seem to be a result of accumulation of toxic levels of Ca but rather an indirect effect of Ca on the maintenance of sufficient levels of Mg. This agreed with the observations on beans that $CaCl_2$ depressed Mg content (Bernstein, 1964).

The property of Na exclusion in sesame also resembles that of beans (Jacoby, 1964, 1965). It may play an important role in the relative resistance of sesame to different Na salts; e.g., the greater sensitivity of sesame to Na_2SO_4 than to NaCl seemed to be correlated with greater Na transport to the leaves in Na_2SO_4 than in NaCl-stressed plants (Table 2). Evidence that Na exclusion from leaves is crucial in salt resistance of sesame was the relatively low level of Na (162 μmole/g fresh wt) associated with leaf necrosis, whereas no injury was associated with Cl concentrations of 225 μmole/g fresh wt. These data also show that Ca is extremely effective in regulating Na transport to the shoots of sesame plants (Fig. 2 and Table 3). Although sesame pods were not mature, the yield of immature pods seemed to be very little affected by NaCl at 0.20 MPa or any ratio of NaCl and $Ca(NO_3)_2 \geqslant l$ at 0.20 MPa (Fig. 1). This agreed with the data of Cerda et al. (1977) that pod yields are less sensitive than vegetative growth to salinity.

The greater sensitivity of sesame to single salts than to salt mixtures demonstrates the importance of avoiding single-salt solutions in salt tolerance studies. Although sesame responded primarily to osmotic stress over a wide range of Na-Ca ratios, extreme ratios caused ionic imbalance and additional growth reduction.

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