BRIEF COMMUNICATION

Triadimefon enhances growth and net photosynthetic rate in NaCl stressed plants of *Raphanus sativus* L.

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Abstract

The effect of sodium chloride and triadimefon (TDM) on the chlorophyll (Chl) content, net photosynthetic rates (P_N), rate of transpiration (E), and intercellular CO_2 concentration (C_i) in *Raphanus sativus* was studied. The effect of NaCl salinity was partially ameliorated by TDM which caused increase in Chl content, P_N, and C_i. TDM also increased root dry matter production, decreased E, and increased the water use efficiency.

Additional key words: chlorophyll; intercellular CO_2 concentration; net photosynthetic rate; radish; root; salinity; shoot; transpiration rate; water use efficiency.

Salinity inhibits plant growth, disturbs pigment composition, and inhibits photosynthesis in various plants. The decline in P_N is generally attributed to stomatal closure under salt stress, which reduces C_i. The triazole derivatives have both fungitoxic and plant growth regulating properties. They increase Chl content, alter saccharide metabolism, increase stress tolerance, and delay senescence (Davis *et al.* 1988). The growth regulating property of TDM is attributed to changes in the balance of gibberellins, abscisic acid, and cytokinins (Fletcher and Hofstra 1985). TDM causes the development of shorter and more compact shoot systems, thicker and greener leaves, and reduces leaf growth, flowering, and E (Fletcher and Nath 1984). The studies of NaCl tolerance induced by TDM are rather limited for tuberous root crops such as *R. sativus*. Therefore, the present study was made to show the effect of TDM on leaf photosynthetic pigments, gas exchange parameters, and root growth of radish under NaCl stress.

Received 25 June 1997, *accepted* 1 August 1997.
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Acknowledgement: We thank the Department of Horticulture, Faculty of Agriculture, Annamalai University for permitting us to use the IRGA.

The plants of *R. sativus* L. cv. 8 were grown in plastic pots filled with 3 kg of soil mixture containing red soil, sand, and farm yard manure in the ratio of 1:1:1 in randomised blocks. The plants were grown in a greenhouse [day/night temperature 33/28±2 °C, relative humidity (RH) 60±5 %, irradiated for 12 h per d at 450 μmol m^{-2} s^{-1}(PAR) provided by fluorescent and incandescent bulbs]. The plants were irrigated with 80 mM NaCl, 15 g m^{-3} TDM, and their combination four times during the growth of radish, at days 0, 15, 30, and 45 after sowing (DAS). In other days, the plants were watered to field capacity using deionised water. The electrical conductivity of 10.75 dS m^{-1} was maintained in the NaCl and NaCl+TDM treatments till the end of the experiment.

The root and shoot biomass was estimated at 15, 30, 45, and 60 DAS. Five plants were removed carefully without damaging the root system from each treatment, washed with tap water, and blotted dry. The fresh and dry masses were recorded. The maximum root length was measured, and the leaf area was determined using a leaf area meter (*LICOR* model *LI-3100*, Lincoln, USA). Chl content was estimated in leaf discs (8 mm diameter) taken from interveinal portions of the 3rd leaves from apex. The pigments were extracted in 15 cm^3 of 80 % acetone, the extracts were centrifuged at 2500×*g* for 10 min at 0 °C. Absorbances were measured at 645 and 663 nm (Asare-Boamah *et al.* 1986). Chl content was calculated according to Arnon (1949). Leaf gas exchange measurements were made on fully expanded 3rd leaves of five plants in each treatment, at intervals of 15 d, using an infra-red gas analyser (IRGA) connected with Parkinson leaf chamber (*ADC* model *LAC 3*). The chamber position after inserting the leaf was identical with the natural position of the leaf. During the measurements, RH was 60±5 %, and temperature was 33±2 °C. P_N, E, and C_i were determined at an external CO_2 concentration of 340 μmol mol^{-1}. The leaf to air-vapour pressure difference was 2.5 to 3.0 kPa, leaf temperature varied between 28-32 °C, and the photosynthetically active irradiance was 1400 μmol m^{-2} s^{-1} (direct sunlight). Water use efficiency (WUE) was determined as P_N/E. The main and interactive effects of salt and TDM treatments were tested using analysis of variance (ANOVA) by the method outlined by Ridgman (1975). Means were compared from the error mean square by LSD at the $p=0.05$ confidence level using the Tuckey's (1953) test.

Preliminary experiments indicated that the 80 mM NaCl treatment reduced the dry matter of *R. sativus* by 50 % when compared to control. Therefore this concentration was chosen for inducing salinity. The main experiments showed that NaCl treatment decreased the root dry mass, and the TDM treatment largely improved this parameter. However, shoot growth was decreased in the TDM treated plants (Table 1). The reduction in dry mass in root and shoot with increasing salinity was reported in various crop plants (Siddiqui and Kumar 1985, Lewis *et al.* 1989). Fletcher and Nath (1984) found that TDM treatment caused decrease in fresh and dry masses of the shoot in radish, but there was an increase in the root/shoot ratio. Triazoles increased root growth in cucumber (Fletcher and Arnold 1986): this was attributed to the increase in concentration of endogenous cytokinins. On the other hand, triazoles inhibited gibberellin biosynthesis (Rademacher *et al.* 1987) and so the elongation growth. In our experiment, NaCl treatment decreased the root length, but the addition of TDM to the NaCl-stressed plants repaired this negative effect. Also the TDM treatment of unstressed plants significantly increased the root length over control. The increase in root length was perceptable from 15 DAS. Reduction in root length with increasing NaCl salinity was observed in barley (Hurkman and Tanaka 1987), mung bean (Nakamura *et al.* 1990), cucumber (Fletcher and Arnold 1986), and maize (Zidan *et al.* 1990).

Table 1. Triadimefon, TDM (15 g m^{-3}) induced changes in growth parameters of control and NaCl-stressed (80 mM) radish plants. Root length [cm $plant^{-1}$], leaf area [cm^2 $plant^{-1}$], and total, root, and shoot masses [g $plant^{-1}$] are means of 7 replications. DAS - days after sowing. Means marked by * and ** were significantly different at p = 0.05 and 0.01, respectively. LSD = least significant difference (p=0.05).

Parameter	DAS	Control	NaCl	NaCl+TDM	TDM	LSD
Root length	15	6.5	5.1	7.2	7.8*	2.590
	30	7.3	5.8**	8.8*	9.3**	1.450
	45	9.1	7.1**	10.9	12.8**	1.540
	60	10.2	7.8**	13.9*	16.8**	1.525
Leaf area	15	13.4	6.4**	8.7**	9.8*	1.017
	30	87.3	55.4**	62.5**	79.8	3.550
	45	202.7	143.8**	159.8**	175.7*	2.551
	60	293.3	187.7**	198.7**	210.6*	5.915
Total dry mass	15	0.173	0.074**	0.195	0.231**	0.076
	30	1.465	0.648**	1.627	1.877**	0.456
	45	15.327	7.771**	16.730*	19.282**	4.427
	60	20.567	9.570**	22.395**	25.150**	1.786
Root dry mass	15	0.029	0.010*	0.099	0.125**	0.038
	30	0.369	0.122**	0.843**	0.987**	0.158
	45	6.420	3.179**	9.465*	10.910**	1.886
	60	9.710	4.519**	13.560*	15.151**	2.376
Shoot dry mass	15	0.144	0.064	0.096	0.106	0.155
	30	1.096	0.526**	0.784**	0.890	0.137
	45	8.907	4.592**	7.265**	8.372**	1.293
	60	10.857	5.051**	8.835**	9.999**	1.375

The salinity decreased the leaf area to 64 % of the control value on 60 DAS. The combination of TDM with NaCl and TDM singly increased the leaf area when compared to NaCl stressed plants. Salinity stress considerably decreased the average plant height, leaf area, and leaf dry matter accumulation in *Phaseolus aconitifolius* (Hemakulkarni and Karadge 1991). TDM reduced the leaf size, induced thicker, sturdier, more errect, and greener leaves than control in maize (Khalil *et al.* 1990).

The Chl (a+b) content of control and treated plants increased till 45 DAS, later it declined. It was reduced by NaCl stress to 57 % of the control value at 60 DAS. The addition of TDM to the NaCl-stressed plants markedly increased the total Chl content to 274 % over control at 60 DAS (Table 2). Pretreatment with a triazole compound, *LAB-150978*, increased the Chl content over control seedlings of sunflower and mung bean under salinity stress (Saha and Gupta 1993). TDM treatment increased the Chl content in the leaves of apple, radish, pea, and soybean (Fletcher and Nath 1984).

Table 2. Triadimefon, TDM (15 g m^{-3}) induced changes in gas exchange characteristics of control and NaCl-stressed (80 mM) radish plants. Chlorophyll (Chl) content [g kg^{-1}(fr.m.)], net photosynthetic rate (P_N) [μmol(CO_2) m^{-2} s^{-1}], intercellular CO_2 concentration [μmol mol^{-1}], rate of transpiration (E) [μmol(H_2O) m^{-2} s^{-1}], and water use efficiency [g(CO_2) kg^{-1}(H_2O)] were measured on fully expanded 3rd leaves of plants; means of 5 measurements. DAS - days after sowing. Means marked by * and ** were significantly different at p = 0.05 and 0.01, respectively. LSD = least significant difference (p=0.05).

Parameter	DAS	Control	NaCl	NaCl+TDM	TDM	LSD
Chl (a+b)	15	0.282	0.190	0.799	0.859**	0.089
	30	0.323	0.241*	0.986*	1.583**	0.119
	45	0.801	0.478**	1.682**	2.687**	0.323
	60	0.776	0.443**	1.497**	2.125**	0.261
P_N	15	6.97	5.39	12.45	12.90**	2.165
	30	18.13	11.11**	30.45**	32.85**	2.150
	45	21.41	13.10**	35.13**	38.93**	2.337
	60	19.31	12.01**	34.92**	37.23**	2.500
C_i	15	60	37**	67**	74**	2.551
	30	162	101**	181*	199**	8.677
	45	202	144**	215*	248**	4.420
	60	175	118**	198**	207**	6.300
E	15	4.56	3.99	3.17*	2.80**	0.504
	30	10.53	9.17**	7.53**	7.21**	0.458
	45	11.99	10.59**	8.35**	7.99**	0.499
	60	10.75	9.95**	7.96*	7.58**	0.337
WUE	15	3.74	3.29	9.62	11.36	
	30	4.22	2.96	9.85	11.20	
	45	4.36	3.02	10.24	11.97	
	60	4.38	2.95	10.74	12.04	

The NaCl stress caused a decrease in P_N. TDM treatment appreciably increased the rate of P_N at all stages of plant development. When the stressed plants were treated with TDM, P_N improved upto 181 % over the control. The C_i increased upto 45 DAS, but subsequently it declined in both control and treated plants. TDM treatment increased the C_i in direct proportion to P_N. Also in other plant species, such as citrus cultivars (Walker *et al.* 1982), *Atriplex annumalaria*, *A. hastata* and *Hordeum vulgare* (Dunn and Neales 1993), salinity stress decreases P_N. The Chl content and P_N were directly proportional: similar observations were made in salt stressed finger millet (Onkware 1990) and wheat (Kingsbury *et al.* 1984).

The sodium chloride stress decreased E in comparison to control. TDM treatment caused appreciable decrease in E to an extent of 74 % over control. NaCl-stressed plants showed a decline in WUE due to the decreased P_N. The TDM-treated stressed and unstressed plants showed higher WUE than control plants due to their higher P_N and lower E. The salt stress affected P_N more drastically when compared to E, and as a result low WUE was found in finger millet (Onkware 1990) and mulberry (Lakshmi *et al.* 1996).

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