Interactive effects of sulphur dioxide and mineral nutrient supply on photosynthetic characteristics and yield in four wheat cultivars

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Abstract

Field experiments were conducted on four cultivars of wheat (*Triticum aestivum* L.) to examine the variability in cultivar response to sulphur dioxide (SO_2) under different concentrations of mineral nutrients. Thirty-days-old plants were exposed for 8 weeks to 390±20 μg m^{-3} (0.15 ppm) SO_2 for 4 h per day, 5 d per week. Decline in net photosynthetic rate, contents of pigments and nitrogen, biomass and grain yield of each cultivars were due to SO_2 at all the nutrient concentrations studied. However, the magnitude of reduction was higher in plants grown without nutrient application. On the basis of the reductions in photosynthesis and yield, the susceptibility of wheat cultivars to SO_2 was in the order of Malviya 213 > Malviya 37 > Malviya 206 > Malviya 234 at recommended dose of NPK, whereas the same without the nutrients was Malviya 206 > Malviya 234 > Malviya 213 > Malviya 37.

Additional key words: biomass; carotenoids; chlorophyll; nutrients; sulphur dioxide; wheat.

Introduction

Adverse effects of SO_2 on various plants are well known (Wilson and Murray 1990, Verma and Agrawal 1996, Kooij *et al.* 1997). SO_2 commonly reduces growth and yield either with or without foliar injury (Rao and DeKok 1994, Khan and Khan 1994). Reductions in the contents of photosynthetic pigments (Verma and Agrawal 1996), inhibition of physiological processes (Darrall 1986, Saxe 1991) and alteration in metabolic functions and enzyme activities (Okpodu *et al.* 1996) and nutrient uptake (Agrawal and Verma 1997) have often been reported effects of SO_2. SO_2 is harmful even at low concentrations (Rao and DeKok 1994), however, Tausz *et al.* (1996) reported no significant adverse effect on growth at low concentration of SO_2. Interspecific and intraspecific variations in the susceptibility of plants to SO_2 were also observed (Alscher *et al.* 1987, Agrawal and Verma 1997).

The phytotoxicity of SO_2 strongly depends on environmental factors - both climatic and edaphic, their concentrations, and duration of exposure. Mineral nutrient supply may increase pollutant injury to crops (Ormrod *et al.* 1973, Pell *et al.* 1990), but some studies have indicated that plants grown at low nutrient supply are more sensitive to SO_2 injury (Van Haut and Stratmann 1970, Ayazloo *et al.* 1980, Rajput and Agrawal 1994).

There is a dearth of information on physiological variation among tropical wheat cultivars to SO_2 and their interaction with the supply of mineral nutrients in the field. The present investigation was, therefore, conducted to quantify the physiological and yield responses of four wheat cultivars grown under SO_2 stress in the field at different mineral nutrient concentrations.

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Abbreviations: C = control; Chl = chlorophyll; E = transpiration rate; F_0 = plants without addition of NPK; F_1 = plants with recommended dose of NPK; F_2 = plants with doubled dose of NPK; P_N = net photosynthetic rate; T = SO_2 treated.

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Materials and methods

Our experiments were done at the Agricultural Research Farm, Banaras Hindu University, Varanasi (25°18'N latitude and 83°1' longitude, at an elevation of about 76 m a.s.l.) situated in the eastern part of Ganges plains in India. The experimental design was a randomised split plot design with three factors (*1*) wheat cultivars, (*2*) mineral nutrient concentrations, and (*3*) SO_2 treatment.

The seeds of wheat (*Triticum aestivum* L.) cultivars Malviya 206 (M 206), Malviya 234 (M 234), Malviya 213 (M 213), and Malviya 37 (M 37) were obtained from the Department of Genetics and Plant Breeding, Institute of Agricultural Sciences, B.H.U. Seeds were sown 15 cm apart from each other in 72 plots each of 1.5×1.5 m size for all cultivars at 3 different nutrient concentrations, *i.e.*, without NPK supplemented (F_0), with recommended NPK dose (120, 80, 40 kg ha^{-1}, respectively) (F_1), and with double recommended NPK dose (F_2). A half dose of N and full doses of P and K were given as basal dressings and another half dose of N was given as a top dressing. N, P, and K were applied as urea, single superphosphate, and muriate of potash. In total for each cultivars, 18 plots were maintained. For each cultivar a set of three plots of each nutrient levels were randomly selected and plants were exposed for 8 weeks to 390±20 µg m^{-3} (0.15 ppm) SO_2 concentration in 1.5 m^3 open top chambers, starting from 30-d age for 4 h daily, 5 d per week (Verma and Agrawal 1996). Chambers were supplied with charcoal filtered air. SO_2 gas was provided by SO_2 cylinders, its amount released into the chamber was regulated and maintained with a valve and calibrated flow meter. The desired concentration within the chambers was achieved by dilution with carrier air (56 000 cm^3 s^{-1}). The control plants were also placed in identical chambers, but without SO_2.

For analyses, the plants were randomly sampled from each plot in triplicate in 30-d intervals up to 75 d. The values presented in this paper are those for 75-d-old plants.

The portable photosynthesis system (*LI-6200, LI-COR*, Lincoln, U.S.A) under ambient conditions was used for measurement of net photosynthetic (P_N) and transpiration (E) rates on the third leaf below the apex of the stem. For total biomass determination, monoliths of 10×10×20 cm^3 with intact roots were carefully dug out randomly for each control and treated plants. The monoliths were thoroughly washed after placing them on sieves of 1 mm mesh size under the running tap water to remove the soil particles adhering to the root system. The plants were then oven-dried at 80 °C until constant mass. The amounts of total chlorophyll (Chl) and carotenoids were measured according to Maclachlan and Zalik (1963), and Duxbury and Yentsch (1956), respectively.

Total nitrogen content was determined using the micro-Kjeldahl technique (Misra 1968). Sulphate sulphur content [g kg^{-1}(d.m.)] was determined by using the turbidimetric method (Rossum and Villarruz 1961). Grain yield was determined [g m^{-2}] after final harvest.

The significance of differences between treatments was calculated by Student *t*- test.

Results

SO_2 fumigation severely hampered plant growth in comparison to control plants. P_N was reduced significantly due to SO_2 exposure as compared to the control one in all cultivars. Reduction varied with cultivars and nutrient concentrations (Fig. 1). E was reduced in all the cultivars at F_oT and F_1T as compared to their respective controls (Fig. 2). In F_2T plants, E either increased or remained unchanged in comparison to control plants of all the cultivars.

Total Chl content decreased in all the cultivars at all nutrient concentrations as compared to their respective controls (Table 1). Carotenoid content also decreased significantly in SO_2-treated leaves as compared to control at each nutrient level but the reduction was larger in F_0T plants of all the cultivars (Table 1). In all the cultivars of wheat, N content decreased significantly due to SO_2 treatment at each nutrient level, whereas sulphate sulphur content increased in SO_2-treated plants (Table 2).

Total plant biomass decreased significantly in all SO_2 treated plants (Fig. 3). At the time of harvest, yield m^{-2} was lower in all the SO_2 treated plants as compared to their respective controls. The highest decrease was always observed in F_0T plants of all the cultivars (Fig. 4).

Discussion

The decrease in Chl content due to SO_2 treatment may be ascribed either to inhibition of Chl synthesis (Malhotra 1977) or its destruction (Shimzaki *et al.* 1980). However, Bytnerowicz *et al.* (1987) did not find any significant change in Chl concentration of wheat plants exposed to 393 $\mu g(SO_2)$ m^{-3}. Nutrient amendment lowered the magnitude of reduction in Chl content as compared to unamended plants. Nitrogen supply increases leaf photosynthesis *via* the amounts of N-containing component such as ribulose-1,5-bisphosphate carboxylase/oxygenase activity (Sivasankar *et al.* 1993) and also by increasing Chl formation (Agrawal and Verma 1997). However, N and P deficiency reduces the Chl concentration (Lawlor *et al.* 1989, Rousseau 1990).

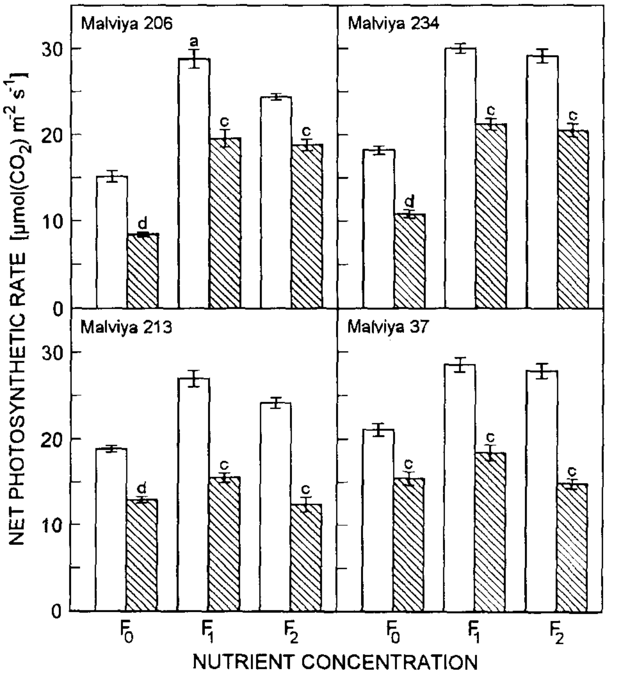

Fig. 1. Net photosynthetic rate (P_N) of control (*empty columns*) and SO_2-treated (*shaded columns*) wheat cultivars grown at different nutrient concentrations. Significant differences between control and treated plants: a - $p<0.05$; b - $p<0.01$; c - $p<0.005$; d - $p<0.001$.

In all cultivars, P_N decreased significantly in SO_2-treated plants. Decline in P_N due to SO_2 was also found in other studies (Führer *et al.* 1993, Niewiadomska and Miszalski 1995, Strand 1995). Continuous exposure to SO_2 even at low concentration inhibits P_N in wheat (Darrall 1989, Verma and Agrawal 1996). Lower P_N was ascribed mainly to the effects on the mesophyll tissue. Both inactivation of ribulose-1,5-bisphosphate carboxylase and lower levels of the substrate, ribulose biphosphate, have been reported (Caemmerer and Farquhar 1981, Darrall 1989). Varietal differences considered above may be attributable not only to differences in the

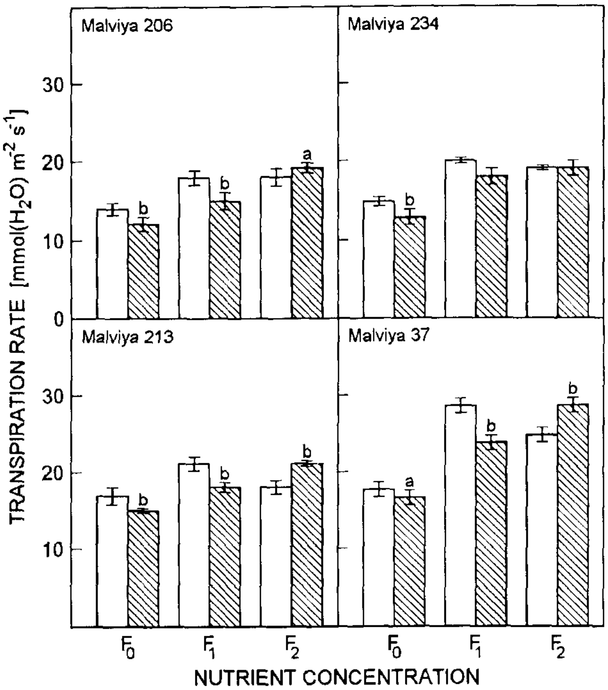

Fig. 2. Transpiration rate (E) of control (*empty columns*) and SO_2-treated (*shaded columns*) wheat cultivars grown at different nutrient concentrations. Significant differences between control and treated plants: a - $p<0.05$; b - $p<0.01$; c - $p<0.005$; d - $p<0.001$.

sensitivity of plant tissues, but also in the proportion of the exposure concentration penetrating to the tissues. P_N was directly correlated with sulphate content in leaves. SO_2 exposure reduced E in F_0T and F_1T plants compared to the respective controls, whereas the same generally increased in F_2T plants which also showed greater decline in P_N compared to F_1T plants (Fig. 2). This suggests that at double recommended dose of NPK more SO_2 entered in plant tissue and, consequently, P_N remained lower in these plants compared to those at recommended dose.

The SO_2 treatment resulted in significant reduction in biomass accumulation in all the cultivars. Accumulation of dry matter was higher in fertilizer-amended plants as compared to the unamended ones. As biomass accumulation and productivity are an integrated result of all biochemical, physiological, and metabolic activities in plants, their reduction confirms that SO_2 directly interferes with various fundamental functional processes of plants resulting in lower biomass.

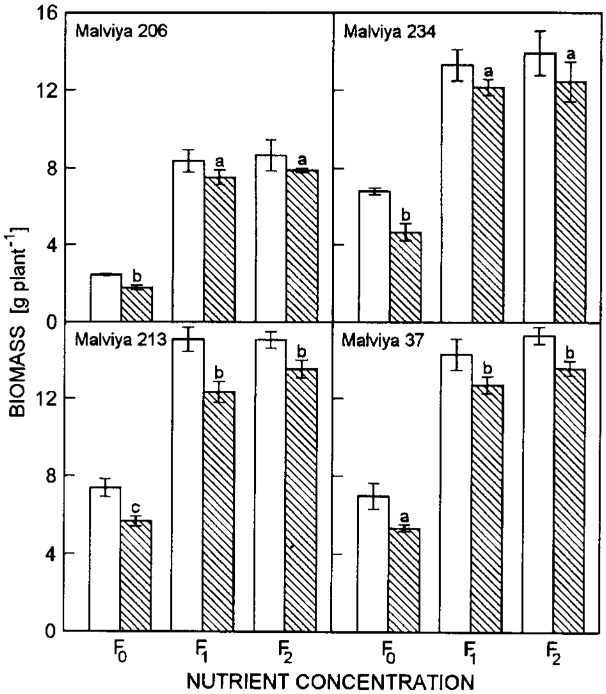

Fig. 3. Total biomass of control (*empty columns*) and SO_2-treated (*shaded columns*) wheat cultivars grown at different nutrient concentrations. Significant differences between control and treated plants: a - $p<0.05$; b - $p<0.01$; c - $p<0.005$; d - $p<0.001$.

In all the cultivars, N content of leaves was lower in all treated plants compared to the control. SO_2 exposure often lowers foliar nutrient concentrations (Garsed *et al.* 1981, Nandi *et al.* 1985, Agrawal and Verma 1997). Foliar N content was almost similar in F_1C and F_2C plants in all cultivars, which suggests that mineral uptake from soil not only depends upon soil nutrient status but also on demand of nutrient during particular growth period. Wilson and Murray (1990) reported higher sulphate sulphur content in plant parts exposed to SO_2. In this experiment, increase in sulphate-S was observed in all the cultivars and maximum accumulation of it was observed in F_0T plants. Response variations between cultivars have also been observed. The lower content of sulphate-S and better growth in SO_2-treated plants grown on nutrient amended soil compared to unammended ones suggest that nutrient application has stimulated plant growth and a large proportion of absorbed sulphur due to SO_2 exposure is being utilised in metabolic processes rather than accumulated as SO_4^{2-}. Mass *et al.* (1987) reported that sulphate-S accumulation represents the accumulation of sulphur in excess of assimilation.

The significant decrease in grain yield due to SO_2 may be attributed to the lowering of P_N. This finding supports the report of Darrall (1989). Increase in yield of fertiliser supplemented plants exposed to ambient air pollutants has also been reported (Anbazhagan *et al.* 1987, Ayer and Bedi 1993, Verma and Agrawal 1996). The supply of macronutrients N, P, and K has increased the yield of all cultivars of wheat by increasing P_N, concentrations of pigments and nutrients, and biomass of fertilized SO_2-exposed plants compared to the unfertilised treated ones. Coleman *et al.* (1989) have also suggested that plants growing in nutrient poor condition may be more sensitive to air pollution with respect to change in carbon gain.

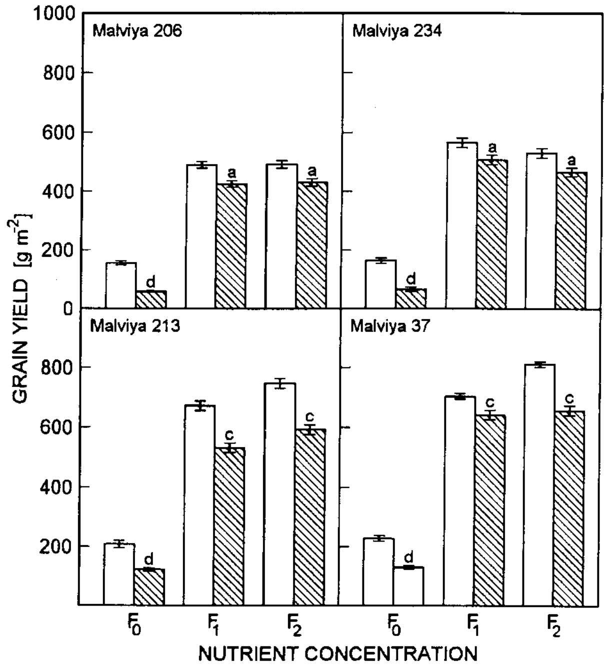

Fig. 4. Grain yield of control (*empty columns*) and SO_2-treated (*shaded columns*) wheat cultivars grown at different nutrient concentrations. Significant differences between control and treated plants: a - $p<0.05$; b - $p<0.01$; c - $p<0.005$; d - $p<0.001$.

Among the different nutrient concentrations, NPK at recommended dose was the best in alleviating the grain yield reduction due to SO_2 exposure in all cultivars. On the basis of photosynthesis and grain yield reductions, the susceptibility level to SO_2 was in Malviya 213 > Malviya 37 > Malviya 206 > Malviya 234 at recommended dose of NPK, whereas the same without the fertiliser application was M 206 > M 234 > M 213 > M 37. This results support that susceptibility of wheat to SO_2 not only varied with cultivars but also due to fertiliser application. Our experiments suggest that nutrient status modifies the response of wheat cultivars to SO_2. Cultivars also differed in their ability to compensate for SO_2-induced loss in yield when supplemented with nutrients.

Table 1: Chlorophyll and carotenoid [g kg^{-1}(f.m.)] and nitrogen and sulphate-sulphur [g kg^{-1}(d.m.)] contents of control (C) and SO_2 treated (T) wheat cultivars grown at different nutrient concentrations. Levels of significant difference between control and treated plants: a - p<0.05; b - p<0.01; c - p<0.005; d - p<0.001.. Values in parentheses represent the percentage increase (+) or decrease (-) relative to controls.

Cultivar	Nutrient concentrations	Chlorophyll C	Chlorophyll T	Carotenoids C	Carotenoids T	Nitrogen C	Nitrogen T	Sulphate-sulphur C	Sulphate-sulphur T
	F_0	6.65	4.48^d (-32.0)	1.45	1.10^d (-24.1)	20.0	16.0^a (-20.0)	8.0	20.0^d (+150.0)
M 206	F_1	8.20	6.56^d (-20.0)	1.55	1.28^c (-17.4)	32.0	30.0 (-6.25)	18.0	26.0^c (+44.4)
	F_2	8.34	6.68^d (-19.9)	1.57	1.28^d (-18.5)	34.0	32.0^a (-5.9)	18.0	26.0^c (+44.4)
	F_0	6.64	4.42^d (-33.4)	1.44	1.14^d (-20.8)	23.0	18.0^a (-21.7)	11.0	20.0^d (+81.8)
M 234	F_1	8.22	6.68^c (-18.7)	1.56	1.30^b (-16.7)	35.0	32.0 (-8.6)	20.0	24.0^b (+20.0)
	F_2	8.36	6.74^c (-19.4)	1.58	1.31^b (-17.1)	35.0	31.0^a (-11.4)	22.0	24.2^b (+10.0)
	F_0	5.60	3.88^d (-23.2)	1.32	1.12^c (-15.2)	24.2	18.8^a (-22.3)	10.6	20.8^d (+96.23)
M 213	F_1	7.32	6.30^b (-13.9)	1.49	1.28^a (-14.1)	31.0	25.8^a (-16.8)	14.2	23.4^b (+64.8)
	F_2	7.35	6.36^a (-13.5)	1.50	1.32^a (-12.0)	30.2	24.6^b (-18.5)	16.2	24.8^d (+53.1)
	F_0	5.65	4.89^d (-22.3)	1.41	1.16^c (-17.7)	24.0	19.5^a (-18.8)	12.4	20.8^d (+67.8)
M 37	F_1	7.48	6.74^b (-9.8)	1.54	1.30^b (-15.6)	32.8	28.6^a (-12.8)	18.2	22.8^b (+25.3)
	F_2	7.63	6.76^b (-11.6)	1.53	1.29^b (-15.7)	32.4	26.5^b (-18.2)	18.0	22.4^c (+24.4)

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