RESEARCH PAPER:

Amelioration of SO_2 induced phytotoxicity in *Triticum aestivum* L. cv. PBW-343

AWANISH AND NARESH KUMAR

Asian Journal of Environmental Science, (June, 2010) Vol. 5 No. 1 : 29-36

See end of the article for authors' affiliations

Correspondence to :
AWANISH
Department of Botany, Faculty of Science, C.C.R. (P.G.) College, MUZAFFARNGAR (U.P.) INDIA

SUMMARY

Field experiments were conducted to examine the impact of 1306 ìm^{-3} SO_2 on growth, yield and some biochemical parameters of wheat (*Triticum aestivum* L. cv. PBW-343) that grew in closed polythene chambers for 2 h at alternate days. On prolonged exposure, significant reduction on all growth parameters, dry weight fractions, net primary productivity, leaf extract pH, content of chlorophyll and carotenoids pigments, carbohydrate and protein and significant increase in sulphur, anthocyanin, proline and phenolics content was observed. However, when these SO_2 treated plants were periodically sprayed with aqueous solution of either of 0.5% $Ca(OH)_2$ or 0.5% sodium benzoate or 0.5% potassium ascorbate, changes in above mentioned plant parameters were reduced and SO_2 exposed plants showed better growth. It was noted that with response to SO_2 phytotoxicity potassium ascorbate was better ameliorating agent than sodium benzoate and sodium benzoate was better ameliorating agent than $Ca(OH)_2$.

Key words : SO_2 pollution, Growth, yield, Biochemical changes, Amelioration

Sulphur dioxide (SO_2) is one of the major phytotoxic pollutants and emission level of SO_2 is increasing rapidly due to industrialization and urbanization. SO_2 gas is absorbed in mesophyll through stomata of plants and alters the metabolic processes of plants (Jeyakumar *et al*, 2003), decreases their photosynthetic activity (Black and Unsworth, 1979) leading to considerable loss in crop productivity and yield (Rao *et al.*, 1985; Kumar and Singh,1986; Rai *et al*., 2007; Rai and Agrawal, 2008).

The effects of SO_2 pollution have been extensively studied in several crop plants but a little work has been done on amelioration of SO_2-induced phytotoxic effects in crop plants. The present study was mainly emphasized on amelioration of SO_2-inuced phytotoxicity by spraying aqueous solution of chemical protectants in *Triticum aestivum* L. cv. PBW-343.

MATERIALS AND METHODS

The present study was conducted at Agricultural Research Farm, C.C.R.(P.G.) College, Muzaffarnagar. Seeds of *Triticum aestivum* L. cv. PBW-343 were sown with line to line distance of 22.5 cm and plant to plant distance of 10 cm in 5 separate beds of 1m x 1m. The fumigation chamber was made up of transparent polythene (1m x 1m x 1m dimension) supported on iron frame. A rubber tube was fixed to each chamber for entry of SO_2 gas. Small fan was used to circulate the air to reduce leaf boundary layer resistance. SO_2 was produced by passing a continuous current of air through aqueous sodium metabisulphite ($Na_2S_2O_5$) solution, which is ionized under pressure to produce SO_2 (Agrawal *et al*., 1982). SO_2 was passed through anhydrous calcium chloride for absorbing moisture from the gas. Gas was introduced within fumigation chamber along with additional flow of air through the perforated alkathene tubes for uniform distribution of gas within chamber. The plants were exposed to 1306 µgm^{-3} concentration of SO_2 on alternate days for two hours from the date of sowing till maturation in the fumigation chamber in four beds. A control was run in identical condition but without any SO_2 fumigation. Three plots of SO_2 treated plants were sprayed separately with 0.5% aqueous solution of calcium hydroxide, 0.5% aqueous solution of sodium benzoate, 0.5% aqueous solution of potassium ascorbate with the help of atomizer every week and the pH of these ameliorating agents ranged from 6.0 - 8.0.

Four harvests of 10 plants were made at 20 days interval so as to analyze the plants with respect to foliar injury, growth parameters, dry matter production and net primary productivity. At the crop maturation, data on yield

Accepted :
March, 2010

parameters were recorded. For dry weight determination, the individual plants were carefully dug out from the soil keeping the root and shoot system intact. They were thoroughly cleaned with water to remove soil particles. The root and shoot of all the plants were separated, oven dried and weighed to obtain dry weight fractions divided by plant age to obtain net primary productivity (NPP) expressed as g plant^{-1} days^{-1}. Some biochemical changes like plant extract pH, sulphur content (Patterson, 1958), chlorophyll content (Arnon, 1949), carotenoid content (Maclachlam and Zalik, 1963), anthocyanin content (Manchinelli *et al*., 1975), phenolics content (Sadasivam and Manickan, 1992), proline content (Bates *et al*., 1973), carbohydrate content through anthrone colorimetric method (Yemm and Willis, 1954), Protein content (Lowry *et al*., 1951) were estimated. The data were statistically anlysed applying *t*-test

Results and Discussion

Plants exposed to SO_2 showed visible foliar injury after 15 days of fumigation when whitish yellow chlorotic patches appeared in interveinal areas. On prolonged exposures these patches became dark brown bifacial necrotic lesions. The injury was mostly confined to mature leaves. SO_2 treated plants when sprayed with $Ca(OH)_2$ or sodium benzoate or potassium ascorbate, very less foliar injury was observed.

On prolonged exposure, decrease was recorded in all the growth parameters, dry matter production and NPP in comparison of control (Table 1). Less reduction was observed in SO_2 treated plants sprayed with 0.5% aqueous solution of $Ca(OH)_2$, sodium benzoate or Potassium ascorbate in comparison of SO_2 alone treated plants. It was also observed that reduction in dry weight fractions of root were more than dry weight fractions of shoot in SO_2 treated plants and recovery after ameliorating agent treatments was lesser in roots.

In comparison to control, the flowering, fruiting and fruit maturation was earlier in SO_2 treated plants. The number, length and weight of spike per plant were decreased significantly. Significant reductions in numbers of seeds, 100-seed weight, seed yield and biological yield per plant were observed. There was about 48% yield reduction in 1306 µgm^{-3} concentration of SO_2. In comparison to SO_2 alone treated plants less reduction was observed in plants treated with SO_2 along with ameliorating agents (Table 2).

On biochemical analysis leaf extract pH was decreased (Table 3) and sulphur content was increased (Table 4) significantly in all the treated leaves in comparison to control. Significant reduction (about 30% in 80 days old plants) was observed in content of photosynthetic pigments (Fig. 1). Ameliorating agents maintained the pH of cell sap and less reduction was observed in content of photosynthetic pigments in comparison of SO_2 alone treated plants. Reduction in chlorophyll content was directly correlated with reduction in carbohydrate and protein contents in seeds (Fig. 2).

Total phenolic contents, anthocyanin contents and proline contents of leaves were increased significantly in all the treatments in comparison to control (Fig. 3) but these biochemicals were lesser in amount in SO_2 along with ameliorating agent treated plants in comparison of SO_2 alone treated plants.

The SO_2 gas is absorbed into mesophyll of leaves through the stomata, and toxicity of SO_2 is largely due to reducing properties of gas. SO_2 gas combines with water in intercellular spaces to form sulphurous acid (H_2SO_3), which dissociates into H^+ and HSO_3^- ions. Thus, the foliar injury in sulphur dioxide treated plants is caused by accumulation of sulphites in the mesophyll tissues of leaves and inside the leaf the SO_2 or its breakdown products react with cellular components, mainly cellular membranes causing injury or death to tissues (Richard, 1965) and eventually leads to interveinal necrosis (Rao *et al.*, 1985). Mature leaves were more susceptible to sulphur dioxide injury. This may be due to increased intercellular spaces in mature leaves which facilitate rapid gas flow (Kumar and Singh, 1986).

Sulphur content was increased in plants exposed to sulphur dioxide. Similar results were also observed by Dwivedi *et al.* (2008) and many other workers. It was noted that the increase in foliar injury of SO_2 exposed plants could be correlated with the decrease in leaf-extracts pH and not to increase in the sulphur content. In the present study, the leaf extract pH value declined significantly due to SO_2. Theoretical and experimental studies have pointed to H^+ exchange as primary reason for cation leaching from the leaf surface and changes of pH in leaf tissue can be correlated to leaf injury. (Rao *et al*., 1985; Wang *et al*., 2005).

Exposure of plants to SO_2 stress leads to oxidative stress. SO_2 gas dissolves in extra cellular fluid of plants and is potentially capable of behaving as an oxidant and reductant depending upon redox potential of the system. In the cell, SO_2 is converted into sulphite and/or bisulphite ions ($HSO3^-$ and $SO3^{2-}$), which react with lipid and proteins in cell walls and membranes, chain reactions are initiated giving rise to more reactive oxygen species (ROS=free radicals) such as $O_2^{\bullet-}$ (superoxide), $OH^\bullet$ (hydroxyl radical), $O^\bullet$ (single oxygen) and H_2O_2, which are generally more reactive than sulphur dioxide (Halliwell and

Table 1 : Long term effect of SO_2 pollution alone and with ameliorating agent treatments on various growth parameters, dry weight fractions and net primary productivity (NPP) of *Triticum aestvium* L. cv. PBW-343.

Parameters	Treatments	Plant age (Days)			
		20	40	60	80
Root length (cm)	Control	9.00 ± 0.42	13.04 ± 1.11	16.86 ± 1.82	17.12 ± 1.54
	SO_2 alone	8.35 ± 0.19**	9.14 ± 1.39**	12.32 ± 1.77**	14.34 ± 1.42*
	SO_2+ $Ca(OH)_2$	8.51 ± 0.34*	10.52 ± 1.53*	13.54 ± 1.64**	15.34 ± 1.35†
	SO_2+ Sodium benzoate	8.64 ± 0.33†	10.72 ±1.48*	13.75 ± 1.65**	15.52 ± 1.46†
	SO_2+ Potassium ascorbate	8.72 ± 0.41†	10.96 ± 1.59*	13.80 ± 1.49**	15.50 ± 1.54†
Shoot length (cm)	Control	16.42 ± 1.11	28.68 ± 2.21	34.56 ± 2.12	35.49 ± 2.89
	SO_2 alone	14.90 ± 1.67*	22.82 ± 2.81**	27.42 ± 2.97**	30.21 ± 2.31*
	SO_2+ $Ca(OH)_2$	15.70 ±1.23†	25.16 ± 1.94**	30.45 ± 1.64**	32.22 ± 1.89*
	SO_2+ Sodium benzoate	15.93 ± 1.00†	25.68 ± 2.34*	31.21 ± 1.45**	32.56 ± 1.88*
	SO_2+ Potassium ascorbate	16.00 ± 1.33†	25.88 ± 2.24*	31.68 ± 1.97**	32.68 ± 1.78*
No. of leaves per plant	Control	2.90 ± 0.84	4.00 ± 0.71	5.40 ± 0.46	6.40 ± 0.81
	SO_2 alone	2.40 ± 0.69†	3.00 ± 0.00**	3.70 ± 0.45*	4.60 ± 0.48*
	SO_2+ $Ca(OH)_2$	2.60 ± 0.54†	3.60 ± 0.55†	4.30 ± 0.41*	5.20 ± 0.46†
	SO_2+ Sodium benzoate	2.60 ± 0.71†	3.60 ± 0.42†	4.40 ± 0.39*	5.60 ± 0.36†
	SO_2+ Potassium ascorbate	2.70 ± 0.65†	3.80 ± 0.38†	4.40 ± 0.71†	5.80 ± 0.54†
No. of tillers per plant	Control	1.00 ± 0.00	3.00 ± 0.71	5.30 ± 1.00	5.40 ± 0.55
	SO_2 alone	1.00 ± 0.00†	2.40 ± 0.55†	4.20 ± 0.84*	4.30 ± 0.67*
	SO_2+ $Ca(OH)_2$	1.00 ± 0.00†	2.60 ± 0.41†	4.60 ± 0.71†	4.60 ± 0.71†
	SO_2+ Sodium benzoate	1.00 ± 0.00†	2.60 ± 0.38†	4.50 ± 0.55†	4.60 ± 0.35*
	SO_2+ Potassium ascorbate	1.00 ± 0.00†	2.60 ± 0.32†	4.70 ± 0.71†	4.70 ± 0.75†
Fresh weight of root per plant (g)	Control	14.98 ± 1.28	21.52 ± 1.56	32.14 ± 2.35	32.68 ± 2.21
	SO_2 alone	12.68 ± 1.19*	15.64 ± 1.33**	22.36 ± 2.14**	23.54 ± 2.54**
	SO_2+ $Ca(OH)_2$	13.15 ± 1.18†	18.34 ±1.23**	25.64 ±1.88*	26.69 ± 1.88**
	SO_2+ Sodium benzoate	13.22 ± 1.12†	18.94 ±1.12**	26.66 ± 1.65**	27.64 ± 1.69**
	SO_2+ Potassium ascorbate	13.65 ± 1.28†	19.32 ±1.14**	26.84 ±1.95**	27.34± 1.57**
Fresh weight of shoot per plant (g)	Control	19.29 ± 2.14	38.40 ± 2.25	48.36 ± 2.54	62.34 ± 3.41
	SO_2 alone	16.73 ± 1.34**	27.48 ± 2.12**	35.54 ± 2.54**	44.98 ± 2.99 **
	SO_2+ $Ca(OH)_2$	17.98 ± 1.75†	32.12 ± 1.94**	39.32 ± 2.02**	50.41 ± 2.68**
	SO_2+ Sodium benzoate	18.38 ± 1.54†	32.96 ± 1.88**	40.26 ± 2.34**	51.55 ± 3.12**
	SO_2+ Potassium ascorbate	18.45 ± 1.95†	33.25 ± 1.74**	40.51 ± 2.11**	52.36 ± 2.48**
Dry weight of root per plant (g)	Control	4.49 ± 0.11	5.29 ± 0.73	9.12 ± 0.97	9.36 ± 0.88
	SO_2 alone	3.80 ± 0.18**	3.98 ± 0.51**	6.20 ± 1.02**	6.26 ± 0.71**
	SO_2+ $Ca(OH)_2$	4.06 ± 0.19**	4.34 ± 0.42**	7.66 ± 0.84**	7.64 ± 0.55**
	SO_2+ Sodium benzoate	4.12 ± 0.22**	4.42 ± 0.35**	7.82 ± 0.66**	7.65 ± 0.47**
	SO_2+ Potassium ascorbate	4.12 ± 0.20**	4.46 ± 0.32**	7.94 ± 0.55**	7.74 ± 0.71*
Dry weight of shoot per plant (g)	Control	4.87 ± 0.12	9.22 ± 0.84	12.52 ± 0.74	17.76 ± 1.21
	SO_2 alone	4.18 ± 0.17**	6.04 ± 1.02**	8.69 ± 1.12**	12.09 ± 0.94**
	SO_2+ $Ca(OH)_2$	4.45 ± 0.10**	7.32 ± 0.78**	9.63 ± 0.96**	14.62 ± 0.86**
	SO_2+ Sodium benzoate	4.54 ± 0.06**	7.74± 0.58**	9.94 ± 0.71**	15.16 ± 0.68**
	SO_2+ Potassium ascorbate	4.60 ± 0.09**	7.98 ± 0.55**	10.12 ± 0.65**	15.16 ± 0.71**
Total dry weight of plant (g)	Control	9.36 ± 0.11	14.51 ± 1.32	21.64 ± 1.33	27.12 ± 1.47
	SO_2 alone	7.98 ± 0.19**	10.02 ± 1.22**	14.84 ± 1.14**	18.35 ± 1.56**
	SO_2+ $Ca(OH)_2$	8.51 ± 0.16**	11.70 ± 1.15**	17.29 ± 1.35**	22.26 ± 1.34**
	SO_2+ Sodium benzoate	8.66 ± 0.24**	12.18 ± 0.71**	17.76 ± 1.04**	22.81 ± 1.12**
	SO_2+ Potassium ascorbate	8.72 ± 0.19**	12.44 ± 0.55**	18.06 ± 0.84**	22.90 ± 1.15**
NPP (g/plant/day)	Control	0.468 ± 0.0053	0.363 ± 0.007	0.361 ± 0.009	0.339 ± 0.014
	SO_2 alone	0.399 ± 0.009**	0.251 ±0.009**	0.247 ± 0.012**	0.229 ± 0.011**
	SO_2+ $Ca(OH)_2$	0.426 ± 0.008**	0.293 ±0.005**	0.288 ± 0.007**	0.278 ± 0.009**
	SO_2+ Sodium benzoate	0..433 ± 0.010**	0.304 ±0.004**	0.296 ± 0.009**	0.285 ± 0.007**
	SO_2+ Potassium ascorbate	0.436 ± 0.005**	0.311 ±0.008**	0.301 ± 0.007**	0.286 ± 0.009**

Values are in mean ± SD; Significance of difference from control.; *P < 0.05; **P < 0.01 and † non significant

Table 2 : Effect of SO_2 pollution alone and with ameliorating agent treatments on flowering and yield parameters of *Triticum aestvium* L. cv. PBW-343

Parameters	Treatments				
	Control	SO_2 alone	SO_2+ $Ca(OH)_2$	SO_2+ Sodium benzoate	SO_2+ Potassium ascorbate
Days to first flowering	60.00 ± 1.58	55.40 ±1.14**	57.00 ± 0.71**	57.40 ± 1.14*	57.60 ± 0.89*
Days to first fruit maturation	119.40 ± 2.70	111.40 ± 2.30**	115.40 ± 1.14**	115.80 ± 1.64*	116.00 ± 1.87*
Length of spike (cm)	10.49 ± 0.45	9.54 ± 0.20**	10.02 ± 0.29*	10.11 ± 0.24*	10.20 ± 0.37†
No. of spikes per plant	5.40 ± 0.55	4.30 ± 0.67*	4.60 ± 0.71†	4.60 ± 0.35*	4.70 ± 0.75†
Spike weight (gm)	2.68 ± 0.18	2.14 ± 0.17 **	2.22 ± 0.17**	2.35 ± 0.26*	2.38 ± 0.33†
No. of seeds per spike	40.80 ± 4.28	33.00 ± 3.48**	35.64 ± 3.15†	36.12 ± 4.25†	36.34 ± 3.54†
100 grain weight (g)	4.92 ± 0.19	3.99 ± 0.30**	4.25 ± 0.27**	4.60 ± 0.25*	4.72 ± 0.34*
Seed yield per plant (g)	10.84 ± 1.34	5.66 ± 1.29**	6.97 ± 1.22**	7.64 ± 1.26**	8.06 ± 1.16**
Biological yield (g)	30.83 ± 1.58	18.11 ±1.49**	21.05 ± 1.57**	22.83 ± 1.27**	23.97 ± 1.29**
Harvest index (%)	35.16 ± 2.17	31.25 ± 2.13*	33.10 ± 2.79†	33.46 ± 1.42†	33.62 ± 2.15†

Values are in mean ± SD; Significance of difference from control.; *P < 0.05; **P < 0.01 and † non significant

Table 3 : Effect of SO_2 pollution alone and with ameliorating agent treatments on leaf extract pH value of *Triticum aestivum* L. cv. PBW-343

Plant age (days)	Treatments				
	Control	SO_2 alone	SO_2+ $Ca(OH)_2$	SO_2+ Sodium benzoate	SO_2+ Potassium ascorbate
20	7.12 ± 0.17	6.35 ± 0.21**	6.60 ± 0.18**	6.68 ± 0.16*	6.72 ± 0.21*
40	6.84 ± 0.22	5.94 ± 0.18**	6.32 ± 0.22**	6.35 ± 0.22*	6.34 ± 0.16*
60	6.70 ± 0.18	5.82 ± 0.23**	6.16 ± 0.16**	6.20 ± 0.14*	6.22 ± 0.31*
80	6.52 ± 0.26	5.70 ± 0.20**	6.02 ± 0.14*	6.05 ± 015*	6.08 ± 0.16*

Values are in mean ± SD; Significance of difference from control.; *P < 0.05; **P < 0.01 and † non significant

Table 4 : Effect of SO_2 pollution alone and with ameliorating agent treatments on sulphur content (mg/g dry wt.) in leaves of *Triticum aestivum* L. cv. PBW-343

Plant age (Days)	Treatments				
	Control	SO_2 alone	SO_2+ $Ca(OH)_2$	SO_2+ Sodium benzoate	SO_2+ Potassium ascorbate
20	1.53 ± 0.14	1.86 ± 0.18*	1.74 ± 0.24†	1.75 ± 0.12†	1.77 ± 0.22†
40	2.96 ± 0.16	3.88 ± 0.22**	3.68 ± 0.18**	3.66 ± 0.22**	3.68 ± 0.14**
60	4.67 ± 0.32	10.94 ± 0.36**	10.12 ± 0.33**	9.02 ± 0.36**	9.10 ± 0.28**
80	4.84 ± 0.45	10.68 ± 0.38**	9.64 ± 0.42**	8.96 ± 0.36**	9.06 ± 0.38**

Values are in mean ± SD; Significance of difference from control.; *P < 0.05; **P < 0.01 and † non significant

Gutteridge, 1999). So, the level of ascorbic acid, phenolic compounds, superoxide dismutase (SOD), catalase, proline, anthocyanin *etc*. increases, which provide protection against SO_2 phytotoxicity by removing free radicals (Jeyakumar *et al.*, 2003; Surowka *et al*., 2007).

SO_2 can easily penetrate into chloroplasts, which are the main place of the action of sulphite ions (Surowka *et al*., 2007). Chloroplast exposed to SO_2 shows disorganization and significant changes at ultrastructural level. Because of the destruction of chloroplasts, leaves become chlorotic (Wellburn *et al.*, 1972). Several other workers also reported in various plant species that SO_2 reduces chlorophyll a, chlorophyll b and carotenoid (Panigrahi *et al*., 1992) (Singh *et al*., 2005). Sulphur dioxide pollution increases the chlorophyllase activity and thus decrease chlorophyll contents (Jeyakumar *et al*., 2003). Carotenoids were highly sensitive to SO2 pollution (Panigrahi, *et al*.; 1992). It may be suggested that perhaps greater sensitivity of carotenoids is responsible for greater loss of chlorophyll in SO2 treated plants (Rao *et al*., 1985).

Calcium hydroxide acts as ameliorating agent in different ways and prevents foliar injury. Ca(OH)2 spray checks chlorophyll degradation by neutralizing the acidity

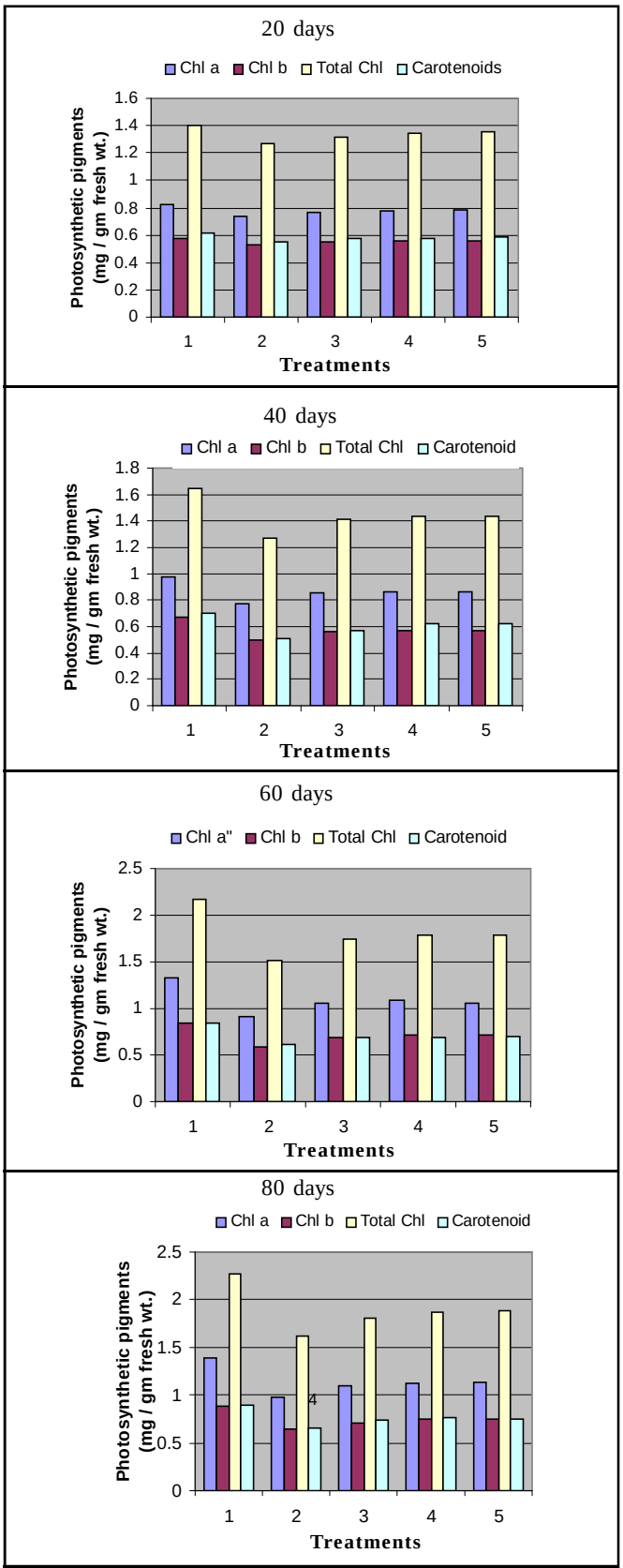


Fig. 1 : Effect of SO_2 pollution alone and with ameliorating agent treatments on content of photosynthetic pigments in leaves of *Triticum aestivum* L. cv. PBW-343

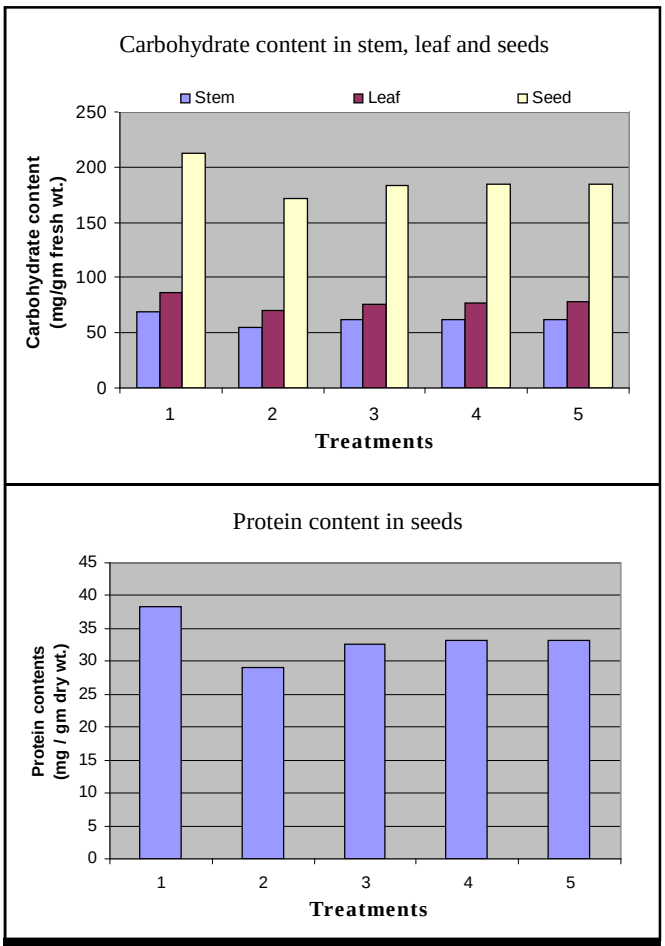
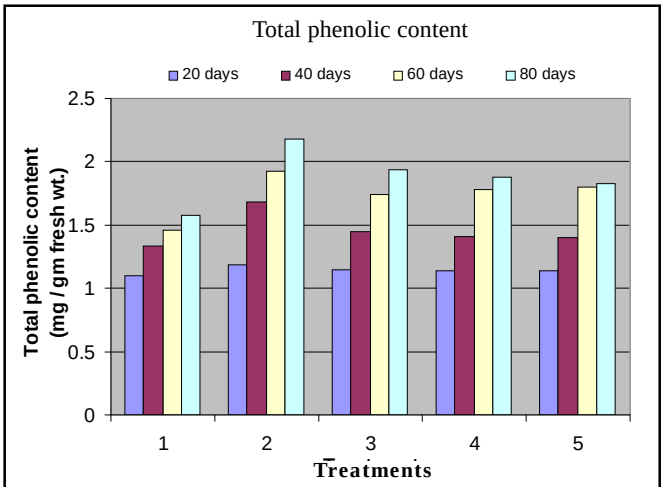
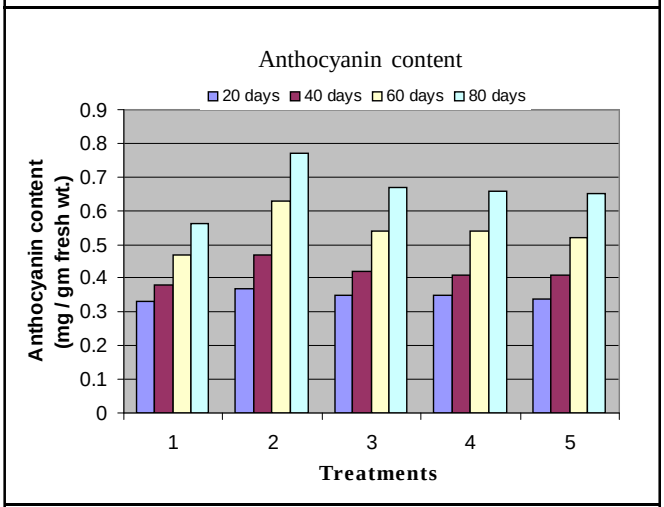


Fig. 2 : Effect of SO2 pollution alone and with ameliorating agent treatments on total carbohydrate (in stem, leaf and seeds) and protein (in seeds) content of *Triticum aestvium* L. cv. PBW-343
where 1= Control plant, 2= plants treated with SO_2 alone, 3= plants treated with SO_2 and lime water spray, 4= plants treated with SO_2 and sodium benzoate spray, 5= plants treated with SO_2 and potassium ascorbate spray

of SO_2 in plants (Nandi *et al*., 1984) and Ca^{++} as mineral nutrient provides protection to SO_2 exposed plants.

Shimazaki *et al*. (1980) have observed that chlorophyll breakdown in SO_2 exposed plants can be checked by using various free radical scavengers. Benzoate acts as scavenger of cytotoxic hydroxyl radicals formed in SO_2 exposed plants (Rao *et al*., 1985). Similarly, ascorbate is a universal reductant and antioxidant of plants and is an integral weapon in the defense against reactive oxygen species (Becana *et al.*, 2000). Further, potassium is known to activate enzymes related to ATP production and release to increase buffering capacity (Rajput and Agrawal, 1994). Therefore, exogenous use of sodium benzoate and potassium ascorbate to SO_2 exposed plants reduce the foliar injury by reducing chlorophyll degradation





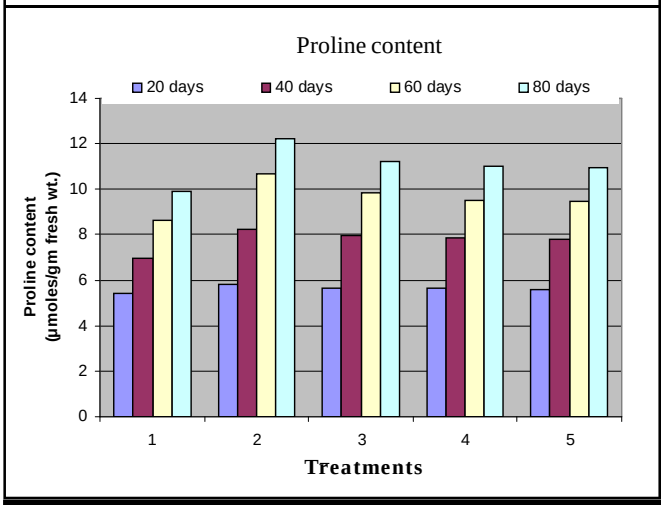


Fig. 3 : Effect of SO_2 pollution alone and with ameliorating agent treatments on total phenolic contents, anthocyanin contents and proline contents in leaves of *Triticum aestivum* L.cv. PBW-343

and better growth was noticed in these plants as compared to SO_2 alone treated plants.

The present study indicates that SO_2 treatments cause considerable reduction in various growth parameters such as lengths of root and shoot, number of leaves, number of roots, number of tillers, dry weight fractions and net primary productivity (NPP) in SO_2 alone treated plants as compared to control. Spraying of ameliorating agents improves the growth of SO_2 exposed plants. The shoot growth of SO_2 exposed plants were affected mostly due to the retarded development of leaves and due to reduced photosynthesis (Rao *et al*., 1985).

Since biomass accumulation is an integrated result of all biochemical, physiological and metabolic activities in plants, its significant reduction further confirms that SO_2 may directly interfere with these functional processes resulting in biomass reductions as well as growth retardation. At final harvest, dry weight fractions of *Triticum aestivum* were found to be significantly reduced in SO_2 treated plants as compared to control. These reductions in dry weight fractions were attributed to significant reductions in photosynthetic activity of plants (Kumar and Singh, 1986). The reduction in phytomass accumulation was lesser in SO_2^+ $Ca(OH)_2$ and SO_2^+ Sodium benzoate plants and minimum in SO_2^+ Potassium ascorbate plants as compared to control plants. This suggested that potassium ascorbate is the better ameliorating agent than sodium benzoate and sodium benzoate is better ameliorating agent than $Ca(OH)_2$ against SO_2 phytotoxicity.

Advance flowering was observed in all SO2 exposed plants as compared to control plants. Fruit maturation was also advanced. This may be due to the fact that under stress conditions plants are in hurry to complete their life cycles (Kumar and Singh, 1986).

Significant reduction in yield and yield contributing factors has been observed in all SO_2 treated plants as compared to control. Similar observations were made by others investigators (Kumar and Singh, 1985; Kumar and Singh, 1986). The decrease in seed yield was mostly attributed to a decrease in number of spikes and this decrease in number of spike per plant may result from either a decrease in flower pollination and fertilization, a decrease in fruit retention or an inadequate development of young fruits. Inhibition of pollen germination and pollen tube growth have been observed by Agrawal *et al*. (1995). Reduction in photosynthesis leads to decrease in weight of seeds, seeds per fruit and number of fruits per plant and hence reduction in total yield.

The carbohydrate contents of stem, leaves and seeds were found to be significantly reduced in all the treatments. Similar observations were made by Saxe (1983) and Kumar and Singh (1986). The decreases in total carbohydrate content probably correspond with the

photosynthetic inhibition or stimulation of respiration rate. Significant reductions were observed in total protein content in mature plants due to exposure of SO_2. It has been suggested that SO_2 interferes with enzymes regulating amino acid synthesis (Pierre and Queiroz, 1982) leading to qualitative and quantitative changes in amino acids. Such changes may reduce the protein content of SO_2 exposed plants (Deepak and Agrawal, 2001). Such decrease can also be attributed to hydrolysis of existing proteins and also to reduced *de novo* synthesis (Khan and Malhotra, 1983).

Conclusion:

Thus, it may be concluded that exposure of *Triticum aestivum* plants to 1306 μgm^{-3} SO_2 caused various physiological and metabolic changes leading to the development of injury symptoms in leaves. These changes reduce the photosynthetic efficiency of these plants which cause the reduction of net primary productivity and over all yield. When these SO_2 exposed plants ware periodically sprayed with calcium hydroxide or sodium benzoate or potassium ascorbate, foliar injury symptoms were very less or did not appear and net primary productivity and overall yield was increased in these plants as compared to SO_2 alone treated plants. Possibly a better buffering capacity, free radical scavenging capacity and an efficient use of primary metabolites for repair processes and their translocation to growth sites contributed towards improved growth of plants exposed to SO_2, sprayed with lime water, sodium benzoate and potassium ascorbate. It is also concluded that potassium ascorbate is better ameliorating agent than sodium benzoate, sodium benzoate is better ameliorating agent than lime water.

Authors' affiliations

NARESH KUMAR, Department of Botany, Faculty of Science, C.C.R. (P.G.) College, MUZAFFARNGAR (U.P.) INDIA

REFERENCES

Agrawal, M., Nandi, P. K. and Rao, D. N. (1982). Effect of ozone and sulphur dioxide pollutants separetly and in mixture on chlorophyll and carotenoid pigments of *Oryza sativa*. *Water Air Soil Pollut.*, **18**: 449-459.

Agrawal, S., Singh, R. and Sahi, A. (1995). Cytogenetic effect of sulphur dioxide on cytotypes of *Solanum nigrum* complex. *Cytobios.*, **83**: 41-47.

Arnon, D. I. (1949). Copper enzymes in isolate chloroplasts, polyphenol oxidase in *Beta vulgaris*. *Plant Physiol.*, **24**: 1-15.

Bates, L. S., Waldren, R .P. and Teare, I. D. (1973). Rapid determination of free proline for water-stress studies. *Plant & Soil*, **39**: 205-207.

Becana, M., Dalton, D. A., Moran, J. F., Iturbe-Ormaetxe, I., Matamorous, M. A. and Rubio, M. C. (2000). Reactive oxygen species and antioxidants in legume nodules. *Physiologia Plantarum*, **109**: 372-381.

Black, V. J. and Unsworth, M. H. (1979). Effect of low concentration of SO_2 on net photosynthesis and dark respiration of *Vicia faba*. *J. Exp. Bot.*, **30**: 473-474.

Bosac, C., Black, J., Black, C. R., Roberts, J. A. and Lockwood, F. (1993). Impact of O_3 and SO_2 on reproductive development in oilseed rape (*Brassica napus* L.). I. Pollen germination and pollen tube growth. *New Phytol.*, **124**: 439-446.

Deepak, S. S. and Agrawal, M. (2001). Influence of elevated CO_2 on the sensitivity of twp soybean cultivars to sulphur dioxide. *Environ. Exp. Bot.*, **46**: 81-91.

Dwivedi, A. K., Tripathi, B. D. and Shashi (2008). Effect of ambient air sulphur dioxide on sulphate accumulation in plants. *J. Envirn. Biol.*, **29**(3): 377-379.

Halliwell, B. and Gutteridge, J. M. C. (1999). *Free radicals in biology and medicine*. Oxford University Press Inc., New York.

Jeyakumar, M., Jayabalan, N. and Arockiasamy, D. I. (2003). Effect of SO_2 on maize (*Zea mays* L.) var. Co.1 seedlings at lethal dose 50. *Physiol. Mol. Biol. Plants*, **9**(1):147 – 151.

Khan, A. A. and Malhotra, S. S. (1983). Protein biosynthesis in jackpine and its inhibition by sulphur dioxide. *Phytochem.*, **22**: 1325-1328.

Kumar, N. and Singh, V. (1985). Effect of SO_2 and NO_2 pollution on *Cicer arietinum*. *Indian J. Eco.*, **12**: 183-188.

Kumar, N. and Singh, V. (1986). Growth response to *Vigna sinensis* to SO2 pollution. *Proc. Indian Acad. Sci. (Plant Sci.)*, **96**: 419-427.

Lowry, O. H., Rosebrough, N. J., Farr, A. L. and Randall, R. J. (1951). Protein measurement with folin-phenol reagent. *J. Biol. Chem.*, **193**: 265-275.

Maclachlan, S. and Zalik, S. (1963). Plastid structure, chlorophyll concentration and free amino acid composition of cholorophyll mutant of barley. *Can. J. Bot.*, **43**:1053-1062.

Mancinelli, A. L., Yang, C.H., Lindquist, P., Anderson, T. and Robion, I. (1975). Photocontrol of Anthoyanin III the action of streptomycin on synthesis of chlorophyll and anthocyanin. *Plant Physiol.*, **155** : 251-257.

Nandi, P. K., Agrawal, M. and Rao. D. N. (1984). SO_2 induced effects and their amelioration by Ca(OH)2 solution in *Vigna sinensis* plants. *Sci. Hort.*, **22**: 47-53.

Panigrahi, N. C., Mishra, B. B. and Mohanty, B. K. (1992). Effect of SO_2 on chlorophyll content of two crop plants. *J. Environ. Biol.*, **13**: 201-205.

Patterson, G. D. (1958). *Sulphur in colorimetric determination of nonmetals.* pp 261-308. Interscience Publishers, Inc, New York.

Pierre, M. and Queiroz, O. (1982). Enzymatic and metabolic changes in bean leaves during continuous pollution by subnecrotic level of SO_2. *Environ. Poll*., **25** : 41-51.

Rai, R. and Agrawal, M. (2008). Evaluation of physiological and biochemical responses of two rice (*Oryza sativa* L.) cultivars to ambient air pollution using open top chambers at a rural site in India. *Sci. Total Environ*., **15** (1): 679-691.

Rai, R. and Agrawal, M. and Agrawal, S. B. (2007). Assessment of yield losses in tropical wheat using open top chambers. *Atmospheric Environ*ment, **40**: 9543-9554.

Rajput, M. and Agrawal, M. (1994). Responses of soybean plants to sulphur dioxide at varying soil fertility regimes. *Biotronics*, **23**: 81-92.

Rao, D. N., Nandi, P. K. and Agrawal, M. (1985). Studies on the amelioration of air pollution effects. *Trends.Pl. Res*., 437-445.

Richard, F. E. (1965). Microscopic analysis of plants and fungi under environmental stress from air pollution. *Arch. Environ. Contam. Toxicol*., **18**: 177-284.

Sadasivam, S. and Manickam, A. (1992). Phenalics : In *: Biochemical methods for agricultural sciences.* Wiley Eastern Limited, New Delhi, India, pp. 187-189.

Saxe, H. (1983). Long terms effects of low levels of SO2 on bean plants (*Phaseolus vulgaris*) I. Immission response pattern on net photosynthesis and transipiration during life-long, continuous measurement. *Physiol. Plant*., **57**: 101-107.

Shimazaki, K., Sakaki., T., Kondo, N. and Sugahara, K. (1980). Active oxygen participation in chlorophyll destruction and lipid peroxidation in SO_2 exposed leaves of spinach. *Pl.Cell Physiol*., 21: 1193-1204.

Singh, A., Agrawal, S. B. and Rathore, D. (2005). Amelioration of Indian urban air pollution phytotoxicity in *Beta vulgaris* L. by modifying NKP nutrients. *Environ. Pollut.*, **134** (3): 385-395.

Surowka, E., Karolewski, P., Niewiadomska, E., Libik, M. and Miszalski, Z. (2007). Antioxidative response of *Mesembryanthemum crsytallinum* plants to exogenous SO_2 application. *Plant Sci.*, **172**: 76-84.

Wang, C., Da Xing, D., Zeng, L., Ding, D. and Chen. (2005). Effect of artificial acid rain and SO_2 on characteristics of delayed light emission. *Luminescence*, **20**: 51–56.

Wellburn, A. R., Majernik, O. and Wellburn, F. (1972). Effect of SO_2 and NO_2 polluted air upon the ultrastructure of chloroplasts. *Environ. Pollut.*, **3**: 37.

Yemm, E.W. and Willis, A.J. (1954). The estimation of carbohydrate in plant extracts by anthrone. *Biochem. J.*, **57**: 508-514.