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Effect of Short-term Sulfur dioxide Fumigation on Photosynthesis in Sunflower and Wheat

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Abstract

Wheat and sunflower plants were exposed to 0.289ppm, 0.578ppm, 1.156ppm, and 2.312ppm of SO_2 for one hour. Photosynthetic rates were measured, after treatment, with a LI- COR infra-red gas analyzer, model 6200. Photosynthetic stimulation was found to occur in wheat at 0.289ppm and 0.578ppm, photosynthetic rates were about the same as the control at 1.156ppm, while inhibition occured at 2.312ppm. Photosynthetic inhibition occured in sunflower at all fumigation concentrations.

Introduction

Short-term fumigation with SO_2, often performed with plants grown in protected environments, does not necessarily reflect conditions in the open field. However, there are advantages in investigating its effects. First, it simulates a common situation in urban areas where SO_2 peaks may reach several hundred parts per billion. Second, it can be used in simple mechanistic studies of interactions between photosynthesis, the stomatal mechanism, and uptake, since these are fundamentally the same with chronic exposures. Third, the effects of short-term fumigation can be used as diagnostic tools, when these effects have been documented to reflect a situation in the "real world" (Saxe, 1991).

Generally, the effect of fumigation on photosynthesis depends on the pollutant, pollutant concentration, and exposure times. It also depends on the intake rate of the plant and this varies with species, cultivar, age, and environmental conditions such as temperature, humidity, light, and CO_2 concentration.

Photosynthetic inhibition was normally found in short-term fumigation when the concentration multiplied by the duration was above 400 ppb h (parts per billion hour), and at the lower concentrations only after 2h or more of exposure. There have been exceptions where inhibition was found at lower exposure concentrations and durations, while a few other authors have found low exposure levels to stimulate photosynthesis. At higher concentrations and durations, however, the stimulation always turned to inhibition (see Table 1 for examples).

The aim of this research was to study and compare the effect of short-term SO_2 fumigation on photosynthesis in wheat and sunflower plants, using concentrations above and below 400 ppb h.

Materials and Methods

Pots containing three or four plants were used for the experiments. Four to seven week old plants were placed, one pot at a time, in an 18.8L polycarbonate plastic chamber and injected with SO_2 ranging from 0.289 ppb to 2.312 ppb. The pots were removed after 1h.

Table 1. Changes in net photosynthesis due to short-term fumigation of SO_2.

Reference	Species and Cultivar	$[SO_2]$ (ppb)	Duration	PS-response (% control)
INHIBITION				
Carlson	soybean	450	2h	73
Furukawa et al.	sunflower	1500	30 min	27
Matsuoka	rice	170	5h	95
Black and Unsworth	broad bean	35	2h	85
STIMULATION FOLLOWED BY INHIBITION				
Takemoto and Noble	soybean strain T219	250	1h	111
		500	1h	91
		500	2h	72
Muller et al.	soybean	79	4h	137
		405	3h 40 min	83
Winner and Mooney	saltbush	500	2h	110
		500	7h	100

conc, concentration; ppb, parts per billion; cv, cultivar.

Photosynthetic rates were measured with a LI-COR IRGA (infra-red gas analyzer), model 6200. The analyzer was set to make three ten-second observations per leaf. One leaf was chosen per plant and enclosed in a 1L leaf chamber. The leaf area enclosed was measured by cutting out the area on a sheet of paper and weighing. A known area of the same kind of paper was weighed, and leaf area calculated by using a conversion factor (known area*weight of cut paper/known weight). The measured leaf areas were used by the analyzer to calculate raw photosynthetic rates ($u$mol m^{-2} s^{-1}). Each raw rate of photosynthesis was then divided by the light intensity ($u$mol m^{-2} s^{-1}) during each measurement.

Statistical analyses were performed using one-way ANOVA to detect significant differences between fumigation concentrations and the control, and within fumigation concentrations.

Results

Photosynthesis was inhibited in the sunflower leaves by SO_2 fumigation. The effects due to the fumigation concentrations differed significantly with the control at the 0.05 level of significance. However, there were no significant differences within the fumigation concentrations. (Table 2).

The effect on wheat was stimulation followed by inhibition. Stimulation occured in the first two SO_2 concentrations. Photosynthetic rate in the third concentration was about the same as the control, while it was inhibited in the highest concentration (Table 3). Statitistical analysis at the 0.05 level of significance showed that the effect due to fumigation at the highest concentration produced a significant difference in photosynthesis compared to the other fumigation concentrations and the control. There was also a significant difference in effects due to fumigation of 0.289 ppm compared to the control, and between 0.289 ppm and 1.156 ppm. However there were no significant differences between 0.289 ppm and 0.578 ppm, nor between the control and 1.156 ppm.

Table 2. Mean and percentage photosynthesis of sunflower plants.

# of samples	SO_2 conc (ppm)	Mean photo	SD photo	% photo leaf (expressed as % of control)
12	control	0.0755	0.1078	100.00
8	0.2890	0.0111	0.0054	15.52
8	0.5780	0.0140	0.0031	18.58
8	1.1560	0.0132	0.0050	17.55
8	2.3120	0.0059	0.0026	7.82

photo, photosynthesis

Discussion

Short-term exposures to SO_2 may cause photosynthesis to decline (or increase) both in response to direct effects on chloroplast structure and function, and indirectly in response to effects on stomata and other factors with a secondary influence on photsynthesis (Saxe, 1991).

Table 3. Mean and percentage photosynthesis of wheat plants.

# of leaf samples	SO_2 conc (ppm)	Mean photo	SD photo	% photo (expressed as % of control)
20	control	0.04	0.02	100.00
8	0.2890	0.06	0.05	150.00
12	0.5780	0.05	0.03	125.00
8	1.1560	0.04	0.02	100.00
8	2.3120	0.01	0.02	50.00

Effect on Chloroplasts

Structure. Swelling of the spaces within the thylakoids, reduction or dissapearance of grana, gradual changes of chloroplast shape from ellipsoidal to oval to spherical, and invaginations from the inner membrane of the chloroplast membrane occur with SO_2 fumigation. Granulation of stroma also occurs at later stages of injury (Treshow and Anderson, 1991).

Function. Ribulose-1,5-bis-phophate-carboxylase (RuBPC) is the enzyme that catalyzes the addition of CO_2 to ribulose 1,5- bisphosphate to form two molecules of 3-phosphoglycerate (carbon fixation). Ziegler (1972) demonstrated that sulphite can inhibit RuBPC *in vitro* by competing with HCO_3^-, enough to explain *in vitro* inhibition of photosynthesis by sulphite.

Other studies (Sugahara, 1984, Shimazaki, 1988) show that high levels of SO_2 and other gaseous pollutants induce effects on the thylakoid electron transport processes. It has even been found that low SO_2 concentrations induced a stimulation of electron transport in cereals, in accordance with the increase sometimes observed in photosynthesis with low pollutant exposures (Saxe, unpublished data). This would explain why the wheat plants were not inhibited until the highest concentration of fumigation.

The few studies on photorespiration are conficting. Increases of photorespiration with increasing SO_2 concentrations have been shown that may result from the greater use of energy in repair or replacement processes (Kozial and Jordan, 1978). On the other hand, SO_2 may reduce or arrest rates of photorespiration (Ziegler, 1975). Since such inhibition would enhance net photosynthesis, it would be beneficial to the plant.

Another mechanism of action for high SO_2 concentrations is in causing the degradation of chlorophylls to phaeophytins, leading to early senescence (LeBlanc and Rao, 1975).

Effect on stomata. Hunt and Black (1988), Winner and Mooney (1980b) and several others, showed for a number of species that inhibition of photosynthesis by acute SO_2 exposures could at the most be partly explained by stomatal closure. Previous studies (Takemoto and Noble, 1982; Biggs and Davis, 1980) show that the stomatal response to low doses is initial opening, but this rarely stimulates photoynthesis. However at 500-600ppb h and with exposures of two hours or longer, the stomata typically closes, which protects plants against further uptake of injurious SO_2.

The opening of stomata in field bean, *Vicia faba*, by low SO_2 concentrations was suggested to be caused by structural injury to surrounding epidermal cells before injury to the guard cells themselves (Black and Black, 1979); once guard cells were also injured, stomatal closure followed. In addition, Bonte and Cormis (1979) claimed acute SO_2 to have a direct effect on the stomatal metabolism in *Pelargonium*, concluding that SO_2 must affect the energy-requiring (opening and closing) mechanism directly.

Other factors. Increased CO_2 levels has been found to protect photosynthesis against SO_2 (Furukawa et al. 1979b). Majernik and Mansfield (1972) found that SO_2 stimulated opening of stomata at low CO_2 levels, while it tended to close stomata at high CO_2 levels in *Vicia faba*. They also found that at low light, 700ppb SO_2 stimulated stomatal opening as much as a doubling of the light intensity. Bonte and Louget (1975) found (*Perlagonium* plants) to be more injured in humid air, since this slowed the stomatal closing response to SO_2. Rist and Davis (1979) found that high temperature and humidity increased absolute stomatal conductance both with or without SO_2. Since it is this absolute conductance that determines uptake, leaf injury was far more severe at both high temperatures and high relative humidities.

Differences in response between wheat and sunflower could be due to species sensitivity, since it took a higher concentration of SO_2 to inhibit wheat, compared to sunflower. Environmental conditions were not kept constant during the experiments, which could have affected the rates of photosynthesis at the different concentrations. However, the effects of sulfur dioxide fumigation are quite clear with respect to inhibition in sunflower and stimulation followed by inhibition in wheat plants

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