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# Correlation between ozone resistance and relative chlorophyll fluorescence or relative stomatal conductance of bedding plants

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**Abstract.** Eight species of bedding plants were exposed to 400 ppb ozone ($O_3$) for 4 h. On the basis of the resulting foliar injury, Madagascar periwinkle (*Catharanthus roseus*) and impatiens (*Impatiens walleriana*) were the most resistant to $O_3$, and wax begonia (*Begonia×semperflorens-cultorum*) was the most sensitive to $O_3$. Clorophyll fluorescence (Fv/Fm) and stomatal conductance were measured before and after the $O_3$ fumigation. There was a significant regression between, the degree of foliage injury by $O_3$ and relative chlorophyll fluorescence (RCF, ratio of post-fumigation Fv/Fm: pre-fumigation Fv/Fm) or relative stomatal conductance (RSC, ratio of post-fumigation stomatal conductance: pre-fumigation stomatal conductance) ($r = -0.84$, $P<0.001$ and $r=0.64$, $P<0.05$ respectively). That is, species of tested bedding plants that had stronger $O_3$ resistance generally had higher RCF and lower RSC values. It is suggested that RCF and RSC measurements could serve as indicators to screen plants for $O_3$ resistance.

**Keywords:** Air pollution; Bedding plants; Chlorophyll fluorescence; Ozone resistance; Stomatal conductance.

## Introduction

Ozone ($O_3$) is an important and widespread phytotoxic air pollutant (Heck et al., 1986; Ormrod and Hale, 1995). It can reduce the growth rate of plants and lower crop yield and induce visible foliage injury (Heagle, 1989). Photosynthesis is a core function in the physiology of all plants and is certainly a primary target of $O_3$ effects even if it is not clear what mechanisms are involved in the limitation of this process (Heath, 1994). Measurements of photosynthesis have therefore often been used in the assessment of $O_3$ injury (Heath, 1996). As part of the methodology assessed for the study of photosynthetic process, chlorophyll fluorescence represents a useful and non-destructive tool for in vivo stress detection (Owens, 1994), and it is widely used to study the effects of $O_3$ on the photosynthetic process, especially photosystem 2 (PS2) in light reaction (Schreiber et al., 1978; Lee, 1991; Guidi et al., 1993, 1997).

Vegetation responses to $O_3$ are dependent on both uptake or flux of $O_3$ into the leaf and the action of defensive mechanisms in plant tissue. Defensive mechanisms operating within plant tissue to detoxify $O_3$ or repair injured tissue are an important component of plant $O_3$ resistance, but they are complex and difficult to quantify (Musselman and Massman, 1999). $O_3$ generally leads to varying degrees of stomatal closure and reduces stomatal conductance (Lehnherr et al., 1987; Mansfield and Pearson, 1996; Guidi et al., 1997). Aben et al. (1990) have shown direct effects of $O_3$ on stomata as well as on photosynthesis, but stomata appeared to be more sensitive. In addition, $O_3$ enters plant tissue primarily through the stomata, so the first step toward control of $O_3$ injury depends on stomatal conductance (Ormrod and Hale, 1995). The change of stomatal conductance may be regarded as a kind of resistance mechanism (Mansfield and Freer-Smith, 1984; Reiling and Davison, 1995). Since standard techniques are available to quantify stomatal conductance, monitoring stomatal behaviour may be a possible method of proving variations in $O_3$ resistance.

The objectives of this study were to: (1) screen $O_3$ resistance in terms of foliar injury in tested bedding plants; (2) study the correlation between foliar injury and the parameters of chlorophyll fluorescence or stomatal conductance; (3) evaluate the feasibility of using the parameters of chlorophyll fluorescence or stomatal conductance as indicators of $O_3$ resistance in bedding plants.

## Materials and Methods

### *Relationship between Ozone Resistance and Chlorophyll Fluorescence of Bedding Plants*

*Plant materials.* Plant species used in this study were wax begonia (*Begonia×semperflorens-cultorum*) 'Encore Red/Bronze', 'Encore Red/Bronze', 'Encore White', and

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'Encore Pink'; Salvia (*Salvia splendens* Ker.) 'Empire White' and 'Empire Red'; Petunia (*Petunia×hybrida* Vilm) 'White cascade' and 'Rose Star'; Impatiens (*Impatiens walleriana* Hook. F.) 'Dazzler White' and 'Dazzler Rose'; Madagascar periwinkle (*Catharanthus roseus* G. Don.) 'Orchid Cooler'; Common lantana (*Lantana camara* L.) 'Roseum' and 'Flava'; Chinese hibiscus (*Hibiscus rosa-sinensis* L.) 'Albo-Strip'. Except for Common lantana and Chinese hibiscus, which were cuttings, the rest of the plants were grown from seeds. The age of the plants averaged four to five months with heights of 20~30 cm (except for Chinese hibiscus, which was one-year-old, 40~50 cm in height). Plants were potted in 12-cm-diameter plastic pots in a mixture of 5 sandy loam: 2 peat moss: 2 vermiculite: 1 perlite (by volume). Osmocote (Scotts Co., distributed by Taiwan Horticultural Co., Taipei, Taiwan) (14N-6.2P-11.6K) was used as basal dressing (6 g/L), and the plants were watered at 1-to-2 day intervals. The growth temperature during the experiment was 21.0~27.5°C, relative humidity was 67~75%, photoperiod was 12~13 h, and light intensity was 480 ± 160 μmol $m^{-2}s^{-1}$.

*Ozone fumigation*. The first $O_3$ fumigation test was conducted on April 12, 1998. Continuous stirred tank reactor systems (CSTRs) were set up in the greenhouse and used for plant exposure tests with $O_3$ (Rogers et al., 1977; Sun, 1994). The cylindrical CSTRs (1.2 m diameter and 1.8 m high) were made of transparent plexiglas. A fan was installed beneath the roof of the chamber to mix the incoming air. $O_3$ produced by an electrostatic discharge in the air was introduced into the exposure chambers through the inlet pipe. The $O_3$ output was adjusted by a voltage controller. The air exchange rate was determined by measuring the air flow rate in the outlet pipe. To quickly and obviously obtain symptom appearance on plants, we decided to apply 400 ppb of ozone after two pretests. Plants were exposed to 400 ppb of $O_3$ for 4 h (10:00~14:00) in CSTRs at a temperature of 23~28°C, relative humidity of 68~76%, and light intensity of 300~350 μmol $m^{-2}s^{-1}$ (490 μmol $m^{-2}s^{-1}$ in maximum and 190 μmol $m^{-2}s^{-1}$ in minimum). Three days after the $O_3$ fumigation, the foliage injury was investigated. The foliage injury was calculated by the following equation:

$$\text{Foliage injury (\%)} = \frac{(N1\times1)+(N2\times2)+(N3\times3)+(N4\times4)}{(N0+N1+N2+N3+N4)\times 4} \times 100\%$$

where N0, N1, N2, N3, and N4 means the number of leaves with zero, first, second, third, and fourth degree symptoms of $O_3$ injury, respectively; and 0~4th degree symptoms means no symptom, symptoms take up < 1/4, 1/4~1/2, 1/2~3/4, and > 3/4 of total foliage area.

*Chlorophyll fluorescence measurements*. Chlorophyll fluorescence (ratio of variable to maximal fluorescence, Fv/Fm) was measured separately in vivo before and at the end of the first $O_3$ fumigation, using a portable fluorimeter (Plant Efficiency Analyzer, Hansatech Instruments Ltd., UK). Prior to the measurements, the leaves were adapted to the dark for 30 min with a clip in order to reverse all non-photochemical fluorescence quenching, provided that photoinhibition of photosynthesis was not involved. After dark adaptation, in a very low illuminating light, PS2 was able to pass on nearly all the electrons excited by the light to photosynthetic processes such that its reaction center was fully open for energy influx. Under these conditions, the fluorescence intensity was at a minimum, referred to as $F_0$. Following the addition of a brief, strong light (an homogenous illumination on a 4-mm-diameter area of the leaf sample by red light [peak at 650 nm] of 1500 μmol $m^{-2}s^{-1}$), which was well above the capacity of the tissue to process the energy, the reaction center was essentially closed to energy influx, and the excited electrons had a tendency to lose their energy as fluorescence. Under these conditions, the fluorescence intensity was at a maximum and was referred to as Fm. Another useful parameter was so-called variable fluorescence (Fv), which equaled the fluorescence increase from $F_0$ to Fm. The ratio Fv/Fm could be shown to be proportional to the quantum yield of photochemistry (Miret al., 1998) while relative chlorophyll fluorescence (RCF, %) = (post fumigation Fv/Fm)/ (pre-fumigation Fv/Fm) × 100%.

## *Relationship between Ozone Resistance and Stomatal Conductance of Bedding Plants*

*Plant materials and ozone fumigation*. Plant species used in this experiment were wax begonia 'Encore White' and 'Encore Pink'; bedding geranium (*Pelargonium× hortorum* L. H. Bail.) 'Dynamo White' and 'Dynamo Deep Scarlet'; salvia 'Empire White' and 'Empire Red'; Petunia 'Rose Star', impatiens 'Dazzler Rose'; common lantana 'Flava' and Chinese hibiscus 'Albo-Strip'. The $O_3$ fumigation was conducted on April 28, 1998. The methods of $O_3$ fumigation and the investigation of foliar injury were the same as in a previous experiment.

*Stomatal conductance measurements*. Stomatal conductance was measured with a Porometer (LI-1600 Steady State porometer, LI-COR Inc., USA) at a light intensity of 300~350 μmol $m^{-2}s^{-1}$. The stomatal conductance of the fully-expanded leaves of each plant was individually measured before and at the end of the $O_3$ fumigation. Each plant species consisted of three replicated plants. Relative stomatal conductance (RSC, %) = (post-fumigation stomatal conductance) / (pre-fumigation stomatal conductance) × 100%.

## *Statistical Analysis*

These experiments were given a single factor design. Because of the limitation of CSTRs' space (only 1.2-meter-diameter), each plant species consisted of three replicated plants arrange in a completely randomized design. For chlorophyll fluorescence and stomatal conductance measurements, each plant offered one datum, which was the average of five records from fully-expanded leaves arrange in a complete randomized design. Differences between means of pre- and post-fumigation $F_0$, Fm, and Fv were determined using the t-test, and differences between means of other parameters were determined using Duncan's multiple range test. The data of foliar injury, RCF, and RSC were transformed using an arcsine trans-

formation before statistical analysis. Finally, correlations between foliar injury and pre- and post-fumigation chlorophyll fluorescence, RCF, pre- and post-fumigation stomatal conductance, and RSC were analyzed.

## Results

### *Relationship between Ozone Resistance and Chlorophyll Fluorescence of Bedding Plant*

Three days after 400 ppb ozone fumigation for 4 h, symptoms appeared on the youngest fully-expanded leaves of tested plants. Symptoms included necroses (wax begonia), blanching or brown stippling (salvia, petunia, impatiens, and Madagascar periwinkle), brown blotching (common lantana), and chlorosis (Chinese hibiscus). $F_0$ values of tested plants slightly increased, but there were no significant differences between $F_0$ values of pre- and post-fumigation (Table 1). Fm values of tested plants decreased significantly except for salvia 'Empire White', petunia, impatiens 'Dazzler White', Madagascar periwinkle, and common lantana 'Flava'. The results of Fv values were the same as those for Fm (Table 1).

The most sensitive species to $O_3$ was four cultivars of wax begonia (foliar injury between 79~89%). Next were two cultivars of common *lantana* (foliar injury between 35~57%) and then two cultivars of salvia (foliar injury between 26~28%). In addition, three cultivars of Madagascar periwinkle and impatiens were more resistant to $O_3$, with foliar injury only between 3~4% (Table 2).

The results of Table 2 show that a great variance exists in $O_3$ resistance in terms of foliar injury in tested bedding plants, not only between species but also between cultivars within some species. For example, wax begonia 'Encore White' and 'Encore Pink' showed an apparent stronger tolerance than 'Encore White/Bronze' and 'Encore Red/Bronze'; and common lantana 'Flava' also had stronger tolerance than 'Roseum'. However, no significant difference was noted between the different cultivars of other species (Table 2).

After $O_3$ fumigation, a reduction in the Fv/Fm value was observed in all tested plants; in addition, when one species had higher foliar injury, its RCF was generally lower (Table 2). For instance, the foliar injury of wax begonia 'Encore red/Bronze' and 'Encore White' was 89% and 79%; and the RCF was 90% and 93%, respectively. In contrast, plants of Madagascar periwinkle, impatiens, and petunia had higher RCFs, and exhibited lower degrees of foliar injury (Table 2). The foliar injuries were significantly correlated with RCF ($r=-0.84$, $P<0.001$) and post fumigation chlorophyll fluorescence ($r=-0.67$, $P<0.01$), but not with pre-fumigation chlorophyll fluorescence (Figure 1)

### *Relationship Between Ozone Resistance and Stomatal Conductance of Bedding Plant*

Three days after 400 ppb ozone fumigation for 4 h, besides the youngest fully-expanded leaves of bedding geranium undergoing chlorosis, the symptoms of tested plants were the same as in the former experiment. The most

**Table 1.** The values of $F_0$, Fm, and Fv in bedding plants before and after 400 ppb ozone fumigation for 4 h.

| Species and cultivars | $F_0$[a] | | Fm | | Fv | |
|---|---|---|---|---|---|---|
| | Pre- | Post- | Pre- | Post- | Pre- | Post- |
| Wax begonia | | | | | | |
| 'Encore White/Bronze' | 526.0 | 538.4 | 2797.9 | 2062.8*[b] | 2271.9 | 1524.4* |
| 'Encore Red/Bronze' | 515.4 | 526.9 | 3014.0 | 2066.3* | 2498.6 | 1539.4* |
| 'Encore White' | 513.1 | 520.5 | 2353.7 | 1913.6* | 1840.6 | 1393.1* |
| 'Encore Pink' | 502.4 | 510.1 | 2427.1 | 1924.9* | 1924.7 | 1414.8* |
| Salvia | | | | | | |
| 'Empire White' | 594.3 | 613.7 | 3063.4 | 2557.1 | 2469.1 | 1943.4* |
| 'Empire Red' | 603.6 | 620.4 | 3210.6 | 2674.1* | 2607.0 | 2053.7* |
| Petunia | | | | | | |
| 'White cascade' | 463.5 | 487.4 | 2135.9 | 1997.5 | 1672.4 | 1510.1 |
| 'Rose Star' | 460.7 | 475.2 | 2258.3 | 2140.5 | 1797.6 | 1665.3 |
| Impatiens | | | | | | |
| 'Dazzler White' | 508.3 | 512.3 | 3279.4 | 2862.0 | 2771.1 | 2349.7 |
| 'Dazzler Rose' | 510.7 | 494.5 | 3294.8 | 2908.8* | 2784.1 | 2414.3* |
| Madagascar periwinkle | | | | | | |
| 'Orchid Cooler' | 483.5 | 490.3 | 3021.9 | 3045.3 | 2538.4 | 2555.0 |
| Common lantana | | | | | | |
| 'Roseum' | 421.6 | 493.8 | 3977.4 | 2904.7* | 3555.8 | 2410.9* |
| 'Flava' | 494.5 | 503.3 | 2842.0 | 2607.8 | 2347.5 | 2104.5 |
| Chinese hibiscus | | | | | | |
| 'Albo-Strip' | 498.0 | 523.7 | 2912.3 | 2631.7* | 2414.3 | 2108.0* |

[a]$F_0$: initial fluorescence; Fm: maximum fluorescence; Fv: variable fluorescence.
[b]*: Means difference between pre- and post-fumigation values reached significance level by t-test, 5% level.

**Table 2.** Foliar injury, pre- and post-fumigation chlorophyll fluorescence, and relative chlorophyll fluorescence of bedding plants after 400 ppb ozone fumigation for 4 h.

| Species and cultivars | Foliar injury (%) | Fv/Fm[a] | | Relative chlorophyll fluorescence (%)[b] |
|---|---|---|---|---|
| | | Pre-fumigation | Post-fumigation | |
| Wax begonia | | | | |
| 'Encore White/Bronze' | 89.3 a[c] | 0.812 bcde | 0.739 hi | 91.0 d |
| 'Encore Red/Bronze' | 89.1 a | 0.829 bcd | 0.745 ghi | 90.0 d |
| 'Encore White' | 79.3 b | 0.782 e | 0.728 i | 93.1 cd |
| 'Encore Pink' | 78.5 b | 0.793 de | 0.735 i | 92.6 cd |
| Salvia | | | | |
| 'Empire White' | 28.1 d | 0.806 bcde | 0.760 fg | 94.3 bcd |
| 'Empire Red' | 25.9 d | 0.812 bcde | 0.768 ef | 94.6 bcd |
| Petunia | | | | |
| 'White cascade' | 4.1 e | 0.783 e | 0.756 fgh | 97.0 abc |
| 'Rose Star' | 4.2 e | 0.802 cde | 0.778 e | 97.1 abc |
| Impatiens | | | | |
| 'Dazzler White' | 3.8 e | 0.845 b | 0.821 bc | 97.2 abc |
| 'Dazzler Rose' | 3.9 e | 0.845 b | 0.830 ab | 98.2 ab |
| Madagascar periwinkle | | | | |
| 'Orchid Cooler' | 2.6 e | 0.840 bc | 0.839 a | 99.9 a |
| Common lantana | | | | |
| 'Roseum' | 34.8 d | 0.894 a | 0.830 ab | 93.5 bcd |
| 'Flava' | 57.4 c | 0.826 bcd | 0.807 cd | 97.7 abc |
| Chinese hibiscus | | | | |
| 'Albo-Strip' | 7.5 e | 0.829 bcd | 0.801 d | 96.6 abc |

[a]Fv : variable fluorescence; Fm : maximum fluorescence.
[b]Relative chlorophyll fluorescence (RCF, %) = (post-fumigation Fv/Fm) / (pre-fumigation Fv/Fm) × 100%
[c]Means separation in columns by Duncan's multiple-range test, 5% level. The data of relative chlorophyll fluorescence and foliar injury were transformed using an arcsine transformation before statistical analysis.

**Table 3.** Foliar injury, per- and post-fumigation stomatal conductance, and relative stomatal conductance of bedding plants after 400 ppb ozone fumigation for 4 h.

| Species and cultivars | Foliage injury (%)[a] | Stomatal conductance (mmol/m$^2$s) | | Relative stomatal conductance (%)[a] |
|---|---|---|---|---|
| | | Pre-fumigation | Post-fumigation | |
| Wax begonia | | | | |
| 'Encore White' | 77.5 a[b] | 195.4 d | 99.5 b | 50.9 a |
| 'Encore Pink' | 76.7 a | 306.4 cd | 128.4 b | 41.9 a |
| Annual geranium | | | | |
| 'Dynamo White' | 21.2 c | 453.9 ab | 225.5 a | 49.7 a |
| 'Dynamo Deep Scarlet' | 18.3 c | 495.5 b | 217.5 a | 43.9 a |
| Salvia | | | | |
| 'Empire White' | 12.5 cd | 321.1 cd | 32.9 d | 10.2 c |
| 'Empire Red' | 11.7 cd | 301.5 cd | 20.4 d | 6.8 cd |
| Petunia | | | | |
| 'Rose Star' | 9.7 cd | 402.1 bc | 21.2 d | 5.3 d |
| Impatiens | | | | |
| 'Dazzler Rose' | 3.8 d | 321.0 cd | 15.8 d | 4.9 d |
| Common lantana | | | | |
| 'Flava' | 59.4 b | 677.7 a | 201.5 a | 29.7 b |
| Chinese hibiscus | | | | |
| 'Albo-Strip' | 17.6 c | 196.1 d | 61.5 c | 31.3 b |

[a]Relative stomatal conductance (RSC, %) = (post-fumigation stomatal conductance) / (pre-fumigation stomatal conductance) × 100%.
[b]Means separation in columns by Duncan's multiple-range test, 5% level. The data of relative stomatal conductance and foliar injury were transformed using an arcsine transformation before statistical analysis.

sensitive species to $O_3$ was wax begonia 'Encore White' and "Encore Pink' (foliar injury between 77-78%), followed by common lantana 'Flava' (59.4%), and then bedding geranium and Chinese hibiscus (18~21%). Impatiens had the most resistance to $O_3$ in this experiment (foliar injury only 3.8%) (Table 3). Stomatal conductance decreased after $O_3$ fumigation in all tested plants. In addition, when one species had lower foliar injury, its RSC was generally lower (Table 3). For instance, the foliar injury of impatiens was only 3.8%, and its RSC was only 4.9%. On the other hand, the RSCs of two cultivars of wax begonia were 42~51%, and their foliar injuries were as high as 77~78% (Table 3). Foliar injuries were significantly correlated with RSC (r = -0.64, $P$<0.05), but not with pre- and post-fumigation stomatal conductance (Figure 2).

## Discussion

Ozone damage to plants varies with species and may be different in cultivars of the same species (Ormrod, 1978; Heck et al., 1986). From the results of two $O_3$ fumigations, according to foliar injury, the wax begonia is the most sensitive to $O_3$ stress, followed by common lantana and then salvia, bedding geranium, and Chinese hibiscus. Madagascar periwinkle and impatiens were the most tolerant (Table 2 and 3). The results are generally in accordance with the previous reports (Adedipe et al., 1972; Ormrod, 1978; Rogers, 1985), except for the performance of petunia. Petunia is often rated as an $O_3$-sensitive species (Adedipe et al., 1972; Ormrod, 1978; Rogers, 1985), but based on our data, it could be an $O_3$-resistant species (Table 2 and 3). This means that the cultivars of petunia could exhibit vary-

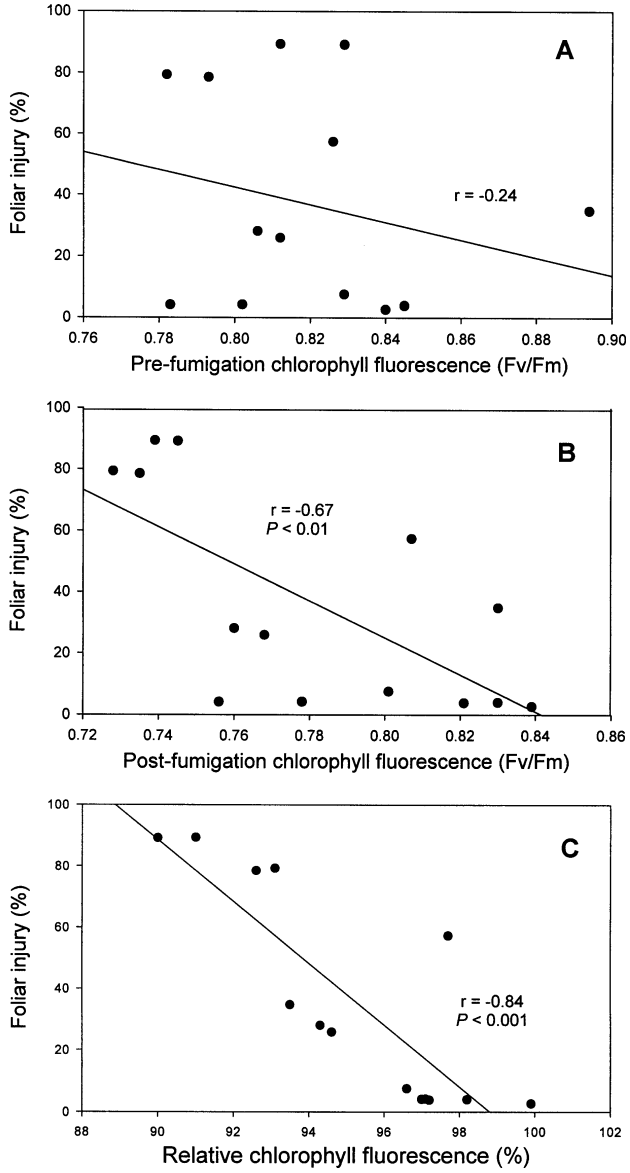


**Figure 1.** Correlation between foliar injury and (A) pre-fumigation, (B) post-fumigation, or (C) relative chlorophyll fluorescence in bedding plants exposed to 400 ppb ozone for 4 h.

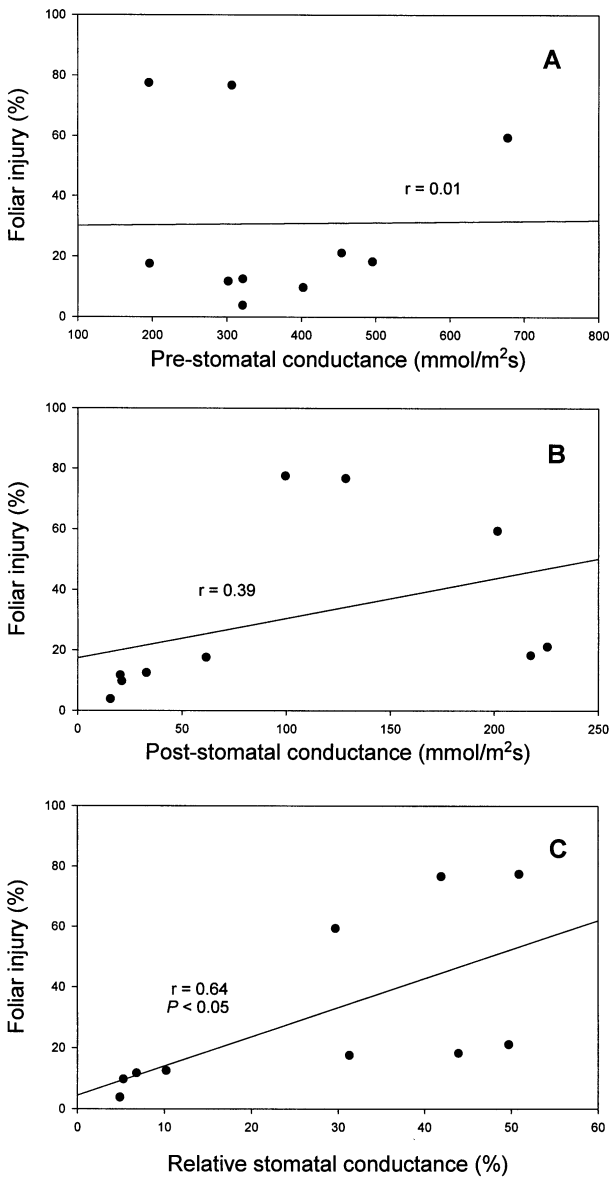


**Figure 2.** Correlation between foliar injury and (A) pre-fumigation, (B) post-fumigation, or (C) relative stomatal co nductance in bedding plants exposed to 400 ppb ozone for 4 h.

ing degrees of tolerance to $O_3$ (Adedipe et al., 1972). Cathey and Heggestad (1972) also have separated petunia cultivars into six classes of sensitivity to $O_3$, and five of 65 cultivars are very insensitive.

All the tested plants exhibited lower Fv/Fm values at the end of $O_3$ fumigation than those of pre-fumigation (Table 2). This result indicates that $O_3$-induced stress could cause damages in the PS2 pigment structure, block photosynthetic electron transport between PS2 and PS1, and result in a drop in Fv/Fm (Krause and Weis, 1984; Lee, 1991). The foliar injury was not correlated with pre-fumigation chlorophyll fluorescence, but was significantly correlated with post-fumigation chlorophyll fluorescence ($r=-0.67$, $P<0.01$) (Figure 1) Guidi et al. (2000) also found a close relationship between post-fumigation chlorophyll fluorescence and the damage index. However, the first experiment indicated that the foliar injury was more closely correlated with RCF than with post-fumigation chlorophyll fluorescence (Figure 1). Our results are in accordance with the suggestion that changes in chlorophyll fluorescence may provide a rapid non-invasive method for detecting $O_3$ damage (Guidi et al., 2000). Relative chlorophyll fluorescence (RCF) may be more suitable than pre- or post-fumigation chlorophyll fluorescence as an indicator of $O_3$ resistance in plants.

All tested plants generally exhibited lower stomatal conductance at the end of $O_3$ fumigation than during pre-fumigation (Table 3). This is in accordance with the suggestion that $O_3$ causes at least partial closure of stomata (Aben et al., 1990; Iqbal et al., 1996). It has often been suggested that stomatal closure in the presence of a pollutant (e.g. $O_3$) could constitute an important mechanism for avoidance of injury to internal tissues (Unsworth and Black, 1981; Mansfield and Pearson, 1996).

Because stomatal conductance is the principal physiological regulator of $O_3$ uptake, it has been proposed that differences in $O_3$ sensitivity among species and within species can be largely explained by differences in stomatal conductance (Reich, 1987; Runeckles, 1992). In general, those species with higher stomatal conductance are more sensitive to $O_3$ (Ormrod and Hale, 1995). However, the result of our second experiment showed that the foliar injury was correlated neither with pre- nor with post-fumigation stomatal conductance, though it was significantly correlated with RSC (Figure 2). Reiling and Davison (1995) also have reported no relationship between mean or maximum stomatal conductance and $O_3$ resistance, but the resistant populations showed a larger reduction in stomatal conductance than the sensitive populations. Therefore, it is suggested that the relative stomatal conductance (RSC) is more suitable than pre- or post-fumigation stomatal conductance for evaluating $O_3$ resistance of plants.

Some physiological parameters, such as chlorophyll fluorescence and stomatal conductance, may play a major role in the early detection of $O_3$ stress (Saxe, 1996). Furthermore, the "relative" values (i.e. RCF and RSC) seemed more correlated with foliar injuries than their "absolute" values, either pre- or post-fumigation chlorophyll fluorescence and stomatal conductance (Figures 1 and 2). Based on our experimental data, those species with higher RCF or lower RSC are, in general, more resistant to $O_3$ foliar injury. Nevertheless, though common lantana had higher levels of foliar ozone injury than Chinese hibiscus, they did not differ in RCF (Table 2) or in RSC (Table 3). This indicates other internal biochemical factors, such as enzyme or non-enzyme free-radical-scavenging systems, which are thought to mediate the $O_3$ resistance of plants (Scandalios, 1993; Kangasjarvi et al., 1994). Further research is needed to make a more precise evaluation.

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# 花壇植物的相對葉綠素螢光及相對氣孔導度與其臭氧抗性之關係

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以台灣常見的八種花壇植物種類作臭氧 400 ppb 熏氣處理，處理時間為四小時，結果顯示：在供試植物中，以日日春及非洲鳳仙花最具抗性；而以四季秋海棠抗性最弱。在試驗前後分別測量植物之葉綠素螢光與氣孔導度，結果顯示，植物的葉綠素螢光及氣孔導度的變化與臭氧對植物的傷害程度均有顯著的相關性存在：植物傷害度與相對葉綠素螢光成顯著負相關（r=-0.84, $P$<0.001），而相對氣孔導度（熏氣前氣孔導度/熏氣後氣孔導度）呈顯著正相關（r=0.64, $P$<0.05）。亦即對臭氧抗性慾佳的種類，其相對葉綠素螢光越高，而相對氣孔導度越低。由實驗結果可知：葉綠素螢光與氣孔導度的測量結果應可作為瞭解植物對臭氧抗性的參考依據。

**關鍵詞：**空氣污染；花壇植物；葉綠素螢光；臭氧抗性；氣孔導度。