Reduction of Ozone Damage to *Petunia hybrida* Vilm. by Use of Growth Regulating Chemicals and Tolerant Cultivars[1]

Henry M. Cathey and Howard E. Heggestad[2,3]
Agricultural Research Service
U. S. Department of Agriculture
Beltsville, Maryland

Abstract. Sixty-five cvs. of petunia, *Petunia hybrida* Vilm., were evaluated for sensitivity to ozone and the reduction in damage afforded by applications of growth regulating and other chemicals. Plants were exposed to ozone concn at 15, 30, 45, and 60 parts per hundred million (pphm) in a growth chamber for 1.5, 3, and 6 hr at 25°C, 78-88% relative humidity, and an illumination of 2,000 ft-c. Chemicals which retarded internode elongation and promoted dark green color of the foliage reduced visible injury induced by ozone.[4,5] The compounds 2,4-dichlorobenzyltributyl phosphonium chloride (CBBP) and succinic acid 2,2-dimethyl hydrazide (SADH) retarded growth and modified sensitivity of the foliage to ozone. Concentration of SADH needed to reduce injury significantly was at least twice that used to retard stem elongation. Adding L. ascorbic acid and a wax coating to the spray solution increased the protection afforded by SADH. Chemicals which did not retard growth of petunia such as the chemical growth retardants (2-chloroethyl) trimethyl ammonium chloride (chlormequat), α-cyclopropyl-α (4-methoxyphenyl)-5-pyrimidine methanol (ancymidol), and the systemic fungicide methyl 1-butylcarbamoyl-2-benzimidazolecarbamate (benomyl) afforded no protection for ozone treated plants. The 65 cvs. were placed in 6 classes based on an average rating of injury after exposures to 4 doses of ozone. Five cvs. were in the very tolerant class and have most potential for use in the development of new petunia cvs. resistant to ozone and possibly to other phytotoxicants.

Petunia plants have been recognized by various research workers as one of the most sensitive species to damage by oxidants including ozone (16, 19, 28), and sensitive cvs. of petunia (27) as well as other plant species are used as indicators of air quality in urban centers. Studies involving ozone were initiated because it is the principal toxicant in photochemical smog and the most damaging air pollutant affecting vegetation in the United States (15). Feder et al. (9) evaluated the responses of 14 cvs. to ozone and other air pollutants, but most reports on petunia plants include only 1 or 2 cvs. and do not indicate the stage of growth at which injuries occurred, or evaluate the growth of plants after first development of air pollution injury. The literature concerned with air pollutants fails to recognize the great range of genetic material available in petunias as inbreds and F-1 hybrids. Their uniformity of plant habit and flowering time resulted from many years of inbreeding and selection which were needed to develop F-1 hybrids of varied growth habits and flower colors. The inheritance of genetic characters which relate to air pollution tolerance is known for certain cvs. of onions in which a single dominant gene pair controlled the resistance response (6, 12). Stomates of the resistant onions closed very rapidly when exposed to elevated levels of ozone.

Cathey and Piringer (5) reported induced resistance to water stress in petunia plants when they were grown in soil treated with the growth retardant 2,4-dichlorobenzyltributyl phosphonium chloride (phosfon-D or CBBP). The chemical suppressed growth, delayed flowering, and at high dosages induced chlorosis of the main veins of the leaves. Later Cathey, Halperin, and Piringer (4) reported that succinic acid 2,2-dimethyl hydrazide (Alar, B-Nine, or SADH) was effective in retarding stem elongation of petunia plants when applied as a foliar spray. For maximum growth response to SADH, the optimum time to apply the chemical was the period of maximum stem elongation (1). Cultivars varied greatly in their response to foliar sprays of SADH, grading from large to a negligible response (2). N-pyrrolidino-succinamic acid (UNI-F529), an analog of SADH, possessed greater activity than SADH, during the summer months, but activity was near equal during the winter months. Other derivatives of succinic acid were considerably less active than SADH (3).

The literature on control of air pollution plant damage by chemical means identifies many compounds (7, 14, 15, 18) including fungicides (22, 23, 24), vitamins (10, 11, 21, 29, 30), the stomatal regulators phenylmercuric acetate and monomethyl ester of decenylsuccinic acid (26) and antitranspirants (13). None of these chemicals have gained extensive use in agriculture largely because of the cost of chemicals and the need for frequent and thorough applications. Most need to be applied just prior to an air pollution episode because their effects persist for only a few days or less if washed off by rain.

Experiments were conducted to determine the effects of chemical growth retardants on altering the sensitivity of petunia plants to ozone and to identify the relative tolerance of petunia cvs. to ozone.

Materials and Methods

Solution preparation: Solutions of

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[3]Research Horticulturist and Research Plant Pathologist, respectively, Agricultural Research Center. The authors gratefully acknowledge the assistance of Kenneth Lehnert, Research Technician.

[4]Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture, and does not imply its approval to the exclusion of other products that may also be suitable.

[5]Chemicals for these experiments were supplied by Uniroyal Chemical, Division of Uniroyal, Inc., Bethany CT 06525; American Cyanamide Company, Agricultural Division, Princeton, NJ 08540; V. C. Chemical Oil Company, Inc., Richmond, VA 23208; Eli Lilly and Company Greenfield Laboratories, Greenfield, IN 46140; Sun Oil Co., Philadelphia, PA 19103; E. I. duPont de Nemours & Company, Wynnewood, PA 19096.

[6]One ppm ozone is equivalent to 1960 $\mu g/m^3$ of ozone at 760 mm Hg and 25°C.

2,4-dichlorobenzyltributyl phosphonium chloride (Phosfon-D or CBBP), (2-chloroethyl) trimethyl ammonium chloride (Cycocel, CCC, or chlormequat), and succinic acid 2,2-dimethyl hydrazide (Alar, B-Nine, or SADH) were prepared by dissolving the chemicals in warm water. Analogs of SADH were also tested, F724-Fumaric acid 2,2-dimethyl hydrazide; C890 - Succinamic acid 2,2-dimethylhydrazide; COII - Maleic acid 2,2-dimethylhydrazide; and F529 - N-pyrrolidino-succinamic acid. The concn of chemicals and application times were varied. Emulsions of α-cyclopropyl-α (4-methoxyphenyl) -5-pyrimidine methanol (EL-531 or ancymidol) were prepared by diluting the 4.5% emulsifible concentrate with water to the desired concn. A wax coating (Folicote), L ascorbic acid (AA) and methyl 1-butylcarbamoyl-2-benzimidazolecarbamate (Benlate or benomyl) were also tested in preliminary experiments. For soil drench experiments, 100 ml of a test solution was poured on the soil around a plant in a 10-cm plastic pot. For the spray treatments, 0.1% polyoxyethylene (20) sorbitan monolaurate (Tween 20) surfactant was added to the experimental spray solutions except for ancymidol which already contains 1.

Test plants: Several different chemical sprays were applied chiefly to 3 cvs. of *Petunia hybrida* Vilm. cv. White Cascade, Pink Cascade and Comanche. Sixty-two additional cvs. listed in Table 8 were also screened for their sensitivity to ozone fumigation. The plants were grown from seed at a minimum night temp of 17°C prior to fumigation. The plants were kept vegetative by covering them with black cloth from 4 PM to 8 AM. They were transferred to flower inductive conditions by interrupting the natural dark period from 10 PM to 2 AM nightly with at least 10 ft-c from incandescent-filament lamps. To establish a consistent stage of plant development for fumigation they were exposed to ozone at the start of anthesis.

Ozone fumigations: Test plants were exposed to ozone at 15, 30, 45, and 60 PPHM[6] for 1.5, 3, and 6 hr in a Controlled Environments (Model PWG 36) growth chamber. The ozone concn was measured with a Mast ozone meter Model 7-242. The concn was controlled by manually adjusting a flow meter. A temp of 25°C, relative humidity of 78-88%, and light intensity of 2,000 ft-c (cool white fluorescent lamps plus 10% of the wattage from incandescent-filament lamps) was maintained during the exposure period. Since the fumigations required 3 hr, 2 replications were treated each day starting at 8:30 AM and 1:00 PM.

After treatment with ozone, plants were returned to a pad and fan cooled greenhouse where they remained for at least 48 hr before the amount of injury on each plant was scored.

Ozone injury: Plants were indexed for injury 48 hr later on a scale ranging from 0 to 10.

Rating	Observation
0	Undamaged green leaf
0.5	Several pale green areas between veins
1.0	Tan specks between veins
2.0	20% of most sensitive leaves dead
3.0	30% of most sensitive leaves dead
4.0	40% of most sensitive leaves dead
5.0	50% of most sensitive leaves dead
6.0	60% of most sensitive leaves dead
7.0	70% of most sensitive leaves dead
8.0	80% of most sensitive leaves dead
9.0	90% of most sensitive leaves dead
10.0	100% of most sensitive leaves dead

Injury scores were analyzed by an analysis of variance and Duncan's Multiple Range Test.

Results

Comparison of activity of various chemicals: 'Pink Cascade' petunia plants were treated with various chemicals which induce growth regulating responses on ornamental plants. The active SADH analogs – F724, COII, and F529 – when applied as a foliar spray were as effective as SADH in reducing the interveinal clearing of chlorophyll and other injury induced by ozone (Table 1). The analog C890, which is inactive as a growth retarding chemical, was also inactive in protecting leaves against ozone.

Chemicals applied to the soil were much less effective in reducing the damage in the plants than foliar sprays of SADH and its active analogs (Table 1). Ancymidol which possesses only slight growth retarding activity on petunias was applied to the soil at 10 PPM dosage. The plants developed leaves with pale green margins and wilted almost daily. Ancymidol offered only slight protection against ozone. Chlormequat, inactive as a growth retardant on petunias, did not increase the tolerance of the plants to ozone. CBBP, the first chemical growth retardant known to be active on petunias, induced some tolerance of the plants to ozone. Benomyl, a systemic fungicide, was also tested because it has wide biological activity on plants. Some protection from ozone injury has been reported (24). At the dosage (100 PPM) tested and a delay of almost 4 weeks between treatment and ozone fumigation, benomyl provided no protection from ozone injury. The plants grown in soil drenched with benomyl and fumigated with ozone developed leaves with interveinal and marginal clearing of chlorophyll. Several of the recently matured leaves were entirely white and persisted chlorophyll-free for several weeks following the fumigation.

Based on these preliminary experiments, SADH was selected

Table 1. Effect of various chemicals on ozone injury and ht of 'Pink Cascade' petunia. Spray and soil drench applied 39 days after sowing the seed. Plants were grown on long days and exposed to 45 PPHM ozone for 3 hr at anthesis.

Chemical	Dosage	Method of application[z]	Ozone injury rating after 48 hr	Ht at time of anthesis
Code	PPM		0 - 10	cm
H_2O control	0	spray	8.0	20.5
SADH	5000	spray	2.0	5.6
F724	5000	"	2.5	5.9
C890	5000	"	7.5	16.9
COII	5000	"	2.5	6.1
F529	5000	"	2.3	5.4
ancymidol	10	Drench	5.0	18.3
CBBP	100	"	3.5	9.4
benomyl	100	"	8.5	21.3
chlormequat	2000	"	6.5	18.9

[z]Application: Sprayed until run off; soil drench; 100/ml of preparation.

Table 2. Effect of dosage of foliar sprays of SADH on ozone injury, ht, flowering time of 'White Cascade' petunia. Sprays applied 32, 39, and 46 days after sowing the seed. Plants were grown on long days and exposed only to ambient air pollution in a pad and fan cooled greenhouse.

SADH dosage (%)	Frequency of spray application	Ozone injury rating[z] After 48 hr	Ht at time of anthesis	Anthesis (days)
		0 - 10	cm	(days)
H_2O control	3x	5.5a	35.1a	55.2
0.125	3x	2.2b	28.1b	57.4
0.25	3x	2.2b	22.8c	57.5
0.5	3x	1.1c	15.8d	58.1
1.0	3x	0.5c	10.5e	59.0
0.25	x	2.5b	22.3c	56.4
0.5	x	0.9c	16.1d	58.3
1.0	x	1.1c	12.3e	58.9

[z]Means (20 plants per treatment) not followed by the same lower case letter differ significantly at the 5% level.

Fig. 1. Effect of natural air pollution on 'White Cascade' petunia. Upper – plant sprayed 3 times at weekly intervals with 0.5% SADH; lower – unsprayed.

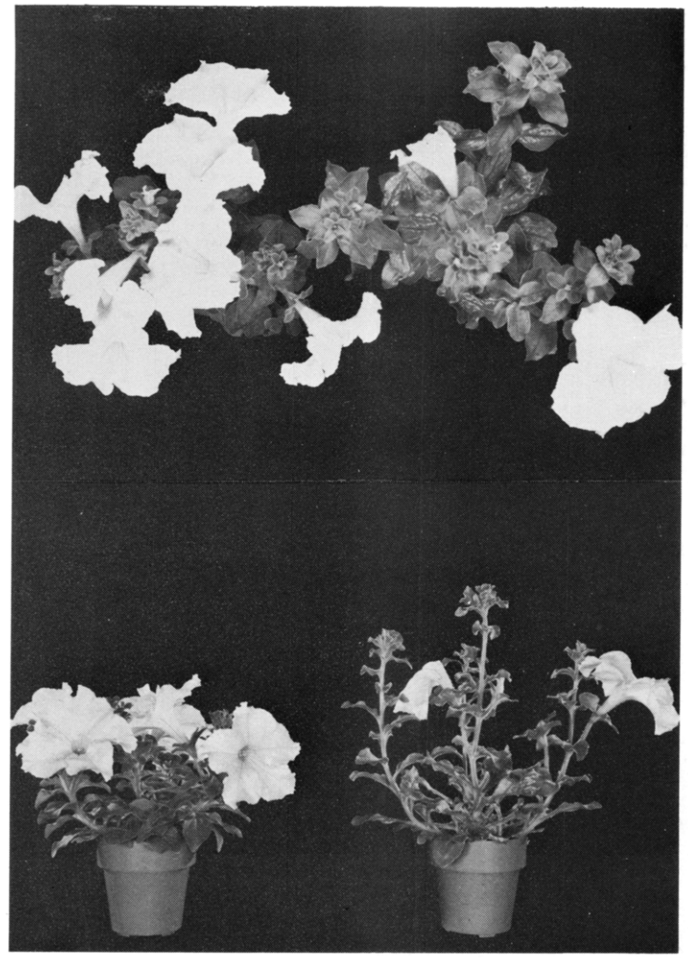

Fig. 2. Effect of natural air pollution on 'White Cascade' petunia: Left: Plant sprayed 3 times at weekly intervals with 0.5% SADH; Right: Plant grown without chemical treatment. (Side and down views).

as the most effective chemical growth regulator to apply to petunia plants to alter their responses to ozone.

Concentration of SADH: Plants of 3 petunia cvs. mentioned earlier were sprayed with SADH at various concn and frequencies of application. Since the 3 cvs. varied in their response, they will be discussed separately.

Responses of 'White Cascade' petunia: 'White Cascade' petunia is very sensitive to air pollution (9). The ambient pollution in the greenhouse with a pad and fan cooling system caused an average rating of 5.5 ozone injury on the untreated plants at the start of flowering (Table 2). For a month prior to ozone fumigation (May, 1971) the maximum hourly average of oxidants at Beltsville was 8.0 PPHM as determined by a Mast Sensor. Plants of a similar age and culture which had been treated with foliar sprays of the chemical exhibited reduced injury in direct relation to the dosage of SADH. A single or a triple application of 0.25% SADH reduced, but did not prevent visual damage to the chemically-treated plants. Dosages of 0.5% or greater, applied once or 3 times, may be needed for satisfactory protection of plants from the pollution in ambient air. On several of the most recently matured leaves a few pale yellow spots appeared between the veins (Fig. 1). Untreated plants exhibited rapid decline in their growth rates, since their older leaves turned pale green (Fig. 2) and died. Flower buds aborted and the stems lost turgor and collapsed.

Responses of 'Pink Cascade' petunia: 'Pink Cascade' is more tolerant of ambient air pollution than 'White Cascade'. Although yellow specks appeared on a few leaves, the plants did not exhibit obvious air pollution damage. After the third spray application of SADH, groups of plants just beginning to flower were fumigated for 3 hr with 15, 30, and 60 PPHM of ozone (Table 3). The unprotected plants were increasingly injured with increasing levels of ozone. Foliar application of SADH reduced the injury rating, compared to the water control, of plants fumigated with 15 and 30 PPHM O_3. Only the maximum dosage of 1.0% SADH applied 3 times at weekly intervals reduced the injury rating on plants exposed to 30 PPHM ozone to that observed on the unfumigated plants. The 60 PPHM O_3 fumigation was equally damaging to all plants with or without SADH spray applications.

Responses of 'Comanche' petunia: 'Comanche' is more tolerant to air pollution than either 'White Cascade' or 'Pink Cascade'. In one experiment none of the spray applications of SADH reduced injury (Table 4). Ozone injury on the leaves of 'Comanche' petunia appeared different from that observed on those of 'Cascade'. 'Comanche' foliage showed little or no interveinal clearing of chlorophyll, injury occurred primarily on margins of leaves. With increasing levels of ozone, the white margins were broader, and with a fumigation level of 60 PPHM, several of the recently matured leaves were killed. Both old and immature leaves were unaffected and immature leaves and flower buds developed normally. Although the plants were held in the greenhouse for several weeks following fumigation, there was no obvious acceleration of aging.

'Comanche' petunia plants, treated with SADH, were exposed to 30 PPHM ozone for 0, 1.5, 3, and 6 hr. All plants

Table 3. Effect of dosage of foliar sprays of SADH on ozone injury of 'Pink Cascade' petunia. Sprays applied 32, 39, and 46 days after sowing the seed. Plants were grown on long days and exposed to ozone for 3 hr at anthesis.

SADH dosage (%)	Frequency of spray application	Injury rating[z] after 48 hr exposure to ozone at 4 concn (PPHM) 0	15	30	60
		0 - 10	0 - 10	0 - 10	0 - 10
H_2O control	3x	0.0d	1.6c	3.6b	7.3a
0.125	3x	0.3d	0.3d	2.6c	7.3a
0.25	3x	0.3d	0.3d	1.6c	7.6a
0.5	3x	0.3d	0.0d	1.6c	7.6a
1.0	3x	0.3d	0.6d	1.0d	7.6a
0.25	x	0.3d	0.3d	3.3b	7.3a
0.5	x	0.0d	0.3d	1.3c	7.6a
1.0	x	0.0d	0.3d	1.6c	7.6a

[z]Means (3 plants per treatment) not followed by the same lower case letter differ significantly at the 5% level.

Table 4. Effect of dosage of foliar sprays of SADH on ozone injury of 'Comanche' petunia. Sprays applied 32, 39, and 46 days after sowing the seed. Plants were grown on long days and exposed to ozone for 3 hr at anthesis.

SADH dosage (%)	Frequency of spray application	Injury rating[z] after 48 hr exposure to ozone at 4 concn (PPHM) 0	15	30	60
		0 - 10	0 - 10	0 - 10	0 - 10
H_2O control	3x	0.0c	1.0bc	2.3b	6.6a
0.125	3x	0.3c	0.3c	1.3b	7.6a
0.25	3x	0.0c	0.0c	1.3b	6.6a
0.5	3x	0.0c	0.0c	1.6b	6.3a
1.0	3x	0.0c	0.0c	3.0b	8.0a
0.25	x	0.0c	0.0c	2.6b	6.6a
0.5	x	0.0c	0.0c	1.6b	7.0a
1.0	x	0.0c	0.0c	2.0b	6.6a

[z]Means (3 plants per treatment) not followed by the same lower case letter differ significantly at the 5% level.

were placed in the chamber at the same time and removed at various time intervals. Foliar applications of SADH significantly altered the plants responses to the length of fumigation (Table 5) with 30 PPHM ozone.

Interaction of SADH with ascorbic acid and a wax coating: Plants of 'Pink Cascade' were sprayed once with various combinations of SADH (0.5%), ascorbic acid (0.1%), and a wax coating (5%) (Table 6). Foliar applications of the chemicals applied separately reduced only slightly the injury rating. When the 3 treatments were combined into a single spray emulsion, however, maximum protection was afforded to the developing plant.

Survey of petunia cvs.: Plants of 65 petunia cvs. were separated into 2 groups. One group was sprayed twice with 0.5% SADH, the other group was left untreated. At the start of flowering, plants from the 2 groups were exposed to various levels of ozone in growth chambers for 3 hr and returned to the greenhouse. The average ozone injury for all cvs. combined was reduced by SADH at all ozone levels including ambient air (Table 7 and Fig. 3).

When exposed to 60 PPHM ozone, injury to the petunia cvs. varied from a few tan spots (rating 2) on 'Capri , 'Purple Plum', and 'Popeye' to at least 70% of the leaf area dead (rating 7) on several cvs. The cvs. are placed in 6 classes based on an average of our ratings after exposure of 1 plant of each cv. to ozone at 15, 30, 45, and 60 PPHM for 3 hr (Table 8). The cvs. in the most tolerant class had low scores and were injured only at the highest ozone level – 60 PPHM. 'Purple Joy' in the second class of tolerants also was injured only at the highest concn of ozone. Its injury rating, however, was higher than that of the 5 cvs. listed as most tolerant. The most sensitive cvs., in class 6, had injury following exposure to all levels of ozone. They actually had ratings of 3 and 4 when exposed to only ambient levels of pollutants. 'Fandango' and 'White Cascade' in class 5 also had a rating of 3 on the control plants which were exposed only to pollutants in ambient air.

Table 5. Effect of dosage of foliar sprays of SADH on ozone injury to 'Comanche' petunia. Sprays applied 35, 42, and 49 days after sowing the seed. Plants were grown on long days and exposed to ozone at anthesis.

SADH dosage (%)	Frequency of spray application	Ozone injury rating[z] 48 hr after 30 PPHM fumigation for 4 durations (hr) 0	1.5	3	6
		0 - 10	0 - 10	0 - 10	0 - 10
H_2O control	3x	0.0d	1.0c	2.3b	4.6a
0.25	3x	0.0d	0.0c	2.0b	3.3a
0.5	3x	0.0d	1.0c	1.6b	2.3b
1.0	3x	0.0d	1.0c	0.6c	1.0c

[z]Means (3 plants per treatment) not followed by the same lower case letter differ significantly at the 5% level.

Table 6. Effect of foliar sprays of SADH (0.5%), Ascorbic Acid (AA) (0.1%), and wax coating (WC) (5%) on ozone injury of 'Pink Cascade' petunia. Spray applied on 39 days after sowing of the seed. Plants were grown on long days and exposed to ozone at anthesis.

Chemical	Ozone injury rating[z] from 3 hr fumigation with 4 concn (PPHM). 0	15	30	60
Untreated	0 - 10	0 - 10	0 - 10	0 - 10
SADH	0.0d	3.3b	3.3b	4.3a
AA	0.0d	2.3b	2.6b	4.0a
WC	0.0d	4.0a	4.0a	5.0a
SADH + AA	0.3d	2.3bc	2.0c	3.6b
SADH + WC	0.0d	3.0b	2.6b	3.3b
AA + WC	0.0d	1.0c	2.0c	2.6b
SADH + AA + WC	0.0d	3.0b	3.3b	3.0b
	0.0d	1.3c	1.3c	1.6c

[z]Means (3 plants per treatment) not followed by the same lower case letter differ significantly at the 5% level.

Table 7. Effect of foliar sprays of SADH on ozone injury of 65 cvs. of petunias. Mean values for 65 cvs. Sprays applied 39 and 46 days after sowing the seed; plants grown on natural long days of April and May and exposed to ozone at anthesis.

Chemical	Injury rating after 48 hr exposure to ozone at 5 concn (PPHM) 0	15	30	45	60
	0 - 10	0 - 10	0 - 10	0 - 10	0 - 10
Untreated	0.78	1.00	2.05	3.46	5.54
SADH – 0.5%	0.25	0.32	0.62	1.44	2.91

Morphological changes of SADH-treated plants: The growth characteristics induced in response to applications of SADH are well documented in previous publications (20, 25). We observed similar responses in the present study. The foliage was darker green, and slightly smaller in size than the untreated plants (Fig. 2, 3). The internode distances were reduced in relation to the concn and frequency of applications of SADH. The basal shoots on the treated plants developed in greater numbers than on the plants without SADH application. Plants sprayed with SADH did not dry out as rapidly as the untreated plants. Silicone peels were made of the upper and lower surfaces of recently mature leaves. In every case, the stomates of the treated plants did not open as wide as those on untreated plants. Some cvs., such as 'Sugar Plum', maintained their stomates closed for many days of growing without apparent injury. Leaves from SADH-treated plants were thinner in cross section than leaves from untreated

Table 8. Average ratings of 65 petunia cvs. after fumigation with 15, 30, 45, and 60 PPHM ozone for 3 hr (in 6 classes).

0 - 1 Most Tolerant	2 - 3 Intermediate I	4 - 5 Sensitive
Capri	Blue Magic	Albatross
Fire Gleam	Comanche	Ambassador
Pink Joy	Coral Magic	Apollo
Popeye	Glitters	Calypso
Purple Plum	Honey Bunch	Chiffon Cascade
1 - 2 Tolerant	Mariner	Fandango
Ace of Hearts	Maytime	Midnight Star
Apple Blossom	Mercury	Minstrel
Blue Lace	Red Joy	Red Satin
Candy Apple	Rose Cloud	Rose Joy
Cherry Blossom	Sky Magic	Rose Star
Crusader	Star Joy	Starfire
El Toro	Zig Zag	Velvet Queen
Pink Magic	**3 - 4 Intermediate II**	White Cascade
Purple Joy	Coral Satin	White Sails
Red Cap	Domino	**5 - 6 Most Sensitive**
Sugar Plum	Flirt	Fiesta
White Magic	Happiness	Harmony
	Lollipop	Pink Paradise
	Orange Bells	Snow Magic
	Pink Cascade	White Joy
	Pink Snow	
	Red Cascade	
	Sabre Dance	
	Snow Lady	
	Sugar Daddy	
	Sunburst	
	Touche	
	Victory	

plants and contained smaller cells and smaller intercellular spaces.

Discussion

The sensitive response of petunia plants to air pollution is documented by many workers (8, 16, 19). Feder et al. (9) reported 'White Cascade' to be the most sensitive of several cvs. tested for sensitivity to pollutants but they did not report the tested sensitivity of this cv. to ozone. Tobacco, also a member of the Solanaceae, has well identified resistant breeding lines which permit the development of ozone-tolerant cvs. More recently, resistant breeding lines of alfalfa were identified (17). Ozone-resistant cultivars of several crops and vegetables are known to exist (15). We provide herein conclusive evidence that petunias have a wide range in genetic sensitivity to ozone. We believe that through breeding and selection it should be possible to develop resistant cvs. of most ornamental plants. Petunia cvs. can be further modified through the use of the chemical growth regulator SADH and perhaps other chemicals yet to be developed.

Variability in response of petunia plants to various doses of ozone is apparent from our data. However, plants in these tests were grown in greenhouses with only control of night temp and photoperiod. Predisposition of the plants to injury with ozone also depends on light intensity, growth rate, water supply, nutritional status and other uncontrolled factors. Data from each test is thus valid only within its own experimental time. Fumigation time was standardized to the start of flowering, thus permitting a comparison of results of plants at a similar stage of physiological development.

SADH is an effective growth retardant of petunias. Its activity in modifying sensitivity of the plant to ozone follows its activity in modifying plant growth. Only leaves developed after the start of applications of SADH were tolerant. Analogs of SADH which possess similar growth retarding activity on petunia also afforded increased tolerance to ozone fumigation. Analogs that do not retard growth of petunia plants were also ineffective in altering the plants sensitivity to ozone. Other types of chemical growth retardants which possessed only weak activity in controlling the growth of petunia plants were also much less effective in reducing damage due to the ozone fumigations.

Fig. 3. Effect of 30 PPHM ozone for 3 hr on 'Happiness' petunia (Upper), 'Coral Magic' petunia (lower): left - plant unsprayed; right plant sprayed twice, 7 days apart with 0.5% SADH. Plants fumigated 14 days later.

SADH is used by commercial growers to keep plants compact and to help to maintain their salability over an extended period of time. The concn of SADH recommended for this purpose is only about half the concn which we found was needed to alter growth characteristics of the plant sufficiently to withstand fumigations with ozone. Greater concn and more frequent applications of SADH than are now used would be needed to protect petunias from ozone. Our observations also explain why significantly increased tolerance of petunia plants to oxidants was not noted by other research workers. They had applied concn which were sufficient to cause growth retardation, but insufficient to alter significantly the sensitivity of developing leaves to ozone.

Chemical protection or reduced visual symptoms on petunias following ozone fumigations has not been reported previously. The exact mechanism by which the growth retarding chemicals protect plants is not known. We know growth retardants modify the formation of leaves and reduce cell size, amount of intercellular spaces, and stomatal opening. Ozone-sensitive palisade parenchyma cells appear to be physically protected from penetration of ozone. In addition, cell walls are thicker, thus decreasing the ease of gas penetration into the cells. Protection exists only within a range of ozone fumigations. Massive levels of ozone overrode the protection afforded by these physical changes of the plant, resulting in plants as severely damaged as unprotected plants.

Reduction of leaf damage with foliar applications of SADH was observed with 65 cvs. of petunias. In view of their wide range of leaf and flower types, it was not surprising that the petunia cvs. displayed considerable variation in their reaction to ozone fumigation. Seventeen relatively tolerant cvs. with a wide range in color, are listed in Table 8. We believe that higher levels of ozone resistance may be developed for many different leaf and flower types by using appropriate breeding and selection techniques. Five of the cvs. were as tolerant to ozone without treatment as any cvs. treated with SADH. They possessed inherent or naturally occurring characteristics, chemical and physical, which afforded protection.

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