J. Amer. Soc. Hort. Sci. 105(3):322–324. 1980.

Foliar Injury and Growth of Tomato Cultivars as Influenced by Ozone Dose and Plant Age[1]

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Additional index words. Lycopersicon esculentum

Abstract. **Six cultures of *Lycopersicon esculentum* Mill. were exposed to 3 doses of ozone (O_3) at 3 ages. Cultivars exposed to O_3 at 2 weeks age ranked differently in sensitivity based on foliar injury than cultivars exposed at 4 and 6 weeks. Cultivars were more sensitive to O_3 at 4 than at 6 weeks but sensitivity rankings based on foliar injury were similar. The highest O_3 dose significantly inhibited the growth of all cultivars, except 'Heinz 1439' at 6 weeks. Cultivar rankings based on average percent change in growth from control plants were more similar at 4 and 6 weeks compared with 2 weeks.**

Differences in cultivar sensitivity to ozone (O_3) and other pollutants have been reported for many plant species (11). Although foliar sensitivity of many tomato cultivars has been compared (3, 4, 6, 9, 10), few have compared foliar injury and plant growth in the same study (9). Sensitivity of plants at different ages and O_3 dose (concentration × exposure duration) is also not well described. Genotypic variation to air pollutant stress needs to be identified in plants at different ages to develop better screening methodologies for resistance to air pollutants.

The objectives of our study were to determine if tomato age and O_3 dose changes cultivar sensitivity based on both foliar injury and growth.

Materials and Methods

Five tomato cultivars, 'Bonus', 'Fantastic', 'Homestead 24', 'Manapal' and 'Walter' grown commercially for the fresh market in North Carolina were selected for this study. A sixth cultivar 'Heinz 1439' was chosen to represent a known sensitivity level (3, 10).

Tomato seeds were germinated in vermiculite and seedlings were transplanted after 7-10 days at the same time to either, 4.4 cm^2 peat pots placed in plastic holders, or to 10 cm plastic pots. The transplant medium consisted of a commercial preparation of peat, vermiculite and perlite (Metro Mix 200, W. R. Grace Co.); methyl bromide treated soil; and sand, by volume (4:2:1). All transplants were grown in a charcoal-filtered greenhouse at 25-30°C, 50-70% relative humidity, and supplemental light of 15 klux supplied by two-1000 Watt multivapor lamps covering a 4.2 m long bench. Plants were fertilized with Peter's 20-20-20 (20N-8.6P-16.6K) soluble fertilizer 2 weeks after transplanting and every other week as needed.

Tomato plants were exposed to 3 O_3 doses: [0, 40 pphm 1 hr, and 40 pphm 2 hr] at 3 ages. Seedlings in 4.4 cm^2 containers were exposed to O_3 after 2 weeks of growth from seed. Tomato plants in 10 cm pots were divided into 2 groups. One group was exposed to O_3 after 4 weeks from seeding and the second group was exposed after 6 weeks from seed. Plants were watered just before each O_3 exposure at 0930-1500 hr. Plants from each age group were exposed twice, 1 week apart. The experimental design consisted of 6 cultivars, 3 O_3 doses, 3 ages, and an experimental unit of 4 plants (216 plants).

The exposure chamber was a continuous stirred tank reactor (CSTR) modified for greenhouse use (7). Ozone was generated with a Welsbach generator by silent electrical discharge in dry oxygen. The generated O_3 was collected in a manifold and passed through ports leading to flow tubes connected by teflon lines for dispensing into the CSTRs. Three CSTRs from a series of 9 were randomly selected for exposing plants. Ozone was monitored continuously during exposure with a chemiluminescence O_3 analyzer (Monitor Labs Inc., San Diego, CA). The O_3 monitor was calibrated by a Monitor Lab O_3 calibrator.

Leaf injury was visually estimated at 5% increments (0-100% scale) 4-5 days after the first exposure. Only cotyledons of 2 week old seedlings were individually evaluated. Each leaf from the 4 and 6 week old transplants was evaluated for injury 5 days after the first exposure. Dry weights of leaves, stems, and roots were determined, separately, for each cultivar by O_3 dose treatment combination for each plant age 2 weeks after the second exposure. Leaf areas were measured, only on the 4- and 6-week-old plants, on a Licor leaf area meter Model L-1-3000 (Lambda Instrument Co.). All data were evaluated by an analysis of variance with treatment combination sum of squares partitioned into age, O_3 dose, cultivars and their interactions.

Results

Cultivar biomass and leaf area. The interaction of age, O_3 dose and cultivar for all biomass and leaf area variables was not significant. Since the biomass and leaf area variables increased with age, the cultivar and O_3 dose effects and their interaction were determined for each age. The significant levels of F for tomato plant parts and leaf area are presented in Table 1. The cultivar × O_3 dose interaction was significant for stem, root, and plant dry weight after harvest of the 2 week old plants. There were no significant cultivar × O_3 dose interactions for stem, root and plant dry weight after harvest of the 4 and 6 week old plants. There was a cultivar × O_3 dose interaction for leaf dry weight after harvest of the 4 week old plants.

Although the plant compartments, leaf, stem and root differed slightly in response to O_3, plant dry weight represented changes in growth of the 6 tomato cultivars due to O_3 (Table 2). 'Walter' was insensitive to O_3 at 2 weeks while 'Fantastic', 'Bonus' and 'Heinz 1439' were highly sensitive to O_3 based on changes in plant dry weight from the control. At 4 weeks 'Fantastic' still showed the greatest change in plant dry weight, while 'Homestead 24' showed the least change, however the plant

[1]Received for publication April 27, 1979. Paper No. 6087 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh. Cooperative investigations of the U. S. Department of Agriculture and North Carolina State University. Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty by the U. S. Department of Agriculture or the North Carolina Agricultural Research Service and does not imply approval of it to the exclusion of other products or vendors that also may be suitable.

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Table 1. Significant levels of F for dry weight of 6 cultivars exposed to 3 doses of ozone at 3 ages.[z]

Source	d.f.	Dry weight					Root/shoot ratio	Total leaf area (cm^2)
		Leaf	Stem	Shoot	Root	Plant		
				2 weeks				
Cultivar (C)	5	**	**	**	**	**	NS	–
Ozone dose (O)	2	**	**	**	**	**	NS	–
C × O	10	NS	*	NS	**	*	**	–
Error	54							
Total	71							
				4 weeks				
Cultivar	5	NS	**	**	**	**	**	*
Ozone dose	2	**	**	**	*	**	NS	**
C × O	10	*	NS	NS	NS	NS	NS	NS
Error	54							
Total	71							
				6 weeks				
Cultivar	5	**	**	**	**	**	**	NS
Ozone dose	2	**	**	**	**	**	NS	NS
C × O	10	NS	NS	NS	NS	NS	NS	NS
Error	54							
Total	71							

[z]The 6 tomato cultivars were exposed to O_3 at 0, 40 pphm 1 hr and 40 pphm 2 hr.
*,**,[NS]Significant at 1% (**) and 5% (*) level or non-significant (NS).

dry weight of all cultivars was less in those treatments containing O_3 compared to the control. At 6 weeks the magnitude of change in plant dry weight due to O_3 was similar in all cultivars except 'Heinz 1439'; plant dry weight of O_3-exposed plants was slightly greater than the control (Table 2).

The effect of O_3 dose averaged across all 6 cultivars for leaf, stem, shoot, root, plant and leaf area for each age is shown in Table 3. Ozone at 40 pphm for 1 or 2 hr significantly inhibited tomato growth averaged across all cultivars when compared to the control at 2 and 4 weeks. The changes in dry weights of leaf, stem, shoot, root and plant were greatest after 2 weeks and 6 weeks at 40 pphm for 2 hr. The magnitude of weight change due to 40 pphm O_3 for 2 hr in tomato was equal to or slightly greater than the change in weight at 40 pphm O_3 for 1 hr after 4 weeks of growth. Leaf area differences due to O_3 dose were not apparent in tomato exposed at 4 weeks except for a significant enhancement of average leaf area/plant in the presence of 40 pphm O_3 for 1 hr. At 6 weeks both doses of O_3, 40 pphm for 1 or 2 hr reduced the average leaf area per plant.

Foliar injury. Foliar injury symptoms of O_3 among the 6 tomato cultivars resembled that previously described (4, 6, 10); very small, tan-colored necrotic flecks. However, we also found

Table 2. The effect of O_3 dose on plant dry weight of 6 tomato cultivars at 3 ages.[z]

Cultivar	Ozone concn (pphm)	Exposure duration (hr)	Dry weight (g) Weeks 2	4	6
Fantastic	0		.30	3.56	4.99
	40	1	.18	2.33	4.27
	40	2	.12	3.15	4.01
Homestead 24	0		.30	3.98	5.44
	40	1	.33	3.57	4.78
	40	2	.21	3.49	4.15
Bonus	0		.39	4.13	5.42
	40	1	.29	3.29	5.13
	40	2	.15	3.50	4.37
Walter	0		.34	4.50	5.76
	40	1	.35	3.82	5.09
	40	2	.30	3.75	4.15
Manapal	0		.38	3.90	5.49
	40	1	.36	2.83	5.33
	40	2	.28	3.61	4.46
Heinz-1439	0		.32	3.31	3.48
	40	1	.21	2.76	3.77
	40	2	.17	3.03	3.50
LSD 5%			.08	.57	.81

[z]Data represent the mean of 4 plants.

Table 3. Effect of O_3 dose on the early growth of tomato at 3 ages.[z]

Ozone concn (pphm)	Exposure duration (hr)	Dry weight (g) Leaf	Stem	Shoot	Root	Plant	Avg leaf area (cm^2)
			2 weeks				
Control		.20	.08	.29	.05	.34	–
40	1	.17	.07	.25	.04	.29	–
40	2	.13	.04	.17	.03	.21	–
LSD 5%		.02	.008	.03	.006	.03	–
			4 weeks				
Control		1.94	1.28	3.22	.67	3.90	54.1
40	1	1.64	1.07	2.70	.56	3.21	61.4
40	2	1.71	1.11	2.83	.60	3.43	53.2
LSD 5%		.14	.08	.19	.07	.23	2.9
			6 weeks				
Control		2.63	1.66	4.29	.81	5.10	73.5
40	1	2.34	1.59	3.93	.80	4.73	65.8
40	2	1.94	1.46	3.41	.70	4.11	64.2
LSD 5%		.20	.10	.29	.07	.33	4.9

[z]Data represent the mean of 24 plants (6 cultivars × 4 plants).

Table 4. Percent foliar injury and percent change in plant dry weight of 6 tomato cultivars exposed to ozone at 3 ages.

Cultivar	Foliar injury per injured leaf[z] (%)			Change in plant dry weight[y] (%)		
	Age			Age		
	2 wks	4 wks	6 wks	2 wks	4 wks	6 wks
Fantastic	34	57	29	50	23	17
Homestead 24	44	32	17	10	11	18
Bonus	22	34	17	44	18	12
Walter	29	21	16	4	16	20
Manapal	66	16	13	16	17	11
Heinz-1439	19	22	7	41	13	0

[z]Data represent the mean of 8 plants (2 O_3 treatments × 4 plants). The control plants were not injured and are not represented in the mean percent. The percent foliar injury at 2 weeks represents the cotyledon leaves and at 4 or 6 weeks the true leaves. These values were not analyzed, but provide a relative ranking based on foliar injury.

[y]The percent change in dry weight was developed by the following equation:

$$\frac{\text{Wt of control} - [(\text{wt of 40-1}) + (\text{wt of 40-2})]/2}{\text{Wt of control}} \times 100$$

The percent values were not analyzed but were used to compare relative ranking of sensitivity based on dry weight change from the control.

bifacial necrosis more common, but no stipple or dark pigmentation. The effect of age on the percent foliar injury per injured leaf for the 6 cultivars is given in Table 4. 'Fantastic' was the most sensitive at 4 and 6 weeks and 'H-1439' was the least sensitive at 2 and 6 weeks. Cultivar ranking at 2 weeks based on foliar injury differed from that at 4 and 6 weeks. At 2 weeks 'Manapal' and 'Homestead 24' were the most sensitive while 'Bonus' and 'H-1439' were the least sensitive. At 4 and 6 weeks 'Manapal' was less sensitive whereas 'Bonus' was more sensitive. A cultivar ranking, expressed as a percent based on the average plant dry weight of the two O_3 treatments divided by the weight of the control, is given in Table 4. The ranking at 2 weeks was variable with 'Fantastic', 'Bonus' and 'Heinz 1439' being the most sensitive, while 'Homestead 24', 'Walter' and 'Manapal' were the least sensitive. The rankings at 4 and 6 weeks based on percent loss difference in plant dry weight were closely related to the rankings for foliar injury.

Discussion

Several reports have described genetic control of O_3 resistance (1, 2, 5). Nearly all of these studies involved older plants and ambient air exposure to O_3. Few studies have been conducted on juvenile plant resistance to O_3, where the effect of different O_3 concentrations, exposure duration, age or optimum number of plants needed to adequately characterize cultivars of similar genetic backgrounds were considered. We feel that differences in cultivar sensitivity, based both on foliar injury and plant weight change, due to age, pollutant concentration, and duration of exposure should be considered in developing screening methods.

Growth media, soil, moisture, nutrition and other edaphic factors must be uniform to determine consistent effects from a pollutant, or pollutants, in a screening program. The tomato culture and greenhouse environment used in these studies produced uniform plants at each of the 3 ages.

The literature suggests that high concentrations of pollutants for short durations cause different rankings in cultivar sensitivity, than do low concentrations for the same exposure duration (12). In our study we concluded that O_3 dose did not change the ranking of cultivars as much as did age. The foliar sensitivity of 2-week-old tomato cultivars differed from 4 or 6 week-old cultivars. The cultivars also ranked differently when changes in biomass at 2 weeks were compared with changes at 4 and 6 weeks. Plant age needs to be considered when testing or screening tomato cultivars for sensitivity to O_3.

Cultivars should also be screened for differences in yield and/or changes in biomass after O_3 stress. Henderson and Reinert (8) reported delay of early season yield in 'Fantastic', 'Homestead 24', 'Walter', and 'H-1439' after several exposures to 40 pphm O_3 for 1 or 2 hr in the seedling-transplant stage. Cultivars differed in their early season yield and this change was not correlated with foliar injury (8). Oshima et al. (9) studied the yields of 5 tomato cultivars, and concluded that foliar injury was not an accurate indicator of yield. However, the above reports did not suggest that attempts to screen tomato at an early age should be disregarded. They did suggest that yield of resistant or insensitive cultivars also needs to be evaluated following O_3 stress.

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