Volcanic Air Pollution: Deleterious Effects on Tomatoes[1]

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ABSTRACT

From the winter of 1969-70 to the summer of 1973, severe yield and quality reductions occurred on field grown tomatoes (*Lycopersicum esculentum* Mill) in the Kona district on the Island of Hawaii. Symptoms of this mysterious disease included blossom drop, poor fruit set, hollow, small, and almost seedless fruits, and a less luxuriant appearance. A definite atmospheric haze appeared at this time, and was apparently caused by fumes from active and degassing vents located 75 km away and associated with Kilauea Volcano since the volcanic eruption period coincided with the appearance of the haze. Tomato plants under plastic rainshelters grew normally. Since rainwater was suspected of causing the symptoms, it was analyzed and found to be acidic (pH 4.0) and to contain appreciable quantities of Cl^- and SO_4^{2-} plus 27 detectable organic compounds in the ppb range. When tomato leaf discs were immersed in rainwater samples, more Ca, Mg, and K were leached from these acidic samples than from less acidic rainwater samples and the distilled water controls. In a pollen germination medium containing rainwater, pollen germination and tube lengths decreased as the pH of the rainwater decreased. However, since increasing the pH of the acidic Kona rainwater with NaOH did not increase pollen germination, factors other than pH are suspected to cause poor pollen germination. The pH of rainwater samples from a single heavy rainfall were less acidic than from cumulative samples of lighter rainfalls.

Additional Index Words: volcano, rainwater, pollen, leaching

G. A. MacDonald has previously pointed out the possibility of volcanic caused injury to plants (5). In Hawaii, active volcanoes have been shown to emit such volatiles as SO_2, Cl^-, H_2S, NH_4, CO, CO_2, and CH_4 (3) while fumeroles and vents in other volcanic areas have been known to emit SO_2 (1). Economic losses to plants from exposure to SO_2 have also been well documented (1). Likens et al. (4) have expressed concern for changes in ecosystems caused by acidic rains.

Tomatoes (*Lycopersicum esculentum* Mill) had been growing successfully outside in the Kona district of the Island of Hawaii, until the winter of 1969-70 when severe yield and quality reductions occurred throughout the district. Symptoms of this mysterious disease included blossom drop, poor fruit set, hollow, small and almost seedless fruits, and a less luxuriant appearance. Soil and tissue testing revealed normal amounts of macro and micronutrients. Insect injury was not apparent and no disease producing organisms could be isolated from affected plants, or the soil in which they were grown.

From the winter of 1969-70 through the summer of 1973 a definite haze has existed over the Kona district. The haze was apparently caused by fumes from active and degassing vents associated with Kilauea volcano about 75 km away. Furthermore, the eruption period of this volcano coincided both with the occurrence of the haze and onset of the symptoms in the tomato plants. The purpose of this study was to determine whether the volcanic pollution caused the injury to tomatoes and, if so, to find the physiological mechanisms involved.

MATERIALS AND METHODS

In 1972, two 18 m^2 clear polyethylene rainshelters were constructed. Five replicates of eight tomato plants (*Lycopersicum esculentum* Mill 'Tropic' and 'N-52') were transplanted under the rainshelter and four replicates of 20 plants each were transplanted outside. The fruit was picked for 2 months and the salable fruit weight was recorded.

Rainwater samples from the Kona district were collected in specially cleaned glass containers covered with aluminum foil (2). They were analyzed for pH and H^+ by titration, Cl^- by potentiometric method, SO_4^{2-} by gravimetric method, and the total anions and cations were measured. In addition, gas chromatography was performed to analyze for organic compounds.

Additional rainwater samples were collected from the Kona district on the western side of the island of Hawaii and from the Hilo and Glenwood areas on the eastern side of the island. Seven tomato leaf discs (8 mm diameter) were immersed in 10-ml rainwater samples from each area for 4 hours and the amounts of calcium, magnesium and potassium which leached out were recorded. The results were compared with controls consisting of distilled water (pH 5.6), distilled water plus HCl (pH 4.0) and Kona rainwater plus NaOH (pH 5.7). At least two water samples and a total of six replicates were tested for each treatment. Data in Table 2 are based upon four replicates of one water sample.

A pollen germination media was made consisting of three parts (i) rainwater or control water; (ii) one part 500 ppm H_3BO_3, 1500 ppm $Ca(NO_3)_2 \cdot 4H_2O$, 500 ppm KNO_3, and 1000 ppm $MgSO_4 \cdot 7H_2O$; and (iii) one part 50% sucrose (Dr. J. L. Brewbaker, personal communication). Tomato pollen (1-day-old) was placed in the above media and the percentage germination and abortion and pollen tube lengths were recorded after 17 hours of incubation at 28C. At least two water samples and a total of five replicates of 100 pollen grains were tested for each treatment. Data in Table 3 are based upon three replicates of 100 pollen grains and one water sample.

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Table 1—Analysis of rainwater taken from Kona district where tomato disease symptoms appeared (time 2 sample)

pH	4.0
H^+ (meq)	[illegible]
Cl^- (meq)	[illegible]
SO_4^{2-} (meq)	[illegible]
Total cations (meq)	0.109
Total anions (meq)	0.121

RESULTS AND DISCUSSION

Tomato plants growing under the plastic rainshelter grew normally and averaged 5 kg/plant of salable fruit whereas plants growing immediately outside the rainshelter demonstrated the previously mentioned symptoms and produced no salable yield (Fig. 1). Since the only difference between the treatments was that rain fell on the unprotected plants, it became apparent that components in the rain were the cause of the disease symptoms.

The rainwater was analyzed and shown to be a dilute solution of sulfuric and hydrochloric acid with a pH of 4.0 (Table 1). In addition, gas chromatography detected 27 organic compounds, the sum of which was in the ppb range. Rainwater from the neighboring island of Oahu (350 km away) contained these types of compounds in the ppt range or about a thousandfold less than rainwater from the Kona district (Dr. J. W. Hylin, personal communication). This might be expected since Oahu is further from the eruption site than Kona. However, rainwater from Glenwood and Hilo located only 15 km and 40 km, respectively, from the eruption site was less acidic than Kona's rainwater (Table 2 and 3). Also, no haze occurred in Glenwood although haze appeared on infrequent occasions in Hilo when the normal wind patterns changed. Both Hilo and Glenwood receive considerably more rainfall than Kona (340 cm versus 100 cm annually, U.S. Weather Bureau, Hilo, Hawaii), and this may act to clean pollutants from the air. Also, the different wind patterns apparently subject Kona to more of the volcanic pollution than Glenwood and Hilo. There are few field grown tomatoes in Glenwood and Hilo because of the high rainfall.

Rainfall has been known to leach various nutrients and compounds from plants (6). Twice as much calcium and magnesium and three times as much potassium were leached from tomato leaf discs when the pH of distilled water was lowered from 5.6 to 4.0 with HCl (Table 2). Kona rainwater leached to a greater extent than either Glenwood or Hilo rainwater. Apparently, other factors including the organic compounds in the rainwater aid in leaching since the Kona rainwater increased to pH 5.7 with NaOH leached considerable more of the cations than distilled water. Therefore, it can be concluded that foliage

Table 2—Amounts of Ca, Mg, and K leached from seven leaf discs (8 mm) immersed in 10 ml of water for 4 hours

Water source	pH	Calcium	Magnesium	Potassium
		ppm		
Distilled water	5.6	0.18	0.12	0.63
Distilled water + HCl	4.0	0.37	0.24	1.87
Glenwood rainwater	5.8	0.30	0.15	0.83
Hilo rainwater Time 1	5.0	0.30	0.13	0.82
Hilo rainwater Time 2	4.5	0.53	0.17	1.53
Kona rainwater Time 1	4.4	0.40	0.17	1.05
Kona rainwater Time 2	4.0	0.65	0.28	2.72
Kona rainwater + NaOH	5.7	0.45	0.18	1.30

Fig. 1—Tomato plants growing outside and thus subjected to volcanic pollutants in the rainwater.

Fig. 2—Tomato plants protected from rainfall by a plastic rainshelter.

of tomato plants growing in the Kona area was subjected to abnormally high leaching by polluted rainfall. Although this study only measured leaching of cations, other nutrients and organic compounds were undoubtedly also leached to a greater degree than normal.

A distinguishing tomato injury symptom was a soft hollow fruit containing few seeds. This could be caused by lack of pollen germination or too short a pollen tube. Pollen germination occurred in the media containing distilled water but not with Kona rainwater at pH 4.0 (Table 3). As the pH of the rainwater decreased, so did the pollen germination and the pollen tube lengths. Factors other than pH influenced pollen germination in the acidic

Table 3—The percentage pollen germination, abortion, and pollen tube lengths when tomato pollen (var. Pinkie) was placed in water plus nutrients necessary for germination and tube growth

Water source	pH	Germination	Pollen tube Length	Abortion*
		%	µm	%
Distilled water	5.6	7.5	660	10.7
Distilled water + HCl	4.0	0.3	--	24.3
Glenwood rainwater	5.8	7.3	610	9.5
Hilo rainwater Time 1	5.0	5.3	625	7.8
Hilo rainwater Time 2	4.5	2.2	373	15.8
Kona rainwater Time 1	4.4	2.5	413	14.0
Kona rainwater Time 2	4.0	0	--	18.7
Kona rainwater + NaOH	5.7	0.3	--	4.7

* Pollen germinated but pollen tube disintegrated

rainwaters because increasing the pH to 5.7 with NaOH did not increase pollen germination. One of these factors may have been the as yet unidentified organic substances.

The pH values of rainwater samples from Kona and Hilo varied with the time of sampling (Tables 2 and 3). Samples from a heavy rainfall (Time 1) were less acidic than cumulative samples from lighter rainfall occurring over a 2-week period (Time 2). Thus, several small rains over a period of time would be expected to cause more damage to the plants by leaching and interfering with pollen germination and pollen tube growth than one large rainfall. The possibility remains that other unidentified injury mechanisms are involved. Apparently, the first portion of a rainfall absorbs most of the pollutants from the air and is thus the most damaging to the plants.

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