# Injury of Three Ornamental Flower Crops from Simulated Acidic Fog

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**ABSTRACT**

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Flowering plants of carnation (*Dianthus caryophyllus* 'Lillipot'), chrysanthemum (*Chrysanthemum* × *morifolium* 'Florida Marble'), and zinnia (*Zinnia elegans* 'Liliput') were exposed in separate experiments to simulated acidic fog, with treatment pH ranging from 1.8 to 5.6. For all three ornamentals, flower injury was assessed to determine damage response levels. Response of carnation and chrysanthemum to acidic fog was similar. The most severe injury occurred near pH 1.8–2.0, and no injury was observed above approximately pH 3.8–4.0. Injury of zinnia was also most severe at pH 2.0 but was approximately 40% less severe than that of carnation or chrysanthemum at this acidity. In addition, zinnia, unlike the other flower species, developed flower injury at pH as high as 4.0. All flowers tested were injured at ambient acidity levels measured in many of the primary cut flower production areas of California. Acidic fog may have an economic impact on ornamental flower crops.

Acidic precipitation has received much attention in recent years. In California, acidic deposition in the form of highly acidic fog is of particular concern and evidence has shown certain fogs to be more acidic than rain (13). Heavy coastal fog and mists are common, and a documented fog event of pH 1.69 has occurred in coastal southern California. Among nearly 100 fog samples collected near Los Angeles in the winter of 1982, pH values ranged from 2.0 to 4.0, with median values below pH 3.0 (16).

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Most agricultural crops are injured by simulated fogs at acidities below pH 3.0 (8,10). Crop species differ in their sensitivity to acidic fog, but acidity levels below pH 2.0 may be necessary to reduce yields. The ability of leaves to neutralize acidity depends on inherent buffering capacity of plants (10). However, many plants with similar acid-neutralizing capacities, as measured by leaf surface pH, differ in amount of necrosis after specific acidic inputs (10).

Little is known about the impact of acidic precipitation, particularly acidic fogs, on ornamental foliage and flower crops. Simulated acidic rain has been shown to injure flowers of zinnia at pH 2.8 and mature leaves and cotyledons at pH as high as 4.0 (5). Dry weight of zinnia was also depressed at pH 2.8 relative to a pH 5.6 control (5). The ornamental cut flower industry accounted for over $86 million in revenue for California in 1987 (14), with a majority of the total acreage in coastal counties. These are areas potentially at risk from periodic episodes of highly acidic fog. The objective of this research was to determine the type and extent of injury from simulated acidic fogs on three ornamental flower crops and to assess potential impact on the cut-flower industry.

## MATERIALS AND METHODS

**Plant culture.** In separate experiments, seedlings of carnation (*Dianthus caryophyllus* L. 'Lillipot'), chrysanthemum (*Chrysanthemum* × *morifolium* Ramat. 'Florida Marble'), and zinnia (*Zinnia elegans* Jacq. 'Liliput') were placed in 473-ml Styrofoam cups containing a uniform soil mixture of peat, redwood shavings, and sand (1:1:2). All plants were watered as necessary and fertilized once weekly. Plants were grown and fogged in a evaporatively cooled glasshouse with carbon-filtered air.

**Fog system.** All flowers were fogged using a system previously described (12). The system provided simulated fog within a portable enclosure constructed from PVC pipe and covered with 0.1-mm polyethylene film. The structure surrounded all plants in each plot and was removed when not in use. Acidic fog was delivered to plots through a commercial stainless steel impingment fog nozzle. Simulated fog solution was forced at high pressure (690 kPa, 100 psi) through a 0.15-mm orifice in the nozzle and impinged on the tip of a J-shaped pin, breaking the solution into aerosol particles of less than 40 $\mu$m diameter. Delivery rate of fog was 2.1 L-hr$^{-1}$. Airflow within chambers was static during exposures. Mean liquid water content of fog was 0.78 g-m$^{-3}$ and was measured utilizing a fog collector developed previously (4). At the conclusion of each exposure, the fog chambers were removed and plants were allowed to dry. Mean drying time was approximately 4 hr but was dependent on ambient temperature and relative humidity. Chemical composition of the fog (11) was adjusted to the mean of several chemical analyses of ambient fog in the southern California basin (2,9,15). Background solutions were acidified to treatment pH with a 2.5:1 ratio of nitric to sulfuric acids, which is typical of ambient fog for this area.

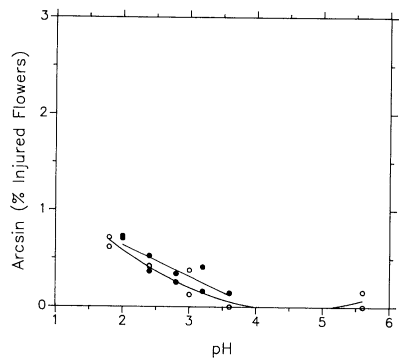


**Fig. 1.** Carnation flower injury after simulated acidic fog exposures. Experiment 1: ○ ($R^2$ = 0.901); experiment 2: ● ($R^2$ = 0.798).

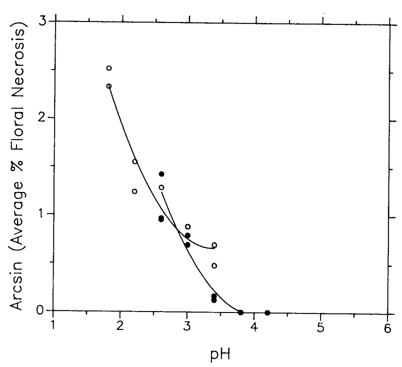


**Fig. 2.** Chrysanthemum floral necrosis after simulated acidic fog exposures. Experiment 1: ○ ($R^2$ = 0.931); experiment 2: ● ($R^2$ = 0.937).

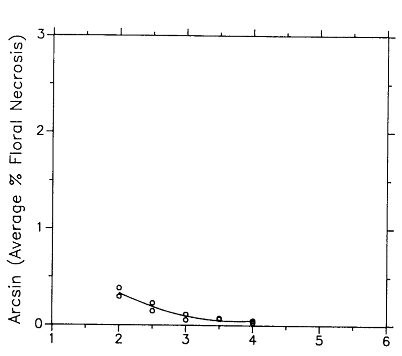


**Fig. 3.** Zinnia floral necrosis after simulated acidic fog exposures. ($R^2$ = 0.921).

**Experimental design.** Flowering carnation plants were exposed in a first experiment to five treatment pH levels: 1.8, 2.4, 3.0, 3.6, and 5.6. Plants were exposed twice, 7 days apart, to simulated fog for 2 hr predawn in the first experiment, and percent flowers injured was determined 6 days after each exposure. A second experiment modified the treatment pH levels to bracket the injury response of the first experiment. Treatment pH levels were 2.0, 2.4, 2.8, 3.2, and 3.6. However, plants were exposed to 2-hr predawn simulated fog events once weekly for 3 wk. Injury assays of percentage of flowers with necrosis were taken 3 days after each fog exposure.

Chrysanthemum cuttings at the flowering stage were exposed in two experiments to one of six pH treatments: 1.8, 2.2, 2.6, 3.0, 3.4, and no fog in experiment 1 and 2.6, 3.0, 3.4, 3.8, 4.2, and no fog in experiment 2. In both experiments, fog exposures were conducted for 1 hr predawn on consecutive days. These consecutive exposures were repeated twice, 7 days apart. Injury assays for experiments 1 and 2 were performed 4 and 9 days, respectively, after the second exposures. Total flower injury per plant, based on area injured, was visually rated on a 0–10 scale, with 0 = no injury and 10 = total death of flower.

A preliminary screening study and a complete experiment were done to determine zinnia flower sensitivity to acidic fog. Based on the preliminary study, sensitivity of zinnia was found to be in the range of pH 2.0 and 4.0. The full experiment consisted of two 1-hr predawn fogs on consecutive days, repeated 7 days apart. Simulated fog treatment pH levels were 2.0, 2.5, 3.0, 3.5, 4.0, and no fog. Injury assays were performed 4 days after the second-week fog episodes. Data collected were flower injury on a scale of 0–10, as described above.

The chrysanthemum and carnation experiments were conducted twice and the zinnia experiment once. All treatment levels were replicated twice, with 12 plants per replication for both chrysanthemum and carnation and 16 plants per replication for zinnia. All data were expressed either as percentage of total flowers showing injury (carnations) or mean percent injury (0–10) per flower (chrysanthemums and zinnias). All injury data were transformed by arcsine transformation and analyzed by polynomial regression.

## RESULTS AND DISCUSSION

Response of carnation and chrysanthemum to simulated acidic fog was very similar. Flower injury levels were severe at treatment pH levels near 2.0 and dropped to zero at pH levels of approximately 3.8–4.0 (Figs. 1 and 2). Zinnia, however, was somewhat less sensitive at low pH levels (Fig. 3). Flower injury was approximately 40% less severe at pH 2.0, but injury was still apparent at the lowest acidic level (pH 4.0), unlike carnation and chrysanthemum. A quadratic response of injury on pH was noted for all flowers except for carnation in experiment 2, and all experiments showed high coefficients of correlation

**Table 1.** Parameters for regression of flower injury vs. fog acidity for ornamental flower crops exposed to simulated acidic fog

| Flower[a] | Regression equation | $R^2$ | Significance ($F$) |
|---|---|---|---|
| Carnation | | | |
| Experiment 1 | $y = 1.926 - 0.859x + 0.094x^2$ | 0.901 | 32.0 ($P = 0.0003$) |
| Experiment 2 | $y = 1.291 - 0.327x$ | 0.798 | 31.5 ($P = 0.0005$) |
| Chrysanthemum | | | |
| Experiment 1 | $y = 8.347 - 4.555x + 0.675x^2$ | 0.931 | 46.9 ($P = 0.0001$) |
| Experiment 2 | $y = 9.900 - 4.909x + 0.607x^2$ | 0.937 | 52.0 ($P = 0.0001$) |
| Zinnia | | | |
| Experiment | $y = 1.378 - 0.711x + 0.094x^2$ | 0.921 | 41.0 ($P = 0.001$) |

[a] Carnation (*Dianthus caryophyllus* 'Lillipot'), chrysanthemum (*Chrysanthemum* × *morifolium* 'Florida Marble'), zinnia (*Zinnia elegans* 'Liliput').

(Table 1). Flower injury of carnation (experiment 1) was noted at pH 5.6 but not at the more acidic pH 3.6 treatment level. The appearance of injury at pH 5.6 is not readily explained but may be due to undetermined environmental factors. No previous crops tested at this acidity level have shown injury (8,11). As a result of the observed injury at pH 5.6, the quadratic regression equation predicts increasing injury at higher pH levels, but the biological significance of this prediction is questionable. Although the regression equation predicts the best fit through the data points, extrapolations should not be made beyond the range of the data.

Response of flowers to fog acidity was very consistent between experiments. Although the flower crops were exposed to different exposure patterns and total acidic input, initial injury was apparent after the first fog episode for all flower cultivars. Repeated exposures changed only the amount of injury, not the pH levels at which injury was observed.

The acidity level eliciting injury from simulated fog exposures varies considerably with crop and cultivar. Previous research has shown that certain crops, such as onion, tomato, and radish, are relatively insensitive to repeated exposures of very acidic fog, whereas other crops, such as bean and spinach, are much more severely affected under the same exposure conditions (11). Generally, those crops with very succulent or tender tissue, either leaf or flower, appear to be most susceptible to impact by acidic input. Therefore, ornamental flower crops would seem likely to be at risk from episodes of acidic fog.

Response of plants to acidic deposition is highly dependent on total acidic loading, determined by hydrogen ion concentration, deposition rate, and duration of acidic input (3,7,9). Ion exchange between the internal portions of the leaf and leaf surface are likely responsible for acid-neutralizing capacity (1). Because acidic precipitation may leach cations from leaf surfaces (6), repeated exposure could cause loss of buffering capacity from these cations that might result in increased injury. The buffering capacity of labile structures such as flowers, unlike normal leaves, is particularly low and results in extreme sensitivity to acidic input from initial exposure. Repeated exposures are not necessary to remove buffering capacity and cause injury to these tissues. Flowers from all three crops examined became injured from their first exposure to acidic fog.

Many of the ornamental flowers produced in California are grown in ambient air or in greenhouses exposed partially to ambient conditions such as fog. Although fog would partially dissipate on entering a greenhouse, the acidic components could impact the plants as dry acidic deposition. These fog episodes, if acidic enough, could result in substantial losses to producers from a blemished crop. Flower injury was observed on these three ornamental crops below pH 4.0. Fogs of this acidity routinely occur in many areas of California (16), including many of the primary cut-flower production areas of the state. Because injury was observed after single episodes of simulated fog in treatments within the ambient fog acidity range, losses to acidic precipitation may occur but may currently be attributed to other environmental factors. These production losses may result in higher costs to growers and consumers. Data from these experiments suggest that many ornamental flower crops are quite sensitive to acidic fog. The range of sensitivity was similar for the species studied, and further screenings would be necessary to determine if other ornamental species or cultivars are equally susceptible.

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