Effect of Acetaldehyde Vapor on Postharvest Decay and Market Quality of Fresh Strawberries

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ABSTRACT

Decay of fresh strawberries, caused by *Botrytis cinerea* or *Rhizopus stolonifer*, was controlled by fumigation with acetaldehyde vapor. Treatments with 1% concns (v/v) for 30 or 60 min were as effective as those with 4% and greater concns. Acetaldehyde vapor at these concns killed conidia of *B. cinerea* and *R. stolonifer*. Treatments with 1% acetaldehyde for 30 or 60 min did not affect quality of the fumigated berries.

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Additional key words: Fragaria sp., surface sterilization, volatile fungicide.

Postharvest decay losses of strawberries (*Fragaria* sp.) during transit and unloading have been estimated to be around $5 million annually (10). The major portion of these losses have been attributed to *Botrytis cinerea* Pers. ex. Fr. and *Rhizopus stolonifer* Ehr. ex. Fr. (4). Several postharvest treatments have been proposed but have limited commercial applications due to residue, phytotoxicity, and other problems (4).

Although high carbon dioxide (CO_2) atmospheres have been used to retard fruit ripening and to prevent decay (6, 8, 9), such atmospheres may produce skin damage or off-flavors in some fruits; e.g., citrus, bananas, apricots, and peaches (11). Certain small fruits, including strawberries, are normally not susceptible to CO_2 injury (8), and high CO_2 atmospheres have been used successfully to control decay during transit (5), without an adverse effect upon the quality of the berries at the recommended dosages. Shaw (7) reported, however, that Maryland strawberries developed off-flavor at CO_2 concns that reduced decay. These berries also produced abnormally high concns of acetaldehyde (Aa), ethyl acetate, and ethanol when held in CO_2-enriched atmospheres (7). The production of off-flavor was prevented when the atmosphere containing these volatiles was scrubbed through a water tower, but this process also eliminated decay control. When Aa was reintroduced into the atmosphere, decay control was also reestablished. Acetaldehyde has both fungidical and bactericidal properties, whereas ethyl acetate, at the concns tested, functioned only as an inhibitor of spore germination (1, 7). Acetaldehyde is also the main carbonyl compound present in the volatile fractions produced by *Trichoderma viride*, and accounted for vapor phase sporostasis (sporulation inhibition) of several fungi (3). Acetaldehyde, at 100 μliters/liter, caused slight growth inhibition of *Fomes annosus* and complete inhibition at 500 μliters/liter and above.

This investigation was undertaken to determine (i) efficacy of Aa vapor as a decay control for fresh strawberries, (ii) fungicidal action of Aa vapor to *B. cinerea* and *R. stolonifer*, and (iii) quality and flavor changes in fresh strawberries exposed to Aa vapor.

MATERIALS AND METHODS.—Strawberry (*Fragaria* sp.) fruits 'Midway' were obtained from a local grower. *B. cinerea* and *R. stolonifer* were isolated from and maintained on strawberries. To obtain inoculum, *B. cinerea* and *R. stolonifer* were grown on pea agar (PA), and potato-dextrose agar (PDA), respectively, at 24 C for 10 days. The PA contained 482 g sweet peas and brine

(one 303 can); 10 g sucrose; 20 g agar and 1.0 liter of water. Spores were collected by flushing the culture plates with sterile distilled water containing one drop of Tween 20 (polyoxyethylene sorbitan monolaurate) per liter to aid spore dispersal. The suspension was adjusted to 2.3×10^6 spores/ml for inoculation.

Culture dishes (3 mm deep × 16 mm in diam) containing PA and PDA were seeded with conidia of *B. cinerea* and *R. stolonifer*, respectively, and maintained at 24 C for 24 h to allow germination. The seeded dishes were fumigated in a sealed chamber. Liquid Aa was injected into the chamber and the resulting Aa vapor was expressed as percent of atmosphere by volume. Gas-tight syringes were chilled on an ice bath prior to injection to provide accurate calibration, since Aa boils at 20.8 C. The experiment was conducted at room temp (23-27 C). Each treatment included ten replicates. Culture dishes of *B. cinerea* and *R. stolonifer* not exposed to Aa vapor were used as controls. The fumigated cultures were transferred to petri dishes containing the same media and incubated for 21 days at 23-27 C. Colony diam of viable cultures was measured at this time and ungerminated conidia were considered to be dead.

Conidia were sprayed on 500 g of strawberries which were then exposed to Aa vapor in a fumigation chamber. Similar uninoculated strawberries were used as controls. The initial concn of Aa vapor (v/v) in the fumigation chamber and the exposure times (min) were 1%/30, 1%/60, 4%/20, 5%/10, 5%/25, and 10%/7. Treated berries were placed in paper bags containing moist paper towels and incubated 72 h at 15 C. The decayed berries in each treatment were counted after incubation for 3, 4, 5, and 6 days. Each treatment was replicated four times.

Berry quality was evaluated by 10 judges at 3, 4, 5, and 6 days after treatment. The uninoculated berries not exposed to Aa vapor were used as a standard by the panel to determine quality. Numerical ratings from seven to one were assigned to descriptive panel judgements of berry appearance, color, and injury. The ratings were as follows: 7 (best in appearance and color with no cap injury), 6 (very good in appearance and color with no cap injury), 5 (good in appearance and color with no cap injury), 4 (fair in appearance and color with minor cap injury), 3 (fair in appearance, slight discoloration with moderate cap injury), 2 (poor in appearance and color with severe cap injury), 1 (unacceptable). Mean scores were calculated for each treatment.

Flavor evaluation of the treated berries was conducted 4 days after Aa vapor exposure. Strawberries, not exposed to Aa vapor, were used as (i) known, and (ii) unknown standards by the panel for flavor evaluation of Aa-fumigated berries. The standards were used to reduce

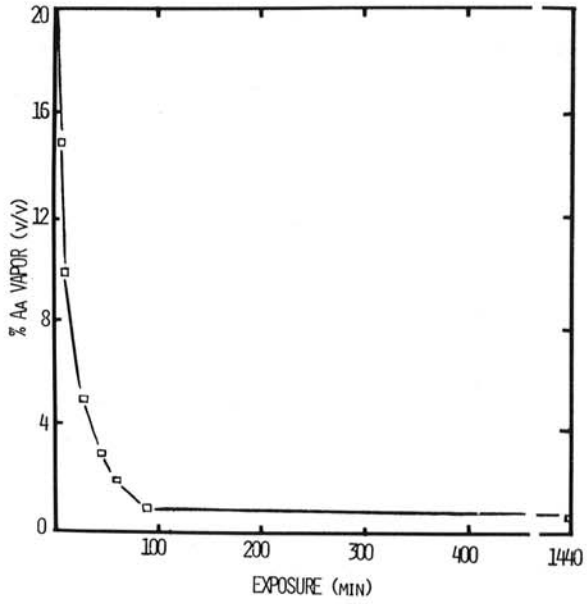

Fig. 1. The effect of concn and exposure time on the fungicidal action of acetaldehyde vapor toward germinated spores of *Botrytis cinerea* and *Rhizopus stolonifer* on agar media. The plotted points indicate combinations of conditions which killed all spores.

TABLE 1. Effect of acetaldehyde vapor on decay of fresh strawberries (cultivar Midway) inoculated with *Botrytis cinerea* and *Rhizopus stolonifer*

Pathogen	Acetaldehyde treatments		% decay at [z]		
	Concn (%, v/v)	Exposure (min)	3 days	6 days	Mean
B. cinerea	0	0	20	55	37.5 a
	1	30	12	6	9.0 b
	1	60	1	4	2.5 b
	4	20	0	5	2.5 b
	5	10	0	7	3.5 b
	5	25	1	5	3.0 b
	10	7	3	2	2.5 b
R. stolonifer	0	0	20	52	36.0 a
	1	60	3	3	3.0 b
	5	25	8	6	7.0 b
	10	7	3	2	2.5 b

[z]Treated berries were incubated at 15 C and 65% relative humidity. Each day's rating was made on a separate lot of fruit. Means followed by the same letter were not significantly different, $P = 0.05$ by Duncan's multiple range test.

flavor bias. Numerical flavor ratings of 5 (better than standard), 4 (equal to standard), 3 (below standard, but no off-flavor), 2 (below standard and definite off-flavor), and 1 (unacceptable) were assigned to the berries and mean scores were calculated for each treatment.

RESULTS.—*Fungicidal activity of acetaldehyde.*—The fungicidal action of Aa vapor against germinated conidia of *B. cinerea* or *R. stolonifer* on agar was a function of Aa concn and exposure time (Fig. 1). Berries inoculated with fumigated germlings of *B. cinerea* or *R. stolonifer*, and incubated for 6 days at 21 C and 65% relative humidity did not decay, whereas nonfumigated spores germinated in 10-12 h and induced decay of berries within 3-4 days.

Decay control.—Effect of Aa vapor in decay control of strawberries is shown in Table 1. Strawberries inoculated with *R. stolonifer* or *B. cinerea* decayed progressively when not exposed to Aa vapor, but decay was prevented by exposing the berries to an atmosphere of 1-10% Aa. At low concentration of Aa vapor, longer exposure was required for control.

Phytotoxicity of acetaldehyde vapor.—Exposure to 1% Aa vapor did not reduce the quality of berries in comparison with unexposed berries (Table 2). Quality was decreased at concentrations of 4% or more. The panel indicated low preference to berries fumigated with 4% Aa or higher. Color of berries exposed to 1% Aa vapor for 60 or 30 min (low concn–long exposure) and 10% Aa vapor for 7 min (high concn–short exposure) remained unchanged. Injury to caps of berries exposed to 1% Aa vapor for 30 min did not differ from that of 1% for 60 min. However, Aa concns of 4% and above increased cap injuries if exposures of 10 min or more were used.

Organoleptic evaluation.—The flavor of berries exposed to 1% Aa for 30 min was below standard, but no off-flavor was detected; whereas, 1% Aa vapor for 60 min did not alter the flavor (Table 2). The panel felt that berries exposed to 1% Aa for 30 min were not as sweet as untreated controls or those exposed to 1% for 60 min. Exposure to 4% Aa or higher vapor concns produced off-flavor in berries.

DISCUSSION.—Decay of strawberries inoculated with *B. cinerea* or *R. stolonifer* was reduced by Aa vapor. The margin of tolerance of strawberries to Aa was narrow, but adequate for decay control. Exposure of fruit to low concns of Aa vapor for 60 min did not cause phytotoxicity or alter appearance and color to the berries. This demonstrates the feasibility of surface sterilizing strawberries by Aa vapor without affecting the market quality.

Spores of *B. cinerea* and *R. stolonifer* on artificial medium were killed by exposure to Aa vapor. Volatile aldehydes are inhibitors of spore germination of some species of fungi (2). This was also demonstrated by the antagonistic properties of *Trichoderma* isolates (3). Acetaldehyde was identified as one of the volatile inhibitors of several test fungi.

Exposure of strawberries to high concns of Aa vapor for a short time is not practical due to the development of objectionable off-flavors. Flavor preferences for berries exposed to 1% Aa vapor for 60 min suggest potential application of this treatment, although berries exposed to 1% Aa vapors for 30 min were given a lower flavor rating because they were sour. Acetaldehyde did not alter total solids, pH, or titratable acidity in fumigated berries (7).

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TABLE 2. Effect of acetaldehyde vapor on market quality and flavor of fresh strawberries (cultivar Midway)

Acetaldehyde treatment		Mean Ratings[z]		
			Flavor	
Concn (%, v/v)	Exposure (min)	Market quality	Standard unknown	Standard known
0	0	5.4 a	4.3 a	4.0 a
1	30	5.6 a	2.5 b	3.0 b
1	60	4.9 a	4.0 a	4.0 a
4	20	3.5 b	1.0 b	1.0 e
5	10	3.8 b	1.5 c	1.5 d
5	25	2.8 c	1.5 c	2.0 c
10	7	3.0 bc	1.2 d	1.5 d

[z]Strawberries were held at 15 C and approximately 65% relative humidity. Market quality of fumigated berries was rated after 3, 4, 5, and 6 days holding and ranged from 7 (best) to 1 (unacceptable). Flavor was rated after 3 days holding and ranged from 5 (better than standard) to 1 (unacceptable). Means followed by the same letter were not significantly different, $P=0.05$ by Duncan's multiple range test.

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