The Use of Vinegar Vapor to Reduce Postharvest Decay of Harvested Fruit

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Abstract. **Vapors of several common vinegars containing 4.2% to 6.0% (= 2.5 to 3.6 mol·L^{-1}) acetic acid effectively prevented conidia of brown rot [*Monilinia fructicola* (G. Wint.) Honey], gray mold (*Botrytis cinerea* Pers.:Fr.), and blue mold (*Penicillium expansum* Link) from germinating and causing decay of stone fruit (*Prunus* sp.), strawberries (*Fragaria ×ananassa* Duchesne), and apples (*Malus ×domestica* Borkh.), respectively. Fruit were fumigated in 12.7-L sealed containers in which vinegar was dripped on to filter paper wicks or vaporized by heating from an aluminum receptacle. Vapor from 1.0 mL of red wine vinegar (6.0% acetic acid) reduced decay by *M. fructicola* on 'Sundrop' apricots (*Prunus armeniaca* L.) from 100% to 0%. Similarly, vapor from 1.0 mL of white vinegar (5.0% acetic acid) reduced decay in strawberries by *B. cinerea* from 50% to 1.4%. Eight different vinegars, ranging from 4.2% to 6.0% acetic acid, of which 0.5 mL of each vinegar was heat-vaporized, reduced decay by *P. expansum* to 1% or less in 'Jonagold' apples. The volume of heat-vaporized white vinegar (5.0% acetic acid) necessary to reduce decay by *P. expansum* on 'Jonagold' apples to zero was 36.6 µL·L^{-1} of air. Increasing the number of conidia on the apple surface reduced the effectiveness of vinegar vapor. The number of lesions caused by *P. expansum* on 'McIntosh' apple decreased exponentially with increasing time of fumigation, approaching zero after about 6 hours. These results suggest that vinegar vapor could be an effective alternative to liquid biocides such as sodium hypochlorite for sterilization of surfaces contaminated by conidia of fungal pathogens.**

Vinegar is used extensively in food processing as an important preservative and acidulant in pickles, salad dressings, tomato products, and mustards. Vinegars are also used in the curing of meat and in the canning of certain vegetables. In many countries vinegar is also used as a condiment with French-fried potatoes. Vinegar is the product resulting from the acetification of alcoholic solutions derived from sugary or starchy materials. In Canada, vinegar is legally defined as liquid obtained from the acetous fermentation of an alcoholic liquid containing ≥4.1% and ≤12.3% acetic acid. White distilled vinegar (vinegar made from pure alcohol diluted with water to which certain nutrients have been added) is the vinegar most commonly used in industry (Young, 1974). In addition to white vinegar, standard table vinegars of France, the British Isles, and the United States are made from grapes, malt, and apples, respectively.

Acetic acid, the principal organic component of vinegar, is known for its preservative and flavoring properties (Busta and Foegeding, 1983). Levine and Fellers (1940) demonstrated a broad range of susceptibilities of microorganisms to acetic acid, but only in the last 10 years has it been extensively tested as a fumigant for control of microorganisms that cause food spoilage. Early fumigation trials on fruit inoculated with conidia of various postharvest pathogens were conducted in specially constructed 12.7-L containers, containing fans to circulate air within the chamber and filter-paper wicks to evaporate the glacial acetic acid (Sholberg and Gaunce, 1995). Surprisingly low quantities of pure acetic acid were required to inactivate the conidia on the various fruit samples that were tested. As little as 1.4 mg·L^{-1} of acetic acid vapor prevented decay of peaches inoculated with conidia of *Monilinia fructicola* or *Rhizopus stolonifer* (Ehrenb. ex Fr.) Lind (Sholberg and Gaunce, 1996). Fumigation with 2.0 or 4.0 mg·L^{-1} acetic acid before wounding prevented apples contaminated with *Botrytis cinerea* or *Penicillium expansum* conidia, respectively, from decaying (Sholberg and Gaunce, 1995). Use of acetic acid vapor controls many microorganisms and has been reviewed by Sholberg et al. (1998).

Vaporizing vinegar allows acetic acid molecules that were in solution to become a gas as an undissociated acid that exists as a mixture of monomers, hydrogen bonded dimers, and trimers (Seaton, 1993). The undissociated form of acetic acid is primarily responsible for its antimicrobial activity (Reynolds, 1975). Therefore, vinegar should be more effective in preventing decay when it is gaseous. This is because the undissociated molecules of acetic acid will easily pass through the membrane of conidia on the fruit surface and either kill or inactivate them by lowering the pH of the cell protoplasm.

The objective of this study was to determine if the vapor of several commercially available vinegars, containing from 4% to 6% acetic acid, would be effective in preventing decay of stone fruit, strawberries, and apples contaminated with conidia of postharvest decay fungi. Characteristics of vinegar as a fumigant, such as optimum concentration, length and temperature of fumigation, and type of delivery system, were also studied. A preliminary report of this research has been published (Sholberg, 1998a).

Materials and Methods

Vinegars. Vinegars were purchased from local merchants. The pH was measured with an analog pH meter with glass electrode (Fisher Accumet; Fisher Scientific, Ottawa, Ont.) and the percentage of acetic acid was determined by an acid-base (NaOH) titration to an 8.30 endpoint with a Brinkman titroprocessor ensemble (Metrohm, Herisau, Switzerland) (Table 1). This endpoint was chosen because it was the midpoint (equivalence point) on the curve where the pH was changing most rapidly.

Fruit. Apples harvested at commercial maturity in Fall 1996 and 1997 were from plots at the Pacific Agri-Food Research Centre, Summerland, B.C., Canada. Similarly, apricots, cherries (*P. avium* L.), and peaches [*P. persica* (L.) Batsch] were harvested ripe from Research Centre plots during Summer 1996. Ripe strawberries were purchased locally on 21 June 1996 for use in these studies. If fruit was not used immediately, it was stored at 1 °C until required.

Inoculum. Fruit were inoculated with pure cultures of fungi originally obtained from infected fruit. Fungi used were *Botrytis cinerea, Penicillium expansum,* strains A, B (resistant to the fungicide benomyl), and *Monilinia fructicola.* The fungi were maintained on potato dextrose agar (PDA) slants at 2 °C. Isolates were grown on PDA for 1–2 weeks at 20 to 23 °C. Conidia were harvested by using 5–10 mL of sterile distilled water (SDW) to wash a sporulating culture into a screw cap test-tube. The number of conidia or colony-forming units (cfu) per mL were adjusted with a hemacytometer. The adjusted suspensions were dispensed in 1-mL aliquots into 2-mL cryovials, frozen, and stored at about –20 °C. Conidial suspensions were thawed for 10–15 min, used for inoculation, and returned to the freezer until needed again. Cherries were inoculated in a laminar flow-hood by inscribing a circle ≈1 cm in diameter with a black marking pen on the fruit surface and placing a 20-µL drop of conidial suspension within the circle, where the drop was allowed to dry. Similarly, apricots were inoculated with three drops, and peaches and apples with four drops, evenly distributed around the suture or calyx end of each fruit. Because of the soft surface of strawberry fruit, pint (0.48 L) baskets of strawberries were misted with ≈1 mL of the

conidial suspension. The suspension was allowed to thoroughly dry for at least 4 h before fruit were fumigated with vinegar or water vapor.

Fumigation procedures. Fruit were fumigated in three 12.7-L chambers made from large tin cans with 0.6-amp, 115-volt circulation fans attached to the lids, as previously described for acetic acid fumigation (Sholberg and Gaunce, 1995). Fumigation of stone fruit, strawberries, and the first series of apples were conducted with filter paper as wicks for evaporating vinegar or water in the chambers. This was achieved by injecting the liquid from a 1-cm sterile, disposable syringe into the sealed chamber through a rubber septum on to a #1 Whatman filter paper. The liquid evaporated in ≈5 min. Because of problems with incomplete evaporation of liquid from the filter paper, a new system was devised. The improved evaporator consisted of a machined aluminum rod, which was drilled to accommodate a 9.5-mm-diameter, 150-W cartridge heater (CIR No. 2012/120; Omega Engineering, Stamford, Conn.) (Fig. 1). The upper surface of the rod was machined to allow 1 mL of vinegar to be boiled off when the cartridge heater was connected to a 120-volt power source. The apparatus thus constructed was attached to the chamber lid, and liquid was placed in the aluminum evaporator via a sterile disposable syringe through a rubber septum. Placement and evaporation of the liquid and functioning of the evaporator were observed through a clear polycarbonate viewing port immediately above the aluminum receptacle. All of the liquid boiled off in <2 min of operation, with very little release of heat into the chamber. During boiling of the liquid, the enclosed circulation fan (Rotron Sprite SU2C1; Electrosonic, Vancouver, B.C.) was activated for 20 min to distribute vinegar vapor over the fruit surfaces in the chamber.

This system was used to conduct the rest of the fumigations described in this study, specifically, studies with apples inoculated with *P. expansum* to determine optimum vinegar concentration, and duration of fumigation, and to compare eight vinegars for efficacy in controlling decay. Fumigation studies were conducted at 20 °C, except for studies on the effect of temperature that were conducted at 1, 10, 20, and 25 °C.

Evaluation of inactivation of conidia by fumigation with vinegar vapor. All fruit except strawberries were wounded to a depth of ≈5 mm with a sterile glass rod (2 mm diameter) within the inscribed circles, and incubated at 20 °C in a temperature-controlled room (Conviron, Winnipeg, Man.). Stone fruit and strawberries were incubated for 3–5 d and apples for 5–7 d. Decay was evaluated by counting the number of decayed wounds on each fruit. For the study on fumigation duration, lesion diameter was measured.

Statistical analysis. A single fumigation was considered a replicate for the purposes of this study. Thus, each replicate of four apples with three or four lesions per fruit were counted to give the percentage of lesions infected. Each fumigation was repeated three or more

times. Data were analyzed by the General Linear Models procedure (SAS Institute, Cary, N.C.), and, where proportions were involved, the data were arcsin-transformed. Means were separated by the Duncan's multiple range test when the analysis of variance showed statistical significance ($P \leq 0.05$). Nonlinear regression curves were fitted to data from studies on vinegar concentration and duration of fumigation for blue mold decay of apples, and appropriate equations derived by analysis provided by GraphPad Software (San Diego).

Results

Acetic acid content and pH of several vinegars. Vinegars used in this study originated from Canada, France, Italy, and the United States (Table 1). They varied in concentration of acetic acid, and similar vinegars often contained different concentrations. Apple cider vinegar had the highest concentration of acetic acid (6.0%) of all the vinegars, although its label reported a concentration of 5.7%. The vinegars never varied by more than 0.4% acetic acid between reported and actual concentrations, and most varied by <0.2%. Malt vinegar had the highest pH (3.4) and white vinegar the lowest pH (2.8) of the 11 vinegars evaluated. The mean pH of the vinegars was 3.1 with a standard deviation of 0.2.

Vinegar vapor for control of fruit decay. Vinegar vapor at 20 °C destroyed conidia of *M. fructicola* on apricots and cherries, as evidenced by zero decay in 'Sundrop' apricot and 'Sweetheart' cherry fruit vs. 100% decay in nontreated fruit (Fig. 2). Vinegar vapor also reduced brown rot to very low levels in both 'Harbrite' and 'Red Haven' peaches compared to 100% brown rot in the controls.

Table 1. Country of origin, pH, and acetic acid content of vinegars used for fumigation of fruit.

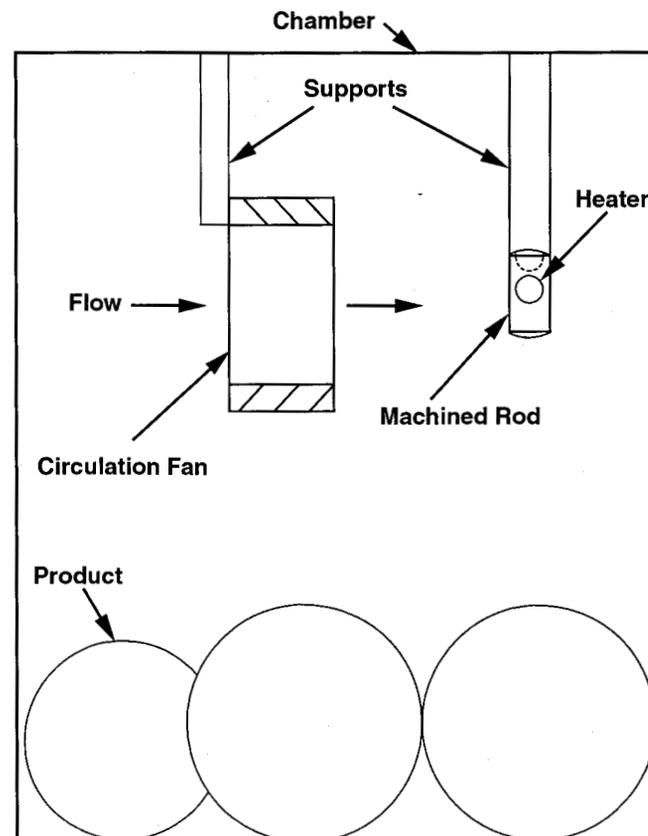|			Acetic acid (%)	
Vinegar	Country of origin	pH	Tested	On label
Apple cider A	Canada	3.1	5.2	5.0
Apple cider B	Canada	3.0	6.0	5.7
Balsamic A	Italy	3.2	5.6	6.0
Balsamic B	Canada	3.1	5.8	6.0
Brown rice	United States	3.0	4.1	4.2
Malt	Canada	3.4	5.1	5.0
Raspberry	France	3.1	6.0	6.0
Red wine A	Canada	2.9	5.0	5.0
Red wine B	United States	3.1	5.8	6.0
White wine	Canada	2.9	5.0	5.0
White	Canada	2.8	5.1	5.0

Fig. 1. Schematic diagram of the improved fumigation chamber. Lid and wiring are removed for clarity.

Although the apricots and peaches used in these trials were very ripe, there were no signs of phytotoxicity, such as browning observed on treated fruit (Fig. 3).

White vinegar vapor (1 mL for 16 h) was the most effective treatment for strawberries inoculated with conidia of *B. cinerea* (1×10^3 cfu/mL), reducing decay from 50% (control) to 1.4% (Table 2). Fumigations with higher concentrations of vinegar for shorter periods of time were not as effective. Although determined without the aid of rigorous sensory tests, strawberries treated with vinegar were indistinguishable from healthy fruit in flavor and appearance.

White vinegar vapor reduced blue mold decay to zero in 'Golden Delicious', 'Delicious', and 'Spartan' apples (Fig. 4). Balsamic vinegar was not as effective as white vinegar, but was more effective than the water vapor control in three of the four apple cultivars. The vinegars did not injure the fruit or result in a vinegar taste if they were allowed to aerate for 10–30 min before tasting.

Effect of spore number, fumigation time, and vinegar concentration. In general, vinegar vapor was most effective in reducing decay when few *P. expansum* conidia were present and became less effective as the number of conidia increased (Fig. 5). Vinegar vapor controlled decay when fruit were inoculated with 1000 conidia/mL but was ineffective when 1 million conidia/mL were used.

The size of lesions on 'McIntosh' apples contaminated with 10^5 cfu/mL of *P. expansum* strain A and fumigated with white vinegar vapor decreased exponentially with time of fumigation, reaching zero after ≈6 h (Fig. 6). The nonlinear regression curve fitted to the data points had an r^2 value of 0.86. The curve is described by the following equation:

$$Y = start\ e^{\ kx} \qquad [1]$$

where start = 23.94 mm, k = –0.7947, x = fumigation time (h), and Y = lesion diameter at time x.

The quantity of vinegar vapor/L of air needed to reduce decay by *P. expansum* on apples was calculated from a dose-response (variable slope) curve generated by plotting percentage decayed blue mold lesions against vinegar volume (Fig. 7). The nonlinear regression curve had an r^2 of 0.75. The equation for this curve is as follows:

$$Y = B + (T - B) / 1 + 10^{(log\ EC50 - X)\ Hillslope} \quad [2]$$

where Y = percentage decayed lesions, B = 13.5, T = 82.8, LogEC50 = 2.366, HillSlope = –14.44, and X = logarithm of vinegar concentration. Thus, the EC50 value (volume that will reduce the number of decayed lesions by 50%) was estimated to be 18.3 μL·L^{-1} of air, assuming complete vaporization of acetic acid. Doubling this value to 36.6 μL·L^{-1} of air almost completely controlled decay with white vinegar containing 5% acetic acid.

The results of studies on the effect of vaporized vinegar at 1, 10, 20, and 25 °C on 'McIntosh' apples were extremely variable. Generally, vinegar vapor was more effective at 20 and 25 °C than at 1 and 10 °C. For
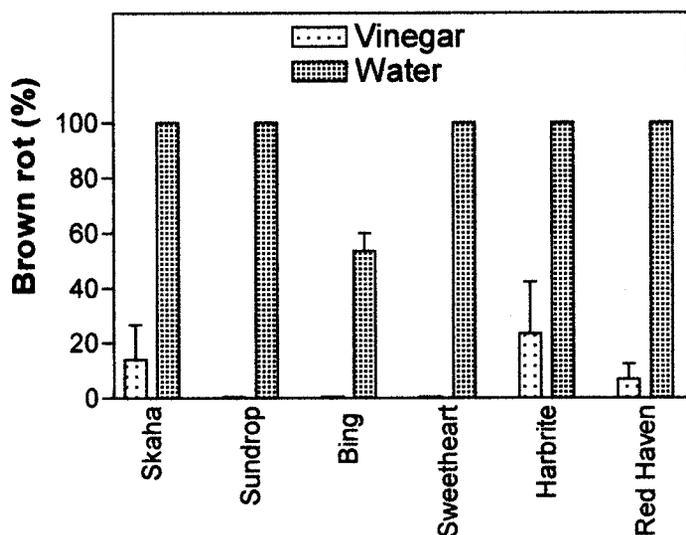
Fig. 2. Control of stone fruit brown rot by vinegar vapor. 'Skaha' and 'Sundrop' apricots, 'Bing' and 'Sweetheart' cherries, and 'Harbrite' and 'Redhaven' peaches were inoculated with 20-μL drops of a conidial suspension of *M. fructicola* (1×10^5 cfu/mL), fumigated for 17 h with 1 mL water or vinegar, wounded with a glass rod and incubated at 20 °C for 5 d after which percentage of decayed wounds were recorded. Each treatment or fumigation was replicated three times.
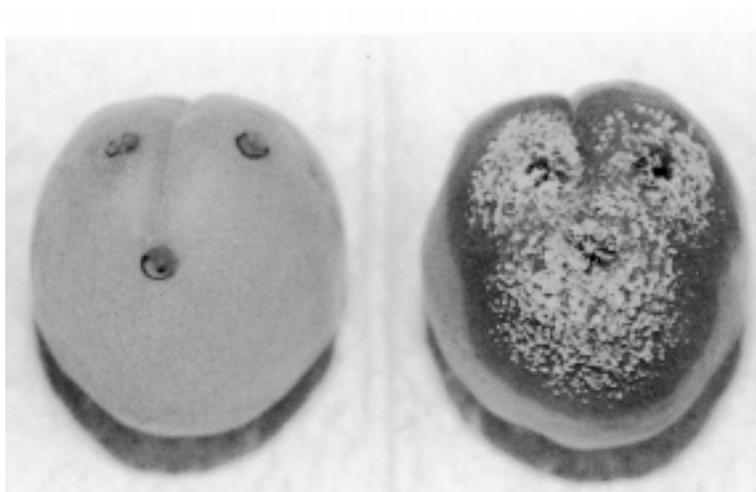
Fig. 3. Control of apricot brown rot by vinegar vapor. Apricots were inoculated with 20-μL drops of a conidial suspension of *M. fructicola* (1×10^5 cfu/mL), fumigated for 16 h with 1 mL of red wine vinegar or water, wounded with a glass rod and incubated at 20 °C for 5 d. (**left**) treated with vinegar, (**right**) treated with water. Note the absence of decay and phytotoxicity on the vinegar-treated apricot.

Table 2. Effect of vinegar or water at 20 °C on conidia of *B. cinerea* (1×10^3 cfu/mL) contaminating strawberries.

Type of vinegar	Amount vaporized (mL)	Duration of fumigation (h)	Fruit decayed[z] (%)
Water (control)	1.0	0.5	50.0 ab
White	1.0	0.5	63.9 a
White	3.0[y]	0.5	12.5 bc
White	1.0	16.0	1.4 c
White wine	3.0[y]	0.5	58.7 a

[z]Data were arcsin transformed prior to analysis of variance. Numbers are the means of three replications. Means separation by Duncan's multiple range test, $P \leq 0.05$.

[y]Not all the vinegar evaporated from the filter paper wicks.
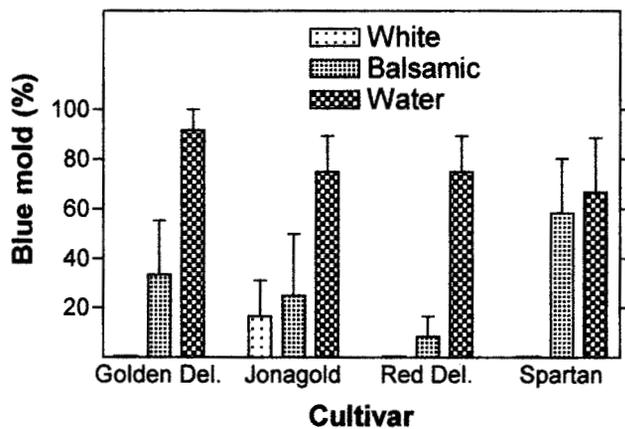
Fig. 4. Control of blue mold decay of apple by vinegar vapor. 'Golden Delicious', 'Jonagold', 'Red Delicious', and 'Spartan' fruit were inoculated with 20-μL drops of benomyl-resistant *P. expansum* (1×10^6 cfu/mL), and fumigated with 3-mL quantities of balsamic, white vinegar, or water for 90 min. The apples were wounded with a glass rod, and incubated at 20 °C for 6 d after which percentage of lesions with blue mold was recorded.
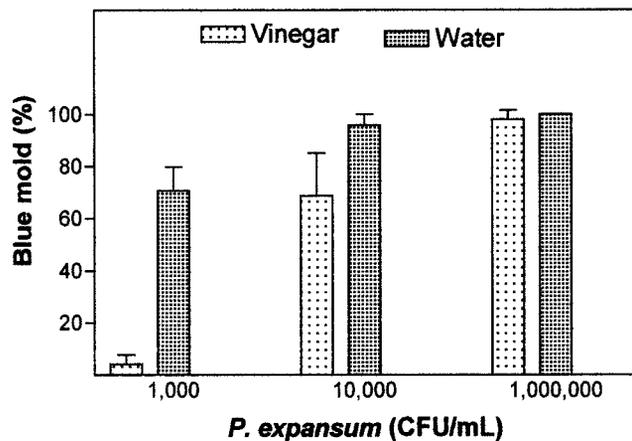
Fig. 5. Effect of number of *P. expansum* conidia on fruit on control of blue mold by vinegar vapor. 'Jonagold' apples were inoculated with 20-μL drops of conidial suspensions containing 1×10^3, 1×10^4, and 1×10^6 cfu/mL of *P. expansum,* fumigated with 3 mL of white vinegar for 30 min, wounded with a glass rod, and incubated at 20 °C for 6 d after which percentage of lesions with blue mold was recorded.
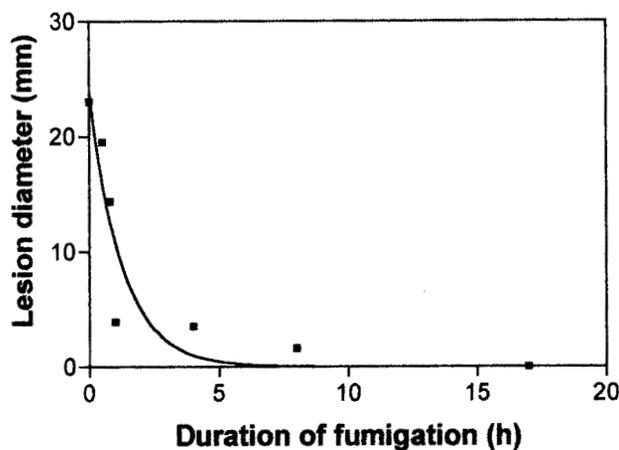

Fig. 6. Effect of duration of fumigation with vinegar on control of *P. expansum* on 'McIntosh' apples. Fruit were inoculated with 20-μL drops of *P. expansum* (1×10^5 cfu/mL) and fumigated with 0.5 mL heat-vaporized white vinegar for 0.5–17 h. The apples were wounded with a glass rod, and incubated at 20 °C for 7 d, at which time rot diameters were recorded. Lesion diameters were plotted against fumigation duration. A nonlinear regression curve for an inverted exponential growth curve fit the data best having an R^2 value of 0.86. Each fumigation duration was replicated three times and each data point represents the mean of 12 lesion diameters.
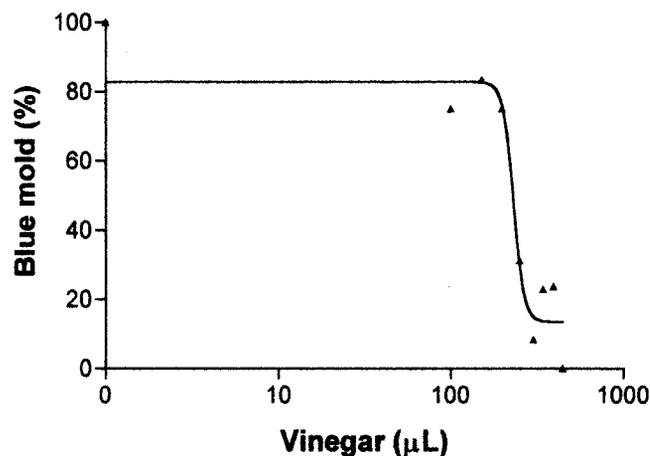
Fig. 7. Effect of volume of vinegar on control of blue mold decay. 'Jonagold' apples were inoculated with 20-μL drops of *P. expansum* (1×10^5 cfu/mL), fumigated with 0 to 500 μL of heat-vaporized white vinegar for 17 h, wounded with a glass rod, and incubated at 20 °C for 6 d, at which time percentage lesions with blue mold decay were recorded. Data were plotted against vinegar volume. A nonlinear regression dose-response curve was fitted to the data, yielding an R^2 value of 0.75. Each fumigation volume was replicated three times.

example, when 300 μL of white vinegar was vaporized at 10 °C, 96% of the lesions decayed vs. 33%, and 31% at 20 and 25 °C, respectively.

Vinegar type and method of delivery of vapor. Nine different vinegars were compared in a trial where vinegar was evaporated from filter paper wick or vaporized by boiling. Vinegars evaporated off filter paper were variable in their effectiveness for control of blue mold on apples and only white vinegar reduced decay to an acceptable level (Table 3). Red wine, balsamic, raspberry, and brown rice vinegars reduced decay but allowed an average of 21% decay. However, all the

vinegars, when heat vaporized, were effective in reducing decay to 1% or less compared to 92% in the control (Fig. 8). Furthermore, none of the vaporized vinegars caused any phytotoxicity to the apples.

Discussion

Vinegar vapor, regardless of its source, effectively inactivated conidia of several decay-causing fungi on several different fruits. However, a significant quantity of the vinegar had to be evaporated to obtain effective sterilization of fruit surfaces when compared with glacial acetic acid. For example, Sholberg and Gaunce

(1995) showed that 2.5 μL·L⁻¹ of glacial acetic acid in air totally prevented decay by *P. expansum* (1×10^5 cfu/mL) on 'Spartan' apples at 20 °C, whereas ≈35 μL·L⁻¹ of white vinegar was required (Fig. 7) to achieve the same effect. Thus, glacial acetic acid was roughly 14 times as effective as vinegar containing 5% acetic acid. Therefore control of decay is proportional to the acetic acid content.

Although vinegar is not as effective as glacial acetic acid, it has several advantages that could make it an important antimicrobial vapor for use in controlling postharvest decay. Important considerations are its safety, low phytotoxicity, antimicrobial spectrum,

Table 3. Effects of fumigation with vinegar on decay of 'Jonagold' apple lesions after inoculation with *P. expansum* at 20 °C.

	Decayed lesions (%)	
Solution	Solution (3.0 mL) evaporated from filter-paper[z]	Solution (0.5 mL) vaporized by boiling[y]
Water (control)	66.9 ab[x]	91.6 a
White wine	71.3 a	0.0 b
Malt	52.1 abc	0.0 b
Apple cider	40.9 bcd	1.0 b
Red wine	32.5 cd	0.0 b
Balsamic	28.9 cd	0.0 b
Raspberry	22.9 d	0.0 b
Brown rice	20.8 d	1.0 b
White	2.8 e	0.0 b

[z]Vinegar or water was dripped on to a filter paper wick in a sealed chamber and evaporated for 30 min at 20 °C. The filter paper remained damp after the fumigation indicating that not all the vinegar evaporated.
[y]Vinegar or water was dripped into an aluminum receptacle, vaporized by heat for 2 min and left for 17 h in a sealed chamber at 20 °C.
[x]Mean separations within columns by Duncan's multiple range test, $P \leq 0.05$.

Fig. 8. Effect of type of vinegar on control of apple blue mold. 'McIntosh' apples were inoculated with 20-μL drops of *P. expansum* (1×10^5 cfu/mL), fumigated with 0.5 mL of heat-vaporized apple cider (**top left**), red wine (**top right**), white (**bottom left**), or water (**bottom right**), for 17 h, wounded with a glass rod, and incubated at 20 °C for 7 d. Note the absence of any signs of decay or phytotoxicity on the vinegar-treated fruit vs. the severely decayed lesions on the water-treated one.

and its ability as a gas to reach parts of the fruit surface inaccessible to liquids. In the vapor form it is not explosive at the amounts used in this study, poses minimal danger to workers or animals, and could be used by a person with very little technical training. Conversely, glacial acetic acid and other short-chain acids in the vapor form can be extremely phytotoxic (Sholberg, 1998b). Use of acetic acid on apricots and peaches is severely limited because concentrations as low as 2.5 μL·L⁻¹ caused brown streaks on the fruit surfaces (Sholberg and Gaunce, 1996). In these trials, we did not observe phytotoxicity on either apricots or peaches fumigated with vinegar.

The antimicrobial spectrum of acetic acid is much wider than the four fungi against which it was tested. Vinegar is known to be effective against most microorganisms except for acetic, lactic, and butyric acid bacteria which are markedly tolerant to acetic acid (Baird-Parker, 1980; Doores, 1993). These organisms are not fruit pathogens, and in general, are not human pathogens. However, acetic acid vapor will inhibit bacteria such as *Salmonella typhimurium* (Leoffler) Castellani and Chalmers, *Escherichia coli* 0157:H7 (Migula) Castellani and Chalmers, and *Listeria monocytogenes* (Murray et al.) Pirie (Delaquis et al., 1999). Perhaps vinegar vapor might also reduce the number of these bacteria and other fecal-derived bacteria that occasionally contaminate the surface of fruit. Finally, as a fumigant, vinegar will penetrate areas of the fruit that are not reached by liquids such as chlorinated or ozonated water. Furthermore, fruit can be fumigated in the container in a sealed chamber or room without handling and potentially bruising or injuring the fruit.

The effectiveness of vinegar vapor can be improved in several ways. As was discovered in these studies, the vinegar must be completely evaporated for optimum effectiveness. When filter-paper was used for evaporation, much of the vinegar remained in the paper, resulting in poor efficiency (Table 3). Evaporating the vinegar by quickly heating it to boiling resulted in much more reproducible results with significantly lower quantities of vinegar.

The fumigation had to be at least 6 h (Fig. 6), leading to fumigations of 17 h because the chamber was kept sealed overnight. This appears to be the optimal duration for commercial use because the produce could be left overnight and the fumigation chamber opened the next morning. If the correct amount of vinegar were used for fumigation, little if any vinegar vapor would remain in the room because it would be completely absorbed by the produce.

Vinegar vapor was more effective at 20 than 10 °C although it still provided good control at 10 °C. Further research must be conducted on the effect of temperature because in this study variability was extremely high at each temperature in all the replicates. However, as with acetic acid, which was effective at 2 °C in repeated trials on table grapes (*Vitis vinifera* L.) for control of *Botrytis cinerea* and *Penicillium* sp. (Sholberg et al., 1996), vinegar should be effective at ambient harvest temperatures as well as at refrigerated storage temperatures.

The number of conidia on the fruit surface also influenced the degree of control vinegar vapor provided. Vinegar was very effective when the number of conidia on the fruit surface was 1000 cfu/mL. A similar effect was found for acetic acid vapor used to fumigate 'McIntosh' apples (Sholberg and Gaunce, 1995). This implies that any sanitation procedures that keep the inoculum low will allow for more effective fumigation with vinegar.

Finally, the concentration of acetic acid in the vinegar could be increased. The 11 most common vinegars tested contained from 4% to 6% acetic acid. A concentrated vinegar (up to 10% to 12.5% acetic acid) can be obtained in the production of distilled vinegar by suitable adjustment of the alcohol and acid content of a denatured vinegar stock (Young, 1974). Vinegars with higher concentrations of acetic acid could be made available by vinegar manufacturers if the demand for them were sufficient. According to Canadian law, vinegars containing up to 12.3% acetic acid can be sold legally. Such vinegars would probably provide the same effectiveness at half the volume that was found effective in these trials.

These preliminary studies indicate that fumigation with vinegar vapor prevents fruit decay and could become an important alternative to liquid sterilants such as sodium hypochlorite. More research is needed on the acetic acid concentration of vinegar vapor to determine required levels for decay control. This could be done by sampling the vapor and determining the concentration either with a

gas chromatograph or continuously with a solid state detector as described by Sholberg et al. (1999). Drawbacks to this method of sterilization are the need for an airtight enclosure and the corrosiveness of the vapor when in contact with steel. However, because alternatives are urgently needed for food sterilization, every effort should be made to adapt the use of vinegar vapor into the arsenal of decay-prevention strategies.

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