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 14%. 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.

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Materials and Methods

Vinegars. Vinegars were purchased from local merchants. The pH was measured with an analog pH meter with glass electrode (Fisher Accuret; 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.

Trichoderma viride. Fungi were harvested from agar plates at Pacific Agri-Food Research Centre, Summerland, B.C., Canada. Similarly, apricots, cherries (P. avium L.), and peaches (P. persica L.) batches 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 sonicating cultures of Monilinia fructicola or Rhizopus stolonifer (Ehrenb. ex Fr.) Lind (Sholberg and Gaunce, 1996). Conidia counts were 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 fungicide, 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).
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* ≤ 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>
<thead>
<tr>
<th>Vinegar</th>
<th>Country of origin</th>
<th>pH</th>
<th>Tested</th>
<th>On label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple cider A</td>
<td>Canada</td>
<td>3.1</td>
<td>5.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Apple cider B</td>
<td>Canada</td>
<td>3.0</td>
<td>6.0</td>
<td>5.7</td>
</tr>
<tr>
<td>Balsamic A</td>
<td>Italy</td>
<td>3.2</td>
<td>5.6</td>
<td>6.0</td>
</tr>
<tr>
<td>Balsamic B</td>
<td>Canada</td>
<td>3.1</td>
<td>5.8</td>
<td>6.0</td>
</tr>
<tr>
<td>Brown rice</td>
<td>United States</td>
<td>3.0</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Malt</td>
<td>Canada</td>
<td>3.4</td>
<td>5.1</td>
<td>5.0</td>
</tr>
<tr>
<td>Raspberry</td>
<td>France</td>
<td>3.1</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Red wine A</td>
<td>Canada</td>
<td>2.9</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Red wine B</td>
<td>United States</td>
<td>3.1</td>
<td>5.8</td>
<td>6.0</td>
</tr>
<tr>
<td>White wine</td>
<td>Canada</td>
<td>2.9</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>White</td>
<td>Canada</td>
<td>2.8</td>
<td>5.1</td>
<td>5.0</td>
</tr>
</tbody>
</table>

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

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**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:

\[
Y = \text{start} e^{kx}
\]

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:

\[
Y = B + \frac{T - B}{1 + 10^{(\log EC50 - X) \text{HillSlope}}}
\]

where \( Y \) = percentage decayed lesions, \( B = 13.5, T = 82.8, \log EC50 = 2.366, \text{HillSlope} = -14.44, \) and \( X = \log \) of vinegar concentration. Thus, the EC50 value (volume that will reduce the number of decayed lesions by 50%) was estimated to be 18.3 \( \mu \)L·L\(^{-1}\) of air, assuming complete vaporization of acetic acid. Doubling this value to 36.6 \( \mu \)L·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

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

<table>
<thead>
<tr>
<th>Type of vinegar</th>
<th>Amount vaporized (mL)</th>
<th>Duration of fumigation (h)</th>
<th>Fruit decayed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (control)</td>
<td>1.0</td>
<td>0.5</td>
<td>50.0 ab</td>
</tr>
<tr>
<td>White</td>
<td>1.0</td>
<td>0.5</td>
<td>63.9 a</td>
</tr>
<tr>
<td>White wine</td>
<td>3.0(^{c})</td>
<td>0.5</td>
<td>12.5 bc</td>
</tr>
<tr>
<td>White</td>
<td>1.0</td>
<td>16.0</td>
<td>1.4 c</td>
</tr>
<tr>
<td>White wine</td>
<td>3.0(^{c})</td>
<td>0.5</td>
<td>58.7 a</td>
</tr>
</tbody>
</table>

\(^{a}\)Data were arcsin transformed prior to analysis of variance. Numbers are the means of three replications. Means separation by Duncan’s multiple range test, \( P \leq 0.05 \).  
\(^{c}\)Not all the vinegar evaporated from the filter paper wicks.
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 × 10⁵ 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,
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 acetoclastic, lactic, and butyric acid bacteria which are markedly tolerant to acetic acid (Baird-Parker, 1980; Doorens, 1993). These organisms are not fruit pathogens, and in general, are not human pathogens. However, acetic acid vapor will inhibit bacteria such as Salmonellatphymurium (Leoffer) 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

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

<table>
<thead>
<tr>
<th>Solution</th>
<th>Decayed lesions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solution (3.0 mL) evaporated from filter-paper</td>
</tr>
<tr>
<td>Water (control)</td>
<td>66.9 ab*</td>
</tr>
<tr>
<td>White wine</td>
<td>71.3 a</td>
</tr>
<tr>
<td>Malt</td>
<td>52.1 abc</td>
</tr>
<tr>
<td>Apple cider</td>
<td>40.9 bcd</td>
</tr>
<tr>
<td>Red wine</td>
<td>32.5 cd</td>
</tr>
<tr>
<td>Balsamic</td>
<td>28.9 cd</td>
</tr>
<tr>
<td>Raspberry</td>
<td>22.9 d</td>
</tr>
<tr>
<td>Brown rice</td>
<td>20.8 e</td>
</tr>
<tr>
<td>White</td>
<td>2.8 e</td>
</tr>
</tbody>
</table>

*Vinegar or water was dripped on to a filter paper wick in a sealed chamber or room without handling and potentially bruising or injuring the produce.

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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.

**Literature Cited**


