# Fumigation of Fruits with 2-Aminobutane to Control Certain Postharvest Diseases

J. W. Eckert and M. J. Kolbezen

Associate Professor and Chemist, respectively, Department of Plant Pathology, University of California, Riverside 92502.

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ABSTRACT

*Penicillium digitatum* and *P. expansum* on citrus and apple fruits, respectively, were controlled by fumigating inoculated fruits with 25-100 ppm (v/v) 2-aminobutane for 4 hr. Treatments comprised of higher concentrations and shorter exposure periods produced similar results when the product of concentration and exposure time (ppm × hr) was in the range of 100-400. An accumulated dosage of 800 ppm-hr controlled *Monilinia fructicola* on peaches. Oranges were not injured by concentrations 50 times greater than those required for control of decay, but lemons, apples, and peaches were injured by exposure to 500 ppm for 4 hr. Penicillium decay of citrus fruits was controlled without damaging fruits by fumigating at 10,000 ppm of 2-aminobutane for less than 1 min. Conidia of *P. digitatum* germinated after exposure to 100 ppm of 2-aminobutane for 4 hr, indicating that the fungistatic residues of 2-aminobutane in the peel of the fruit may prevent infection by *P. digitatum*. Phytopathology 60:545-550.

Relatively few fumigation treatments have been developed for the practical control of postharvest diseases. Sulfur dioxide, carbon dioxide, nitrogen trichloride, and biphenyl have been used successfully to combat specific postharvest diseases on certain fruits, but all of these treatments are of rather limited utility (4, 11). Certain chlorinated hydrocarbons have been suggested as antifungal fumigants for peaches and citrus fruits (1, 23, 24), but have not been utilized commercially because of phytotoxicity and other problems. Ammonia gas has been evaluated critically for control of Penicillium decay of citrus fruits, both by direct fumigation of fruit in storage rooms (17, 20, 22) and by generation of the gas in individual packages of fruit (8, 13). Limited attempts also have been made to apply ammonia for control of Rhizopus rot of peaches (3). Concentrations of ammonia required for effective control of decay of citrus and peaches were relatively high compared to the injury threshold, and adverse effects were observed under some circumstances (2, 3). Evaluation of a number of volatile aliphatic amines for control of Penicillium decay of citrus fruits (6) revealed that 2-aminobutane was more active than most of the compounds tested. The effectiveness of 2-aminobutane gas in controlling decay of citrus and papaya was confirmed in recent tests in Florida (12) and Hawaii (14), respectively. Liquid 2-aminobutane and high concentrations of the gas in air are flammable, and may cause severe injury to the surface of fruit. The present investigation was undertaken to determine if the antifungal properties of 2-aminobutane gas could be utilized in a practical fumigation treatment for citrus and other fresh fruits after harvest. Certain phases of this work have been published in abstract (7).

MATERIALS AND METHODS.—For most experiments, lemon and orange fruits were inoculated with *Penicillium digitatum* Sacc. by scratching the peel with a circular saw blade rotating in a suspension of conidia (21). In experiments on the mechanism of fungitoxicity of 2-aminobutane residues, fruits were inoculated by puncturing the peel with a steel tool (0.5 mm diam × 3 mm long) previously dipped in the conidial suspension. Peaches were inoculated with conidia of *Monilinia fructicola* (Wint.) Honey or *Rhizopus stolonifer* (Ehr. ex Fr.) in the same manner. Apples were inoculated with conidia of *Penicillium expansum* Lk. ex Thom by gently breaking the skin in five locations on the shoulder of the fruit with a stiff wire dipped in the conidial suspension. The inoculum consisted of $10^6$ conidia/ml in all cases. Inoculated fruits were incubated for 18-20 hr at 20 C before fumigation, except for peaches inoculated with *R. stolonifer* which were incubated for only 12 hr.

Most of the fumigation experiments were conducted in the continuous flow system illustrated in Fig. 1-A. The 2:aminobutane:air mixtures flowed through the stainless steel fumigation chambers (280-liter volume) at rates which varied from 28-50 liters/min in individual experiments. The concentration of 2-aminobutane varied only a few per cent during an experiment, and was approximately 10% lower at the chamber outlet than the inlet. Inoculation sites on the fruit were positioned upward so that they would all be exposed to a uniform dosage of 2-aminobutane. Larger scale tests were conducted with oranges in standard wooden picking boxes (30 × 60 × 30 cm) stacked in a 22.6 $m^3$ fumigation room. The fumigant was introduced into the room by bubbling compressed air through liquid 2-aminobutane and conveying the concentrated gas into the space above the fruit. The atmosphere in the storage room was continuously agitated with a small fan. Concentration of 2-aminobutane in the atmosphere under these conditions was analyzed frequently, and the flow of concentrated gas entering the room was adjusted to maintain approximately the desired concentration. Because the concentration of 2-aminobutane was not constant in these large-scale experiments (that is, navel oranges, Table 1), the accumulated dosage was determined by integration of the area under the curve obtained by plotting the analyzed concentration vs. time.

The accumulated dosage is reported as the product of ppm × hr, hereafter referred to as "ppm-hr". The temperature in the fumigation chambers ranged from 21-24 C and relative humidity from 30-40%.

Oranges and lemons were exposed for from 5-60 sec to atmospheres containing 12,000-78,000 ppm (v/v) 2-aminobutane in the fumigation chamber illustrated in Fig. 1-B. The walls of the chamber were fabricated with 0.5-inch plywood sealed with a coating of epoxy resin. Approximately 500 ml of pure liquid 2-aminobutane or water solutions ranging from 7-80% (w/w) 2-aminobutane were placed in a tray on the floor of chamber A. The atmosphere above the solutions was gently agitated with a fan to hasten the establishment of equilibrium of 2-aminobutane between the liquid and gas phases. The composition of the solution required to give a gas concentration of 2-aminobutane in the desired range was determined by analyzing the atmosphere above a number of solutions of different strength. After equilibrium was reached in compartment A (136-liter volume), rack C holding 12 fruit was inserted into chamber B (18-liter volume, empty). The shutter (D) isolating compartments A and B was then withdrawn to initiate the fumigation. Shutter D is shown in withdrawn position in Fig. 1-B. The speed of the fan was increased for a few seconds to bring about rapid equilibration between compartments A and B. Fumigation was terminated after the desired exposure period by returning the shutter to its original position and withdrawing the fruit carrier. The fruit were aired for several min, then stored at 20 C.

Oranges and lemons were fumigated in individual shipping containers by injecting a mist of pure 2-aminobutane into the atmosphere inside the container filled with fruit. Lemons of size 115 (6.12 cm diam) were inoculated with conidia of *P. digitatum* and packed in telescopic fiberboard citrus cartons (28 × 43 × 27 cm).

TABLE 1. Control of decays of inoculated apples, peaches, and oranges by exposure for 4 hr to gaseous 2-aminobutane

| ppm-hr 2-aminobutane[a] | % Infection |
|---|---|
| Apple (Delicious)—*Penicillium expansum* | |
| 0 | 88[b] |
| 100 | 2 |
| 200 | 1 |
| 400 | 1 |
| Peach (Rio Oso Gem)—*Monilinia fructicola* | |
| 0 | 100[c] |
| 400 | 76 |
| 800 | 8 |
| 1,600 | 4 |
| Orange (Navel)—*Penicillium digitatum* | |
| 0 | 90[d] |
| 350 | 4 |
| 400 | 7 |

[a] Apple and peach fumigations conducted in chamber shown in Fig. 1-A, and orange fumigation in a 22.6 $m^3$ chamber with static atmosphere; ppm-hr is product of ppm × hr.

[b] Based on 300 inoculations (75 fruit with 4 inoculations each). Mean of two experiments.

[c] Based on 25 inoculated fruit. Mean of two experiments.

[d] Based on 300 inoculated oranges.

Vent holes in the carton walls, except for one in the bottom, were sealed with paper tape. The atmosphere of the carton filled with fruit was approximately 13 liters. The lid of the carton was raised 8 cm above the position of complete closure, and the nozzle of a DeVilbiss No. 153 atomizer was inserted through a small hole near the top of the end wall of the carton lid. The atomizer was connected to a source of compressed air or carbon dioxide via an electrically operated solenoid valve. The atomizer was primed with liquid 2-aminobutane to correct for hold-up volume, and then was allowed to draw up a measured volume of 2-aminobutane from a small tube and propel this quantity as a mist into the head space above the fruit in the carton. The solenoid valve to the propellant gas supply was closed after the charge of 2-aminobutane had cleared the nozzle of the atomizer. The carton lid was pushed down to the fully closed position and the cartons were stored at 20 C.

The concentration of 2-aminobutane in the fumigation chambers was determined by aspirating a gas sample by water displacement through a scrub solution of a standard acid, usually 50 ml of $1.0 \times 10^{-4}$ N $H_2SO_4$, containing 8 drops of a mixed indicator (0.1% methyl red + 0.05% methylene blue). The volume of water displaced by the aspirated gas was measured when the equivalence point was observed in the acid trap, and the concentration of 2-aminobutane in the fumigation atmosphere was calculated by the expression, ppm gaseous 2-aminobutane (v/v) = 127/liters $H_2O$ displaced. This routine acidimetric method of analysis was compared with a spectrophotometric method (16), and values obtained for a single atmosphere by both methods were in close agreement. Residues of 2-aminobutane in fruits were determined spectrophotometrically (15, 16).

Conidia of *P. digitatum* were dusted on glass rods and equilibrated in a water-saturated atmosphere at 16 C for 14-16 hr before fumigation. Fumigated conidia were streaked on potato-dextrose agar and incubated at 25 C to determine their viability. Partially-germinated conidia (swollen and about 10% germinated) were produced in the same environment by incubating them for 16 hr on uncoated cellophane discs (38 mm diam) overlaying a solid medium consisting of 5% orange juice (clarified with Celite), 1% $KH_2PO_4$ and 1.5% agar adjusted to pH 5.5 before autoclaving. The medium was formulated to simulate the pH shifts of the injured peel of citrus fruits during fumigation with 2-aminobutane. Partially germinated conidia on cellophane over agar were fumigated, then transferred by pressing the cellophane disc against fresh orange juice agar.

The flammability of gas mixtures of 2-aminobutane and air was determined by injecting weighed quantities of liquid 2-aminobutane into calibrated glass jars of approximately 20-liter volume. The atmosphere in the jar was agitated with a fan until the amine evaporated and the gas phase was homogeneous. Concentration of 2-aminobutane in the atmosphere was determined by gas chromatography, and samples of the atmosphere were aspirated into an Explosimeter (Mine Safety Ap-

pliance Co. Model No. 2) that indicated the ratio and concentration of test mixture: concentration of flammable mixture. The lower explosive limit of 2-aminobutane in air was approximated by extrapolation of the measured ratio to unity.

RESULTS.—*Fumigation with gaseous 2-aminobutane.*—Reduction in disease following exposure of lemons inoculated with *P. digitatum* to gas concentrations of 2-aminobutane ranging from 25-300 ppm for 1-8 hr is shown in Fig. 2. The points plotted represent the number of decayed fruit in a 100-fruit lot stored at 20 C for 14 days after fumigation treatment. Since the experimental set-up (Fig. 1-A) allowed only a control and three concentrations of 2-aminobutane in a single experiment, the plotted points are average values for a number of individual experiments conducted over a period of several months. The inoculated, untreated fruit showed more than 95% decay in every experiment. An accumulative dosage of 200 ppm-hr provided effective control of decay of lemons, irrespective of the specific gas concentration applied or the length of the exposure period (Fig. 2). That is, a concentration of 25 ppm 2-aminobutane for 8-hr exposure provided essentially the same degree of disease control as 100 ppm for 2 hr or 200 ppm for 1 hr. The same relationship appears to hold for other equivalent dosages,

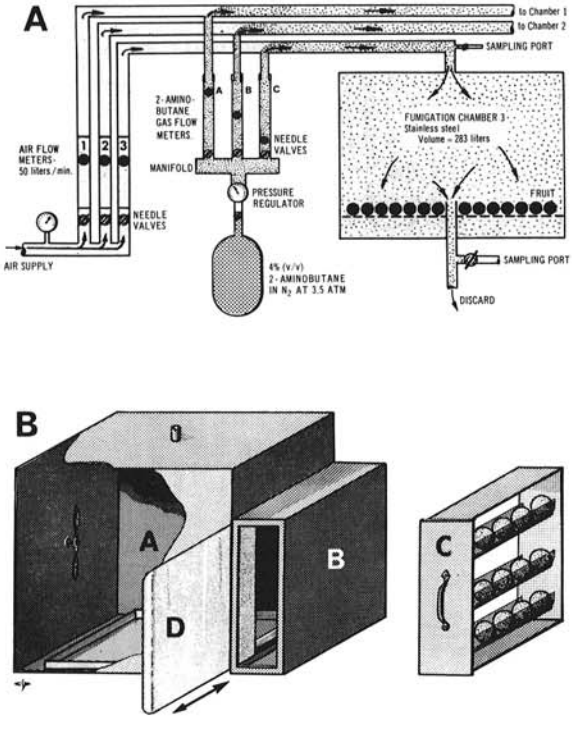


**Fig. 1.** **A)** Apparatus for continuous-flow fumigation of fruits with 50-10,000 ppm 2-aminobutane in air for 1-8 hr. **B)** Apparatus for fumigation of oranges with 10,000-80,000 ppm 2-aminobutane for 60 sec or less. The concentration of 2-aminobutane in the atmosphere of chamber A is regulated by strength of aqueous solution in tray. Fruit carrier C is inserted in chamber B and fumigation is initiated by withdrawal of shutter D (shown in withdrawn position).

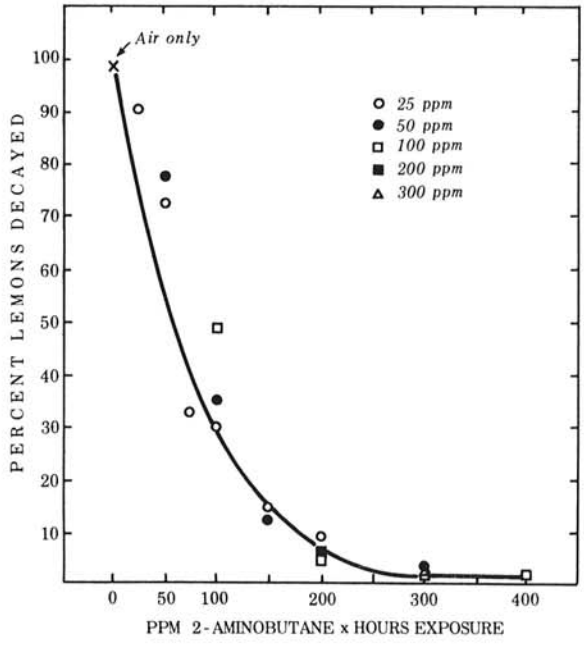


**Fig. 2.** Effect of 2-aminobutane dosage on decay of lemons inoculated with conidia of *P. digitatum*. Plotted points are the means of % decay values from several independent experiments. The abscissa scale is the product of the gas concentration (indicated by the plotted symbols) and the hr the fruit were exposed to that gas concentration.

within the limits of experimental error. Additional experiments with oranges in small plastic boxes, the atmosphere of which could rapidly be brought to equilibrium with the incoming gas stream, showed that decay of inoculated oranges exposed to 1,200 ppm 2-aminobutane for 5 min (200 ppm-hr) was reduced to 10% of the untreated control.

Fumigation of apples with dosages of 100-400 ppm-hr provided very effective control of *P. expansum* on inoculated fruit stored for 14 days at 20 C after fumigation (Table 1). Higher dosages (800-1,600 ppm-hr) were required to control *M. fructicola* on wound-inoculated peaches, whereas decay caused by *R. stolonifer* was not significantly reduced by any of the treatments shown in Table 1.

*Tolerance of fruits to gaseous 2-aminobutane.*—Noninoculated navel oranges were fumigated with 1,000, 5,000, and 10,000 ppm 2-aminobutane for 4 hr. Fruit fumigated with 1,000 ppm were indistinguishable from untreated fruit. A few fruit receiving 5,000 ppm showed small red spots on the peel after storage for 7 days, whereas extensive red discoloration was immediately apparent on the peel of fruit which received 10,000 ppm. Valencia oranges were at least as tolerant to 2-aminobutane as navel oranges. Yellow lemons were slightly darkened by exposure to 500 ppm for 4 hr. With all citrus fruit varieties, existing injuries to the peel were darkened by all dosages of 2-aminobutane that reduced decay. Red Delicious and Golden Delicious apples were unaffected by 100 ppm 2-aminobutane for 4 hr, but 250 ppm for the same time period caused

permanent darkening of the lenticels in Golden Delicious and temporary darkening of lenticels in Red Delicious. The lenticels of Red Delicious apples appeared normal 7 days after the fruit were fumigated with 500 ppm 2-aminobutane. Anjou pears were unaffected by 500 ppm for 4 hr.

*Effect of brief exposure of oranges to high concentrations of gaseous 2-aminobutane.*—Liquid 2-aminobutane condensed on the surface of fruit exposed for only 5 sec to an atmosphere in equilibrium with pure liquid 2-aminobutane, and severe injury to the peel of the fruit was apparent after treatment. Valencia oranges were not injured by exposure to 40,000 ppm gaseous 2-aminobutane for 60 sec or to 78,000 ppm for 10 sec. Exposure to the latter concentration for 20 sec or longer resulted in injury to the peel of the fruit. Dosages as low as 11,900 ppm for 5 sec reduced decay to at least 50% of the untreated inoculated fruit. Exposure for longer than 10 sec provided more reproducible decay control, especially at the lower concentrations (Table 2).

*Injection of liquid 2-aminobutane into fruit containers.*—Atomization of 0, 0.25, 0.5, and 1.0 ml liquid 2-aminobutane into duplicate containers filled with 113 inoculated lemons each resulted in 100, 54, 24, and 12% decay, respectively, after storage at 20 C for 16 days. The possibility of damaging fruit by this method of application was evaluated by treatment of containers filled with 57 oranges and 57 lemons, with the excessive doses of 2 and 4 ml liquid 2-aminobutane. Lemons were more sensitive indicators of injury than were oranges. The specified dosage of liquid 2-aminobutane was propelled by compressed air or $CO_2$ into the fruit container. $CO_2$ was used to partially neutralize the amine and thereby reduce injury to the fruit. Two ml 2-aminobutane, propelled either by air or $CO_2$, produced very slight bronzing of the surface of 7% of the lemons. Four ml propelled by $CO_2$ gave almost identical results, whereas the same dose propelled by compressed air caused conspicuous bronzing of 7% and very slight discoloration of 35% of the lemons. None of the treatments visibly affected the fruit button (calyx and sepals).

TABLE 2. Penicillium decay of Valencia oranges following brief exposure to high concentrations of gaseous 2-aminobutane

| 2-Aminobutane | | Decayed fruit per 24 inoculated after exposure to atmosphere for indicated time (sec)[c] | | | | | |
|---|---|---|---|---|---|---|---|
| Source, % (w/w) in water[a] | Atmosphere, ppm (v/v)[b] | 2 | 5 | 10 | 20 | 30 | 60 |
| 80 | 77,800 | 5 | 3 | 0 | 0[d] | 0[d] | 0[d] |
| 50 | 40,300 | | 6 | 1 | 1 | 1 | 0 |
| 20 | 22,900 | | 9 | 5 | 6 | 2 | 2 |
| 7 | 11,900 | | 10 | 7 | 3 | 3 | 0 |

[a] Solution placed on floor of fumigation chamber.
[b] Initial concentration in atmosphere; 80-90% of this value was found by analysis after fruit were exposed for 60 sec.
[c] Untreated controls had greater than 90% decay in all tests.
[d] Fruit exhibiting moderate to severe injury with intensity proportional to length of exposure period.

TABLE 3. Residues of 2-aminobutane in oranges, lemons, and apples after exposure to different gas concentrations for 4 hr[a]

| Fruit | ppm (v/v) 2-aminobutane fumigation | | |
|---|---|---|---|
| | 100 | 300 | 1,000 |
| Navel oranges | 5.09 ± 0.17[b] | 7.75 ± 0.15 | 19.0 ± 0.72 |
| Lemons | 9.15 ± 0.67 | 19.4 ± 0.65 | 71.2 ± 1.97 |
| Apples (Red Delicious) | 1.38 ± 0.24 | 5.42 ± 0.27 | 24.6 ± 0.19 |

[a] Mg 2-aminobutane/kg whole fruit, corrected for background. Mean of 3 replicate analyses.
[b] Average deviation from the mean.

*Residues of 2-aminobutane in fumigated fruits.*—Exposing fruits to 100 ppm 2-aminobutane for 4 hr, a dosage which reduced decay to at least 10% of the inoculated control, resulted in residue values of 1.38, 5.09, and 9.15 mg 2-aminobutane/kg fruit for apples, oranges, and lemons, respectively (Table 3). Higher concentrations of 2-aminobutane resulted in higher residue levels. Lemons absorbed considerably more gaseous 2-aminobutane than either oranges or apples. Gaseous 2-aminobutane appears to penetrate the wax and cuticle of the fruit since the residues were not substantially reduced by washing the fruits.

*Flammability of gaseous 2-aminobutane in air.*—Determinations made on five gas mixtures gave values for the lower explosive limit ranging from 21,000 to 25,000 ppm 2-aminobutane in air. The lower explosive concentration is at least 200 times greater than the concentration (100 ppm for 4 hr) which gave very effective control of *Penicillium* on citrus and apple fruits.

*Fungicidal and fungistatic action of 2-aminobutane on conidia of P. digitatum.*—Conidia of *P. digitatum,* in the absence of free water, were not killed by a 4-hr exposure to 1,000 ppm 2-aminobutane, a dosage at least 20 times greater than that required for decay control (see Fig. 2). A dosage of 100 ppm for 4 hr, which was highly effective in controlling decay of inoculated fruit, did not kill conidia in vitro irrespective of their degree of hydration or stage of germination. The acidity of the orange juice agar decreased from pH 5.5 to about pH 7 during the course of the 100-ppm fumigation, as 2-aminobutane was bound by the constituents of the medium. Conidia dusted on this fumigated medium 48 hr later did not germinate because of the fungistatic action of the neutral 2-aminobutane salts that had accumulated in the agar medium. Conidia fumigated on an agar surface were not viable following exposure to 400 ppm 2-aminobutane for 4 hr. Since the pH of the agar was about 8.5 at the end of the 400 ppm fumigation, the conidia were probably killed outright by the comparatively high concentration of undissociated amine, which is lethal to conidia (6).

*Effect of residues of 2-aminobutane on infection of fruit by P. digitatum.*—Gaseous 2-aminobutane was absorbed and permanently bound by the cells and milieu exposed by punctures in the peel of the fruit (Table 4). Furthermore, the quantity of amine bound at these potential infection sites increased with concentration of 2-aminobutane in the atmosphere during the 4-hr ex-

posure period. Absorption of the amine decreased the acidity of the peel sap from pH 5.5 to about 8 for lemons exposed to 100 ppm 2-aminobutane, and to about pH 9 for lemons exposed to 400 ppm 2-aminobutane. In both cases, the sap returned to its original value of pH 5.5 within 24 hr after fumigation. Residues of 2-aminobutane in wounds on the peel surface apparently were responsible for the reduction in decay, since lemons fumigated with as little as 50 ppm 2-aminobutane for 4 hr were resistant to inoculation at punctures which existed prior to the fumigation.

DISCUSSION.—The effectiveness and lack of phytotoxicity of neutral solutions of 2-aminobutane for the treatment of certain postharvest diseases have been demonstrated in several laboratories (5, 11). Earlier investigations (6) demonstrated the potential value of treating citrus fruits with gaseous 2-aminobutane, but the hazards of phytotoxicity and flammability associated with this method of application were recognized as major problems in its development. Our results show that *P. digitatum* and *P. expansum* on citrus and apple fruits, respectively, can be controlled by exposure to gas concentrations of 2-aminobutane which are neither flammable nor phytotoxic to uninjured fruits when applied for the prescribed period of time. We found that a fumigation schedule consisting of 100 ppm 2-aminobutane applied for 4 hr is a highly effective and practical treatment, although combinations of concentration and time which give a product in the range of 100-400 ppm-hr are also effective. Oranges tolerated about 50 times this dosage without visible signs of injury. The margin of safety was narrower, but adequate, for lemons, apples, and peaches. Decay of oranges and lemons was controlled by exposure to relatively high concentrations of 2-aminobutane for short time periods, demonstrating the feasibility of treating citrus fruits as they are conveyed through a tunnel-like fumigation chamber or, alternately, atomizing 2-aminobutane into individual packages of fruit wherein immediate vaporization produces a high concentration of 2-aminobutane gas in the atmosphere for a short period of time. The results of large scale trials of the fumigation treatment were reported elsewhere (9).

TABLE 4. Effect of residues of 2-aminobutane on the susceptibility of puncture wounds of fumigated lemons to infection by *Penicillium digitatum*

| ppm (v/v) 2-aminobutane for 4 hr | % Infection of puncture wounds[a] inoculated: | | 2-aminobutane residue (ppm,w/w) in fumigated lemon peel[b] | |
|---|---|---|---|---|
| | Before fumigation | After fumigation | Uninjured | Ten punctures/lemon |
| 0 | 100 | 58 | 3.04 | 2.60 |
| 50 | 10 | 2 | 8.22 | 16.8 |
| 100 | 5 | 13 | 6.24 | 18.0 |

[a] The peel of each lemon was punctured once on its equator 20 hr before fumigation. Each treatment was applied to 40 lemons and decay was evaluated 12 days after fumigation.

[b] Lemons were aired for 48 hr before peel was removed for analysis. Values for fruit not fumigated are due to naturally occurring amines.

Exposure of citrus fruits to gaseous 2-aminobutane could prevent infection by *P. digitatum* in two ways: (i) by killing conidia associated with the fruit during the period of fumigation; or (ii) by making the peel of the fruit an unsuitable substrate for germination and development of this fungus. Fumigation of conidia on glass rods indicated that conidia on the intact surface of citrus fruit would not be killed by dosages of 2-aminobutane which are highly effective in preventing decay of inoculated fruit.

Conidia associated with moist wounds on the surface of the fruit should be more vulnerable to the fumigation treatment because absorption of the gaseous amine by the aqueous phase of the wound would result in a high concentration of undissociated amine in the environment of the conidia. Direct fungicidal action could explain the effectiveness of fumigating inoculated fruit with 400 ppm 2-aminobutane for 4 hr, since this treatment was lethal to conidia on the surface of agar. In contradistinction, the resistance of conidia on agar to 100 ppm negates the possibility that this dosage reduced fruit decay through its fungicidal effect on the conidia during the fumigation period. It might be argued that residues of 2-aminobutane resulting from this treatment are lethal when they contact the conidia for several days, but previous investigations (6) showed that relatively high concentrations of 2-aminobutane at the pH of the fumigated fruit surface are not lethal to all conidia exposed to this environment for 48 hr, the period when fruit injuries remain susceptible to infection. The most plausible explanation for a reduction in decay of citrus fruit fumigated with 100 ppm for 4 hr is that 2-aminobutane, bound as salts of organic acids in wounds on the fruit surface, is fungistatic to *P. digitatum* at these sites. This contention is supported by observations that conidia of *P. digitatum* did not develop upon orange juice agar or on injured fruit after these substrates were fumigated, even though the pH was suitable for germination. Furthermore, analysis of lemon peel punctured before fumigation revealed that substantial quantities of 2-aminobutane persist indefinitely in wounds on treated fruit.

Fumigation of citrus fruits with 100 ppm 2-aminobutane for 4 hr is at least as effective as 100 ppm ammonia for 10 hr (20, 22). The full effect of the ammonia treatment is exerted during the fumigation, and for the few hours thereafter when the wounds on the surface of the fruit are alkaline as a result of absorbed ammonia. The fungitoxicity of residues of these neutral ammonium salts would be negligible. McCallan & Weedon (18) observed that several species of fungi growing on agar medium were killed by exposure to 250 ppm ammonia gas for 16 hr, but that the fumigated agar, following 12 hr of aeration, supported normal growth of the fungi. In contrast, *P. digitatum* did not grow on agar 48 hr after fumigation for 4 hr with 100 ppm 2-aminobutane. This difference in the fungistatic activity of the residues is probably a major reason for the superiority of the 2-aminobutane over ammonia as a fumigant for control of fruit decays.

It is sometimes assumed that chemicals applied to fruits after harvest to control decay are fungicidal in action, since the time of contact between the fungus and the chemical ostensibly is brief in comparison to the usual protectant fungicide (19). Evidence that fungicidal action may be the exception rather than the rule for antifungal chemicals applied in water to fruit after harvest has been presented elsewhere (4, 10). Likewise, fungistasis appears to be the primary mechanism whereby low concentrations of 2-aminobutane gas prevent infection of citrus fruits.

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