Hydrocooling and Hydraircooling with Fungicides for Reduction of Postharvest Decay of Peaches

John M. Wells and A. H. Bennett

Plant Pathologist and Agricultural Engineer, respectively, U.S. Department of Agriculture, Agricultural Research Service, Southeastern Fruit and Tree Nut Research Station, Byron, Georgia 31008; and R. B. Russell Research Center, Athens, Georgia 30604, respectively.

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ABSTRACT

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Average diameter of lesions formed on peaches inoculated with *Monilinia fructicola* and *M. laxa,* incubated at 14.5 C for 20 hours, then hydrocooled or hydraircooled with 0, 225, 450, or 900 μg/ml Botran, and held for 5 days at 4.5 C and 4-5 days at 21 C, decreased linearly with increasing Botran concentrations. Lesions on fruit inoculated with *Rhizopus stolonifer* were controlled with a treatment of 225 μg/ml Botran. Treatments of 225 μg/ml Botran plus 300 μg/ml benomyl controlled lesion development on inoculated fruit incubated at 24 C for 20 hours. Hydraircooling treatments generally reduced lesion development as effectively as hydrocooling treatments. Naturally-occurring decay of peaches due to brown rot (*M. fructicola* and *M. laxa*) was reduced from 38.2% in the checks to 2.5% in fruit hydrocooled with 225 μg/ml Botran plus 300 μg/ml benomyl. Losses due to brown rot and Rhizopus rot of peaches treated with 900 μg/ml Botran or 225 μg/ml Botran plus 300 μg/ml benomyl by hydrocooling were not significantly different from those treated by hydraircooling.

Additional key words: fungicides, brown rot.

Postharvest decay of peaches (*Prunus persica* [L.] Batsch) has been estimated to cause 9% losses during transporting and marketing in the United States (8). The major types of decay are brown rot, caused by *Monilinia fructicola* (Wint.) Honey and *M. laxa* Aderh. & Ruhl., and Rhizopus rot, caused by *Rhizopus stolonifer* (Fr.) Lind. Such losses can be minimized by postharvest precooling and fungicidal treatments (6).

Hydrocooling, first used in 1947 in Berrien County, Michigan, to rapidly precool peaches for transit (2), has become conventional commercial practice in the southeastern United States since the 1950's (9). McClure (3) demonstrated that hydrocooling peaches with 0.1% sodium *o*-phenylphenoxide (Dowicide A) significantly reduced losses due to brown and Rhizopus rots compared to hydrocooling with chlorine. Dowicide A, however, was not generally adopted because of the difficulties of maintaining effective concentrations and the resultant dangers of phytoxicity (5).

Chlorination of hydrocooling water had been only partly or irregularly effective in reducing decay on peaches under commercial conditions (3, 6). Phillips and Grendahl (4), however, recently reported that chlorine effectively reduced decay development on peaches artificially-inoculated with the brown rot fungi, and that the effect was related to concentration within the range of 0 to 100 μg/ml.

Hydrocooling peaches in water containing varying amounts of the organic fungicides 2,6-dichloro-4-nitroaniline (Botran) or methyl 1-[butyl-2-carbamoyl] benzimidazolecarbamate (benomyl) has been commercial practice in recent years. We found no published reports of controlled testing of these materials for use in hydrocoolers or in modifications of hydrocooling equipment.

Hydraircooling, a modification of hydrocooling, was recently developed by Bennett and Wells (1). Its principal feature is the combination of forced-air cooling with a low-volume spray of unrecirculated water. Recirculating water in conventional hydrocoolers causes phytosanitation problems due to accumulations of organic debris and fungal spores (7). This is minimized with hydraircooling. There is no information, however, on the effectiveness of hydraircooling with fungicides as a means of reducing or controlling postharvest decay.

The purpose of this report is to, (i) determine, under controlled conditions, optimal concentrations of fungicides presently approved by the Environmental Protection Agency (EPA) for use in hydrocoolers for the control of postharvest decay, and (ii) to test the effectiveness of these fungicides in a hydraircooling system.

MATERIALS AND METHODS

Inoculated tests.—Freshly-harvested peaches from packing sheds in Houston and Peach counties, Georgia, were selected for uniformity of size and maturity, and for freedom from bruises or blemishes.

In tests with inoculated peaches, individual fruits were wounded on each cheek by breaking the skin with a puncture 2 mm wide and deep; a drop of a spore

suspension of *M. fructicola, M. laxa,* or *R. stolonifer* was placed on the wound. Fruits were then incubated at 14.5 C or at 24 C under a polyethylene bag for 20 hours, defuzzed with 0.03% sodium dodecylsulfonate in a commercial brushing unit, and then rinsed with fresh water.

Ten fruit constituted a treatment lot. Treatments were replicated three times, each time with a different cultivar or with the same cultivar harvested at different dates.

Two series of tests were conducted with inoculated fruit. In the first series, peaches were incubated at 14.5 C and hydrocooled in suspensions of Botran at 0, 225, 450, or 900 μg/ml.

Benomyl was not tested alone as it is not active against *Rhizopus* spp. (11). In the second series of tests, fruit were incubated at 24 C, for rapid development of lesions, and hydrocooled or hydraircooled with 2 to 10 or 65 to 100 μg/ml of chlorine, or with 225 μg/ml Botran plus, 0, 75, 150, or 300 μg/ml benomyl. Treated fruit were stored under polyethylene bags for 5 days at 4.5 C, then ripened for 4-5 days at 21 C. Diameters of decay lesions were measured and averaged for each treatment lot.

Peach cultivars 'Red Globe', 'Blake', 'Redskin', and 'Dixiland' were used for tests with fruit artificially inoculated.

Noninoculated tests.—Tests on noninoculated fruit included only selected treatments, replicated three times. Seventy-five to 120 fruit per treatment were hydro- or hydraircooled in open 18 kg packing boxes. The fruit was then held for simulated transit and holding times of 5 days at 4.5 C and 3 days at 21 C. Fruit was considered decayed if infected by *Monilinia* (brown rot) or *Rhizopus* at any stage of development.

Hydrocooling treatments were conducted for 20 minutes in an experimental, mechanically-refrigerated hydrocooler of 2000-liter capacity. Water temperatures and flow rates were 1 C at 630 liters/minute/m^2 — comparable to those of commercial hydrocoolers. Hydraircooling was conducted for 30 minutes in the experimental unit with water and air temperatures of −3.5 C and 1 C, respectively, and water and air flow rates of 3 liters/minute/m^2, and 74 m^3/minute/m^2, respectively.

Chlorine, as calcium hypochlorite, was introduced into precooling water and monitored throughout the treatments by sodium thiosulfate titration. Initial chlorine levels of the low and high concentration treatments were about 10 and 100 μg/ml, respectively. Final concentrations after treatment ranged between 2 and 6 μg/ml, and 65 and 73 μg/ml, respectively.

Hydro- and hydraircooling tests were conducted simultaneously and were considered to be paired treatments. Analyses of variance of the data were based on a split-plot experimental design. Data from noninoculated tests were treated by analysis of variance and by Duncan's multiple range test.

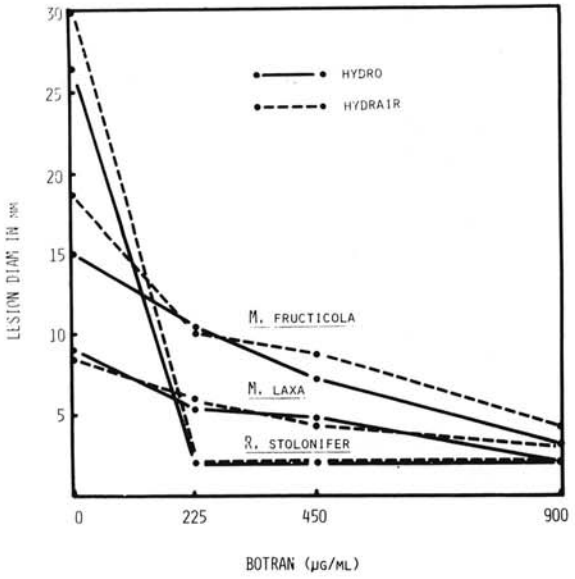

Fig. 1. Average lesion diameter of 'Red Globe', 'Blake', and 'Redskin' peaches inoculated with *Monilinia fructicola, M. laxa,* and *Rhizopus stolonifer,* incubated for 20 hours at 14.5 C, and hydro- or hydraircooled with Botran at three concentrations.

RESULTS

Decay of inoculated fruit incubated at 14.5 and precooled in Botran.—Average lesion diameter of peaches inoculated with *M. fructicola* or *M. laxa,* incubated at 14.5 C then hydrocooled in water (check) was 18.6 and 8.1 mm, respectively, after 5 days at 3 C, then 4 to 5 days at 21 C (Fig. 1). Decay development of fruit hydrocooled in Botran decreased linearly as the concentration increased from 225 to 900 μg/ml. *Monilinia fructicola* and *M. laxa* lesions on fruit hydrocooled in 900 μg/ml Botran averaged 3.9 mm and 2.6 mm, respectively. Lesion development on fruit inoculated with *R. stolonifer* was completely arrested by hydrocooling with 225 μg/ml Botran.

There were no significant differences in lesion diameter between hydro- and hydraircooled fruit.

Decay of inoculated fruit incubated at 24 C and precooled in chlorinated water or in Botran and benomyl.—Botran at the concentration inhibitory to *R. stolonifer,* 225 μg/ml, was tested with benomyl in the second series of experiments with inoculated fruit. After incubation at 24 C for 20 hours prior to treatments, wound sites inoculated with *M. fructicola* and *R. stolonifer* developed to lesions 3-4 mm in diameter. Average lesion diameter on fruit inoculated with *M. fructicola* then hydrocooled with water was 25.4 mm (Fig. 2-A). Lesion diameter were significantly reduced by treatments with 100 μg/ml chlorine (19.3 mm), 225 μg/ml Botran (14.1 mm), and 225 μg/ml Botran plus 75 to 300 μg/ml benomyl (7.6 to 6.3 mm).

Monilinia fructicola lesions on hydraircooled fruit were generally larger than those on hydrocooled fruit (mean diameter for all treatments was 17.9 mm compared to 14.4 mm). Relative treatment effects, however, were the same with both methods.

Lesion diameter of the hydrocooled and hydraircooled checks inoculated with *M. laxa* was 14.4 and 13.0 mm, respectively (Fig. 2-C). Reduction of lesion development (4.0 to 4.4 mm) was greatest with treatments of 225 μg/ml Botran plus 300 μg/ml benomyl. There were no significant differences between hydro- and hydraircooling treatments.

Rhizopus stolonifer development on inoculated fruit incubated at 24 C (as with fruit incubated at 14.5 C) was controlled by hydro- or hydraircooling with water containing 225 μg/ml Botran (Fig. 2-B).

Decay of naturally-infected fruit precooled in fungicide suspensions.—Naturally occurring decay of peaches due to brown rot (*M. fructicola* and *M. laxa*) was reduced from an average of 37.2% in the untreated (dry) checks to 2.5% in fruit hydrocooled with 225 μg/ml Botran plus 300 μg/ml benomyl (Table 1). Hydrocooling in water alone (wet check) reduced decay to 15.8%, but the reduction was not significant. With chlorination at 100 μg/ml, decay was not significantly less than that of the wet check, but was significantly lower than that of the dry check. The combination Botran-plus-benomyl treatment was significantly more effective than Botran alone at 225 μg/ml (7.4% decay) or than chlorination.

Rhizopus rot on naturally-infected fruit was 29.9% in the dry checks and 42.2% in the wet checks. Hydrocooling with chlorine, Botran, or Botran-plus-benomyl reduced decay to a range of 0.5 to 6.5%.

In a comparison of hydro- and hydraircooling methods with naturally infected fruit (Table 2), brown rot on fruit chlorinated by hydrocooling (17.7%) was not significantly different from that chlorinated by hydraircooling (23.7%). Similarly, there was no statistical difference ($P = 0.05$) between brown rot or Rhizopus rot on hydrocooled and hydraircooled fruit treated with Botran or with Botran plus benomyl.

DISCUSSION

Hydraircooling or hydrocooling peaches with fungicides generally resulted in the same degree of decay

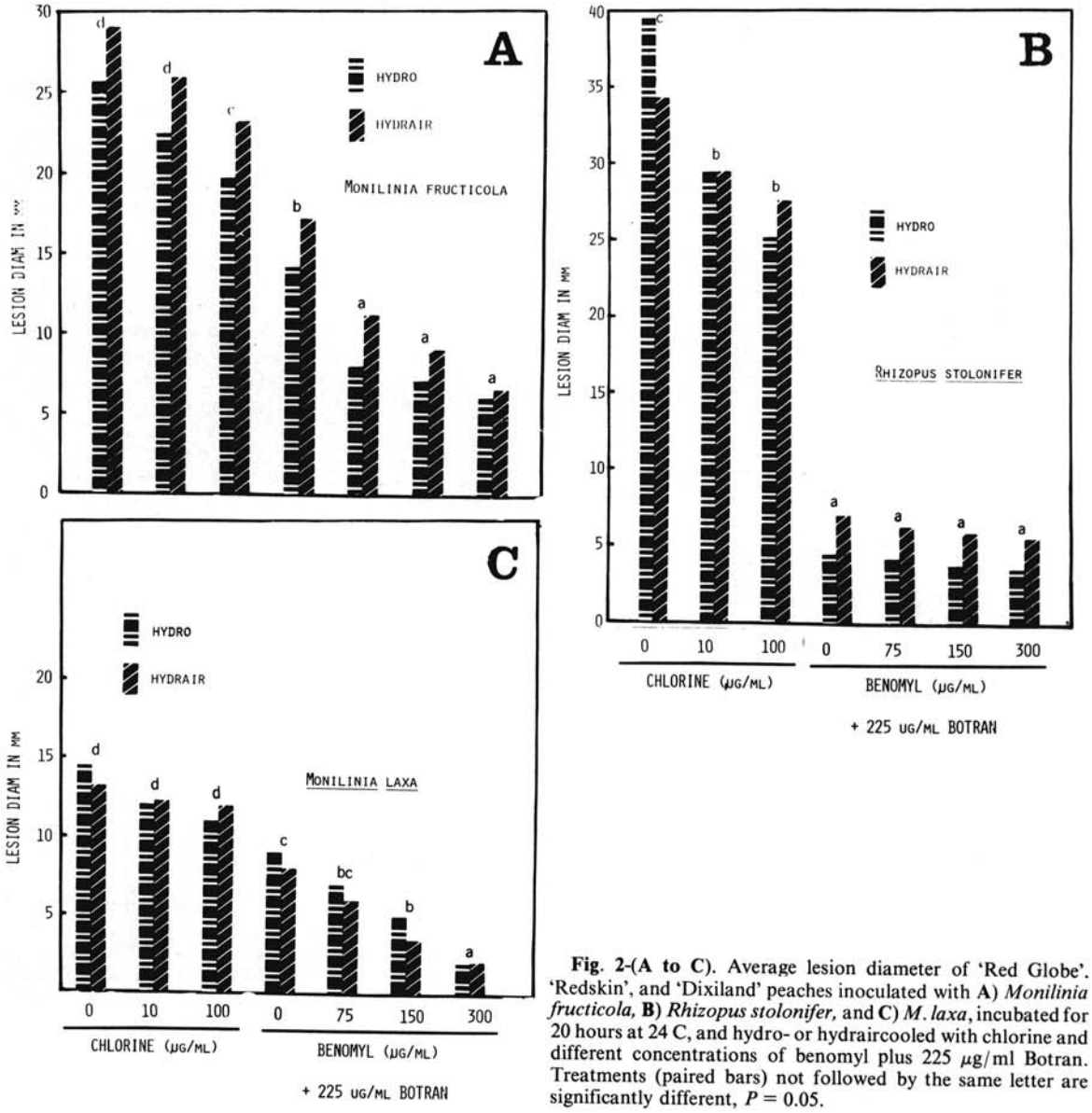

Fig. 2-(A to C). Average lesion diameter of 'Red Globe', 'Redskin', and 'Dixiland' peaches inoculated with **A)** *Monilinia fructicola,* **B)** *Rhizopus stolonifer,* and **C)** *M. laxa*, incubated for 20 hours at 24 C, and hydro- or hydraircooled with chlorine and different concentrations of benomyl plus 225 μg/ml Botran. Treatments (paired bars) not followed by the same letter are significantly different, $P = 0.05$.

TABLE 1. Percent brown rot and Rhizopus rot on naturally infected peaches hydrocooled in chlorinated water or in fungicides

Hydrocooling treatment[x]	Brown rot[y] in cultivars: Elberta (%)	Dixiland (%)	Redskin (%)	Average[z] (%)	Rhizopus rot[y] in cultivars: Elberta (%)	Dixiland (%)	Redskin (%)	Average[z] (%)
Dry check	52.1	27.1	32.4	37.2 d	20.0	39.2	30.5	29.9 b
Water alone	16.3	15.7	15.4	15.8 cd	55.0	19.1	52.6	42.2 b
Chlorine (100 μg/ml)	14.1	9.7	14.1	12.6 bc	0	19.5	0	6.5 a
Botran (225 μg/ml)	7.9	4.2	10.0	7.4 b	1.6	0	0	0.5 a
Botran (225 μg/ml) + benomyl (300 μg/ml)	1.6	2.6	3.3	2.5 a	4.7	1.2	0	1.9 a

[x]Fruit hydrocooled for 20 minutes in an experimental unit with 1 C water circulated 630 liters/minute/m^2.
[y]Percent rot after 5 days at 4.5 C and 3 days at 21 C.
[z]Averages not followed by the same letter are significantly different at $P = 0.05$.

TABLE 2. Percent brown rot and *Rhizopus* rot on naturally infected peaches treated with fungicides in a hydrocooler or a hydraircooler

Treatment		Brown rot[y] in cultivars:				Rhizopus rot[y] in cultivars:			
Fungicide	Cooling Method[x]	Redglobe (%)	Loring (%)	Redskin (%)	Average[z] (%)	Redglobe (%)	Loring (%)	Redskin (%)	Average[z] (%)
Check	...	31.0	45.4	25.8	34.1 c	11.3	16.9	11.6	13.3 b
Chlorine (100 μg/ml)	Hydro	18.7	17.9	16.4	17.7 b	7.2	4.6	10.0	7.3 ab
Chlorine (100 μg/ml)	Hydrair	13.7	26.9	16.4	23.7 b	12.9	4.8	1.5	6.4 ab
Botran (900 μg/ml)	Hydro	5.2	8.0	1.4	4.9 a	13.4	10.0	1.4	8.3 ab
Botran (900 vg/ml)	Hydrair	10.0	14.0	5.2	9.7 a	14.3	10.0	5.0	9.8 ab
Botran (225 μg/ml) + benomyl (300 μg/ml)	Hydro	0	7.0	6.0	4.3 a	1.5	0	0	0.6 a
Botran (225 μg/ml) + benomyl (300 μg/ml)	Hydrair	2.9	10.8	14.1	9.3 a	7.1	0	0	2.4 a

[x]Fruit hydrocooled for 20 minutes in 1 C water flowing at 630 liters/minute/m^2, or hydraircooled for 30 minutes after 1 C water and −3.5 C air flowing at 3 liters/minute/m^2 and 74 m^3/minute/m^2, respectively.
[y]Percent rot after 5 days at 4.5 C and 3 days at 21 C.
[z]Averages not followed by the same letter are significantly different, $P = 0.05$.

reduction under our experimental conditions. Lesion diameter on peaches inoculated with *M. fructicola, M. laxa,* and *R. stolonifer,* incubated at 14.5 C for 20 hours, and then hydraircooled with fungicides, was statistically comparable to those on hydrocooled peaches. However, *M. fructicola* lesions on fruit incubated at 24 C and hydraircooled were consistently greater than those on hydrocooled peaches. Similarly, in the noninoculated tests, brown rot in hydraircooled peaches tended to be consistently greater than that on hydrocooled peaches. Further testing with higher levels of inoculum may demonstrate that these differences are statistically significant. Continued testing is also needed under commercial packing shed conditions with large fruit volumes and with high inoculum levels to determine if further adjustments of fungicide concentrations in hydraircooling water are necessary to maintain satisfactory decay control.

Chlorination of hydro- or hydraircooling at the rate of 100 μg/ml generally had a significant effect in reducing decay, as observed by previous workers (4, 5) but provided no extended protection against decay. However, chlorination of hydro- or hydraircooling water is a good supplementary treatment in packing sheds for peaches treated with a fungicide-impregnated wax (10).

Hydro- or hydraircooling with 225 μg/ml Botran plus 300 μg/ml benomyl controlled naturally-occurring decay of peaches. Applications at these concentrations are approved by registration labels, and deposit fungicide residues within the tolerances established by EPA (11). Under these conditions, however, Botran alone did not control Rhizopus rot. The disparity between control of Rhizopus rot in tests utilizing artificial inoculation and those utilizing natural infection emphasizes the importance of confirming laboratory data under natural conditions.

Botran and benomyl are approved by the Environmental Protection Agency for use on peaches.

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