Evaluation of Low-volume, Non-recycling Drenches for Controlling Postharvest Diseases and Disorders of Apples

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Editors Note: *Dr. Rosenberger offered the following guidelines and comments for grower applications: "For a commercial grower, the grower should mix up DPA at the appropriate labeled rate for the variety involved and then just spray 2.5 quarts of that solution over the top of the usual 20 bushel field bins. A handgun sprayer or even a solo sprayer would work if one can maintain an constant output, determine the time to deliver 2.5 quarts, and then just spray over the top of the bin for that predetermined amount of time. I just poured the solution over our minibins last year, but we used a sprayer this year and I think that we get more even distribution across the top of the bin by using a sprayer rather as opposed to just pouring the solution over the apples. Growers may find it necessary to cover bins to retain the volatiles if growers are treating only a few bins in a larger room. At the this time (October 2010) we are still not certain if one really needs a fungicide added to the drench when using this method. I don't think that a fungicide should be needed in most situations."*

Abstract

Diphenylamine (DPA) and postharvest fungicides were applied to apples using either a low-volume non-recycling drench (NRD) or a traditional high-volume recycling drench (RD). Effectiveness of the two application systems were compared by evaluating decay control in wounded Cortland fruit and by observing fruit for storage scald and carbon dioxide injury after cold storage. Each treatment was replicated four times by applying treatments to fruit in specially constructed minibins that were 15 inches square but equal in height to commercial harvest bins. Fruit treated with water (controls) via RD developed blue mold decay at 69% of puncture wounds whereas water applied as via NRD resulted in decay at only 24% of puncture wounds. However, Scholar/Captan/DPA and Penbotec/Captan/ DPA mixtures applied via RD provided >99% control of decay whereas those same combinations applied via NRD provided only 86-92% control of decay. Where fungicides were applied via NRD, the incidence of decay was 3 to 5 times greater in fruit at the bottom of the bin than in fruit located near the tops of the bins. Although fungicide treatments applied via NRD were not as effective as RD treatments, the NRD treatments may be effective enough to provide acceptable decay control under commercial conditions where fruit would be exposed to lower levels of inoculum than those used for this trial, and where relatively few fruit would have wounds. In treatments where diphenylamine (DPA) was applied via either NRD or RD to control superficial scald, the two different treatment methods were equally effective. When a fluorescent dye was added to DPA, the dye could be detected on only 40% of the fruit surface, but this method may under-estimate actual coverage. Results suggest that DPA treatment via NRD is effective because the vapor action from DPA is sufficient for suppressing scald on portions of the fruit that receive incomplete coverage.

Methods

Experiments were designed to compare the effectiveness of postharvest treatments applied to apples in a low-volume non-recycling drench (NRD) with results from the same treatments applied using a conventional high-volume recycling drench (RD). Because NRDs involve only small quantities of solution, we were specifically concerned about whether enough treatment solution would reach apples in the bottom of bins to control decays on those fruit.

To avoid the difficulties inherent in using full bins of apples as experimental units, we designed and constructed 24 plywood mini-bins that were 15 inches square (interior measurements) by 36 inches high so that we could work with "columns" of fruit equal in depth to those in full-size commercial storage bin. Each minibin held roughly 2.4 bushels of fruit and had an interior footprint area equal to 12% of that found in a MacroPlastic model 32FV bin. Data were collected from 50 fruit in the bottom of each mini-bin, 25 fruit from the mid-height part of the bin, and 25 fruit from the top of the bin. We used Cortland fruit as data fruit and Golden Delicious to fill the intervening spaces. The color difference between the two cultivars allowed us to quickly separate "data fruit" from filler fruit when experiments were being evaluated.

Fruit used in these trials were picked and transported to the Hudson Valley Lab on September 21. Fruit were held at ambient temperature until they could be transferred into our mini-bins on September 22 and 23. Maturity analyses performed on September 22 showed that Cortland fruit used for this trial had an average starch-iodine rating of 3.0 and mean pressure of 14.9 lb. However, seven of the 24 fruit in the random sample used for maturity evaluations had moldy core. When fruit with moldy core were excluded, the average starch-iodine rating for the remaining fruit was

Left: Filling minibins with alternating layers of Cortland "data fruit" and Golden Delicious filler fruit. Although bins were 36 inches deep, six inches of headspace was left at the top to minimize splashing of treatment solutions. The full-size field bin in the rear was elevated on cement blocks for easier access to fruit. **Right:** A high-volume recycling drench is applied to fruit in a filled minibin while an assistant tracks time for the 30-second drench treatment.

2.2 and mean pressure was 14.7 lb. Cortland destined for CA storage are considered mature enough to harvest when they have a starch index of 2.5-3.5 and internal firmness greater than 15.0 lb (from Mike Fargione's Apple Maturity Report for September 23, 2009). We specifically tried to get Cortland fruit harvested toward the beginning of the maturity window so as to increase the probability that untreated fruit would develop scald during storage.

For logistical reasons, we divided the research into three separate trials. Trial 1 was designed to compare the efficacy of two DPA-fungicide combinations applied either via RD or via NRD. Trial 2 was designed to assess effectiveness of those same treatments for controlling storage scald and carbon dioxide injury. Trial 3 was a dye experiment designed to assess fruit coverage achieved with RD and NRD.

Trial 1: The Cortland fruit used in the experiment were wounded three times on each of three sides by puncturing the skin using a large cork fitted with three finishing nails that produced wounds that were 3 mm deep and 2 mm in diameter. Groups of 25 wounded fruit were held in plastic half-bushel "handle bags" until they could be placed in bins. After all fruit were wounded, 50 wounded fruit (2 bags) were placed in the bottom of each minibin and a layer of Golden Delicious was added to bring the fruit level to about 15 inches from the floor of the bin. A third bag of wounded Cortland fruit was added at the mid-level in the bin, then more Golden Delicious were added to bring the fruit level close to the 30-inch mark on the bin, and finally a fourth bag of wounded Cortland fruit was added to top off the fruit column while keeping the top layer of fruit at about 30 inches from the floor. The number of data fruit in the bottom of the bin was double that used for the top and middle levels of the bin because we anticipated that we might need more data points to sort out treatment differences at the bottom of bins where NRD treatments were expected to result in incomplete coverage of fruit surfaces. To minimize the amount of treatment solution that might be absorbed by dry bins, the plywood minibins were thoroughly hosed down with water several times over a 4-hr period before fruit were placed into them.

Inoculum was prepared by removing spores from 10-day old cultures of *Penicillium expansum* isolate 301, an isolate that is not controlled by benzimidazole-plus-DPA treatments. Hemacytometer counts revealed that the inoculum suspension contained 19.5×10^6 spores/ml. The inoculum suspension was poured into a plastic finger-pumped spray bottle. Before bags of wounded fruit were emptied into bins, the open bag was misted with one squirt (ca. 3.2 ml) of the spore suspension. One additional squirt was applied over top of each layer of Cortland apples after they had been transferred from the bags into the minibins. We used four bags of 25 wounded fruit per minibin (2 bottom, 1 center, 1 top) and had 3 layers (bottom, center, top) of data fruit within the bin. Thus, we applied seven inoculum squirts per bin for a total application of 22.4 ml of inoculum per minibin or a total of 439.9 million spores per minibin. We opted to apply the inoculum by misting fruit rather than dipping fruit into inoculum suspensions so as to more closely simulate exposure to airborne spores that might contaminate fruit during harvest and transport to storages under commercial conditions.

For recycling drenches (RD), we placed minibins in a fiberglass catch basin that had a large drain hole cut into one corner and that was supported on cement blocks so that solutions draining from the catch basin could be recaptured. Treatment solutions were mixed in a volume of 9 gal of water held in a 10-gal plastic garbage pail. The pail containing treatment solutions was placed beneath the catch basin drain. A sump pump in the garbage pail delivered 48 gal/min through a 1.75-in diameter flexible hose. Solution that ran through the minibins was rapidly recirculated back to the sump pump via the drain in the catch basin. We directed flow from the hose over the top of the minibin for 30 seconds and then allowed the minibin to drain before removing it from the fiberglass catch basin. The same treatment solution was used for treating four replicate bins for each treatment. The pump and catch basin were rinsed with clean water between treatments.

For non-recycling drenches (NRD), we used products at the same concentrations as those used for the recycling drenches. A double-layer of window screen was placed over the top of each bin and 500 ml of clean treatment solution was applied to each bin by pouring it through the double layer of screening in such a way that all apples on the upper layer were evenly wetted by the treatment solutions. Solution that drained from the bottoms of the minibins was recaptured in the catch basin and was measured to determine how much of the 500 ml/bin was retained by the fruit and bin surfaces.

Treatments in Trial 1 were applied on September

22 as follows:

1. NRD: Water control
2. NRD: No Scald DPA 1500 ppm plus Scholar 230SC 10 fl oz/100 gal plus Captan 80 1.25 lb
3. NRD: No Scald DPA 1500 ppm plus Penbotec 16 fl oz/100 gal plus Captan 80 1.25 lb
4. RD: Water control
5. RD: No Scald DPA 1500 ppm plus Scholar 230SC 10 fl oz/100 gal plus Captan 80 1.25 lb
6. RD: No Scald DPA 1500 ppm plus Penbotec 16 fl oz/100 gal plus Captan 80 1.25 lb

Treatments 4-5-6 were applied first. Roughly an hour after those treatments were applied, the fruit from these bins was removed so that the bins could be reused. The Cortland data fruit were placed on spring cushion trays that were labeled to indicate treatment, rep, and position (top, center, bottom) within the bin. The Golden Delicious filler fruit were discarded. After they were emptied, the bins were washed with a high pressure washer, refilled with apples used for treatments 1-2-3, and the NRD treatments were applied as described above. Because we wanted to know if the orientation of wounds on fruit in the bin would affect the control achieved with NRD treatments, treatments 1-2-3 were left in the bin and moved to cold storage along with the fruit from treatments 4-5-6 that were boxed on spring cushion trays. All of the bins and boxes were placed into plastic bags. All fruit had been moved into cold storage at 35° F by 4:00 PM on September 22. We bagged the containers to maintain high humidity that would favor decays and to ensure that volatiles produced by the treatments would be retained within the treated fruit and would not be diluted by air movement through the boxes/bins.

Fruit from treatments 4-6 were removed from cold storage on November 12 and were evaluated for decays. The number of wounds on each fruit was recorded. Fruit from treatments 1-3 were removed from cold storage on November 16 Fruit were removed from the bins with careful attention to maintaining the exact orientation of the fruit within the bin so that we could assess the number of wounds and number of infections that occurred on the upward-facing one-quarter of the fruit, on the downward facing quarter of the fruit, and on the sides of the fruit that represented the center half of the fruit.

Trial 2: Three treatments were applied to fruit in minibins on September 23 to evaluate effects of treatments on development of storage scald and CO_2 injury. Minibins were filled as described for Treatments 1-6 above except that none of the fruit were wounded and no inoculum was applied. Treatments were as follows:

1. NRD: Water control
2. NRD: No Scald DPA 1500 ppm plus Scholar 230SC 10 fl oz/100 gal plus Captan 80 1.25 lb
3. HVRD: No Scald DPA 1500 ppm plus Scholar 230SC 10 fl oz/100 gal plus Captan 80 1.25 lb

Each treatment was applied to four replicate minibins. Treated fruit were left in the minibins, and the bins were enclosed in large plastic bags and moved into the same cold room as the other fruit within an hour of the time that treatments were applied.

Trial 3: This experiment was conducted in a greenhouse on February 16, 2010. Golden Delicious fruit from cold storage were placed into minibins and were given a non-recycling drench treatment No-Scald DPA at 1500 ppm to which a fluorescent dye had been added. Immediately after treatment, fruit were removed from the bin and placed on spring cushion trays while keeping the same fruit orientation that fruit occupied in the bin (i.e., the upward facing side of the fruit in the bin was also upward facing on the spring cushion trays). Fruit were evaluated for surface coverage under a black light.

Results

Trial 1: Means were calculated by averaging the incidence of decay for fruit at the bottom, middle, and top of the bin, thereby providing an equal weighting for each of the three fruit positions within bins even though there were twice as many data apples at the bottom of the bins as compared to the other two positions. Fruit in the RD water control (trt 4) developed decay at 68.7% of the wounds whereas fruit in the NRD water control (trt 1) developed decay at only 24.3% of the wounds (Figure 1). Thus, the recycling water picked up the spores that we had misted over the fruit and effectively inoculated other fruit in the bins whereas that occurred to a much lesser extent in the NRD treatment. The fruit inoculation effects of the recycling water in treatment 4 is further illustrated by the fact that the first bin treated with recycling water

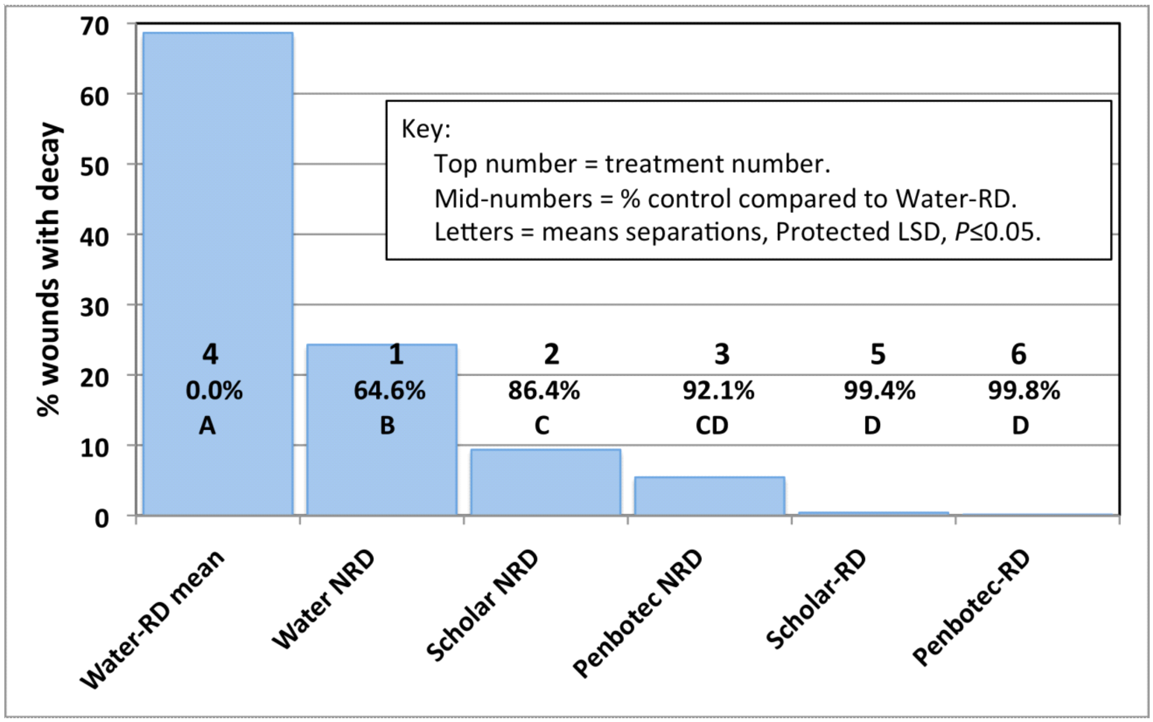

Figure 1. Effects of fungicide treatments on disease incidence in Cortland fruit that were wounded, mist-inoculated with spores of *Penicillium expansum*, then treated with water, Scholar, or Penbotec using either recycling drenches (RD) or non-recycling drenches (NRD).

had only 52% of wounds with decay whereas subsequent bins had 68, 78, and 76%, respectively. This sequence is logical if one considers that spore concentrations in the recycling drench water would have increased as each bin was treated in turn, but the effect of increasing inoculum concentration leveled off after several bins had been treated.

If results for other treatments are converted to percent control using trt 4 as the basis for the maximum infection rate, then just switching away from the RD to the NRD treatment system in the absence of any fungicide provided a 65% reduction in disease incidence (Figure 1). When Scholar and Penbotec were applied as RD treatments, they provided greater than 99% control of blue mold, but they only provided 86% and 92% control, respectively, when applied as NRD treatments.

Where water alone was applied as an NRD treatment, disease incidence for fruit at the top, middle, and bottom of the bins was virtually identical, indicating that inoculum was evenly distributed among fruit in the top, middle, and bottoms of the minibins (Figure 2). However, where Scholar was applied as an NRD treatment, decay incidence was nearly 5 times greater in the bottoms of the bins than in the tops of the bins (15.2 % vs. 3.3%). For Penbotec NRD treatments, disease incidence averaged 7.6% for fruit at the bottoms of bins compared to 2.3% for fruit at the tops of bins. Thus, it appears that fruit in the bottoms of bins received less complete fungicide coverage than those in the tops of bins.

For the NRD treatments, the orientation of the wound on apple surfaces within bins appeared to have relatively little impact on the probability that wounds would become infected. Looking at the total numbers of wounds across all of the NRD treatments, we found that 2,792 wounds faced upward, 5,660 wounds faced toward the sides of the bin, and 2,349 wounds faced downward. Infection percentages for those same categories were 14.2, 14.2, and 11.5%, respectively. Thus, there was a slightly lower incidence of infection in wounds facing downward in the bins where NRD treatments were applied, but the effect of wound position was relatively small.

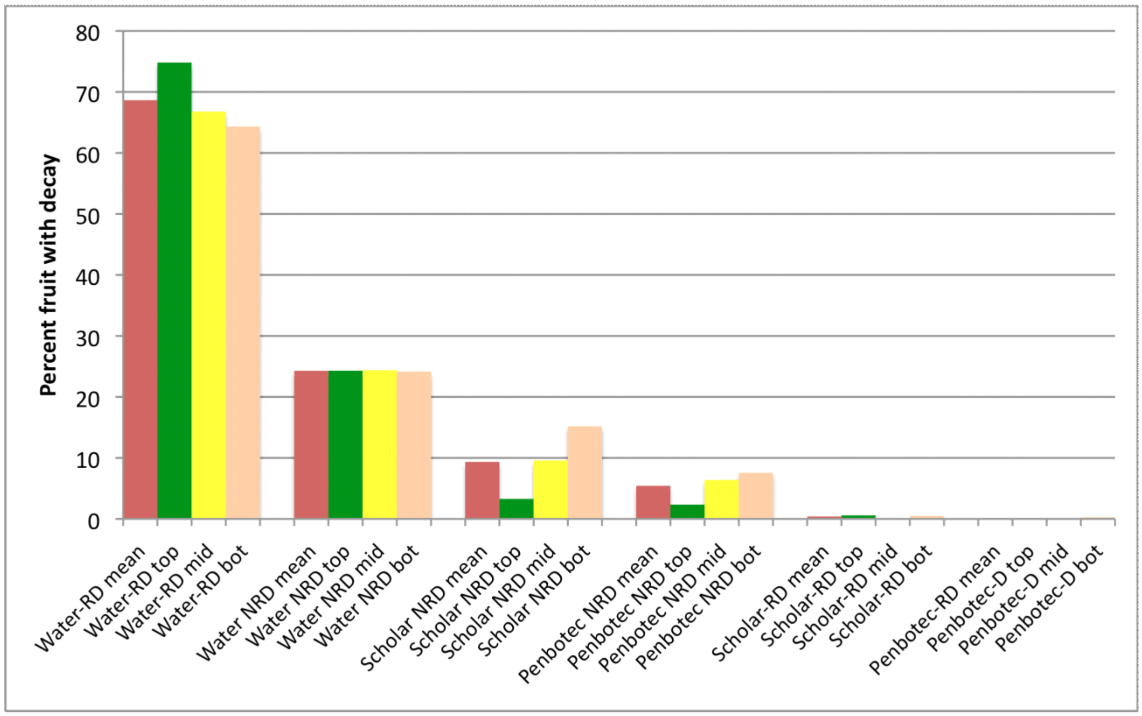

Figure 2. Effects of fungicide treatments on disease incidence in Cortland fruit that were wounded, mist-inoculated with spores of *Penicillium expansum*, then treated with water, Scholar, or Penbotec using either recycling drenches (RD) or non-recycling drenches (NRD). For each treatment, the first bar on the left shows the mean decay incidence throughout the minibin and the other three bars show the incidence for fruit in the top, center, and bottom of the minibins.

Trial 2: Fruit were removed from cold air storage and evaluated for superficial scald on February 1, 2010. Fruit with scald, decay, or senescent breakdown were discarded during the first evaluation. The remaining fruit were held for an additional seven days at 70° F and were then evaluated again to determine how many additional fruit developed superficial scald during the shelf-life test. When results were tabulated, we found that 61% of fruit treated with water only (applied as a non-recycling drench) developed scald by the end of the trial whereas fruit treated with diphenylamine in either a recycling drench or in a non-recycling drench had only 2% of fruit with scald (Figure 3). Furthermore, there was slightly more scald in the tops of bins treated with water only via NRD, but there was no difference between scald incidence in the tops and bottoms of bins treated with DPA regardless of which treatment method was used. The fruit and the storage conditions in this trial were very conducive for development of superficial scald, thereby providing a harsh test for effectiveness of DPA. Nevertheless, DPA applied as a non-recycling drench was just as effective as when applied using the traditional recycling drenching method.

Trial 3: Evaluation of fruit treated with DPA solution containing a fluorescent dye showed that roughly 40% of the total fruit surface was contacted by the solution applied as an NRD. As expected, coverage was better in the tops of bins (55% coverage) than in the bottoms of bins (27% coverage). However, the dye fluoresced strongly only in locations where pooled solution dried on the fruit surfaces, so our analysis of fruit surface coverage may have under-estimated the actual proportion of fruit surface that was contacted. An alternative approach will be used next year to assess the proportion of the fruit skin that contacts the drench solutions.

Discussion

Results from Trial 1 showed the advantages and disadvantages of RD and NRD postharvest treatment

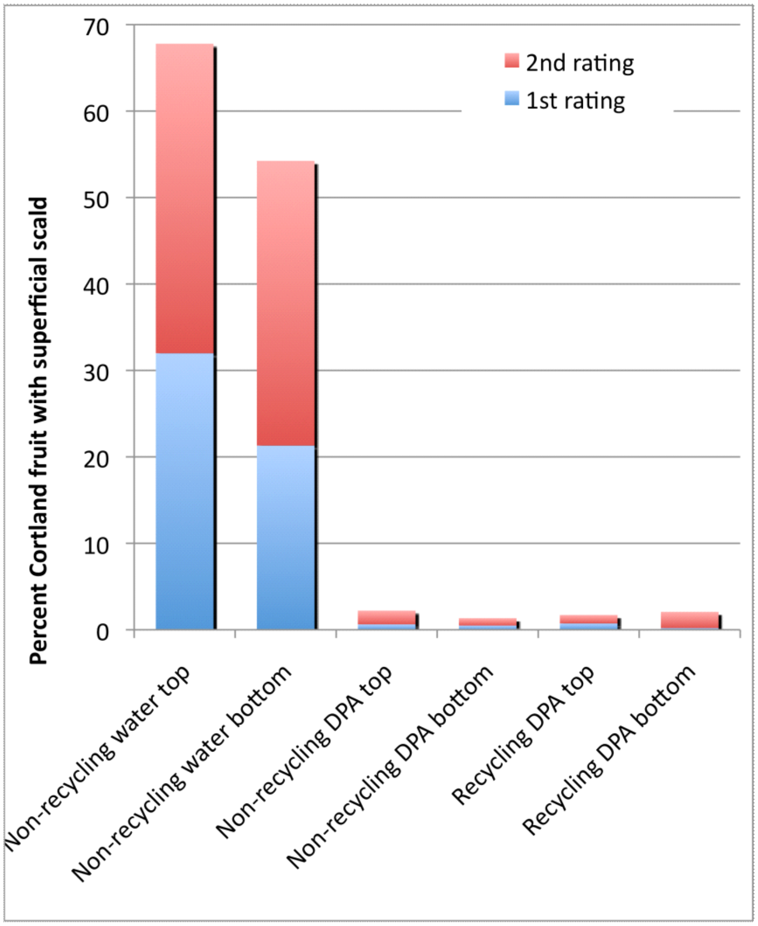

Figure 3. Effects of DPA treatments on the incidence of superficial scald noted on Cortland fruit that had been held in air storage from 23 September through 1 February and that were then evaluated a second time after a 7-day shelf-life test at 70° F. Data is presented separately for fruit from the tops of the bins and fruit from the bottom half of the bins.

systems. In the RD water treatment, the recycling solution rapidly picked up spores from the fruit surface and redistributed them to a high proportion of wounds on the fruit surfaces in the same way that spores in commercial DPA applications are redistributed to fruit wounds in the absence of an effective fungicide. By switching to the NRD treatment system (i.e., applying water without recycling it), we reduced decay incidence by nearly 65% in the absence of any fungicide. This reduction in decay with NRD treatment alone might have been greater if we had applied less inoculum to the fruit as we were filling the bins. Previous work has shown that fruit coming from the field rarely carry more than 30,000 *P. expansum* spores per commercial-size bin (Rosenberger et al. 2006). However, we misted fruit with the equivalent of 3.7 billion spores per full-size bin. Badly contaminated bins can carry more than 2 billion spores on bin surfaces (Rosenberger et al. 2006), so spores can accumulate in very high numbers in recycling drenches. In this trial we purposely used high levels of inoculum so as to ensure that we would be able to detect effects of different treatments.

Applying Scholar or Penbotec in NRD treatments further reduced disease incidence below that observed in the water NRD. However, fungicides applied via NRD were less effective than comparable RD treatments. (Although we included DPA and Captan in all of the Scholar and Penbotec treatments, Scholar and Penbotec provided most of the disease control and we therefore refer to the treatments using those fungicide names.) Disease control with Scholar was especially compromised for fruit in the bottoms of bins, presumably because coverage was less complete in the bottom than in the tops of bins. Further work is required to determine if activity of Scholar in NRD treatments can be improved by adding a surfactant, but any surfactant used in postharvest treatments must be approved as a "food-grade" product.

Packinghouse operators who pioneered the NRD concept reported that they used only about 2.5 qt of postharvest solution per bin or the equivalent of 283 ml per minibin. We increased the amount of solution applied in our NRD treatments to 500 ml per minibin (equivalent to 4.4 qt per commercial bin) because we were concerned that 2.5 qt per full-sized bin might be less than optimal. However, when we recaptured and measured the solution that ran through our minibins following the application of a total of 2000 ml to four bins, we found that we recaptured 1000 ml following Scholar NRD treatments and 910 ml following Penbotec NRD treatments. The fact that we recovered almost half of the 500 ml that we applied to each minibin indicates that previous observations on how much solution can be retained by each bin were pretty accurate. In future tests, NRD treatments should be applied at the equivalent of 2.5 qt per commercial bin or 283 ml per minibin because higher rates of application will result in excessive run-off where large numbers of bins are treated in the same location.

The reduced disease control that we noticed with fungicides applied via NRD as compared to RD applications may be insignificant if inoculum levels are kept low by using clean bins and sanitizing storage rooms at the end of each packing season. Factors in our methodology that favored disease development included having nine wounds/fruit, introduction of artificially high inoculum levels, and maintenance of 100% relative humidity following treatment by bagging the minibins while fruit inside the bins were still wet. Another factor that may have artificially raised disease levels in the Penbotec and Scholar NRD treatments is the fact that, whereas we used clean water for the water NRD treatment, we reused the Penbotec and Scholar solutions that we had used earlier for the RD treatments. Thus, in addition to the spore load introduced by misting fruit with a spore suspension, the Scholar and Penbotec NRD treatments were also exposed to the spore load in that accumulated in the solutions as RD treatments were applied.

The NRD method for applying DPA was more effective than the NRD approach for applying fungicides. Despite conditions that favored a high incidence of superficial scald in our controls, both the NRD and the RD treatments provide equivalent levels of scald control, and there was no difference in scald incidence for fruit in the upper half of each bin and fruit in the lower half of each bin. It seems likely that the volatility of DPA allows DPA vapors to suppress scald on the portions of fruit that may escape direct contact with the DPA solution when DPA is applied as a non-recycling drench. However, this method may fail to provide adequate scald control if small quantities of treated fruit are placed into large storage rooms because the DPA vapors may become too diluted to be effective. This is not a problem when large storage rooms are filled rapidly and all in-coming fruit has been treated, and we avoided this problem by bagging the fruit in our trials. However, more work is needed to determine the limits of this method when only a small proportion of the fruit in a room are treated via NRD.

Conclusions

- Simply switching from RD to NRD applications of water reduced decay by 65% (from 68% of wounds infected for RD application to 24% following NRD application). The fact that NRD applications do not accumulate and recirculate spores gives it a distinct advantage over RD applications.
- Both Scholar and Penbotec were more effective when applied in RD as compared to NRD treatments, although for Penbotec the effect of application method was not significant.
- Penbotec and Scholar applied as NRD treatments reduced decay levels significantly compared to the NRD water control. Benefits of these fungicides might have been even greater if we had used lower levels of inoculum. Alternatively, it is also possible that fungicide treatments could be completely eliminated if DPA can be applied as an NRD treatment under low-inoculum conditions that usually persist in commercial storages.
- Results from the DPA trial showed that, unlike the case with the fungicides, both the RD and NRD treatments provided nearly complete control of superficial scald and control was uniform throughout the minibins.
- These experiments should be repeated using several different levels of inoculum to determine if NRD fungicide treatments are more effective with reduced inoculum levels or if fungicides can be eliminated completely at low inoculum levels and also to determine if DPA applied via NRD provides scald control when bins are not bagged and only a small portion of the fruit in the storage room are treated.

Literature Cited

Rosenberger, D., A. Rugh, and F. Meyer. 2006. Keeping apples disease-free during storage and shipping. *New York Fruit Quarterly* 14(2):9-11.