FINAL PROJECT REPORT
WTFRC Project Number: PR-06-603 **(WSU Project #13L-4164-1207)**

Project Title: Managing storage scald in Anjou pears

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Cerexagri - contribution of chemicals.

Total Project Funding: Year 1: $34,277 Year 2: $45,301 Year 3: $60,585

Budget History:

Item	**Year 1:** 2004	**Year 2:** 2005	**Year 3:** 2006
Salaries	16,890	13,301	13,634
Benefits	5,067	5,985	6,681
Wages	4,500	6,500	7,000
Benefits	720	715	770
Equipment	700	2,000	0
Supplies	5,400	15,300	31,000
Travel	1,000	1,500	1,500
Miscellaneous	0	0	0
Total	34,277	45,301	60,585

OBJECTIVES:

This project was funded by WSU and the Washington Tree Fruit Research Commission for crop years 2004-2006 to initiate new research and integrate previous research on the prevention of storage scald on Anjou pears into a systems approach suitable for use by the industry.

The five specific objectives were:

1. Predict the risk of storage scald through knowledge of preharvest temperatures.
2. Determine the timing of antioxidant application using fruit with different risk levels.
3. Determine the effectiveness of applying antioxidants as a bin drench.
4. Determine the potential for chemical burn from antioxidants and fungicides applied as bin drenches.
5. Evaluate the use of thermofogging to control storage scald and decay (2006 crop).

SIGNIFICANT FINDINGS:

OBJECTIVE 1: Predict the risk of scald through knowledge of preharvest temperatures.

Methods: The risk of scald was estimated through knowledge of orchard temperatures by analyzing temperature data using techniques developed by Ma and Chen (2001) for the Hood River Valley in Oregon. To test whether this system would work to predict the risk of scald temperature, data loggers were placed into eight orchards (five in the Wenatchee Valley and three in the Yakima Valley). Data loggers were placed within the canopy 6 weeks prior to anticipated harvest and set to record temperatures on an hourly basis. The incidence of scald was compared to the hourly temperature data for each orchard to correlate cool nighttime temperatures (<50 ºF) with scald development.

Each year, pears from all orchards were harvested at the same firmness level to reduce the effect of maturity on scald development (Table 1). In 2005, fruit were removed from RA (33 ºF) storage at weekly intervals for 12 weeks, starting 30 days after harvest; ripened for 7 days and examined for scald. 2006 crop fruit were stored longer (pullout starting after 60 days in RA), and evaluated for a longer period of time (14 weeks). In addition to the scald evaluation after 7 days ripening, the 2006 fruit was also tested for ripeness (firmness, flesh juiciness and taste) after 7 days and re-evaluated for scald after 14 days.

Dr. Chen's model for Hood River (Ma, et al. 2001) was developed to predict when scald would develop on 10% of the fruit. When this was applied to temperatures in Wenatchee and Yakima the predicted range for 2005 was 62 to 92 days (Table 1). The predicted range for 2006 was 74 to 91 days. This prediction was the reason the first pull-out was increased from 30 days in 2005 to 60 days in 2006.

Results and Discussion: In 2005, scald developed only on fruit from one orchard within the inspection period. The orchard that developed scald had the lowest number of hours below 50 ºF. However, other orchards which also had very low accumulated temperatures (Wenatchee 1, 3 and Yakima 1) did not develop scald within the evaluation period (data not shown).

In 2006, scald did not develop on fruit prior to 100 days in storage (Fig. 1). The same orchard as 2005 (Wenatchee 2) developed the most scalded fruit. Scald was evaluated after both 7 and 14 days ripening, based on the theory that fruit taken out of storage early in the season would take more than 7 days to develop scald symptoms. In all cases, scald symptoms developed on fruit within 7 days, although the severity generally continued to increase up to the 14-day evaluation (data not shown).

Table 1. Harvest maturity and predicted days in storage after which 10% of the fruit will show scald symptoms following 7 days of ripening at 68ºF. Based on (Ma, et al. 2001).

	2005 Crop					2006 Crop					
Orchard	Harvest	Firm (lbf)	Hours <50 ºF*	Scald prediction**		Harvest	Firm (lbf)	Hours <50 ºF*	Scald prediction**		Actual Scald^
Wen1	19-Aug	15.1	9	74d	1-Nov	4-Sep	14.3	28	80d	23-Nov	2-Jan
Wen2	29-Aug	13.6	0	62d	30-Oct	7-Sep	14.3	9	74d	20-Nov	21-Dec
Wen3	29-Aug	13.6	11	75d	12-Nov	7-Sep	15.4	32	81d	27-Nov	4-Jan
Wen4	1-Sep	14.8	55	84d	24-Nov	14-Sep	14.1	76	87d	10-Dec	28-Dec
Wen5	12-Sep	15.0	137	91d	12-Dec	18-Sep	13.5	145	91d	18-Dec	NA
Yak1	23-Aug	15.6	11	75d	6-Nov	31-Aug	14.7	39	82d	21-Nov	18-Jan
Yak2	13-Sep	14.7	181	92d	14-Dec	11-Sep	14.9	141	91d	11-Dec	29-Jan
Yak3	13-Sep	14.5	61	85d	7-Dec	11-Sep	14.9	57	85d	5-Dec	2-Jan

* Accumulated hours below 50 ºF in the 42 days prior to harvest

** Predicted days in storage after which 10% of the fruit will show scald symptoms following 7 days ripening at 68ºF, based on the formula: $DIS\ (10\%) = 62.3827 \times ACU^{0.0757}$
DIS = the number of days fruit was held in air storage, ACU = accumulated cold units (hours <50ºF)

^ Actual date by which 10% of fruit developed scald

Summary conclusions. Within the first 100 days of storage there was surprisingly little scald in fruit from the Wenatchee orchards and even less from Yakima. Hood River pears developed scald earlier and at much elevated levels within this first 100 days (Ma et al. 2001). In Washington orchards that had accumulated over 140 hours below 50 ºF there was very little scald. The orchard with the most severe level of scald was that with the lowest number of hours below 50 ºF. However, the relationship between scald and temperature does not appear to be linear for Washington fruit, and more research over additional years is needed before this system can be utilized with confidence.

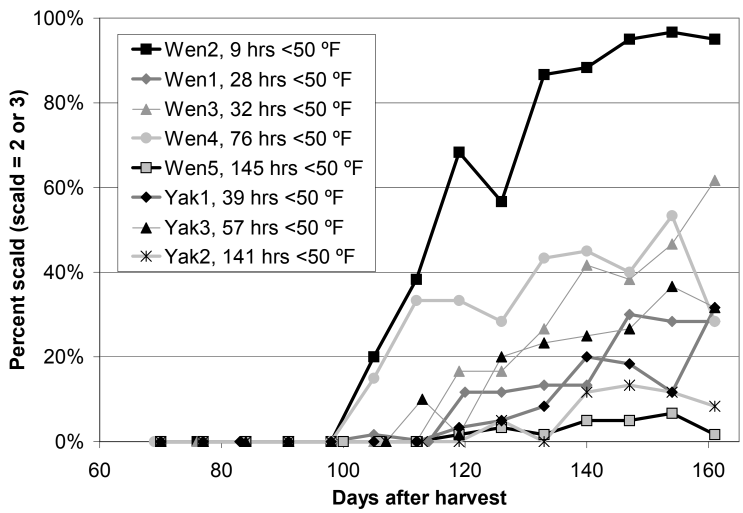

Figure 1. Scald development by orchard, 2006 crop. Rated weekly starting 60 days after harvest, RA storage, followed by 7 days ripening at 70ºF.

Note on the uniformity of ripening: The ripening of the 2006 crop was not uniform. Approximately half way through the 14-week evaluation period (December 28, 2006) firmnesses of "ripened" pears (7 days at 70 ºF) from the eight orchards ranged from less than 1 to over 16 lbf, with an average of 7.2 lbf (Fig. 2). It is not apparent that this wide range of firmness following exposure to time and warm temperatures is typical of what is seen in commerce. It would be valuable to have more information on the uniformity of ripening.

OBJECTIVE 2**: **Determine the timing of effective antioxidant application on fruit.

Methods: In 2006, two bins of commercially harvested fruit from each of the five Wenatchee orchards were drenched with TBZ only or ethoxyquin (1350 ppm) + TBZ within 1 week of harvest. Bins were stored in RA at 32 ºF for 7, 14 and 42 days prior to packing.

After each storage interval, fruit were passed over the wax section of the USDA ARS-1 packingline using one of three line spray treatments: 1) Penbotec only, 2) 675 ppm ethoxyquin + Penbotec or 3) 1350 ppm ethoxyquin + Penbotec. The fruit were tray packed and placed in CA storage. Fruit were evaluated for phytotoxicity and scald after 7 days ripening in March 2007.

Results and discussion: In 2004, superior control of scald was obtained when the antioxidant wrap was applied within 7 days of harvest when compared with delayed application (28, 56 or 112 days after harvest). However, even application at 7 days did not provide effective commercial control. Ethoxyquin wrap was more effective at controlling storage scald than diphenylamine (DPA) wrap (data not shown).

In 2005, to increase scald control, bins were first drenched with either 1350 ppm ethoxyquin or 1350 ppm ethoxyquin +TBZ. Antioxidant wraps were applied 7, 14 or 42 days after harvest. The most effective scald control was an ethoxyquin drench followed by antioxidant wrap applied within 7 days. Ethoxyquin wrap provided superior scald control to DPA wrap (Fig. 3).

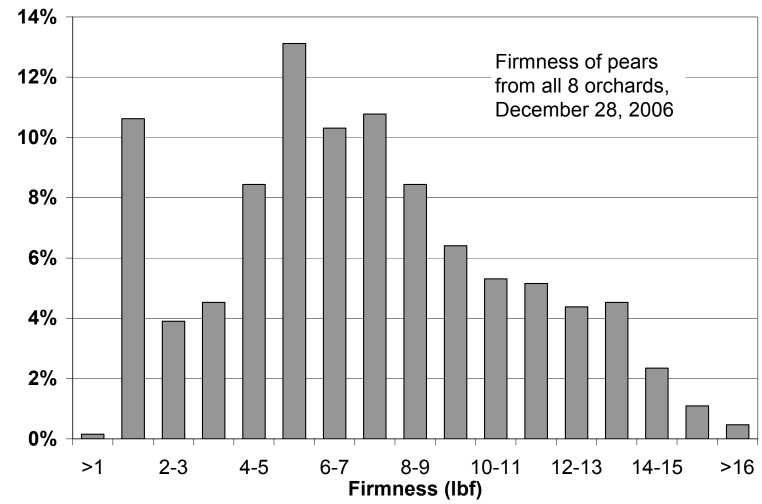

Figure 2. "Ripened" firmness of Anjou from 8 orchards. Data shown is approximately mid-point through 14-week evaluation period (95 to 116 days after harvest, depending on orchard), RA storage, 7 days ripening at 70 ºF, 2006 crop.

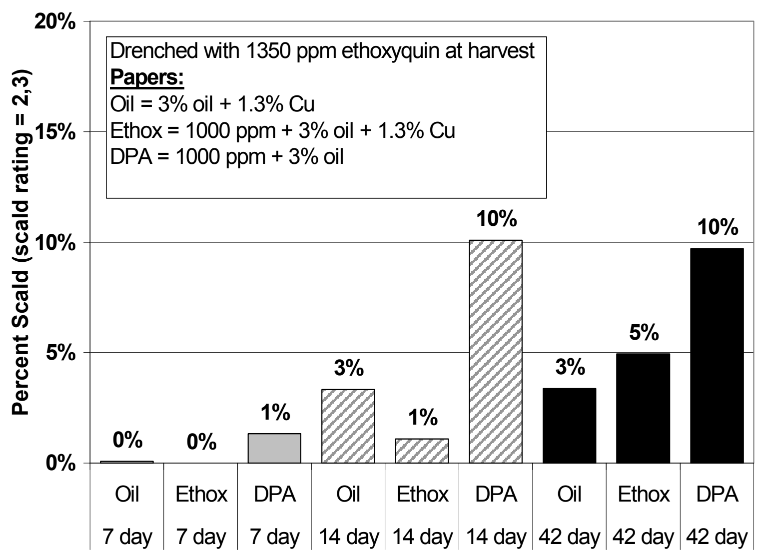

Figure 3. Scald development by antioxidant wrap type and application date. Average of five orchards. 2005 Crop, CA stored, ripened at 70ºF for 7 days, evaluated May 2006.

In 2006, fruit were drenched with either TBZ or ethoxyquin and antioxidant was applied as a line spray rather than a paper wrap. Fruit was evaluated in March 2007 following long-term CA storage. For fruit that was drenched with ethoxyquin at harvest, effective scald control was obtained with a line spray applied within 14 days. A line spray of Penbotec alone was nearly as effective as ethoxyquin in controlling scald on fruit that was previously drenched with ethoxyquin (Fig. 4). For fruit that was drenched with TBZ only at harvest, the most effective scald control was a line spray treatment of 1350 ppm ethoxyquin applied within 7 days (Fig. 4).

Summary conclusions. As other scientists (Chen, Drake) have found previously, in order for the ethoxyquin to be effective at controlling scald it must be applied within 7 days after harvest. Delayed application significantly reduced the effectiveness of the antioxidant. A combination of a half concentration ethoxyquin drench and a paper wrap applied within 7 days of harvest was the most powerful method to control scald. A half-strength drench of ethoxyquin at harvest, followed by a line spray of low concentration ethoxyquin was also very effective in controlling scald.

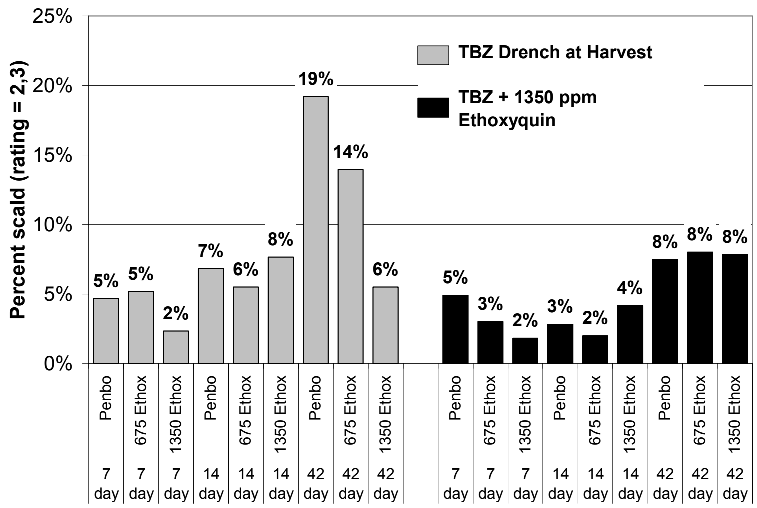

Figure 4. Scald on pears from the 2006 crop after a harvest drench with either TBZ or TBZ + ethoxyquin followed by line sprays at 7, 14 or 42 days after harvest. Fruit were evaluated following long-term CA storage in March 2007.

OBJECTIVE 3: Determine the effectiveness of applying antioxidants as a <u>bin drench</u>.

Methods: In 2006, three bins of commercially harvested pears from three different Wenatchee orchards were purchased and divided into cherry bins for drenching within 1 week of harvest. Drench solutions included control (TBZ only); 675 ppm ethoxyquin + TBZ; 1350 ppm ethoxyquin + TBZ, Penbotec or Scholar; and 2000 ppm ethoxyquin + TBZ.

Fruit was placed in CA and samples were removed for evaluation in January, March and April 2007. Samples were examined for chemical burn and scald after 7 days ripening. Additional samples were passed over the packingline for additional treatment with either Penbotec alone or ethoxyquin + Penbotec. The packed fruit was held in RA for 30 days and then evaluated for scald and chemical burn and scuffing. Ethoxyquin concentrations on the packingline were 1350 ppm for the 675 and 1350 ppm drenches and 700 ppm for the 2000 ppm drench to stay under the maximum label rate of 2700 ppm.

Results and discussion: In 2004, fruit were drenched with antioxidants and/or fungicides at harvest, stored in CA and evaluated for phytotoxicity and scald. Samples were held in RA for an additional 30, 60 or 90 days following CA storage and evaluated for scald after 7 days of ripening. Following storage for 30 days in RA, only fruit from orchards with few cooling hours developed scald; by 90 days, fruit from all orchards had developed significant scald. The ethoxyquin-treated fruit developed the least amount of scald, but even drenching with a fungicide alone reduced scald by approximately half compared to untreated control fruit.

In 2005 and 2006, fruit were drenched with antioxidants and/or fungicides at harvest and stored in bins in CA. In February, April and May four samples of each treatment were removed from storage and evaluated for scald: 1) after 7 days of ripening; 2) held in RA for 30 days and 7 days of ripening; 3) line spray of Penbotec only, 30 days in RA and 7 days ripening; and 4) line spray of ethoxyquin (not to exceed a total of 2700 ppm for the year) + Penbotec, 30 days in RA and 7 days of ripening.

In both 2005 and 2006, undrenched fruit developed significantly more scald than any of the antioxidant drenches. A 1350 ppm ethoxyquin drench provided equivalent control to the 2000 ppm ethoxyquin and superior control to 675 ppm ethoxyquin or 1000 ppm DPA (DPA included in 2005 trial only). Effective concentration was related to specific orchards. The longer the fruit was stored, the more scald it developed (February vs. April vs. May).

In both years, there was no significant reduction in scald after the application of ethoxyquin as a line spray following storage, even though the ethoxyquin application was maxed out at 2700 ppm. In addition, scuffing was a major problem on the fruit that was run over the packingline after storage (45% scuffed in February, increasing to 70% by May). This is another indication of the importance of applying the antioxidant immediately after harvest, rather than following storage.

Summary conclusion: Application of ethoxyquin as a drench at harvest provided superior control of scald to applying it on the line after storage; however, phytotoxicity was unacceptably high (see Objective 4). Ethoxyquin provided greater suppression of scald than DPA. More scald developed on fruit that was stored longer. Applying a line spray of antioxidant on Anjou after storage did not provide additional scald control.

OBJECTIVE 4: Determine the potential for chemical burn from antioxidants or fungicides applied as bin drenches.

Methods: Fruit used in Objectives 2 and 3 was evaluated for phytotoxicity at time of removal from storage. Fruit from Objective 3 was also evaluated after packing. Because of high phytotoxicity from the antioxidants in the 2004 and 2005 crops, antioxidant application methods in 2006 used lower concentrations applied multiple times.

Results and discussion: The inclusion of the fungicides TBZ, Scholar (fludioxonil) or Penbotec (pyrimethanil) in antioxidant drenches did not increase chemical burn in any years. In 2004, pink-colored permanent chemical burn was found at fruit-to-fruit contact points on a high percentage of fruit treated with ethoxyquin (up to 49% burned fruit). Brown chemical burn was not related to fruit contact and was found on the ethoxyquin-treated fruit (10% burned) and more severely on the DPA-treated fruit (average of 27% burned).

In 2005 and 2006, the pink burn from the Objective 3 ethoxyquin treatments increased with increasing concentration and was unacceptably high in all cases (Figs. 5 and 6). Again, the orchard factor comes into play because pink burn was only a minor problem on fruit from Wenatchee 4 in 2005 and was not present in the 675 ppm ethoxyquin treatment in 2006.

Brown burn in 2005 was associated with DPA treatments and was a relatively minor problem on fruit pulled out of storage in February (data not shown). Brown burn became a serious problem on fruit stored longer and was a more severe problem on fruit from Wenatchee 4, which did not have a problem with pink burn (data not shown).

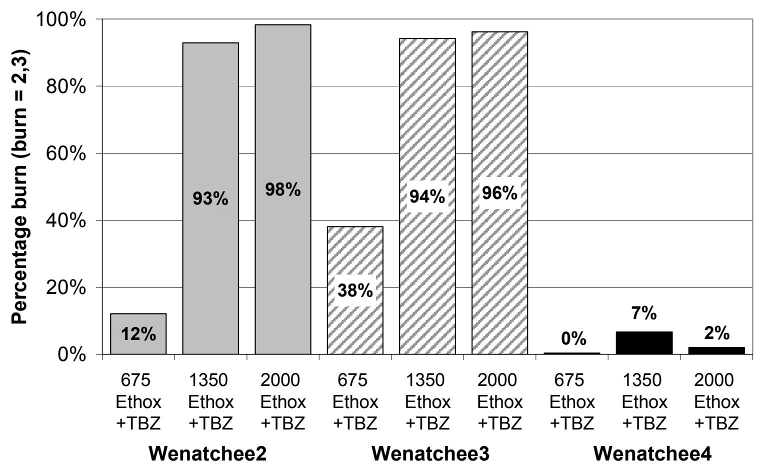

Figure 5. Pink burn on Anjou pears (2005 crop) following ethoxyquin drench and mid-term CA storage (February 13, 2006).

In contrast with Objective 3, fruit from Objective 2 (2006 crop) that was drenched at harvest with 1350 ppm ethoxyquin sustained little or no burn following long-term CA storage (Fig. 7). This fruit was given a second treatment of fungicide or fungicide + antioxidant mixed with wax and applied as a line spray. It is likely that the ethoxyquin residue from the drench was washed off of the fruit during the waxing process, before the excess ethoxyquin could penetrate the skin and permanently damage the fruit.

Summary conclusion: In drenching experiments conducted over the past 3 years, the presence of pink staining on the ethoxyquin-treated fruit has been a severe problem. Any benefit in scald reduction derived from the application of an ethoxyquin drench has been outweighed by the potential for damage from the treatment. The exception has been a line spray treatment applied within 6 weeks of the drench, which seems to rinse off the excess ethoxyquin residue, which can cause burning, while still providing effective scald control. In future projects, the use of a second rinsing drench will be explored to see if the pink residue from the ethoxyquin can be reduced without the chemical losing its effectiveness.

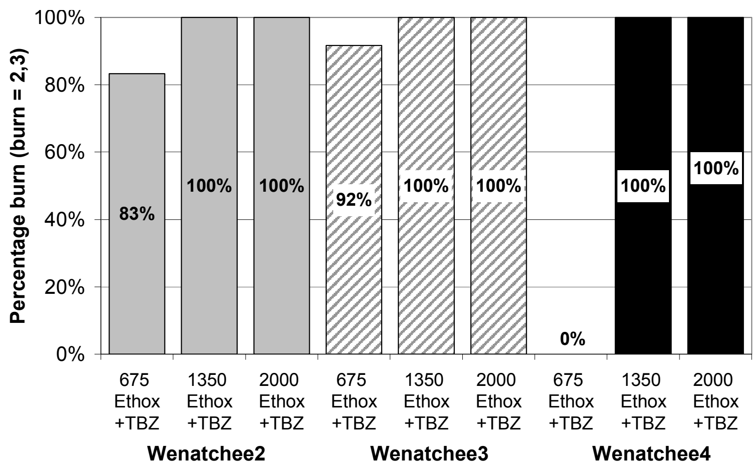

Figure 6. Pink burn on Anjou pears (2006 crop) following ethoxyquin drench and mid-term CA storage (January 15, 2007).

OBJECTIVE 5: Evaluate the use of <u>thermofogging</u> to control storage scald and decay.

Methods: In 2006, we began to study the feasibility of thermofogging with ethoxyquin and/or pyrimethanil on Anjou pears in cooperation with Dr. Peter Sanderson of Pace International. Sixteen bins of pears (4 growers, 4 bins each) were thermofogged in small CA rooms (40 bins capacity) immediately following harvest with one of the following treatments:

- Ethoxyquin alone;
- Pyrimethanil alone;
- Ethoxyquin + Pyrimethanil;
- Not fogged.

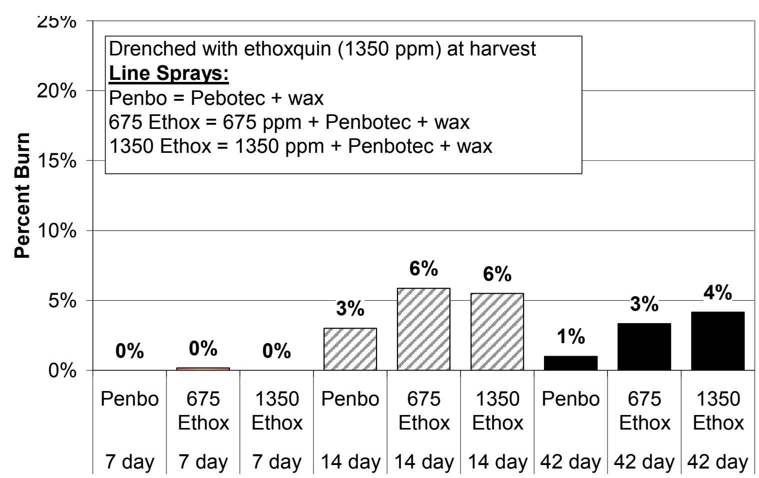

Figure 7. Burn on pears from the 2006 crop after a harvest drench with TBZ + 1350 ppm ethoxyquin followed by line sprays 7, 14 or 42 days after harvest (average of five growers). Fruit were evaluated following long-term storage in March 2007.

This fruit was stored in CA and sampled in January, March and April 2007 for evaluation of phytotoxicity immediately after storage and scald after 7 days.

Results and discussion: Scald control was effective on fruit removed prior to April 2007, 7 months after harvest (Fig. 8). There was a large increase in scald between March and April. Side effects of thermofogging included the development of pink burn on the tops of several bins that had likely been on the top of the stack while treated (Table 2; Fig. 9) and the high level of residue on fruit (Table 3).

The top layer of fruit on all ethoxyquin-treated bins was pink (Fig. 9). Two hundred fruit from the top of each ethoxyquin-treated bin were examined for burn and given a severity rating from 0 to 3. Each fruit was wiped with a glove; superficial marking that wiped off was not considered "burn" and not included in the table. Up to 95% of the top layer of fruit was burned in one bin (Table 2).

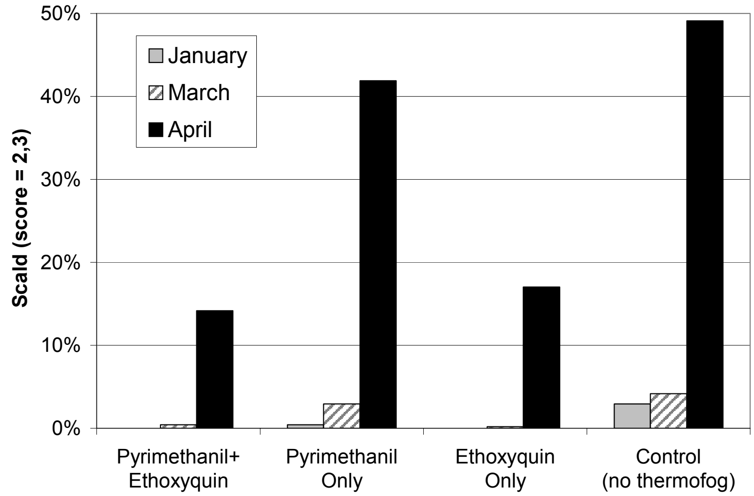

Figure 8. Scald development over three monthly pullouts by thermofog treatment. Average of four orchards. 2006 crop, CA stored, ripened at 70ºF for 7 days.

The thermofogging technique must be refined to promote even distribution of chemical throughout the room. In some bins, fruit had an excessive amount of residue on the top of the pear while the bottom of the same pear developed scald. In some bins, residue levels taken after treatment and again after mid-term CA storage were over the legal limit (3 ppm for both ethoxyquin and pyrimethanil) (Table 3). This procedure might require improved air movement, bin covers or other modifications to disperse the chemicals more evenly.

Table 2. Pink-colored burn from thermofog treatments, rated at packinghouse on January 4, 2007. Percentage of fruit on the top layer of the bin with commercially unacceptable burn (score of 2 or 3).

Treatment	Grower	Pink burn (% of burned fruit)
Pyrimethanil + Ethoxyquin	Grower1	2%
	Grower2	30%
	Grower3	95%
	Grower4	7%
Ethoxyquin Only	Grower1	31%
	Grower2	24%
	Grower3	4%
	Grower4	14%

Commercial experiment with thermofogging is very limited in Washington, especially with ethoxyquin on pears. One packer reported that they have thermofogged ethoxyquin alone on pears for 2 years and plan to expand the trial this season. They said that the burn was limited to the top fruit in the top bins and this was an acceptable amount of damage. Pace International has been working with the European developer of this technology (Xeda) on a larger number of commercial trials on apples with DPA. The same problems appear to exist when DPA is applied to apples—both burn on the top fruit and uneven residues.

Summary conclusion: Additional research is needed to develop a consistent deposition of chemical on all fruit in the room and within the bins so targeted residue concentration are achieved. Chemical burn, although restricted to the uppermost fruit in the top bins, needs to be ameliorated.

Figure 9. Photos of pink (left) and not pink (right) on top layer of pears at packinghouse. Bin A (left) is the ethoxyquin + pyrimethanil treatment and Bin D (right) is the control treatment.

Table 3. Pyrimethanil and ethoxyquin residues taken immediately after thermofogging (18-Sep-06) and after CA room opened (4-Jan-07). (All results in parts per million (ppm).) The legal allowable residue for ethoxyquin or pyrimethanil is 3 ppm in the United States.

			18- Sep Residues		4-Jan Residues*	
Grower	**Pyrimethanil**	**Ethoxyquin**	**Pyrimethanil**	**Ethoxyquin**	**Pyrimethanil**	**Ethoxyquin**
1**	Yes	Yes	5.6	4.3	1.3	nd
1	Yes	No	2.2	--	2.7	nd
1	No	Yes	--	7.3	0.1	nd
1	No	No	--	--	nd	nd
2	Yes	Yes	1.7	2.1	3.1	1.0
2	Yes	No	0.4	--	0.8	nd
2	No	Yes	--	5.0	nd	4.0
2	No	No	--	--	0.2	nd
3	Yes	Yes	4.2	2.5	1.3	nd
3	Yes	No	4.9	--	1.0	nd
3	No	Yes	--	1.4	0.2	nd
3	No	No	--	--	nd	nd
4	Yes	Yes	4.2	1.7	3.0	1.7
4	Yes	No	5.1	--	0.2	nd
4	No	Yes	--	1.9	0.2	2.3
4	No	No	--	--	nd	nd

* nd = not detectable

** Additional samples from the top middle and bottom layers of this bin were analyzed on 4-Jan:

- Top = 5.7 pyrimethanil, 0.9 ethoxyquin
- Middle = 1.8 pyrimethanil, nd ethoxyquin
- Bottom = 1.7 pyrimethanil, 0.5 ethoxyquin

Literature cited:

Ma, S., D.M. Varga and P.M. Chen. 2001. Using accumulated cold units to predict the development of superficial scald disorder on Anjou pears during cold storage. J. Hort. Sci. & Biotechnology 76(3):305-310.