FINAL REPORT

WTFRC Project #AH-02-212 **WSU Project #13C-3655-4179**

Project title: Improving fruit finish in apple
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Overall objective: To understand the factors that influence fruit finish of apples and develop and implement management procedures that will lead to better fruit finish for growers. A number of specific objectives related to improving fruit finish are outlined below:

1. Expand the development and field testing of a new sensor and control system for evaporative cooling of apples to provide better sunburn protection, more efficient water use and improved fruit finish of apples.
2. Investigate the causes of the disorder called “flecking” in ‘Fuji’ apples and study ways to prevent its occurrence.
3. Characterize a third type of sunburn, discovered late in the 2002 season, that occurs when shaded fruit is suddenly exposed to sunlight even though air temperatures are low. This disorder differs from sunburn necrosis and sunburn browning which are induced at much higher fruit surface temperatures.
4. Investigate color development as it relates to the above disorders and improving fruit finish.
5. Investigate causes of lenticel marking and ways to reduce lenticel breakdown during cold storage.

Significant findings:

1. A new fruit surface temperature (FST) sensor (patent pending) for controlling evaporative cooling (EC) was invented and has been tested with various control systems. Following are the various options tested: 1) irrigation pump turned on and off on signal from FST sensor; 2) solenoid valves activated or de-activated on signal from the FST sensor (“real-time system”); and 3) timer-type controller “asks” FST sensor each time it returns to zone 1 whether EC should stay on or shut off.

2. The FST sensor was also tested independently (i.e. no control system) to help growers decide when EC should be activated manually: 1) portable FST sensor can be read by receiver with radiotelemetry; 2) FST sensor connected to AgWeatherNet stations and read remotely.

3. Sunburn was significantly reduced in several orchards by using the “real time” EC system (Figs. 1-3), and water usage was reduced substantially with the new FST sensor. Fogging was compared to the “real time” EC and did not differ from EC (Figs. 2-3).

4. ‘Fuji’ flecking was induced by increasing relative humidity (RH) with overhead sprinklers from May 20 to June 9 in 2003. As RH increased, fruit flecking got worse than in the control with no EC (Fig. 4).

5. Results from 2003 and 2004 clearly indicated that the highest incidence of ‘Fuji’ flecking occurred in orchards with extremely high RH due to high density planting, dense canopies, or heavy use of overhead irrigation systems. The highest incidence of ‘Fuji’ flecking was 70.7%. The new FST sensor-controlled EC system (described above) decreased ‘Fuji’ flecking to 17% (Fig. 5).

6. To reduce ‘Fuji’ flecking, formulations that contained gibberellic acid (GA) were applied in 2002 and 2004. The most effective suppressants of ‘Fuji’ flecking were GA alone and RAYNOX mixed with GA (Fig. 6).

7. A third type of sunburn was discovered during 2002. It can even occur when air temperatures are below 70°F and fruit surface temperatures are below 87°F. Sunburn occurs when shaded fruit is suddenly exposed to sunlight (e.g. thinning, pruning, turning fruit for color development). Sunlight is required to induce this new type of sunburn, but blocking UV-B radiation does not prevent its occurrence.

8. Extenday, a reflective material, improved color on both ‘Fuji’ and ‘Gala’ in Tasmania (Tables 1 and 2, Gordon Brown data).

9. Lenticel marking was seen in several cultivars during 2003 and generally appeared on the sun-exposed side of fruit. It was most prevalent on apples with Class 3 or 4 sunburn browning and therefore appears to be another heat-induced disorder of apples.

Methods:

1. Evaporative cooling: We invented and made two kinds of fruit surface temperature (FST) sensors (EC-R and EC-T) (patent pending) for controlling EC to protect apples from attaining a FST that causes sunburn. In one orchard, a fogging system was installed for comparison. Before harvest, sunburn was evaluated to compare the various systems with the controls (no EC). Fruit color and fruit quality were examined. Additional work is in progress to reduce this concept to practice for growers at an affordable price.
2. Flecking of ‘Fuji’: ‘Fuji’ flecking was induced by increasing relative humidity (RH) with overhead sprinklers from May 20 to June 9 in 2003. Studies were conducted in orchards with EC and orchards with overhead irrigation. Leaf wetness detectors and HOBO RH sensors were placed in these plots to compare various orchards and relate that to flecking. Based on training systems, a canopy was divided into different sections to evaluate the profile of flecking within the canopy to determine where and why the flecking occurred. Finally, the data from different orchards were compared to identify the key factor that resulted in fruit flecking.
3. Third type of sunburn: This new type of apple sunburn was discovered in 2002 and was characterized further during 2003 to distinguish it from sunburn browning and sunburn necrosis.
4. Color development in apples: We have limited data on chlorophyll, flavonoids, carotenoids and xanthophyll pigments. We are cooperating with Dr. Lailiang Cheng at Cornell University on his new project entitled “Photoprotection of apple fruit by xanthophyll cycle.” Earlier, we showed that chlorophyll decreases as fruit matures and that anthocyanins increase. However, there are many other pigments that have not been characterized. We propose to initiate those characterizations to explain some of the peculiar color changes that occur especially in ‘Fuji’ apples during maturity. Dr. Brown, a cooperator on this project, already has two years of data on

use of Extenday, a reflective cloth, on cherries and apples in Tasmania, Australia. He has kindly shared his data (see results section below).

5. Lenticel marking: Several hundred apples were harvested at a commercial orchard and stored at Stemilt. 'Fuji' apples (180) with lenticel marking and 180 apples without marking were passed over a commercial packing line. Half of each group was waxed and dried, and the other half was not waxed. Following this processing, digital images for each apple were taken at intervals of 2 weeks to track the changes during the cold storage period.

Results and discussion:

1. **Evaporative cooling:** During 2002, a new control system for EC was developed and tested. The system was designed to turn on and off based on fruit surface temperature (FST) rather than using timers to control the system. Water and energy were conserved, as the system was activated on only 45 days between June 10 and October 20, 2002, and ran only 63.2 hours total. This compares to 110 hours of use if we had turned the system on when air temperature reached 86ºF (55 days during 2002) and if we cycled the system to run one-third of a 6-hour period daily. In 2003, the EC system was activated 74 days when FST exceeded 104ºF (40ºC). The system was "on" for 86.9 hours for the season, as compared to 260 hours for a conventional timer-controlled EC system. Thus, the new control system can save substantial water and electricity for the pumps. Fruit finish was improved with EC and fruit size increased. Some quality parameters like sugars and titratable acidity were increased with EC. With EC, sunburn damage was below 1% at maturity, whereas the controls without EC had sunburn damage of 16% on October 28, 2002 (Fig. 1). In 2003, sunburn damage with EC was less than 2%, whereas controls had 36% sunburn damage.

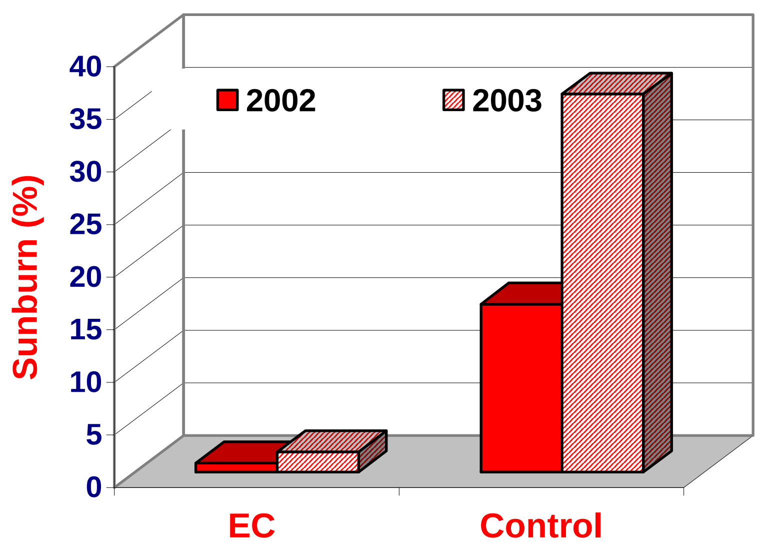

Fig. 1. Effect of EC on 'Fuji' sunburn in 2002 and 2003 (TFREC, Wenatchee).

Two kinds of sensors were tested in 2004 for activating solenoid valves as needed for EC and were compared to Fogging and a control. No difference was observed among EC-R, EC-T, and Fogging, but all three treatments significantly differed from the control in preventing fruit sunburn in both ‘Gala’ and ‘Golden Delicious’ in 2004 (Figs. 2,3). We hope to have a limited number of the FST sensor and control systems available for test marketing in 2005. During 2004, FST sensors were also tested in the AgWeatherNet system being developed by Fran Pierce et al. at Prosser. Another configuration involved a portable readout unit that displayed FST to a grower via radiotelemetry.

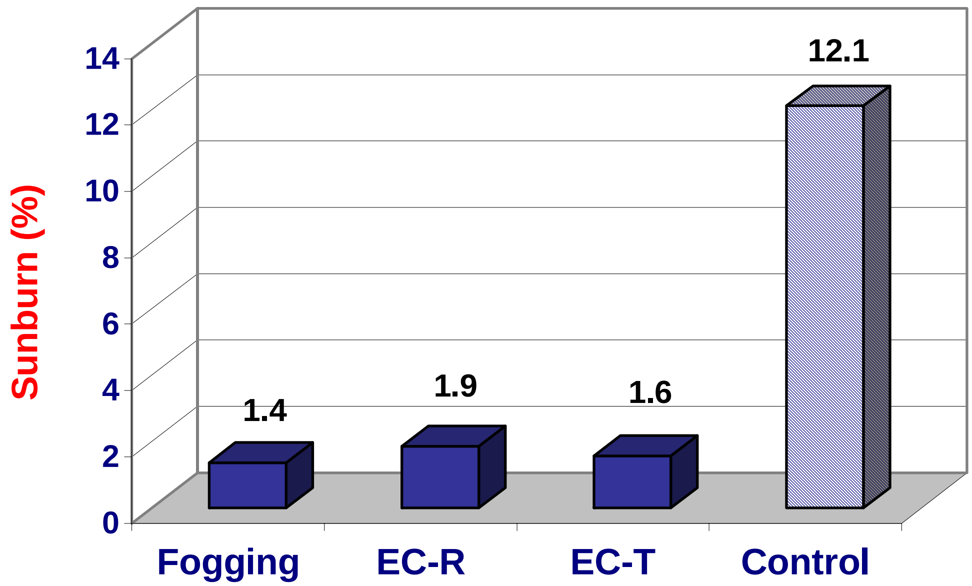

Fig. 2. Effect of EC and Fogging on ‘Gala’ sunburn (Brewster, Aug. 6, 2004).

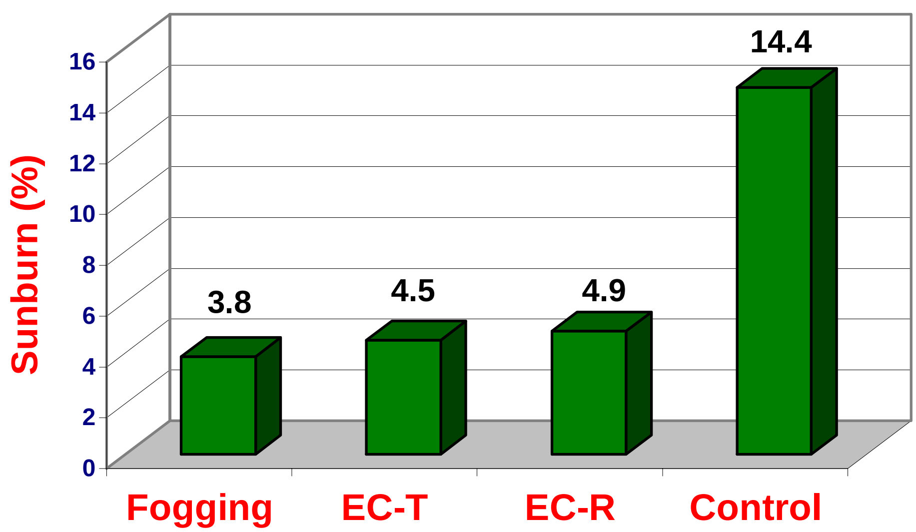

Fig. 3. Effect of EC and Fogging on ‘Golden Delicious’ Sunburn (Brewster, Sept. 15, 2004).

2. <u>'Fuji' flecking</u>: An experiment to induce 'Fuji' flecking was conducted by increasing relative humidity (RH) with sprinklers from May 20 to June 9 in 2003. As RH increased in trees with the sprinklers, fruit flecking increased as compared to the untreated control (Fig. 4).

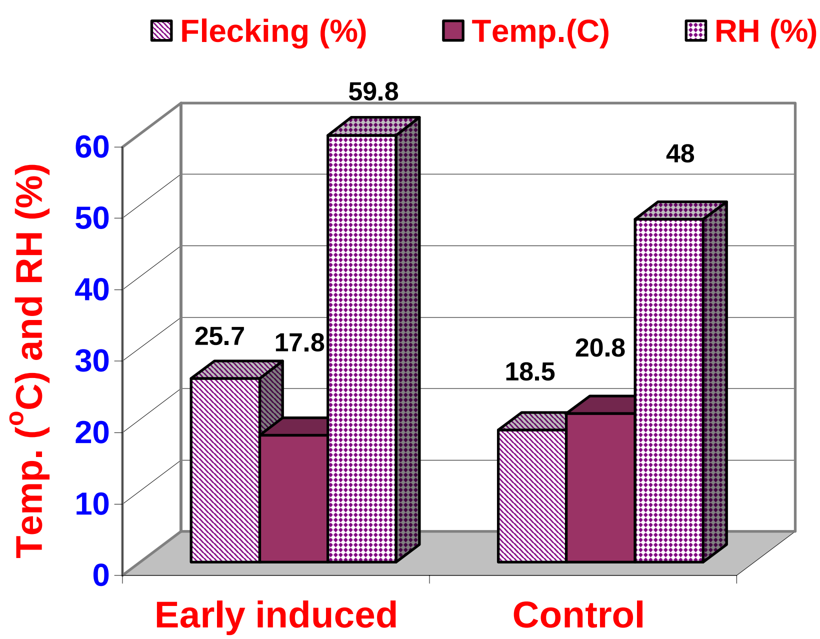

Fig. 4. Effect of temperature and relative humidity (RH) on 'Fuji' flecking (TFREC, 2003).

During 2003 and 2004, investigations were done in several orchards with different irrigation and training systems. The results clearly indicated that the highest incidence of 'Fuji' flecking occurred in the orchards with extremely high RH through much of the growing season due to either planting in high density or installing an overhead irrigation system. The worst scenario (70.7% flecking) was in an orchard with high-density plantings on a V-shaped training system with an irrigation system installed on both the top and in the middle of the canopy (OH + M) (Fig. 5). The risk of flecking increased as RH increased in the orchard. Flecking was much lower in the orchard with no EC (i.e. Treatment G - undertree irrigation only). 'Fuji' flecking was markedly decreased in an orchard where our new FST sensor controlled EC system was installed (treatment EC-S in Fig. 5). These findings point up the importance of limiting the amount of water applied to 'Fuji' trees from above the canopy.

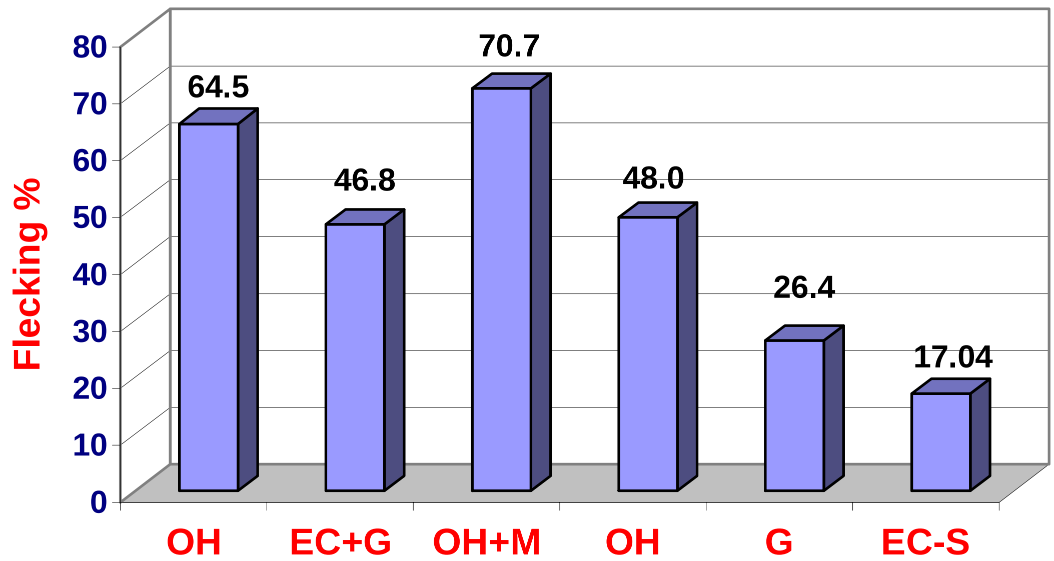

Fig. 5. Effects of irrigation and training systems on ‘Fuji’ flecking.

Legend for Fig. 5: OH = overhead irrigation only; EC+G = evaporative cooling system plus irrigation under trees; OH+M = overhead cooling and irrigation system within canopy (3 ft. above ground level); G = ground-level undertree irrigation without EC; EC-S = evaporative cooling with FST sensor control system.

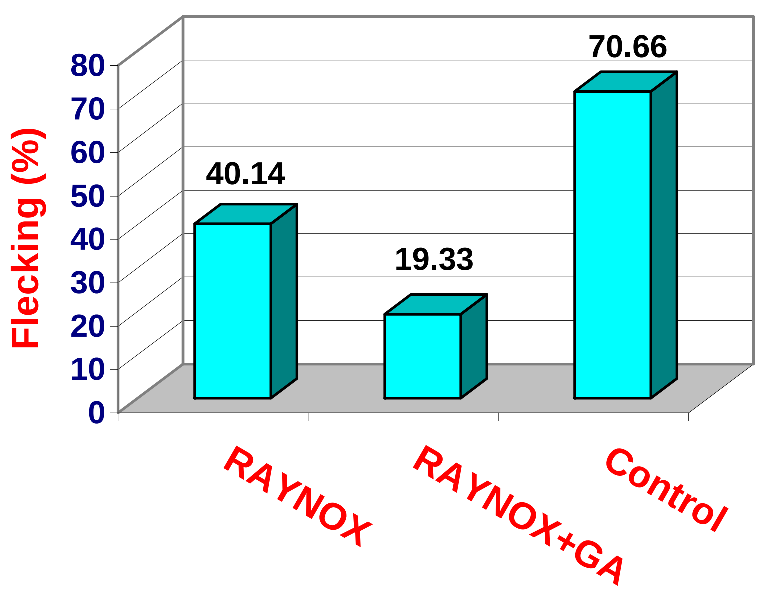

Fig. 6. Effects of formulations on ‘Fuji’ flecking (Chelan, Sept. 28, 2004).

To reduce ‘Fuji’ flecking, formulations that contained gibberelllic acid (GA) were applied in 2002 and 2004. RAYNOX alone suppressed ‘Fuji’ flecking substantially, but RAYNOX mixed with GA was most effective in suppressing ‘Fuji’ flecking (i.e. decreased flecking from 71% in control to 19%) (Fig. 6).

Another experiment done in 2004 with treatments that included GA, RAYNOX, and a mixture of both applied at different stages of fruit development showed that GA and a mixture of RAYNOX with GA suppressed flecking (Fig. 7). Additional research is needed to establish the best timing of these applications.

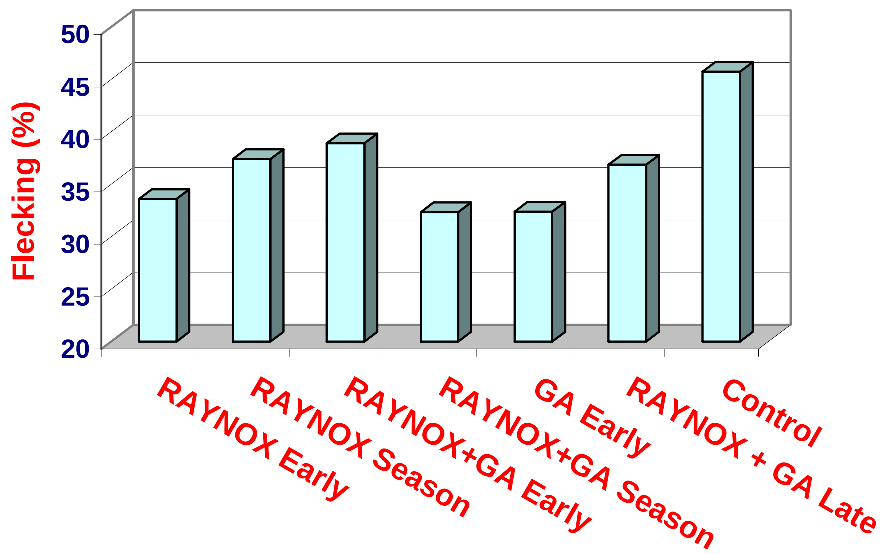

Fig. 7. Effects of RAYNOX and GA on ‘Fuji’ flecking (Quincy, Oct. 2, 2004).

3. <u>New type of sunburn</u>: This new form of sunburn I am calling Type 3 occurs on fruit that have been shaded (that is, non-acclimated to sun and high temperature) before sudden exposure to sunlight. Both ‘Fuji’ and ‘Pink Lady’ apples were quite vulnerable to this type of sunburn damage during late September and October when air temperatures were far below those experienced when sunburn browning occurs. Sunlight is required to induce Type 3 sunburn. Blocking UV-B had no effect, so type 3 sunburn differs from sunburn browning in which UV-B is required. Fruit damaged by the new type of sunburn are different in appearance than fruit that have sunburn necrosis or sunburn browning. Examples of practices that can cause the new type of sunburn are as follows: a heavily loaded branch shifts position and exposes green fruit; fruit are suddenly exposed by pruning; fruit are turned to obtain better color on the back side of the fruit; fruit are exposed to sun in bins left in the field or in bins during transport to the packing shed. Two experiments were conducted in 2003 at the Wenatchee Valley College orchard to determine whether sudden exposure of shaded apples during thinning results in this type of sunburn. Experiment 1 with ‘Gala’ ran from June 24 to July 14. The apples were fully exposed to sunlight. Two-thirds of the apples newly exposed by removing the fruit that shaded them developed slight photobleaching, the first symptom of this type of sunburn. Experiment 2 on ‘Gala’ ran from July 14 to August 1, 2003. The apples in this orchard were hand thinned traditionally by farm labor on July 14-18, 2003. The fruit were monitored for Type 3 damage. Damage was observed by July 21, 2003, and ranged from noticeable photobleaching to severe necrosis. Fruit surface temperature of damaged apples varied widely, adding further evidence that Type 3 sunburn is light induced, rather than heat induced.

The practical significance of this finding is that growers risk inducing this type of sunburn early in the season after thinning when the top fruit is removed and suddenly exposes fruit previously covered by that fruit. Turning apples late in the season to enhance color development is also risky. Apples that are not held in the shade after picking and apples that are not covered during transport to the packing shed are also at risk of Type 3 sunburn.

4. Color development: Dr. Brown in Tasmania has observed that Extenday significantly enhanced yield and skin color for 'Gala' apples. He observed enhanced color in both 'Fuji' and 'Pink Lady' with no detrimental effects on other fruit quality attributes (Tables 1 and 2). We plan to confirm these results next year in Washington State.

Table 1. Effect of Extenday, Retain and summer pruning on color development of 'Pink Lady' apples in Tasmania, Australia. From Gordon Brown, Scientific Horticulture, Tasmania, Australia.

'Pink Lady' apples	Skin red color area (%)
No reflective cloth	28 a
Retain®	40 ab
Summer pruning	48 b
Reflective cloth-EXTENDAY	68 c

Table 2. Effect of Extenday on color development in 'Gala' apples. Extenday was in place at the start of the season, end of the season, or at start and end of season. Data provided by Dr. Gordon Brown, Scientific Horticulture, Tasmania.

Treatment	**Yield t/Ha** (*p*=0.1)	**Skin color** % area	**Fruit firmness** kg	**Fruit weight** g	**TSS** %
No reflective cloth	31 a	70 a	15.8 a	132 a	14.8 a
Start of season	33 b	70 a	16.0 a	135 a	14.7 a
End of season	31 a	88 b	17.5 a	127 a	14.7 a
Start and end of season	34 b	86 b	16.8 a	134 a	15.4 a

5. Lenticel marking. In 2003, 180 'Fuji' apples with lenticel marking and 180 without marking were run through a commercial packing line. Half of each group had been treated with three applications of RAYNOX during the season, and the other half was from untreated control blocks. One group (from each preharvest treatment) was waxed on the line with a finishing wax and dried in a drying tunnel before being returned to cold storage. The other group was not waxed with the finishing wax, but was passed through the drying tunnel before being returned to cold storage. A third group (both treatments) remained in cold storage (no wax and no drying tunnel). Based on 1,440 digital images taken periodically after treatments, 'Fuji' fruit with lenticel marking did not develop more lenticel breakdown than the controls on this particular packing line. However, we are aware that problems with lenticel breakdown were common on many packing lines in 2003 so this will be investigated further in future studies.

Budget:

Project title: Improving fruit finish in apple
PI: Larry Schrader
Project duration: 3 years (2002-2004)
Current year: 2004
Project total (3 years): $221,852
Current budget request: $78,475

Year	Year 1 (2002)	Year 2 (2003)	Year 3 (2004)
Total	$71,018	$72,359	$78,475

Current year breakdown

Item	**Year 1 (2002)**	**Year 2 (2003)**	**Year 3 (2004)**
Salaries[1]	49,036	50,036	54,016
Benefits[2] (%)	11,252	11,993	13,199
Wages[3]	3,000	3,000	3,000
Benefits (16%)	480	480	480
Equipment	2,000	0	0
Supplies[4]	4,500	4,000	4,700
Travel[5]	750	850	1,080
Miscellaneous[6]	0	2,000	2,000
Total	$71,018	$72,359	$78,475

[1] Salary for Ag Project Assistant ($25,016); Salary for Research Associate ($29,000). David Felicetti is the Ag Project Assistant and is a Ph.D. candidate. Mr. Felicetti worked on the third type of sunburn and is now working on color development and other fruit finish issues in apples. Dr. J. Sun is the Research Associate and has worked primarily on the 'Fuji' flecking disorder, evaporative cooling, lenticel marking, and other fruit finish issues.

[2] Benefits for Ag Project Assistant ($1,599); 40% for Research Associate ($11,600).

[3] Hourly help to assist with setting up experimental apparatus, collection and analysis of data.

[4] Supplies will include chemicals and laboratory supplies for color analyses and for electron microscopy; supplies, relays, and controllers for fabricating overhead cooling systems, and cell phone charges.

[5] Travel to experimental plots.

[6] A productive collaboration has been established with Dr. Gordon Brown in Tasmania, Australia. Dr. Brown is a research scientist with Scientific Horticulture and works closely with the apple industry in Tasmania. He has interests in 'Fuji' stain, color development of apples, and russet (flecking) of 'Fuji'. This cooperative effort provides the advantages of two crops per year and fosters collaboration among scientists with common interests. We requested only $2,000 per year for Dr. Brown's efforts. Dr. Brown sought most of his support from the Australian apple growers through Horticulture Australia and searched his research results with us.