FINAL PROJECT REPORT

Project Title: Effect of early spring temperature on apple and sweet cherry blooms

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Percentage time per crop: Apple: 50% Pear: 0% Cherry: 50% Stone Fruit: 0%

Other funding sources

Indirect support through the existing infrastructure of AgWeatherNet and its 159 weather stations.

Total Project Funding: **Year 1: $95,000** **Year 2: $80,000** **Year 3: $80,000**

Budget History:

Organization Name: ARC-WSU **Contract Administrator:** Carrie Johnston
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Item	2012	2013	**2014**
Salaries	14,040	38,646	**37,661**
Benefits	5,616	7,803	**7,102**
Wages	42,400	20,860	**21,694**
Benefits	4,240	2,086	**2,169**
RCA Room Rental	0	0	**0**
Equipment	10,000	0	**0**
Supplies	10,204	2,605	**2,874**
Travel	8,500	8,000	**8,500**
Plot fees	0	0	**0**
Miscellaneous	0	0	**0**
Total	95,000	80,000	**80,000**

Footnotes: Salary for an Assistant Research Professor (Dr. Melba Salazar) for four months. Dr. Salazar will be supported by a graduate student, budgeted for two years of the project. One year of 0.5 FTE technical support to build the automated sampler system. The automated sampler will be integrated with a freezer, which is budgeted at $10,000. Additional budget items include part-time hourly labor to help with sample collection and sample analysis for all three years, goods and services for the parts associated with the automated sampler and travel for collection of the samples in the region.

Goal and Objectives

The overall goal of this project was to investigate the effect of early spring temperature on apples and sweet cherries at different developmental stages and to determine the hardiness. We used a traditional methodology through exposure to freezing temperatures, and automated part of this procedure. One of the general goals was also to develop a updated hardiness charts for apples and sweet cherries.

The following were the specific objectives:

1. To determine the effect of early spring temperature on bloom development for different apple and sweet cherry cultivars.
2. To develop a cold resistance curve from dormancy to bloom for apples and sweet cherry.
3. To update the charts for the different stages of blossom buds of apples and sweet cherry cultivars for local weather conditions in the Pacific Northwest.

Significant Findings

- Differences in hardiness and lethal temperature were found during different phenological stages for the same cultivar as well as among the sweet cherry and apple cultivars.
- We developed an automated sampler machines referred to as the "vending machine" to determine the hardiness of the crops when DTA was snot effective. The results indicated differences between apples and sweet cherries and among cultivars.
- The results from dissection indicate that there was a variation in cold hardiness for the different bud sizes of apples for the same sampling date and differences among phenological stages.
- A decision support tool was developed on the AgWeatherNet portal (www.weather.wsu.edu) were the cold hardiness information for cherries and apples is being posted.
- One alert was distributed during the early winter season in 2013 and one alert was distributed during the early winter season of 2014 with the respect to risk of damage in cherry buds.

Methods

Bud samples were collected throughout late winter and early spring in 2013 season to determine the effect of temperature on bloom development for apple and sweet cherry cultivars. We started our measurements in October 2012 and ended them around early bloom. For apples we evaluated the varieties Gala, Red Delicious and Fuji. For cherries we evaluated the varieties Bing, Chelan and Sweetheart. The sweet cherry and apple cultivars at different bud development stages were sampled from the field and tested in the laboratory. We restarted our sampling on October 2013 and ended in April for the 2013-2014 winter season. For the 2014-2015 growing season sampling was started again during October 2014 and will continue through the end of April, 2015.

Cold hardiness was assessed using differential thermal analysis (DTA) for the first phenological stages. When the DTA was not effective, beyond open cluster, a new automated sampling device was developed and used. For the new device we load the tissue samples into color coded cans and expose the material to different durations and controlled cold temperatures combinations in a freezer. After the cold temperature treatment has been completed each tissue sample is dissected to determine frost damage based on browning of the tissue.

Simultaneously to the process described above we collected dormant apple and cherry shoots that were 6 to 10 inches long with terminal flower buds. The shoots were kept in containers filled with water. The base of the shoots was recut every week and water was replaced every other day and forced in 3 different growth chambers with days/nights at a controlled temperature each one (54/39°F; 64/43°F; 75/54°F) similar to the procedures of Proebsting and Mills (1978), to simulate tree different spring environmental conditions. The samples were processed at three-day intervals and classified accordingly with its hardiness.

Digital pictures were taken for the different growth stages to illustrate, identify, and define the key growth stages for apple and sweet cherry to update the charts, these pictures were combined with the data obtained from the cold hardiness exposure described previously. All information was integrated to develop a digital system that can be accessed via the AgWeatherNet (www.weather.wsu.edu) portal.

Results and Discussion

Critical injury temperatures for apple buds and flowers of Fuji, Gala, and Red delicious and cherry buds and flowers of Bing, Chelan and Sweetheart were evaluated during the winter spring seasons of 2012-2013, 2013-2014, and 2014-2015. The relationship of the cumulative percentage of dead buds and the temperature was modeled using a logistic function (Fig 1). The following equation represents the fitted model:

$$CDF = c + \frac{(d-c)}{1+e^{-K(t-G)}} \qquad (1)$$

where CDF is the cumulative dead bud flower, in a logistic growth curve (Eq. 1), *c* and *d* represent the lower and the upper asymptote respectively which means the percentage of mortality presented already in the field (*c*) and the maximum percentage of mortality (*d*), *K* is the so called 'slope parameter', t is the gradient of temperature in the freezer and *G* is the temperature where the inflexion point of the curve occurs.

Significant logistic curves ($p < 0.01$) were adjusted for each of the cultivars and for different sampling dates. An example is shown for apple for three different dates in 2013 (Fig 1). The estimated parameter values of the model and the a few corresponding dates are presented in Table 1. As the confidence intervals for the *G* parameter are different, the overlapping curves are different. This means that the cultivars are different with respect to their resistance to lethal temperature (Table 1.)

The Probit procedure was used to calculate the percent of mortality (LT) for 10, 50 and 90. The resulting LT_{10}, LT_{50}, and LT_{90} values for each cultivar and each date of sampling were then used to model the behavior over time. A quadratic function was initially developed. However, it will be necessary to complete the measurements until bloom to develop the full model. The comparison among cultivars shows that there are variations in the temperatures at which injury occurs for each of the cultivars. The pattern of the injury is different at 10, 50 and 90 for each cultivar (Fig. 2).

The cold hardiness is greatly affected by bud development, since the temperature at which the buds become injured changes over time. These results support the earlier report that changes in hardiness were observed for different dates of sampling among cultivars and size of the buds. Buds from the first two sampling dates were less sensitive to cold temperature as compared to the latest sampling dates (Fig. 3). This shows that plants at the latest dates had less hardiness and that the deacclimation process has begun.

Until now there is a quadratic relationship between LT and the day when the sampling was conducted. We found this relationship for both apples (Fig. 3) and for cherries (Fig. 4). However, more data are required for model development. Each point represents the value of the temperature where the buds was frozen and dead on that date.

We also developed a simple decision support tool to present the cold hardiness data on the AgWeatherNet portal. For both sweet cherries and apples the user can select one of the three cultivars that are sampled, the two locations where the samples are collected and either the current growing season or past growing season for which data are available. These tools are currently still under developed and require evaluation by stakeholders. An example for apples for Fuji for the complete 2013-2014 growing season is shown in Fig. 5 and for cherries for Bing is shown in Fig. 6. In addition, we provided several early warnings during both the 2013-2014 and 2014-2015 growing season using the alert system of AgWeatherNet.

The initial results obtained from this project are very promising, although so far we only have one season of complete data for the 2013-2014 growing and limited late winter-early spring data for the 2012-2013 growing season and late fall-early winter for the 2014-2015 growing season due the funding cycle of this grant. The results confirm earlier cold hardiness observation obtained with the DTA system by others. However, our results have been collected at a weekly basis during the entire fall-winter-spring season, showing the change in acclimation and deacclimation over time of the reproductive buds and flowers. Our results also confirm that the DTA system cannot be very well used for apples. Therefore, we developed an automated sampling system that has worked well during the past growing season. The cold hardiness results obtained with the vending system are similar to those obtained with the DTA system. The initial data sets collected are insufficient for model development, but have shown a trend that can be easily reproduced during the growing seasons of this project. However, further data collection is needed for model development and evaluation. We already implemented the initial observations on the AgWeatherNet portal. Once the model is complete, hopefully during the second phase of this project, both the current season observed data as well as the modeled cold-hardiness data will be disseminated via the AgWeatherNet portal. The decision support system can then also be linked to an automated alert system to inform growers when conditions are favorable for potential damage to occur.

Table 1. Estimated parameters values of the logit model fitted for selected sampling dates for the three apple cultivars that are being evaluated.

Cultivar	**Sample Date**	***d***	***C***	***K***	***G***	**95% Confidence Limits (G)**	
Fuji	10/23/2013	1	0.1	-1.0	11.8	10.6	13.0
	11/22/2013	1	0.0	-0.6	-6.1	-7.1	-5.0
	12/16/2013	1	0.0	0.1	-25.1	-26.2	-23.9
	01/06/2014	1	0.0	0.1	-12.5	-13.3	-11.6
Gala	10/23/2013	1	0.0	-1.0	12.3	11.6	13.1
	11/22/2013	1	0.0	-0.5	-4.8	-5.3	-4.2
	12/16/2013	1	0.1	-0.6	-18.3	-19.4	-17.2
	01/06/2014	1	0.0	-0.5	-8.9	-11.1	-6.6
Red Delicious	10/23/2013	1	0.0	-1.5	11.2	10.6	11.8
	11/22/2013	1	0.0	-0.5	-4.9	-6.5	-3.3
	12/16/2013	1	0.0	-0.6	-13.8	-14.3	-13.2

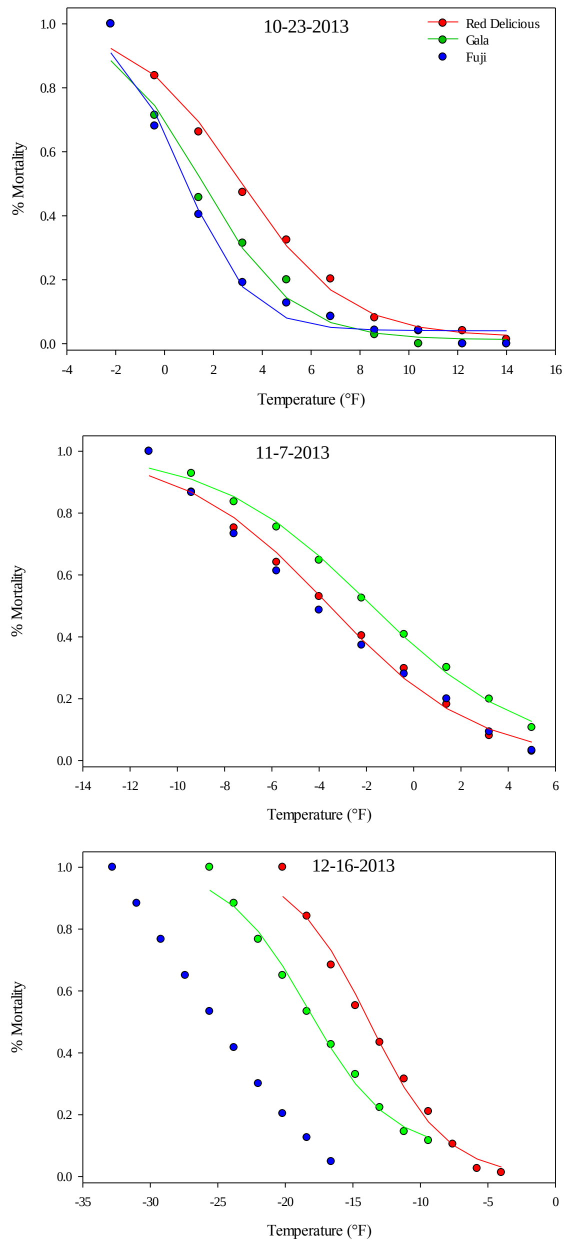


Figure 1. Probability of injured buds as function of temperature for apple cultivars at different evaluation dates.

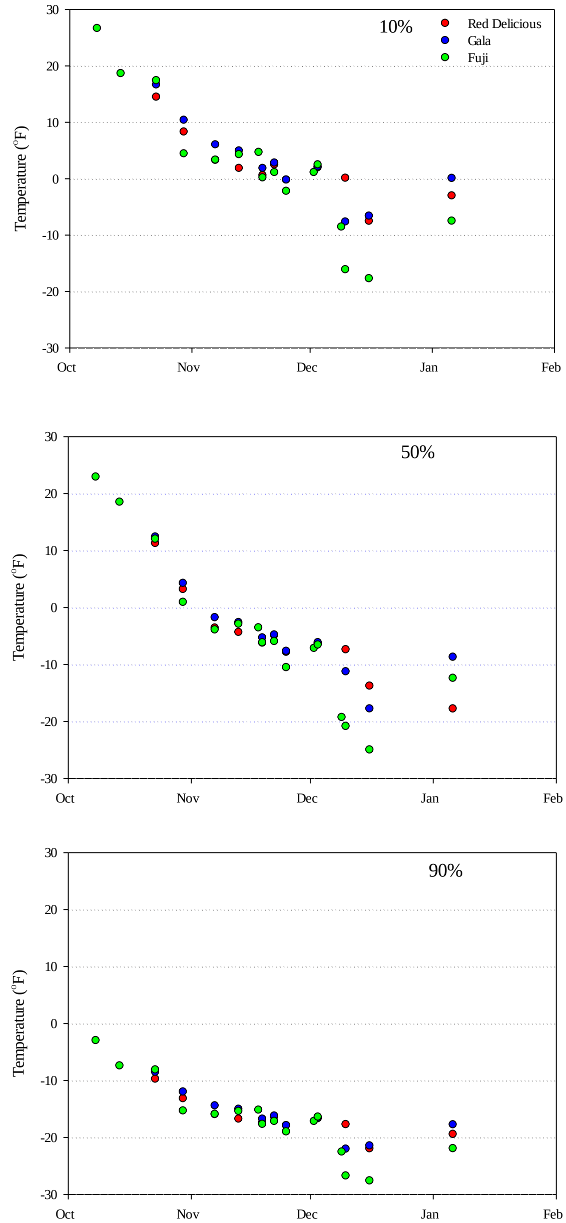


Figure 2. Seasonal pattern comparison of the LT temperatures (10, 50, and 90%) for the three apple cultivars evaluated on different dates in 2013

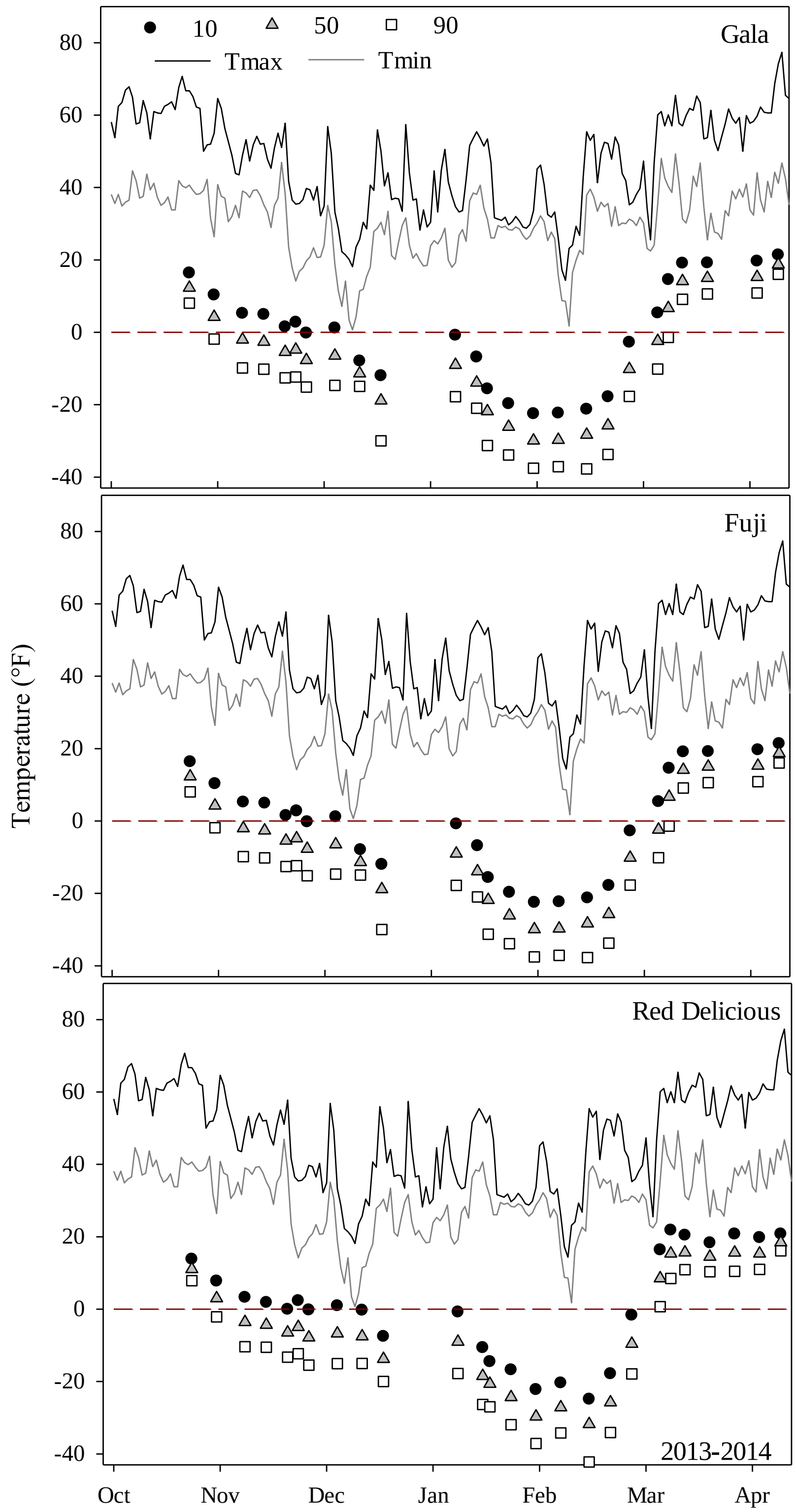
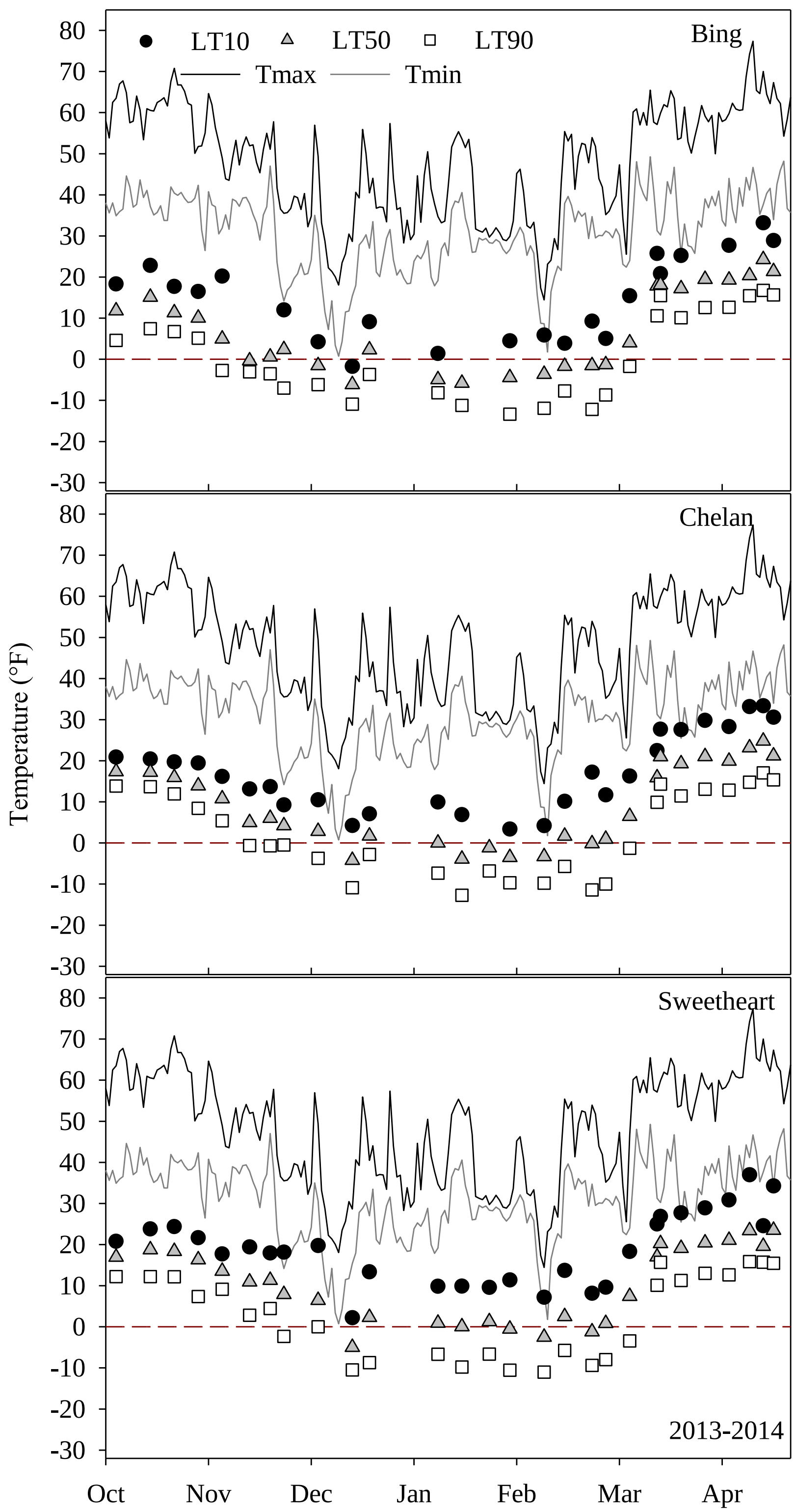


Figure 3. Daily maximum (Tmax) and minimum (Tmin) temperature for the 2013-2014 winter season and early spring for Prosser, WA, and progression of the critical injury temperatures for Gala, Fuji and Red Delicious. 10, 50 and 90 represent the lethal temperature (LTs) for each cultivar.



LT10
LT50
LT90
Tmax
Tmin
Bing
Chelan
Sweetheart
2013-2014
Temperature (°F)
80
70
60
50
40
30
20
10
0
-10
-20
-30
Oct
Nov
Dec
Jan
Feb
Mar
Apr

Figure 4. Daily maximum (Tmax) and minimum (Tmin) temperature for the 2013-2014 winter season and early spring for Prosser, WA, and progression of the critical injury temperatures for Bing, Chelan and Sweetheart. 10, 50 and 90 represent the lethal temperature (LTs) for each cultivar.

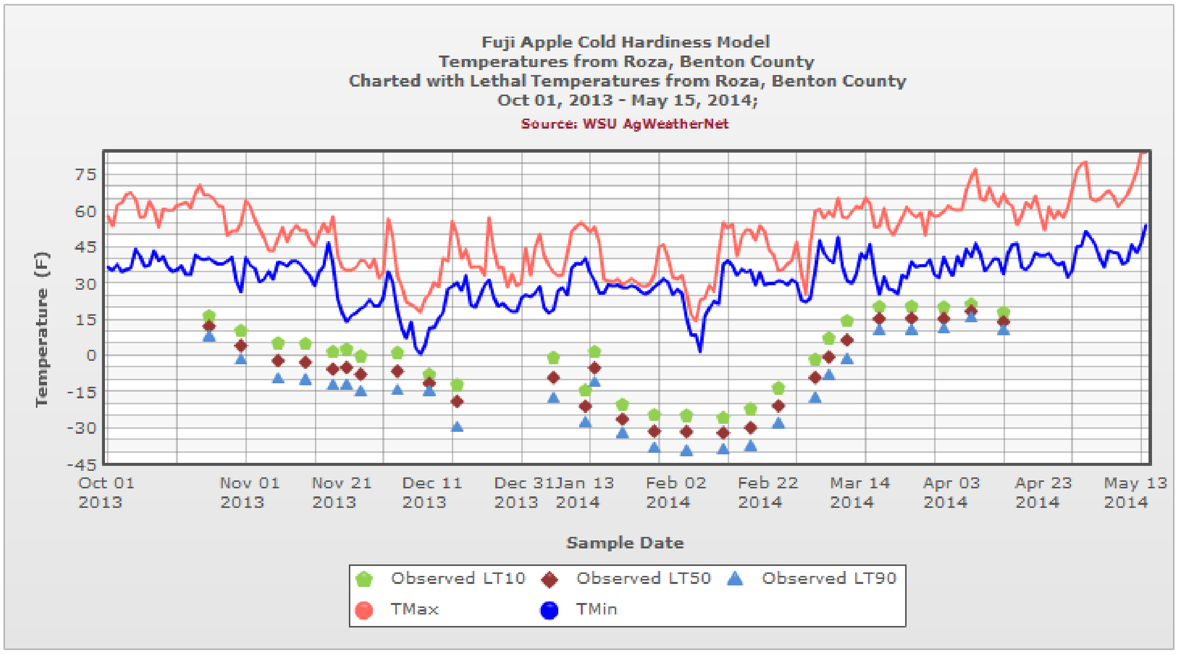


Figure 5. Data locally collected available through the AgWeatherNet web site at http://www.weather.wsu.edu/awn.php?page=cherrycoldhardness during 2013-2014 winter season and early spring for Prosser, WA, and progression of the critical injury temperatures for Fuji.

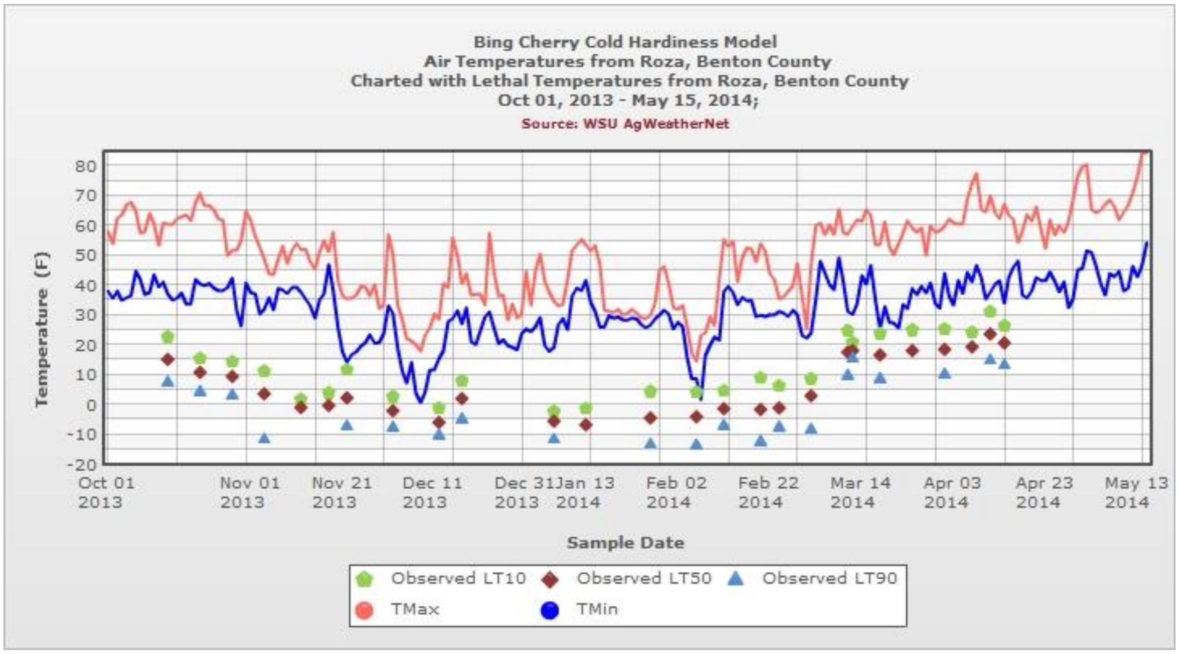


Figure 6. Data locally collected available through the AgWeatherNet web site at http://www.weather.wsu.edu/awn.php?page=cherrycoldhardness during 2013-2014 winter season and early spring for Prosser, WA, and progression of the critical injury temperatures for Bing.

EXECUTIVE SUMMARY
Temperature swings during the fall and early spring are common in the Pacific Northwest, but they can have a major impact on tree fruit crops such as apples in cherries. Low temperatures during early fall can damage buds that have not been exposed yet to low temperatures and are thus not cold hardy. During the spring early bud development or bloom can also be impacted by low night temperatures, especially during clear sky conditions at night. The overall goal of this project was to investigate the effect of early spring temperature on apples and sweet cherries at different developmental stages and to determine the hardiness. We used a traditional DTA methodology through exposure to freezing temperatures. For apple buds, apple flowers and cherry flowers we designed and built an automated sampling system that was installed in a controlled freezer, referred to as the "vending" machine.

- We found that there are differences in hardiness and lethal temperature during different phenological stages for the same cultivar as well as among the sweet cherry and apple cultivars.
- We found that there was a variation in cold hardiness for the different bud sizes of apples for the same sampling date and that there were differences among phenological stages.
- We found that the "vending" machine can be used for determining cold hardiness of samples that are not suitable for the DTA technology.
- We developed a decision support tool for the AgWeatherNet portal (www.weather.wsu.edu) where the cold hardiness information for cherries and apples can be posted.
- We distributed several alerts using the AgWeatherNet portal and alert distribution system during the 2013-2014 and 2014-2015 growing seasons based on the data we collected and the predicted low air temperatures.

This project was the first phase where we emphasized the development of appropriate methodologies for the determination of cold hardiness of apple and cherry flower buds and flowers. Further work is need for collection of additional data representing different growing seasons and this different weather conditions. Further work is also need to determine the impact of relative humidity and dewpoint temperature on cold hardiness. Additional data are also needed for the development and evaluation of robust models that can be implemented on the AgWeatherNet portal. The project could also be expanded to add other cultivars for apples and sweet cherries or to add other tree fruit crops, such as peaches.