Project Title: Sweet Cherry Bud Cold Hardiness Model
Report Type: Final Report

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Project Duration: 1-Year

Total Project Request for Year 1 Funding: $ 87, 341

	Kelsey Galimba OSU	**Gwen Hoheisel WSU**	**Lav Khot WSU**
Salaries	$12,000	$8779	$8750
Benefits	$8592	$4748	$3950
Wages	$5760	$8120	
Benefits	$576	$1626	
Equipment			
Supplies	$200	$500	
Travel	$500	$3240	
Miscellaneous	$20,000[1]		
Plot Fees			
Total	$47,628	$27,013	$12,700

[1] Fee for the now-independent (previously WSU) statistician (C.K.) to continue the modeling.

OBJECTIVES

The goal of this proposed project is to replicate the data collection performed in 2020-2021, providing an additional year of data to both improve and validate the constructed models. By the conclusion of this project, growers will have access to cold hardiness models for the four cultivars on AgWeatherNet, and will have characterizations of both how accurate the models are, and how they could potentially improve with more data collections in the future.

Objective 1: Gather an additional season of weekly phenology and lethal temperature data using Bing, Chelan, Sweetheart and Regina buds gathered in Washington and Oregon to improve the current model.

Objective 2: Quantify the uncertainty in the model after the two years of data collection, validate the model, and predict if and how additional collections would improve model accuracy.

Objective 3: Make the sweet cherry cold hardiness models publicly available on AgWeatherNet.

SIGNIFICANT FINDINGS

- Phenology is not the most accurate predictor of bud lethal temperature, especially in the early stages of dormancy to bud swell where internal development can occur without external appearances changing.

- Between dormant to first swell (stage 0 to 1), there is significant bud development internally where cold hardiness is lost, yet the external phenology appears unchanged. Some orchardists have noted this and look for yellow pollen development by cutting open dormant buds. Any yellow typically means some loss of lethal temperatures compared to the traditional Critical Temperature Chart.

- Between the two cherry cold hardiness proposals (2021 and 2022) we collected from eight field locations for Bing, Chelan and Sweetheart and five field locations for Regina.

- We define a full season's worth of data as a dataset (fall-spring). In the model, we are using seven full and one partial dataset for Bing, six full and two partial for Chelan and Sweetheart, and two full and three partial for Regina. Partial datasets were either a result of missing weather data or from the 2021 sampling that was initiated in the middle of the season for Oregon collections.

- Error in the mean LT is currently roughly ±1.8ºF/~1ºC Analysis of sample size indicates that an additional eight datasets, effectively doubling the size of the data collection, would be needed to reduce error in the mean LT to roughly ±1.2ºF/~0.7ºC. Collecting more freezer and weather data per cultivar decreases the error around the mean LT, but there is also error associated with the model.

- There are two sources of error inherent in this model. The first is error around the mean LT (e.g. 28 ± 4ºF). This is used to set wind machines and heaters. Additionally, there is error in damage because not every field will experience 10, 50, or 90% damage exactly, the error in lethal temperature (LT± 4ºF) does not directly translate to error in predicted loss. Some fields may experience much greater or less than 10% damage. Therefore, our model prediction of LT is conservative and predicts an LT in which the aggregate damage across fields will average 10% damage. Meaning, mitigation at the predicted LT10 will ensure that a majority of fields experience 10% or less mortality. But it is likely that many fields will be more cold-hardy and could modify their mitigation practices if they understand their specific orchard hardiness.

- Discussions with other researchers in this field have indicated that there are currently two cold hardiness models being developed. Our traditional scientific techniques and modeling are one effort. Additionally, Dr. Paola Pesantez Cabrera under the AgAID project has developed a cold hardiness model with AI techniques. Data from Dr. Whiting’s lab is used in that model. Both teams are keen on collaborating together for the best outcome.

RESULTS AND DISCUSSION

Objective 1: Collect more LT data.

In the 2020-2021 season, collaborators from OSU and WSU evaluated all available previously-gathered data while also collecting new data, with the goal of constructing and validating a sweet cherry cold hardiness model. Ultimately, data gathered prior to 2020 was deemed unreliable, with various concerns ranging from labeling inconsistencies to apparent early LT shifts that are biologically improbable. This caused the priority to shift to constructing a model using current-season data, and prompted an increase in the amount of data that was gathered, starting in early February.

Through the 2022-2023 winter season, cherry buds were collected in Washington and Oregon (Fig. 1). In the Yakima Valley, WA, three separate orchards for Bing, Sweetheart, and Chelan provided weekly samples. In The Dalles, OR, three orchards for Bing, Chelan, Sweetheart, and Regina were used, and one collection for each of these cultivars was also made in Hood River, OR. Both hobo dataloggers and commercial weather stations were used to collect temperature. The maximum number of samples that fit in the freezers were collected in the 2022-2023 season.

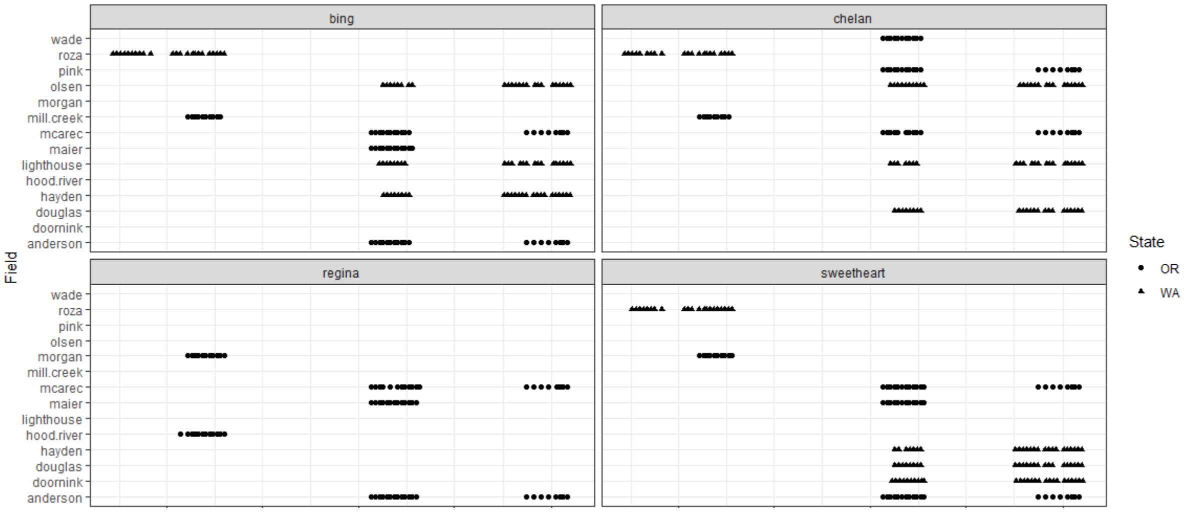

Figure 1: Depiction of the collection points aligned with reliable weather data for four different cultivars over the 2021 and 2022 grant proposals. Farms with two distinct data sets (ex. Olsen) indicate a full dataset of fall and spring collection. Some farms have partial datasets due to loss of weather data, but all viable data was included in the model to improve predictions.

Objective 2: Model development, uncertainty, and future needs

With any model, there is an analysis of uncertainty and assessment of improvements in the model.

1) Analysis of Sample Size:

From two grant proposals, we have collected lethal temperature data on four cultivars. In the first year, we collected one full dataset and one partial dataset each for Bing, Chelan and Sweetheart, and two partial datasets for Regina. In 2022-2023 we collected six full datasets for all four cultivars. In the model, we are using seven full and one partial dataset for Bing, six full and two partial for Chelan and Sweetheart, and two full and three partial for Regina. Partial datasets in the 2020-2021 season were due to Oregon being included in the project after sampling had already been initiated. Partial datasets from 2022-2023 are due to data being excluded because weather data was either missing or untrustworthy.

Two questions can be asked about the current datasets: 1) If we collect more data, can we better predict lethal temperature (LT)? 2) How much data are needed to predict LT? Figure 2 shows how much we would expect the mean LT25 to vary across replicate experiments comprised of a fixed number of datasets, suggesting that the improvement in the precision of the mean is minimal as we move past 16 datasets. **To sufficiently reduce the error in the mean for, we recommend that a total of 16 datasets are created to reduce the standard error in the LT25 to under ±0.7ºC/~1.2ºF.** As we reduce the standard error in the mean, the prediction error gets reduced. Currently for three cultivars, we have nearly six complete datasets and while an error ±1.8F is low, any error in the mean is going to systematically increase prediction error. Collecting an additional 2 years of data would help improve the standard error and model.

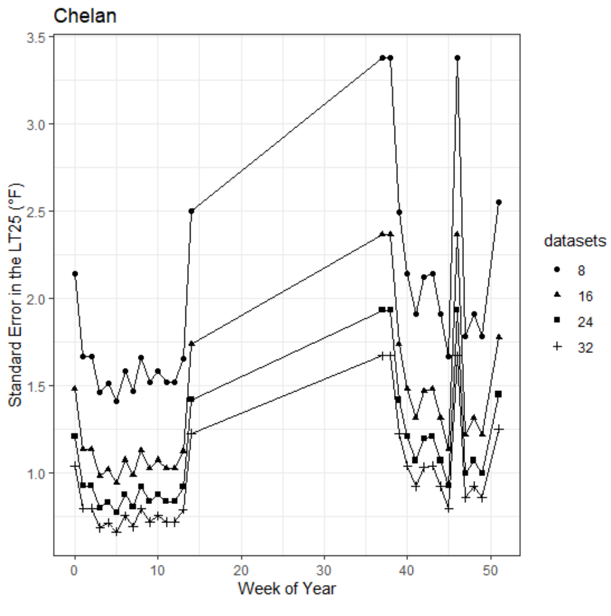

Figure 2: Standard error of the mean lethal temperature (LT25) for Chelan for a hypothetical project that is 1x – 4x times the scale of this project. Other varieties have similar characteristics. Week 0 = Jan 1. Weeks 15-36 are spring-summer months with no measure of cold hardiness, thus ignore the line. Notice that the more samples, the lower the error.

2) Cherry Cold Hardiness Model:

The Cherry Cold Hardiness Model (CCHM) was developed in similar fashion to the Blueberry Cold Hardiness Model (BCHM), however, in blueberries there are twice the number of datasets, meaning this co-analysis offers the opportunity to draw on similarities between the cold hardiness models. The

CCHM was developed to weight weather data that causes damage that could have occurred earlier in the season (Fig. 3). Furthermore, the LT predictions compute "population-level lethal temperature". To do this we created a code library that takes bud death data from both years of cold hardiness experiments, fits Bayesian Generalized Linear Mixed Models (GLMM), extracts population-level lethal temperatures. We plan to perform model approximation via lookup tables and uses AWN data to forecast lethal temperatures, similar to what is done with the BCHM.

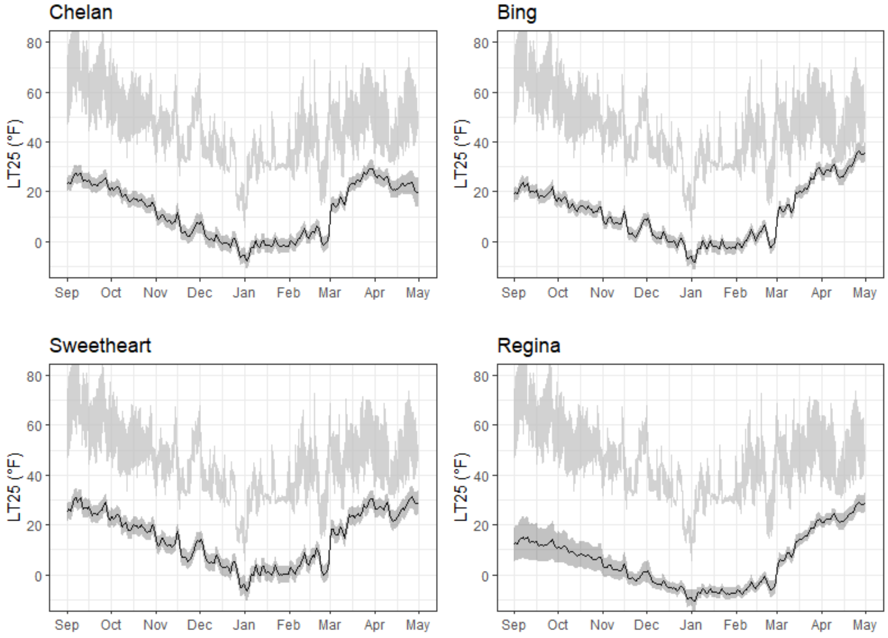

Figure 3: Depiction of the LT25 for four cultivars. The solid black line is the predicted LT25 with 95% confidence intervals around the mean (darker grey). The upper shaded line is the maximum and minimum daily temperatures from a weather station. Note higher error around the mean in fall months for Regina, an effect of less data from those months for that cultivar.

Predicting LT from "population level lethal temperatures" is key to accurately representing true damage across all fields. There are two ways of characterizing prediction error. The error around the mean LT shown as a temperature ± error in °F. This is used to set wind machines and heaters. Additionally, there is error in damage. **Because not every field will experience 10, 50, or 90% damage exactly, the error in lethal temperature (LT± error in °F) does not directly translate to error in predicted loss.** Grower financial loss is better characterized by error in predicted loss (e.g., an LT10 is predicting 10% loss but some fields my experience 40% loss), rather than just using the error in lethal temperature (e.g., if the predicted LT10 is 10°F then LT can range from 6-14°F actual is 12°F) (Fig. 4). The variability in predicted loss might be translated directly into revenue loss (e.g., losing 50% instead of 10% of the buds might be estimated as a $0.5M revenue loss, depending on size of farm) and errors in the positive direction (meaning less damage from a less sensitive field) could correspond to a potentially loss in labor and fuel for unnecessary mitigation. Averaging and minimizing lost revenue due to prediction error across growers is one way to try and minimize the overall loss experienced by growers. While more complex modeling, "population level lethal temperatures" estimates the lethal temperature in a manner that targets better grower decision making for cold mitigation.

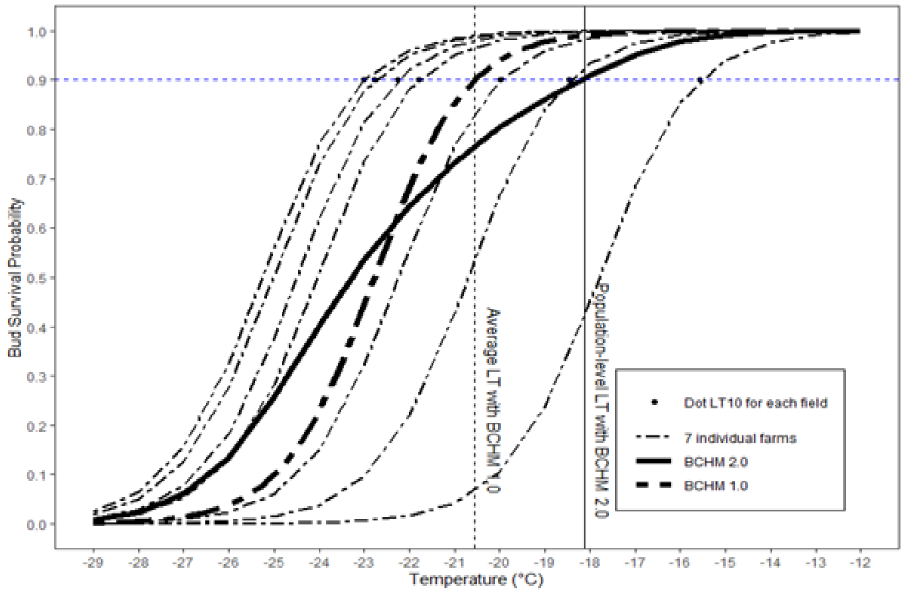

Figure 4: This is example is of a blueberry analysis as it is very clear, but similar results are seen in cherries. These are survival curves for seven blueberry fields on any one day. 90% survival equates to 10% mortality, LT10 (dots). In prior blueberry studies, a simple mean LT (dashed line at –20.5^{o}C) can often overestimate hardiness on some farms. Because large farm-to-farm variability, seen from the wide range of different LT10s per farm, management (heaters/wind machines) with a simple mean LT10 would cause damage in the 3 farms with curves to right of the average LT line because they are less cold hardy than the predicted LT10. The industry as a whole would experience 24% mortality with some farms faring better (0% damage) and others fairing much worse (40+%). Using the 'Population-level LT' in CCHM results in a higher LT10 (-18.2^{o}C) because it accounts for more of the farm-to-farm variability and averages across a larger simulated dataset. But **essentially most of the farms will not suffer severe loss at this LT10. The expected loss across the industry is 10% for CCHM. However, there are many farms that are far more cold-hardy than the LT and could save in mitigation expenses. Monitoring how in individual field is responding to cold could lead to tailored field management decisions that allow savings in propane and other expenses.**

In addition to this project, there is a separate, but cooperative project with AgAID. Scientists are creating cold hardiness models in cooperation with Dr. Markus Keller's and Dr. Matt Whiting's labs grape and cherry, respectively. The grape cold hardiness model will be live on AWN this winter for industry review and use. The AgAID team uses traditional models such as the one in this proposal to validate the reliability of AI techniques being used.

Objective 3: Cold hardiness model available on AWN

While the CCHM is developed it is still being ported to AgWeatherNet (AWN). There needs to be a conversation and a clear understanding with industry on the limitations and accuracy of the model (objective 2). Our team will be speaking with the cooperating growers and other interested partners. However, in general, **we expect the model and outreach information to be very similar to the information presented on the blueberry AWN portal, seen below:**

Estimating Lethal Temperatures and Damage

Mitigating freeze or cold injury is challenging. There is a balance between applying protective measures and economic losses from failing to do so. There are three key factors that a grower needs to understand to determine total risk from a cold event;

1. *Knowing the average lethal temperature*
2. *Knowing the range of damage that can occur*
3. *Assessing how your fields vary from the average; meaning is there more or less damage than expected compared to the average prediction (e.g., 10, 50, or 90% mortality). Then cold mitigation can be adjusted.*

Interpreting the Graph

- *LT10: Estimates the temperature in which 10% of flowers within a bud will die*
- *LT50: Estimates the temperature in which 50% of flowers within a bud will die*
- *LT90: Estimates the temperature in which 90% of flowers within a bud will die*
- *Tmin: Represents the minimum temperature for the day.*
- *Lethal temperatures are determined with forecasted weather data, shown as FCLT. Care should be taken as actual temperatures can vary from the forecasted weather.*

How to use LT

The critical lethal temperatures (LT) shown in the graph are predicted values from separate cold hardiness models created with years of data collected in multiple locations across the state. The cultivar can be changed across the top menu bar.

The model accurately predicts LT50 within +/- 3.6-4.1°F (2.0-2.3°C). The LT can be used to determine cold mitigation strategies (e.g., when to initiate wind machines and heaters). However, fields vary greatly due to location, fertility programs, plant vigor, and pruning practices. This leads to some fields experiencing more (or less) damage than the 10, 50, or 90% average in the LT.

Range of damage

Because there is high variability, we recommend looking at this table showing the range of damage that occurred across fields and years at any given lethal temperature. This indicates that actual damage in a field will often differ substantially from model predictions. We strongly encourage growers to assess damage in their field(s) after freezing events and record the damage. Learning this will give an understanding of the field(s) vigor and the ability to adjust mitigation temperatures in the future.

	Majority (90%) of the fields will experience this range of bud mortality.			
LT associated with bud survival	*'Duke'*	*'Liberty'*	*'Draper'*	*'Aurora'*
LT10	*1% - 34%*	*0% - 44%*	*1% - 32%*	*2% - 28%*
LT50	*17% - 87%*	*15% - 89%*	*14% - 84%*	*20% - 79%*
LT90	*65% - 99%*	*48% - 99%*	*63% - 98%*	*70% - 97%*

Examples:

1. *If temperatures drop to a predicted level of LT10 in a 'Duke' field, then we would expect 10% of the flowers within buds to die on average across all fields. But any single field can vary from the average so some fields will experience no damage (1%) while others may have 34% death.*
2. *If a catastrophic temperature decline occurs associated with a LT90 in a 'Draper' field, then we estimate across all blueberry fields that 90% of the flowers will die. However, individual fields will experience somewhere between 63% and 98% death.*

How will your field differ from the model?
A model is a highly educated estimate. Actual field conditions can vary. If lethal temperatures presented in the model are used to inform cold mitigation in a field or on a farm (e.g., heaters or wind machines), then it is helpful to understand whether and how much your field temperatures differ from the AgWeatherNet station(s) you are using. The actual cold hardiness values at your site will vary depending on preceding local environmental conditions. In general, if the temperatures in your field have been colder than those at the AgWeatherNet weather station used to run the model, then your blueberry buds may be more hardy than the stated temperatures. Conversely, if the temperatures in your field have been warmer than those at the AgWeatherNet weather station, then your buds may be less hardy.

EXECUTIVE SUMMARY

Project title: Sweet Cherry Bud Cold Hardiness Model

Key words: lethal temperature, dormancy, bud loss, winter kill, cherry

Abstract:

Spring frost is a significant production hazard to all temperate fruit tree species. Because sweet cherry (*Prunus avium*) is among the earliest to initiate development in the spring, it is particularly susceptible to late frost events. In order to avoid frost damage to buds, growers use a variety of mitigation practices throughout the critical spring period, such as orchard heating, irrigation, frost fans, and spray applications. These strategies are expensive and require that growers make time-critical decisions based upon the current bud lethal temperature (LT), a parameter that changes as trees transition from dormancy to full bloom. Currently, the LT of a given orchard is estimated based on phenology charts that correlate developmental stage with LT, requiring the grower to accurately characterize the bud stage most prevalent in their orchard. This is complicated by the fact that the available phenology charts vary in their listed LTs, and by the fact that a remarkable amount of internal development (and LT changes) occur without a visible change to the outside of the bud in early stages. These issues highlight the need for a weather-related decision-support tool based on Growing Degree Days (GDD) to guide sweet cherry growers in their response to spring cold weather events.

One of the objectives of this grant was to collect more field data. Both WA and OR collected ‘Bing’, ‘Chelan’, ‘Sweetheart’, while ‘Regina’ was collected only in OR. The analysis in sample size indicates that the error around the mean LT would be minimized with at least 16 data collections. As we reduce the standard error in the mean, the prediction error gets reduced. Currently for three cultivars, we have at least six complete datasets and while the resulting error of ±1.5°F is low, any error in the mean is going to systematically increase prediction error. Collecting an additional two years of data, increasing datasets to 16, would help improve the standard error and the model.

There is also error associated with the prediction and field variation. Assessing how grower fields vary from the average; meaning is there more or less damage than expected compared to the average prediction (e.g., 10, 50, or 90% mortality) is critical. Then cold mitigation can be adjusted. Because not every field will experience 10, 50, or 90% damage exactly, the error in lethal temperature (LT± 4°F) does not directly translate to error in predicted loss. An average LT will be predicted according to the closest public weather station. In general, if the temperatures in a field have been colder than those at the weather station, then those buds may be more cold-hardy. Conversely, if the temperatures in your field have been warmer, then your buds may be less hardy. Additionally, fertility, vigor, crop load all influence hardiness. We strongly encourage growers to assess damage in their field(s) after freezing events and record the damage. Learning this will give an understanding of the field(s) vigor and the ability to adjust mitigation temperatures in the future.