BOTH Research and Extension
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xx. TITLE: Improving Shelf Life of Fresh Pack Maine Wild Blueberries

OBJECTIVE(S)
This project aims to improve post-harvest handling of fresh pack wild blueberries to extend the berries' shelf life by:

- Identifying optimal cold storage temperatures for wild blueberries that cannot be kept cold throughout the entire cold chain
- Surveying current temperature and relative humidity of fresh pack buildings across Maine

LOCATION(S): Blueberry Hill Research Farm, Jonesboro, ME & Welch Farm, Roque Bluffs, ME

PROJECT TIMEFRAME: April 2021 – February 2023

INTRODUCTION
Many family wild blueberry farms in Maine (20-200 acres) do not have the capital to invest in the development of complete cold chain infrastructure that would extend the shelf life of their berries. A complete cold chain keeps berries at a consistent cold temperature from field to market and requires investment in on-farm cold storage and cold transportation. It also means ensuring that the end market has a cold place to store the berries until they are sold. Significant physiological differences between wild (lowbush) and highbush blueberries have led Maine producers of wild blueberries to develop a suite of innovative methods for maintaining berry quality, but many growers are hesitant to cool berries because they do not have a complete cold chain (Callahan, 2018; Boyette et al., 1993). The concern is that when berries are cooled down and then moved into a warmer space for transport, storage, or sale, condensation builds up on the fruit causing a severe decrease in quality. Growers have indicated that fresh wild blueberry storage temperatures range from 40°F to 70°F, and airflow and humidity within the storage unit are not often considered. Cold storage units were constructed in 2020 and 2021 on two farms to test berry freshness over time when stored at three different temperatures.

For an explanation of how the cold storage unit at Blueberry Hill Farm was constructed and for an approximate cost, see the 2020 report summary, entitled "Coolbot Cold Storage Room Construction and Costs" (page 148). A brief summary follows here.

Eight by eight foot insulated rooms were constructed at Blueberry Hill Farm in summer 2020 and 2021 (Fig. 1). Instructions from All One Farm and the University of Vermont were followed: https://www.uvm.edu/extension/produceportal/case-studies/coolbot-shoestring/

Materials were purchased, cold storage units were constructed of plywood (4 walls + ceiling), the box was insulated (with two stacked insulation boards and by using foam in the corners), and CoolBot and air conditioning units were installed. Tips and tricks about materials, purchasing, and construction methodology can be found in the University of Vermont resources and the 2020 report summary. When constructing the additional units at BHF in 2021, the walls and ceiling were insulated by two stacked pieces of R-10 instead of the planned single board of R-20 value, because of limited inventory at Home Depot. Higher R-values are ideal since this ensures the unit will be better insulated. The air conditioning unit in the 34° F unit was 16,000 BTU and the units in the 40°F and 50° F units were 12,000 BTU.

Figure 1. Left: finishing installation of the plywood roof. Right: view inside the cold storage unit while installing the air conditioning unit and CoolBot device.

METHODS

This two-year study is being carried out at Blueberry Hill Research Farm (BHF) in Jonesboro, Maine, at Welch Farm (RB) in Roque Bluffs, Maine. Twenty additional fresh pack facilities across Maine will be included in a survey of current fresh pack processing methods, which will be included in next year's report.

At RB there is an existing, homemade walk-in cooler (8ft x 24ft) made of a refrigerated truck trailer that is kept at 46-50°F by cooling with a 12,000 BTU air conditioning unit. At RB, an additional 8ft x 8ft cold storage unit was constructed using plywood, R-10 insulation panels doubled up, spray foam insulation, an industrial fan for airflow, a 12,000 BTU air conditioning unit, and a temperature and relative humidity (RH) sensor. This new cold storage unit was kept at 40°F with 95% RH and was installed in the same building as RB's existing cold storage unit, enabling the farm to pack and process berries as usual while integrating the new unit into their production process. The existing cold storage unit at RB will provide a valuable comparison between a homemade cold storage unit and a planned unit. At BHF, there is an existing cold storage unit, constructed in 2020. An additional two cold storage units were constructed there so all three units are 8ft x 8ft, with the same R-value 10 insulation panels doubled up, spray foam insulation, industrial fans for airflow, 12,000 BTU air conditioning units, and temperature and relative humidity sensors. These three units are kept at 34°F, 40°F, and 50°F.

Table 1. Summary of cold storage unit specifications.

	Cold storage units			Target relative humidity (RH)	Fruit storage size	Harvest date
	1	2	3			
Roque Bluffs (RB)	N/A	40°F	46-50°F	95%	Pints	8/9/21
		12,000 BTU	12,000 BTU			
		R-10 (doubled)	R-10 (doubled)			
Blueberry Hill Farm (BHF)	34°F	40°F	50°F	95%	Quarts	7/29/21
	16,000 BTU	12,000 BTU	12,000 BTU			
	R-10 (doubled)	R-10 (doubled)	R-10 (doubled)			

Berries at both RB and BHF were hand-raked. At BHF, berries were raked on July 29, 2021, then winnowed and transferred into industry-standard quart-size molded pulp produce baskets and immediately stored in the cold storage unit with baskets directly abutting one another. At RB, berries were hand-raked on August 9, 2021, then winnowed, put through a cleaning line, and transferred into industry-standard pint-size molded pulp produce baskets before immediate storage in the cold storage unit. At RB, berry quality was measured every 3 days for 26 days (total: 6 collection dates) because RB typically sells fresh pints within 7 – 14 days of harvest. At BHF, berry quality was measured every 3 days for 37 days (total: 11 collection dates) to mimic longer-term storage conditions for some growers. Berry quality measures taken at each site and during each sampling time included cold storage unit temperature and RH, internal temperatures of individual berries, internal pint temperature, berry firmness, and pint moisture level.

Continued berry sampling in the 2022 season (and hopefully beyond) is necessary to understand how outside weather conditions can impact the cold storage units' internal temperatures and RH.

In addition to directly sampling berry quality, surveys of conditions and practices within fresh pack facilities were conducted and will continue in the 2022 season. These surveys occurred on a packing day during harvest. Investigators asked growers and processors about their current post-harvest handling and storage practices, facilities' temperature and RH levels, timing for harvesting and processing, equipment providers and costs, customers, and markets. In addition, a portable temperature and RH sensor measured conditions in the processing and storage rooms. These surveys were conducted to foster discussion of current post-harvest handling and storage practices, and possibilities for improving these processes.

<u>Data collection</u>

Berries harvested at BHF were sampled two times per week over the course of 37 days from July 29 - September 3 while berries harvested at RB were also sampled two times per week over the course of 26 days from August 9 - September 3. The BHF units were constructed solely for this trial and therefore the doors of units were hardly opened unless berries were actively being sampled for this trial. The RB units were actively functioning on a farm and therefore integrated into the harvest, processing, and sales operations so they were opened as many as 30 times per day.

Temperature and RH data was gathered from a mounted sensor in the newly constructed cold storage units. A handheld DigiSense sensor or a separate, non-digital thermometer was used to verify the data on the mounted sensors. Berry and pint temperature were measured using a food-grade electronic thermometer (ThermPro Ultra-Fast Digital Food Thermometer TP-03B). Three separate berries were randomly selected and penetrated by the thermometer to obtain a temperature reading; these berries were then discarded from the quart or pint. Pint temperature was obtained by sticking the thermometer into the center of each pint three times, taking care not to place the probe right next to the edges or bottom of the pint container.

Berry firmness was measured by blindly selecting 3 separate berries and rating the firmness on a scale of 1 to 3, with 1 being a firm, salable berry and 3 being a mushy or nonsalable berry; these berries were then discarded from the pint or quart. Pint moisture was documented by visual inspection of the exposed top of the pints (as a customer would) and rating the moisture on a scale of 1 to 3, with 1 being dry and 3 being wet.

Surveys of post-harvest handling and storage practices were conducted verbally by the investigators. Facility temperature and RH levels were measured using a handheld, portable DigiSense sensor.

<u>Data analysis</u>
Due to the nature of the data collected, especially the ranked data, much of the data failed the assumptions of normality and equal variance required to run parametric statistical tests. Transforming the data via a square root transformation visually improved the distribution, but the data continued to statistically fail the test of normality. All the data, including berry temperature, berry moisture and berry firmness, were transformed using a square root transformation prior to all statistical testing and statistical tests were carried out despite non-normality after establishing there were no serious problems with the data.

The effects of long-term storage on berry quality (firmness) were analyzed using a multivariate correlation to generate an R^2 in Microsoft Excel (Excel® Version 2110) to observe the level of change over time. Overall treatment differences were tested using a full-factorial repeated-measures mixed model design in JMP (JMP®, Version 15.2) for berry temperature only. Here, the full-factorial model tested the effects of date, treatment and any interaction between date and treatment.

RESULTS

Maximum daily air temperature and relative humidity (RH) were collected at a field-based weather station 180 meters from the Jonesboro cold storage units and 9 miles from the RB cold storage units. Maximum daily outside air temperature ranged from 71°F to 88°F and showed the greatest correlation with the two colder storage treatments (34°F and

40°F) for the Jonesboro location (Fig. 2). This suggests that the cold unit likely declined in efficiency when cooling to colder temperatures. This increased the temperature variability inside cold storage units. The warmer cold storage treatment (50°F) showed less temporal variability in air temperature fluctuations compared to the other units and outside temperatures. High variation in unit temperatures in the first week of storage may correspond to manual adjustments made by our team to obtain target temperatures. Outside RH ranged from 69% to 99% and correlated with all three cold storage units (Fig. 3).

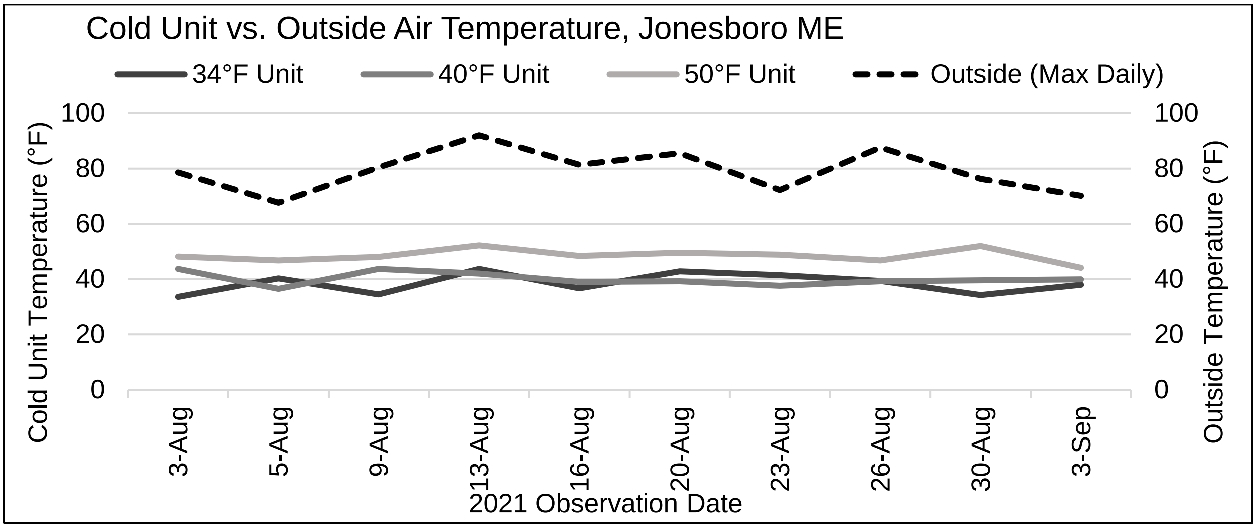

Figure 2. Cold storage air temperature of the Jonesboro units compared with outside maximum daily air temperature for BHF (Batch 1), on the dates that sampling occurred.

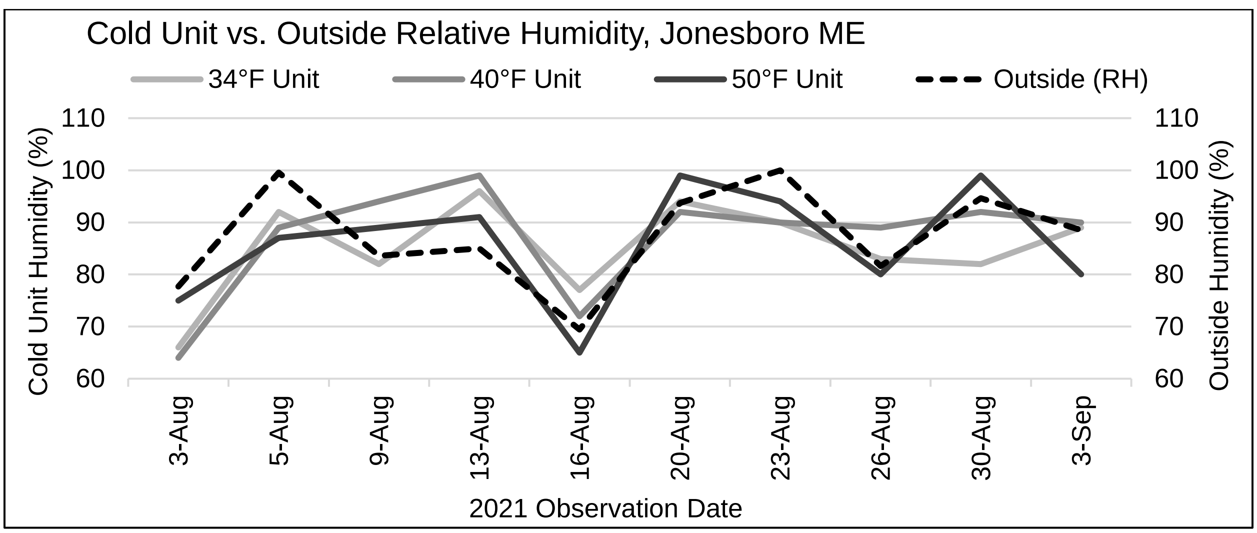

Figure 3. Cold storage unit relative humidity (bars) of the Jonesboro units compared with outside relative humidity (line) for BHF (Batch 1), on the dates that sampling occurred.

At BHF, when Batch 1 of berries first came out of the field following hand raking on July 29, 2021 (a full sun, 78°F day), internal individual berry temperatures averaged 75°F. The berries from this batch had cooled by the next sample date of August 3 (Fig. 4). Berry temperature fluctuations between 1 and 9°F were observed within the three temperature treatments during the 4 to 5 weeks after harvest. Units' air temperature at time of sampling also fluctuated despite having preset target temperatures. The 50°F cold storage unit exhibited the most stable trend over time. The 34°F and 40°F degree units require some troubleshooting.

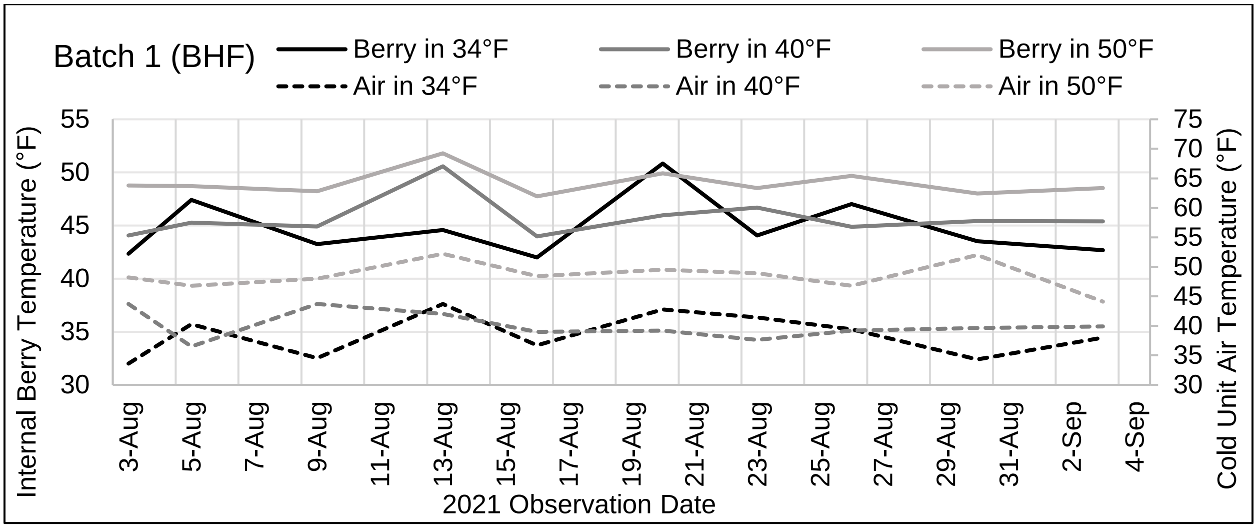

Figure 4. Berry temperature (°F; lines) and cold storage unit air temperature (°F; bars) by temperature treatment for Batch 1 at BHF (harvested and cooled 07/29/2021), monitored for 5 weeks following harvest.

Individual berry temperatures were not taken after harvest and before cooling for the second batch of berries ("Batch 2"), harvested on August 9, 2021, in RB due to logistics. Similar berry temperature fluctuations occurred often in response to fluctuations in cold storage unit air temperatures. The 40°F unit, maintained a relatively stable berry temperature trend over time. The higher temperature treatment, 50°F showed a steady decline in berry temperature over time (Fig. 5). The shift in berry temperature mimics a shift in cold storage unit air temperature in the 50°F temperature treatment as air temperature dropped from 55°F on August 9 to 45°F on September 3.

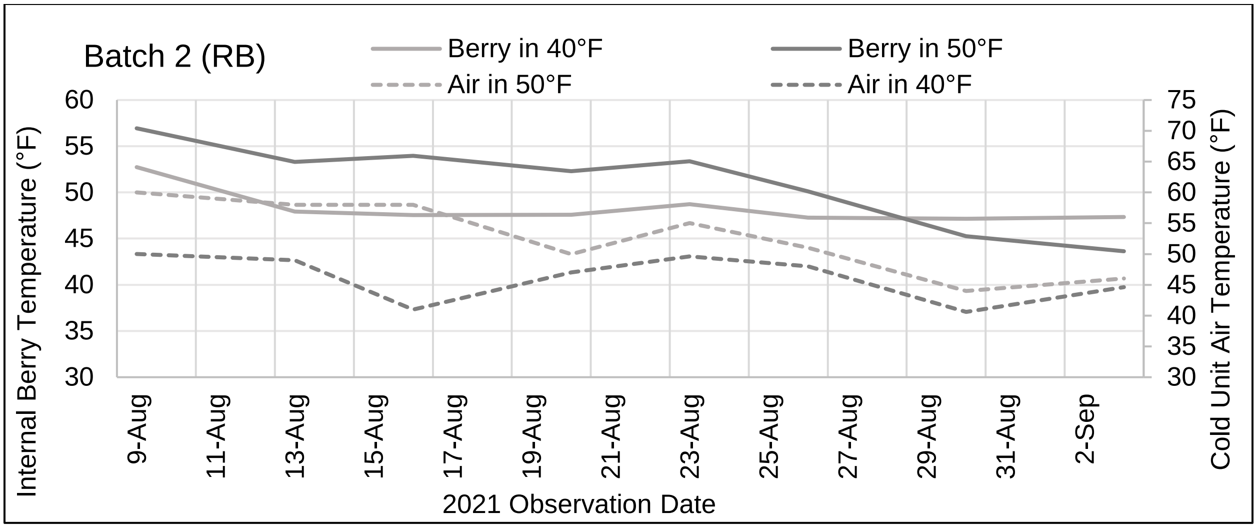

Figure 5. Berry temperature (°F; lines) and cold storage unit air temperature (°F; bars) by temperature treatment for Batch 2 (RB harvested 8/9/21 and stored 8/10/21), monitored for 4 weeks following harvest.

Overall, average berry temperatures were significantly different across all temperature treatments for both Batches (Fig. 6), with lower temperature treatments yielding significantly colder berries than warmer temperature treatments within the cold storage units. For Batch 1, the lowest temperature treatment (34°F) had an average internal berry temperature of 44.5°, while the middle treatment (40°F) and the warmer treatment (50°F) had internal berry temperatures of 45.5°F and 48.4°F, respectively. Batch 2 berries, stored in pints, had warmer internal temperatures compared to Batch 1 that were stored in quarts by an average of 7°F in the first 5 weeks. As a result, Batch 2 at RB internal berry temperatures were warmer than Batch 1 (although not statistically compared) with internal berry temperatures averaging 48°F and 51°F for the 40°F and 50°F treatments, respectively. The warmer internal berry temperatures in Batch 2 further exhibits the direct relationship between cold unit air temperature and internal berry temperatures.

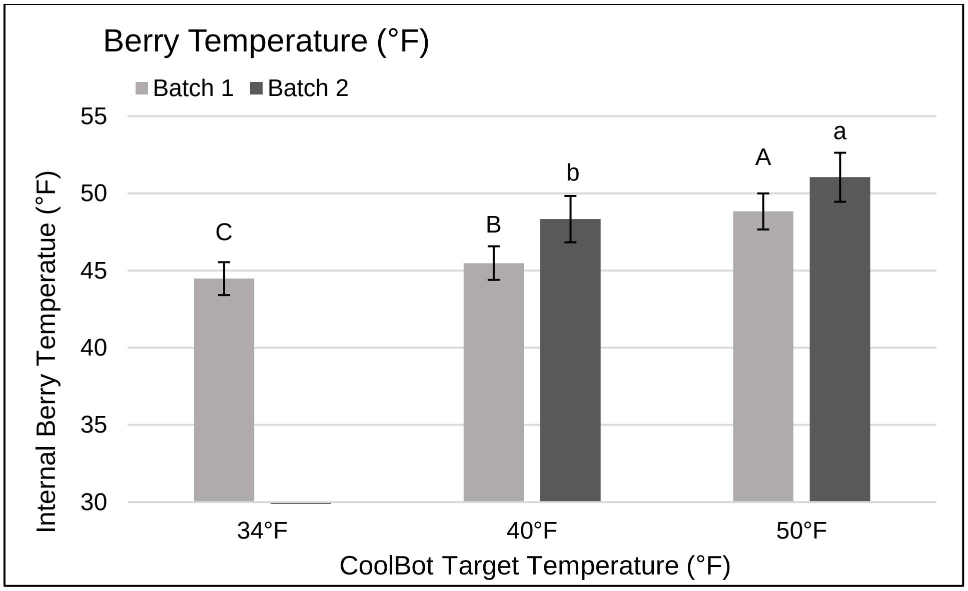

Figure 6. Berry temperature (°F), for Batch 1 (BHF harvested and stored on 7/29/21) and Batch 2 (RB harvested 8/9/21 and stored 8/10/21), monitored for 4 to 5 weeks following harvest, all measures averaged. Letters indicate significance at the 0.05 level of significance for berry temperature. Capital letters are to be compared separately from lowercase letters. Error bars indicate the standard error of the mean.

Ranked berry moisture data was variable and therefore decided to not be robust enough in this first year to present. Overall Batch 1 berries were very wet and not marketable due to the fact they were not cleaned after harvest. Berry moisture was clearly correlated to unit relative humidity. Cleaning removed most burst and damaged berries in Batch 2 leading to drier berries. Fluctuations in berry moisture greatly affect berry quality and berry firmness. As another indicator of berry quality, berry firmness declined drastically in Batch 1 over time with the greatest decline occurring under the warmest temperature treatments 40°F and 50°F. The coldest temperature treatment (34°F) saw declines in berry firmness over time, however, these reductions were not as dramatic as the warmer cooling treatments (data not shown).

By August 30, approximately 4-5 weeks after entering the cold storage unit, both batches of berries had clearly lost their volume and form at the 50°F cooling treatment and were classified as “unsaleable”. Mold growth was first observed on Batch 1 berries on August 26, approximately four weeks after entering the cold storage unit, across all three cooling treatments. Mold growth was first observed on Batch 2 berries on August 30 at the 50°F cooling treatment and on September 3 at the 34°F cooling treatment. Mold growth was not as prominent in Batch 2 at the 40°F cooling treatment. Mold growth was also observed on the walls of some cold storage units toward the end of sampling due to condensation.

DISCUSSION

Growers currently store their fresh pack berries for 24 – 48 hours on average. The length of this trial (4 – 5 weeks) greatly exceeds the current storage time because our aim is to extend fresh pack shelf life. Our short-term goal is for growers to be able to deliver higher quality fresh pack wild blueberries to consumers in Maine with a long-term goal for growers to be able to ship high quality fresh pack berries to markets outside of Maine.

This trial's year one results clearly showed the importance of relative humidity and outdoor weather conditions in wild blueberry storage. Fluctuations within the units' air temperature and humidity combined with the natural respiration and ripening processes contributed to the decline in berry firmness and losses of berry shape and volume and the mold that was observed. These changes were particularly evident in the 50°F temperature condition. Under the 34°F temperature condition, these changes and losses were less pronounced. Relative humidity and temperature variation within the units may be related to berry respiration, whereby berries continue to convert glucose into carbon dioxide, water vapor, and heat, even after being harvested. Like most produce, blueberries produce ethylene gas as they ripen, which accelerates their ripening as the rate of respiration increases. Storing berries at colder temperatures reduces the rate of respiration and can thus slow the ripening process. For every 10°F reduction in temperature, the respiration rate decreases by 50% (Callahan, 2018). Slowing the rate of respiration would also reduce the amount of heat and water vapor being produced by the berries. The berries in this study did not leave the cold storage unit and therefore only represent the first part of the fresh wild blueberry journey from the field to consumer. If the 34°F berries were removed and transported or stored at a temperature warmer than 34°F, condensation would occur, reducing berry quality dramatically.

Overall, RB's Batch 2 berries were less moist and of better quality than berries harvested at BHF due to better raking techniques and cleaning. Berries in pints (Batch 2) showed a trend towards having a warmer internal temperature than berries in quarts (Batch 1), yet this must be confirmed in 2022 by removing confounding variables. Possible reasoning for this is that the smaller pints are more vulnerable to temperature fluctuation within cold storage temperatures whereas quarts were able to hold their cooler temperature until the unit's temp dropped back down. Berries from both batches stored at 50°F had significantly warmer internal temperatures than those stored at 34°F and 40°F. Additionally, when relative humidity was low, our measure of berry moisture was also low indicating that our subjective method of monitoring berry moisture is a good indicator of relative humidity. Berry moisture presented significant treatment differences in Batch 2, such that the 40°F cooling treatment had significantly higher moisture than the 50°F treatment. This indicates that more condensation may develop on the berries at this temperature or the rate of cooling was a factor in moisture buildup within the system. The coldest temperature treatment (34°F) saw declines in berry firmness over time, however, these data were very variable and need to be repeated in 2022.

Some Maine wild blueberry growers have cold storage rooms, yet their berries remain warm and wet. Observationally, the harvest and cleaning techniques used greatly impacted berry quality, even more so than the temperature at which they are stored.

When constructing a cold storage unit, it is important to have a well-insulated and tightly sealed cold storage unit. Our units exhibited condensation, which caused mold buildup, which we plan to troubleshoot to eliminate this mold in 2022. Tilting the air conditioner back slightly so that condensation water drips out and away from the berries stored inside is critical. Managing relative humidity and air movement inside cold storage rooms is necessary to achieve high-quality berries. Constructing a unit akin to the cold storage units studied in this trial can cost a few thousand dollars per unit (including all materials and labor, building one unit in 2020 at BHF cost $2,600), and operational costs for the system are similar to that of a refrigerator or walk in cooler (Callahan, 2013). Cooling to lower temperatures (such as 34°F and 40°F) will cost more than cooling to higher temperatures (such as 50°F) but the improved length of shelf life and resulting high-quality berries will likely justify the additional expense.

CURRENT RECOMMENDATIONS

- Field conditions at the time of harvest and the method of harvest impact berry quality and cannot be fixed with cooling measures.
- Consistently cool temperature is best.
- Temperature fluctuations cause wet berries.
- The earlier harvested berries can enter a cold storage unit, the better.
- For more information on post-harvest storage of wild blueberries please visit the Quality and Food Safety page of our website: https://extension.umaine.edu/blueberries/factsheets/quality/.

NEXT STEPS

- Adjust insulation, AC units, and CoolBot devices to maintain more stable temperatures within cold storage units.
- Make adjustments to make relative humidity stable within the cold storage units.
- Conduct surveys of 13 additional fresh pack facilities in summer 2022 season.
- Replicate study in summer 2022 season.
- Seek funding to test whether improving airflow and reducing humidity can improve berry quality.

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