Research

INVESTIGATOR: L. Calderwood

xx. Efficacy of a Homemade Forced Air Cooling (FAC) System on Wild Blueberry Quality

OBJECTIVES

This project aimed to prolong berry quality post-harvest by demonstrating the use of forced-air cooling to improve air flow in cold storage units for high-quality fresh pack.

LOCATION: Blueberry Hill Research Farm, Jonesboro, ME
PROJECT TIMEFRAME: July and August 2022

INTRODUCTION

Many family-run 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. When berries are cooled and then moved into a warmer space for transport, storage, or sale, this temperature fluctuation causes condensation to form on the fruit, and the combination of warmer temperatures and increased fruit surface moisture decreases fruit 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.

Wild blueberry is harvested at the peak of ripeness leaving growers and processors with a short amount of time to get fresh wild blueberries to consumers. Wild blueberry continues to respire after being harvested, and this respiration increases the temperature of the fruit and contributes to its eventual, inevitable decay in quality. Thus, slowing the rate of respiration is critical to maintaining higher-quality fruit for longer. The easiest way to reduce fruit respiration (and associated decay) is by lowering the temperature of the fruit: highbush blueberries stored at 80.6°F respire at a rate twenty times higher than that of fruit stored at 40°F (Boyette et al, 1993). Sanford et al. (1991) demonstrated that the ideal storage temperature for wild blueberries is close to 32°F, taking extra care to prevent the fruit from freezing, since that would ruin the fruit destined for the fresh market. Postharvest wild blueberries decay at a slower rate than do highbush blueberries (Sanford et al., 1991), but any loss of saleable product harms small growers.

One method to reduce fruit temperature is by removing harvested fruit from the field and placing it in a cold or refrigerated room. This ambient cooling does not cool the fruit quickly enough, so use of a forced air cooling system ("FAC system") can cool the berries by several degrees in just several hours, as opposed to several days. FAC systems increase airflow by using a blower or fan to pull cooled air over the fruit, thereby "effect[ing] rapid heat transfer" through the "close contact" of the warm fruit and cool air (Boyette & Rohrbach, 1993). FAC systems do not cool the berries by cooling air that is directed at the fruit but instead pulls already-cooled air over the fruit. By positioning a fan or blower at one end of the system, an air pressure gradient is created and so the air moves from the high-pressure side (where the focused air of the blower or fan is pointed) to the low-pressure side (further from the blower or fan) (Boyette et al., 1989). As air moves from high- to low-pressure, the cooled air is forced between the packaging and the individual fruit and the contact of that cooler air with the warm fruit effects a heat transfer from the high-energy object (the packaging or the fruit) to the low-energy object (passing air molecules). Thus, passing cooled air cools down the individual berries. The constant movement of air passing from high-pressure to low-pressure can also accelerate the rate of evaporation of moisture found on the surface of the fruit, thereby drying the fruit surface. Rates of fruit cooling and moisture reduction are thus dependent on fruit temperature, air temperature, rate of airflow, and type of fruit being cooled (Boyette et al., 1989). FAC systems cool berries ten times quicker than simply placing the fruit in a refrigerated room (Boyette, 1996).

By design, refrigeration and/or air conditioning units remove moisture from the air as the air is cooled, but very low air humidity is associated with a decline in fruit quality, so the humidity levels of the storage areas cannot drop too low (Boyette & Rohrbach, 1993). Removing moisture from the fruit surface is ideal because moisture can decrease quality and increase risk of postharvest disease (Boyette, 1996), but removing all moisture from the storage area will decrease quality of all the fruit, not just the wet fruit (Boyette & Rohrbach, 1993).

FAC systems can be found in shipping containers and refrigerated trucks all over the world. Since FAC systems do not directly cool the fruit, they operate in refrigerated spaces and pulled that cooled air through the system. Commercial systems can be prohibitively expensive for small and family farm operations but fortunately there are a range of smaller, homemade systems that achieve the same effect at much lower cost. Using resources from the University of Vermont Extension Ag Engineering website (https://blog.uvm.edu/cwcallah/2018/10/09/forced-air-cooling-on-the-farm/), a small version of a forced air cooling system was constructed at Blueberry Hill Farm in Jonesboro, ME. UVM's team constructed two versions of the FAC systems, the "countertop" version sized for one to three cartons (bulb crate or 1/9th bushel box) and a larger one sized for a partially- or fully-loaded pallet.

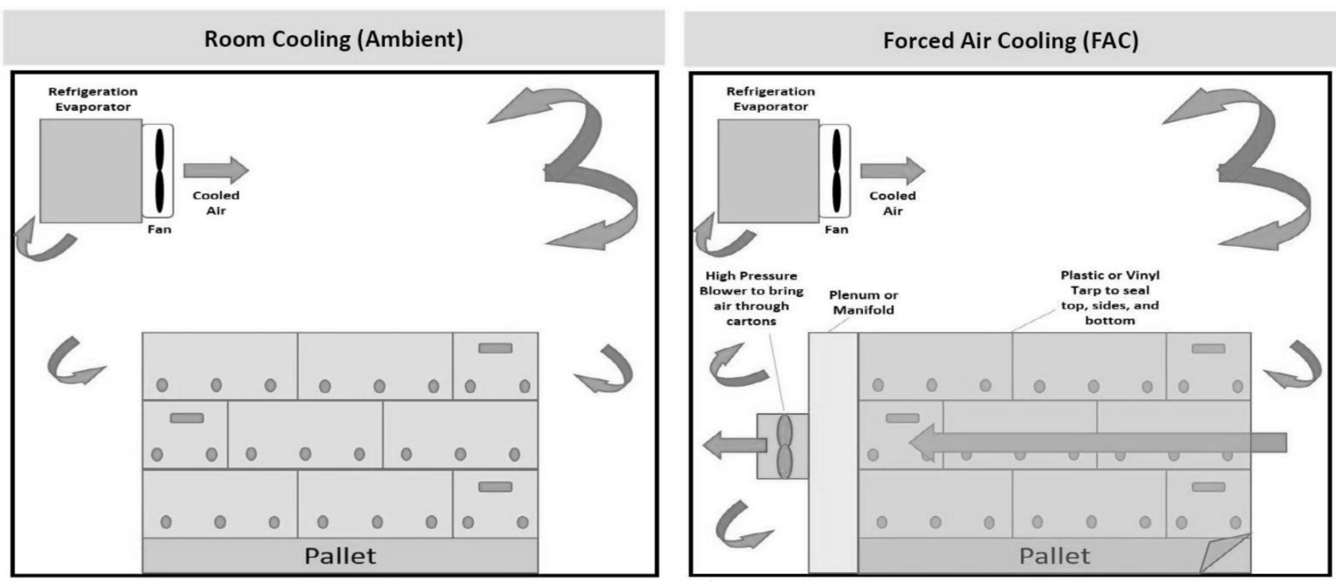

Image 1. Left, a diagram showing how cooling the entire room or space does not generate sufficient pressure or velocity to pass through the stacked produce crates to quickly cool the harvested produce. Right, a diagram showing how using a forced air cooling system to pull air over stacked produce crates completely sealed in plastic generates enough pressure and velocity quickly cool and dry the harvested produce. Images taken from the UVM Extension Ag Engineering site (Callahan, 2020).

Homemade forced air cooling systems can be constructed in an afternoon and require just a short list of easily accessible materials. In Table 1, the materials used to make the small FAC in Jonesboro are listed. This small unit was built in one day in July 2022 and cost roughly $250. Full building plans are described and should be followed from the University of Vermont Extension site listed above.

Table 1. Table showing materials to construct a FAC system.

Framing lumber	Fender washers
Plywood	Plastic (4 mil poly)
Decking screws	Blower (12" portable blower fan)
Decking screws	

This project builds on earlier research into the optimal wild blueberry storage temperature within homemade cold storage units. Earlier research measured fruit quality for 30 days post-harvest in cold storage units and found that cooler berries maintained good quality for longer, but berry surface moisture was not studied. The question explored in 2022 was, does forced air cooling inside a cold storage unit reduce moisture on the berries?

For a more thorough explanation of the need for, construction, and costs of the cool temperature storage facilities used at Blueberry Hill Farm, please see the 2020 report summary, entitled "Coolbot Cold Storage Room Construction and Costs" (page 148) and the 2021 report summary entitled, "Improving Shelf Life of Fresh Pack Maine Wild Blueberries" (page 200).

METHODS

Fruit quality was measured through photographs and visual inspection in conjunction with long-term storage unit temperature and relative humidity measurements. This study was conducted at Blueberry Hill Research Farm (BHF) in Jonesboro, Maine. At BHF, there are three 8ft x 8ft cold storage units, constructed in 2020 and 2021 (Table 2).

Table 2. Summary of cold storage unit specifications.

Cold storage units at Blueberry Hill Farm		
1	2	3
34°F	40°F	50°F
16,000 BTU	12,000 BTU	12,000 BTU
R-10 (doubled)	R-10 (doubled)	R-10 (doubled)

Fruit was harvested at BHF on August 2 and 10 into BerryMate plastic bins with aeration slits called "fresh pack bins"; the fruit was not winnowed and so contained some leaf debris and other organic matter. Two separate tests were completed to test the effectiveness of forced air cooling on berry surface moisture. The first test occurred from August 2-3 in the 50°F cold storage unit and the other occurred August 10-13 in the 40°F cold storage unit (Table 3).

On August 2, berries were hand raked into the fresh pack bins, kept in the shade when in the field, then brought to the cold storage units to have photos taken. Photos were again taken of these bins on August 3 and were later used to count total, wet, and shriveled fruit. On August 2, ten bins were photographed before being placed in any cold storage unit. On August 3, ten bins were photographed after 24 hours in the FAC system in the cold storage unit set to 50°F, ten bins were photographed after 24 hours in the cold storage unit set to 50°F (not inside the FAC system), and two bins were photographed after 24 hours being left in ambient temperatures outside any cold storage units; all photos were later used to count total, wet, and shriveled fruit.

On August 10, berries were hand raked into the fresh pack bins, kept in the shade when in the field, then brought to the cold storage units to have photos taken. When still in the field, iButtons (small, quarter-sized buttons that continuously measure temperature; Maxim Integrated, San Jose, CA) were placed in the centers of each bin, approximately one inch below the surface of the harvested fruit, and then covered up again by the fruit. Photos were again taken on August 13 and were later used to count total, wet, and shriveled fruit. On August 10, ten bins were photographed before being placed in any cold storage unit. On August 13, five bins were photographed after 72 hours in the FAC system in the cold storage system set to 40°F, and five bins were photographed after 72 hours in the cold storage unit set to 40°F (not inside the FAC system). iButtons continuously measured internal bin temperature and remained buried in the harvested fruit in the bins until the end of the study.

Table 3. Summary of bin samples.

Sample	Harvest date	Dates sampled
Bins	August 2	August 2 & 3
Bins plus iButtons	August 10	August 10 & 13

Image 2. Left, unwinnowed berries from BHF stored in a fresh pack bin with slats for aeration. Right, the countertop FAC system before being loaded with fresh pack bins and/or turned on.

Photographs of each bin during each sampling event were processed using FIJI/ImageJ's cell counter mode (FIJI software version 2.9.0, Madison, WI). Images were first scaled and a 4" x 4" square was drawn on the image, to approximate the area that would be visible if fruit were stored in a pint container. The berries in the images were then counted using the cell counter mode, which had three counter options: total fruit, wet fruit, shriveled fruit. Every single piece of fruit was hand-counted using the program's total fruit mode, and when appropriate, the fruit was also counted using the wet or shriveled berry counters. Each photo then generated three numbers, which could be compared across time and treatment: total fruit, wet fruit, and shriveled fruit.

<u>Data analysis</u>

Berry wetness data collected from the two storage units (40°F and 50°F), were analyzed using a One-way ANOVA, followed by a Tukey's Pairwise comparison in JMP (JMP®, Version 16.0, SAS, Cary, NC, USA). Due to the nature of the data collected, the berry wetness data collected Aug 10-13, 2022, in the 40°F storage unit failed the assumptions of normality and equal variance required to run parametric statistical tests. Transforming the data via a square root transformation resolved these issues. Berry wetness data collected August 2 – 3, 2022, passed assumptions for parametric statistical testing and a transformation was not required. All graphs were designed using Microsoft Excel (Excel® Version 2110, Microsoft Corporation, Redmond, WA, USA).

RESULTS

iButtons were placed within the bins while the bins and berries were still in the field but stored in the shade, and internal bin temperatures dropped from 77.4°F to 74.5°F after two hours post-harvest

(Figure 1). The bins were then placed into the 40°F cold storage unit and the bin temperature dropped down to 65.9°F after one hour, and then 57.6°F after another hour in the unit. The internal bin temperatures then continued to cool for the next seventeen hours, at which point temperatures reached as low as 43.6°F and hovered between there and 44.2°F for another fourteen hours (Figures 1 and 2). Bin temperature then spiked at one hourly reading, without any accompanying cold storage unit temperature spike, to 45.7°F, before dropping down to 43.9°F the next hour, and remaining between 43.6°F and 43.9°F for eight more hours, until temperatures increased again above 44.0°F. These slight increases mimicked the slight increases in cold storage unit temperature.

Temperatures in the cold storage unit increased when the unit's door was opened to place the bins, from 45.1°F to 50.1°F (Figures 1 and 2, below). Unit temperatures then steadily dropped over the next three hours, to 44.6°F, and continued to drop to 43.6°F over the next ten hours. Temperatures did then begin a steady increase over the next twelve hours, peaking at 45.5°F and steadying there for three hours before decreasing again. Temperatures reached a low of 44.2°F overnight before beginning a steady increase up to 46.4°F, hovering there for about four hours, and dropping down again to lows of 43.7°F.

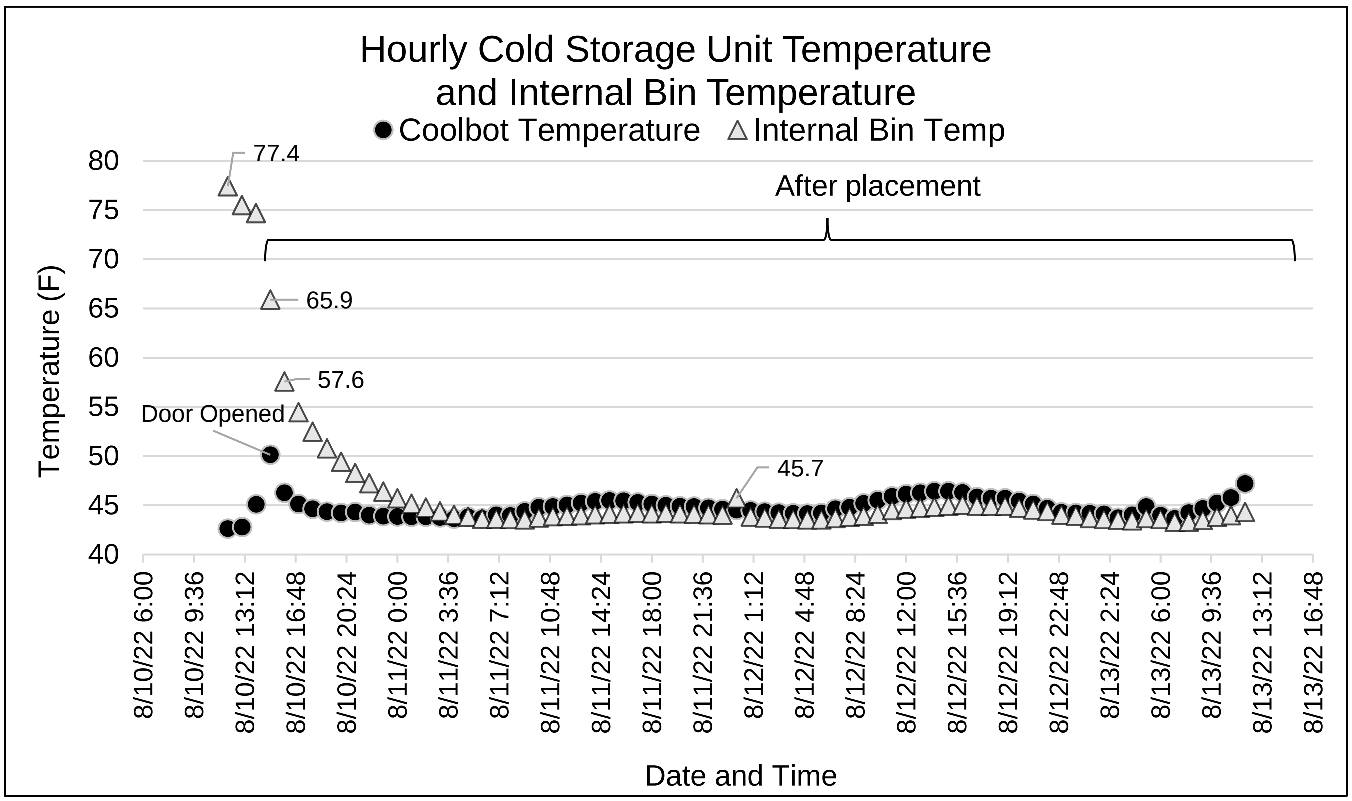

Figure 1. Hourly cold storage unit temperature (dark gray circles; °F) and average internal bin temperature (light gray triangles; °F) in the 40°F collected August 10 – 13, 2022. Internal bin temperatures were collected using Maxim Integrated iButton technology. "After" placement refers to the moment the bins were physically placed into the cold storage unit. See Figure 2 for more detail.

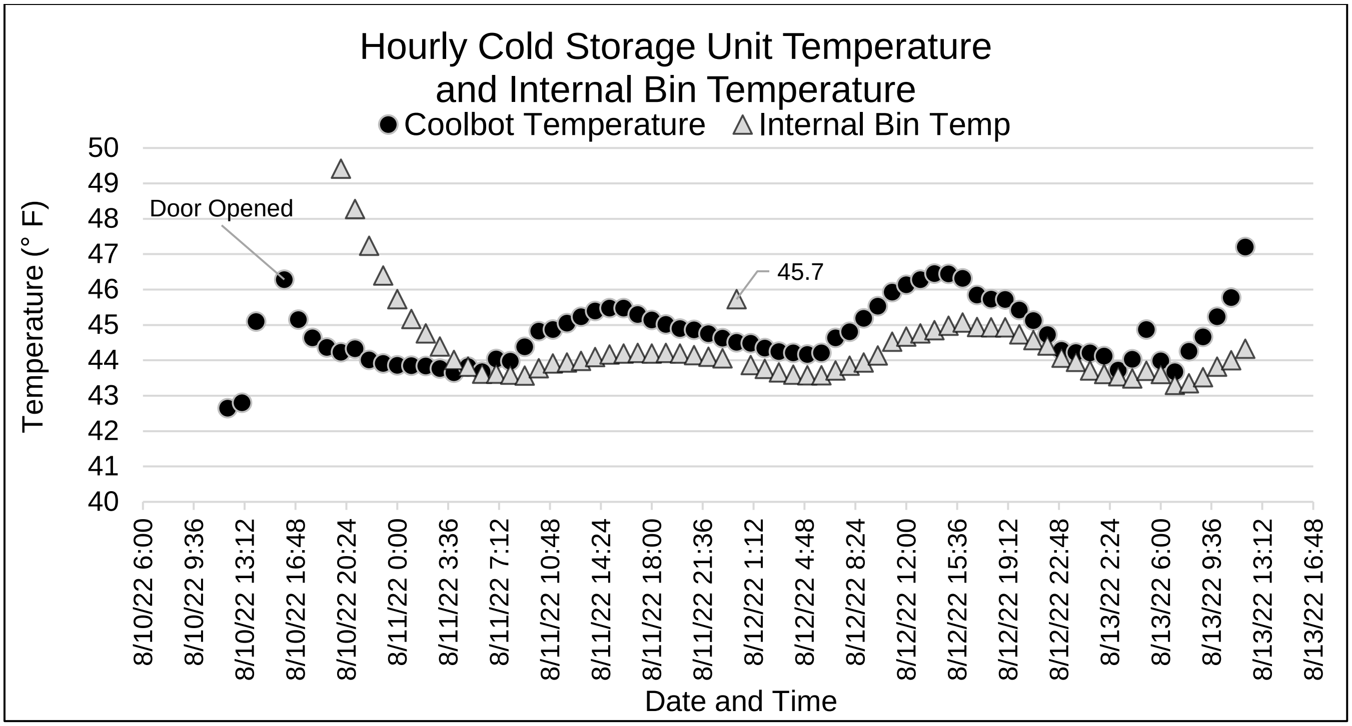

Figure 2. Hourly cold storage unit temperature (dark gray circles; °F) and average internal bin temperature (light gray triangles; °F) in the 40°F collected August 10 – 13, 2022. Internal bin temperatures were collected using Maxim Integrated iButton technology. This graph is a zoomed-in version of Figure 1 to facilitate better understanding of temperature variations.

Berries were harvested into bins and placed in the 50°F cold storage unit from August 2 - 3, 2022. In the 50°F cold storage unit, the wetness and shriveling of berries varied over time (Figure 3). Before being placed in the cold storage unit, 24% of the berries were wet and 8% were shriveled. After one day of cooling in the FAC system, 36% of berries were wet and 56% were shriveled (a statistically significant increase). After one day of cooling outside of the FAC system, 27% of berries were wet and 10% were shriveled (a slight increase).

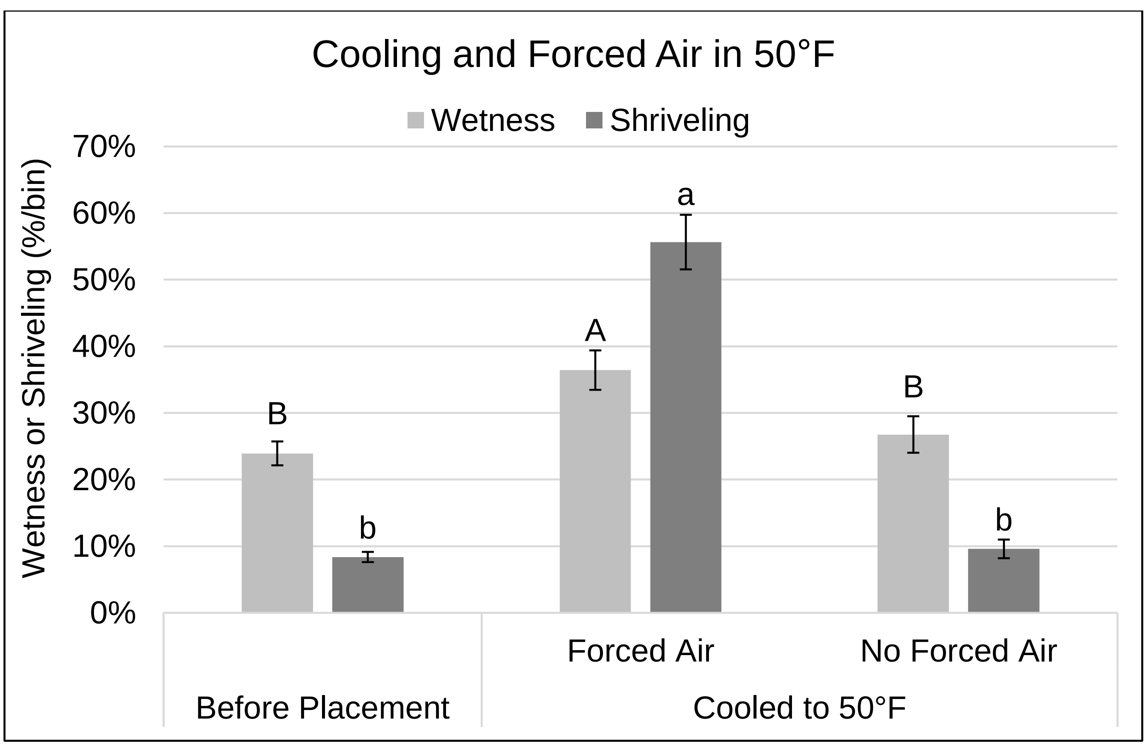

Figure 3. Average berry wetness (%/bin) and shriveling (%/bin) in 50°F cooling unit measured 24 hours after cooling and forced air treatments which took place from August 2 – 3, 2022. Letters indicate significant differences at the 0.05 level of significance. Treatment differences in berry wetness were not significant. Error bars represent the standard error of the mean.

Berries were placed in bins and placed in the 40°F cold storage unit from August 10 - 13, 2022. In the 40°F cold storage unit, the wetness and shriveling of berries increased over time (Figure 4). Before being placed in the cold storage unit, 12% of the berries were wet and 20% were shriveled. After 3 days of cooling in the FAC system, 18% of berries were wet (a slight increase) and 40% were shriveled (a statistically significant increase). After 3 days of cooling outside of the FAC system, 19% of berries were wet (a slight increase) and 40% were shriveled (a statistically significant increase).

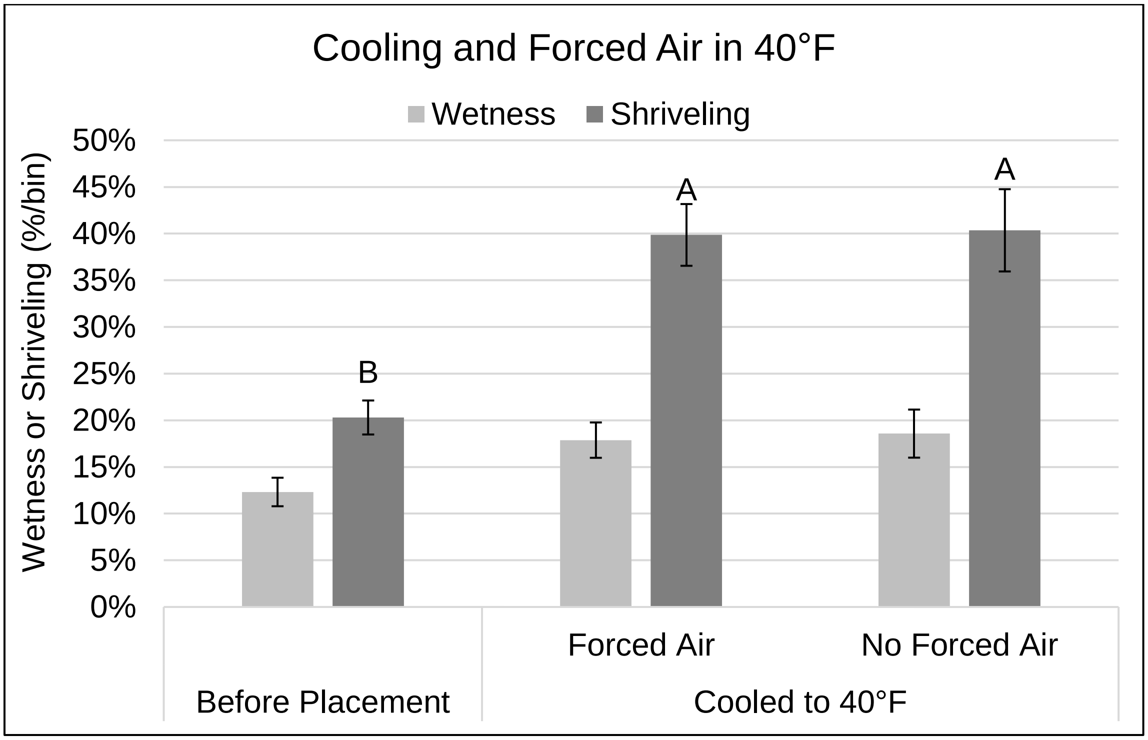

Figure 4. Average berry wetness (%/bin) and shriveling (%/bin) in 40°F cooling unit measured immediately after cooling and forced air treatments which took place from August 10 – 13, 2022. Letters indicate significant differences at the 0.05 level of significance. Treatment differences in berry wetness were not significant. Error bars represent the standard error of the mean.

DISCUSSION

Berries placed in the 50°F cold storage unit for 1 day grew significantly wetter and more shriveled over the storage time, regardless of whether the bin was situated in the FAC system or not. Berries placed in the 40°F cold storage unit for 3 days grew slightly wetter and significantly more shriveled over the storage time, regardless of whether the bin was situated in the FAC system or not.

These results are the opposite of what was expected indicating that we did not use the FAC unit correctly. Improvements that will be made for next year's trial of this include: not purposefully wetting berries before entering storage, placing more bins of berries into the FAC unit for it to run at full capacity, and not including any other bins of berries in the cold storage unit while the FAC unit is running. Several confounding factors influenced this first attempt at forced air cooling.

Fluctuations in the temperatures of the cold storage unit coincided with daily temperature changes associated with the time of day. At dawn (generally the coldest point of any day), unit temperatures were the lowest, unit temperatures increased as the sun came up and significantly increased during the hottest point of the day (late afternoon, early evening), before gradually cooling during the night. Accordingly, internal bin temperature mimicked the changes in unit temperature. The relationship between atmospheric temperature and unit temperature can likely be attributed to three things: the ambient temperature of the garage housing the unit, the airtightness of the unit, and the ability of the air conditioning unit, particularly in the 34°F unit (data in other Cold Storage Report, see page XX), to maintain temperatures at the programmed temperature. As outdoor temperatures increased, the ambient temperature of the garage also increased and would eventually increase the temperature of the cold storage unit if the air conditioning unit did not kick on and cool the air.

CURRENT RECOMMENDATIONS

- Place the cold storage units under some shelter (e.g., in a garage bay or barn) and ensure the unit is well-insulated and leak-free so the cold storage unit is not releasing dry, cold air or pulling in warm, moist air.

NEXT STEPS

- Modify methods and repeat in 2023.

ACKNOWLEDGEMENTS

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REFERENCES

Boyette, M. D. (1996). Forced-air cooling packaged blueberries. *Applied Engineering in Agriculture*, *12*(2), 213–217. doi.org/10.13031/2013.25641

Boyette, M., E. Estes, and B. Cline. (1989, July 1). *Forced-Air Cooling.* North Carolina State University Extension. Retrieved December 5, 2022, from https://content.ces.ncsu.edu/forced-air-cooling

Boyette, M., E. Estes, and B. Cline. (1993, August 1). *Postharvest Cooling and Handling of Blueberries.* North Carolina State University Extension. Retrieved November 4, 2022, from https://content.ces.ncsu.edu/postharvest-cooling-and-handling-of-blueberries

Boyette, M. D., & Rohrbach, R. P. (1993). A low-cost, portable, forced-air pallet cooling system. *Applied Engineering in Agriculture*, *9*(1), 97–104. doi.org/10.13031/2013.25971

Callahan, C. (2018). Personal communication.

Callahan, C. and A. Chamberlin. (2020, January 27). *Forced Air Cooling on the Farm.* UVM Extension AG Engineering. Retrieved November 4, 2022, from https://blog.uvm.edu/cwcallah/2018/10/09/forced-air-cooling-on-the-farm/

Sanford, K. A., Lidster, P. D., McRae, K. B., Jackson, E. D., Lawrence, R. A., Stark, R., & Prange, R. K. (1991). Lowbush blueberry quality changes in response to mechanical damage and storage temperature. *Journal of the American Society for Horticultural Science*, *116*(1), 47–51. doi.org/10.21273/jashs.116.1.47