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Temperature effect on wild blueberry fruit quality during mechanical harvest

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Abstract.

Mechanical harvesters, utilizing a range of technologies, have been developed for timely operations and remain the most cost-effective means of picking the wild blueberry crop. Approximately 95% of wild blueberries in Atlantic Canada are immediately frozen and processed, while only a small percentage is sold in the fresh market. However, the producers can benefit by increasing the value of their harvested crop through fresh market sales. The objective of this study was to determine the optimum meteorological and field conditions required for maximizing fruit quality during mechanical harvesting to remain competitive in the fresh fruit market. Temperature values, and the quality components of the harvested berries were recorded throughout commercial wild blueberry fields of Nova Scotia during August 2021. Eighteen harvest replications during four temperature ranges at harvest; ≤ 20 °C, 20.1-25 °C, 25.1-29.9 °C, and ≥ 30 °C were analyzed for the effects of meteorological variables under the varying sky and plot conditions. Increased ambient air temperatures at harvest resulted in significantly higher fruit surface temperature, leaf temperature, and soil surface temperature (P≤0.05). The fruit surface temperature was greater than the ambient air temperature during all temperature ranges. The leaf and soil temperatures were lower than ambient air temperature below 25 °C and higher than ambient air when above 25 °C. The analysis of the data determined the increase in temperature during harvesting causes decreased berry quality and a potential for lower revenue. The results can be used to aid wild blueberry growers in making informed decisions when pursuing favorable harvesting conditions to maintain optimum fruit quality when harvesting for the fresh market.

Keywords.

Fruit quality, temperature, harvest, wild blueberry, fresh market

Introduction

Nova Scotia's wild blueberries (*Vaccinium angustifolium* Ait.) are a leader among agricultural exports. Together with highbush blueberries (*Vaccinium corymbosum* L.) the lowbush wild blueberries are ranked as the second most economically important berries, after strawberries, in North America (USDA, 2013). Blueberries have a world-class high economic value bearing the title of "the king of berries" (Hu et al., 2006; Nie and Zang, 2014; Li et al., 2015; Zhang et al., 2015). They contribute to a healthy diet with different beneficial bioactive compounds such as flavonoids with multiple phytonutrients (Lila, 2004; Wang et al., 2005), which help to avoid dangerous human diseases including different cancers (IARC, 2003; WCRF/AICR, 2007). With antioxidant capacity, blueberry fruits are rich in anthocyanins and low in sugar and fat (Kalt et al., 2020).

About 90% of the total wild blueberry crop area in Canada is mechanically harvested and the remaining berries are harvested with a metal-based hand rake (Ali, 2016). Mechanical harvesters started replacing hand raking during the early 1950s (Kinsman, 1993) with the major underlying factors including high labor costs, short quality of labor, and short harvesting seasons (Yarborough, 1992). Hall et al. (1983) reported that numerous mechanical harvesting systems had been developed to improve berry recovery and reduce harvesting losses, but a viable commercial machine was not adopted until the 1980s due to the low stature of plants, uneven field topography, and the presence of weed species, which present formidable obstacles to mechanical harvesters (Yarborough, 2002). Therefore, operators of the harvesters keep their picker teeth clean of weed/plant biomass to reduce berry loss and damage.

Two basic concepts during the postharvest decision making include 1) the fruit is alive and responsive to its environment and, 2) the fruit's quality potential never increases after the fruit has been picked (Beaudry, 1992). A high storage temperature develops a bitter taste and storage flavor in the stored samples (Rosenfeld et al., 1999). Good quality harvested fruit may sustain such external effects to a certain extent. Definition of good fruit quality includes firm, clean, dry, and damage-free fruit. Good quality fruit is especially susceptible to mechanical damage, with injured berries resulting in loss of firmness leading to reduced fruit quality and shelf-life (Xu et al., 2015).

Field conditions such as the presence of weeds as well as the meteorological variables and their concurring impacts, and the harvesting methods affect the quality of the harvested berries (Yarborough, 1994). In most crops, the prevailing meteorological conditions, particularly ambient air temperature, relative humidity, and solar radiation, are critical determinants of the levels of health-promoting compounds and should be considered when planning optimal harvesting dates for a specific area and specific crops (Kårlund et al., 2014). Prevailing meteorological conditions of a region may affect differently to the quality of the harvest. Several factors associated with the time of day can influence the physiology and postharvest quality of horticultural commodities (Edgley et al., 2019). Meteorological and environmental variables such as temperature, sun exposure, humidity, and moisture content have all been reported to affect firmness and bruise susceptibility across a range of horticultural commodities including strawberries, apples, and apricots (Paull, 1999; Sams, 1999; Hussein et al., 2018). Paniagua et al. (2013) reviewed the causes of deterioration of blueberry firmness and concluded that the mechanisms defining postharvest firmness changes in blueberries are not completely understood, although fruit moisture loss (Forney et al., 1998), skin toughness, presence of stone cells (Bunemann et al., 1957; Allan-Wojtas et al., 2001) and cell wall modifications (Allan-Wojtas et al., 2001; Angeletti et al., 2010) have been related to this phenomenon. All the causes mentioned by Paniagua et al. (2013) are related to weather/temperature conditions and mechanical impact on berry surface during harvest.

Unlike for harvesting of several fruits and vegetables, very limited research has been done to evaluate proper harvesting techniques and conditions for wild blueberries in relation to fruit quality. Weather and field conditions have less of a burden on operator comfort with the advancement of mechanized harvesting and cabbed tractors with climate control. Literature has suggested that harvesting in wet conditions results in reduced harvesting efficiency (Zaman, n.d.). A report published by Zaman (n.d.) on precision harvesting technologies to improve berry yield and quality summarizes work on developing i) sensor fusion system for quantification of blueberry fruit yield losses and ii) models for identification of sources of losses to improve harvesting efficiency to increase fruit yield. An extensive literature search has revealed that limited work has been done to understand the factors that dictate berry quality. Harvest of wild blueberries is highly time-sensitive requiring several operators working through sub-par environmental conditions to get the job done. Nonetheless, rising production costs, adverse weather conditions, and fluctuating farm gate prices have decreased the profit margins for wild blueberry growers. However, farmers may benefit from efforts with increasing the berry field price by entering the fresh fruit market to increase their profit margins.

Performance of the harvesting methods has been assessed with emphasis on improving and/or automation of blueberry harvesting technology (see Farooque et al. 2020 and the references therein) but the effects of meteorological variables (e.g., the temperature at harvest (TH) during events of harvesting) and plant characteristics (e.g., presence of weeds, berry fruit surface temperature, plant leaf temperature, plant height, plant density, weed density, fruit firmness, and fruit diameter) soil properties (soil moisture content and soil temperature), and weather conditions on the quality of berries harvested with different methods have yet to be fully explored. Numerous other factors of interest such as on-field storage conditions of berries and their impact on berry quality have not been studied and/or reported in the literature.

Materials and Methods

Study Sites

This study was conducted during the 2021 harvesting season of wild blueberry in various fields of Nova Scotia located in Middle Musquodoboit, Portapique, and New Glasgow. These fields were well managed but had instances of common weed infestations including hair fescue, red sorrel, and narrow-leaved goldenrod (Fig. 1).

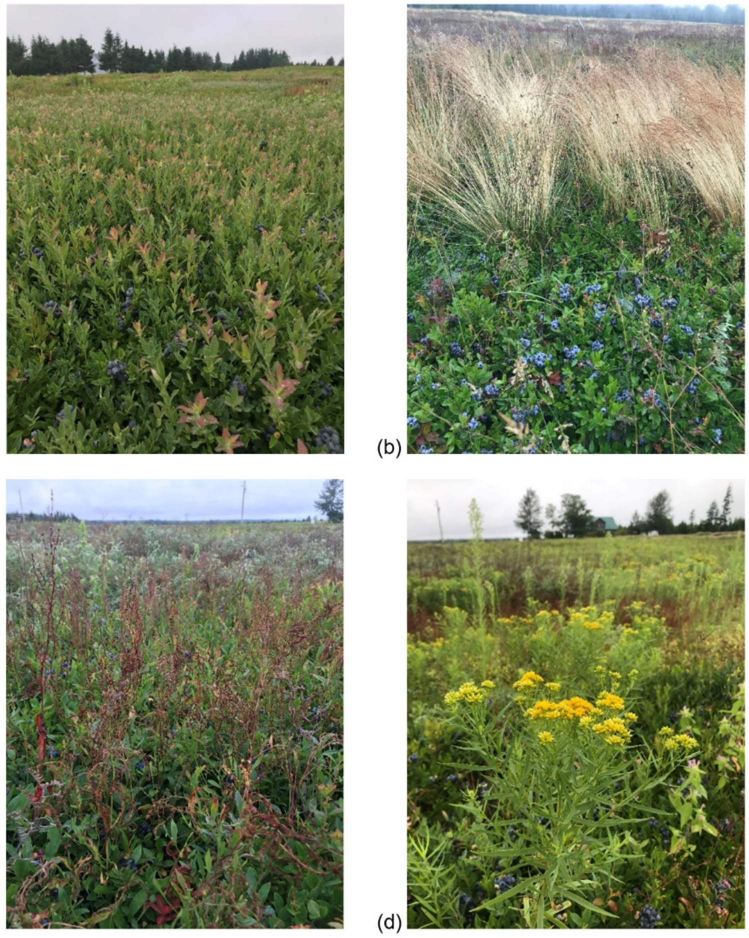

Figure 1: Images of (a) clean field sections versus areas affected with (b) hair fescue (Festuca filiformis Pourr.), (c) red sorrel (Rumex acetosella L.), and (d) narrow-leaved goldenrod (Euthamia graminifolia (L) Nutt.) weeds.

Sampling Plots, Tools, and Methods

Sampling plots were flagged for harvesting with a mechanical harvester (Fig. 2). Five meters long plots were needed for data collection with the mechanical harvesting method. The length (5 m) and width (1.69 m) of plots were based on the time of travel of the harvested berries to be transported to the rear storage tote of the mechanical harvester.

Figure 2: Doug Bragg Enterprises mechanical harvester mounted on a farm tractor.

Temperature at Harvest

Berry data was collected from multiple replications of mechanical harvesters during four temperature ranges namely TH-I (≤20 °C), TH-II (20.1-25 °C), TH-III (25.1-29.9 °C), and TH-IV (≥ 30 °C) in selected plots (Table 2). Each of the four temperatures at harvest (i.e., TH-I: 8:30 am-11:00 am, TH-II: 11:00 am-1:30 pm, TH-III: 1:30 pm-4:00 pm, and TH-IV: 4:00 pm-6:30 pm) events had 7 to 8 harvesting events totaling to 85 replications from plots, respectively.

Table 1: Ambient air temperature (˚C) and total replications during the data collection events from weedy plots for the four temperature at harvest ranges (TH-I to TH-IV).

Temperature at harvest	Temperature range, °C	Harvest plots, °C
TH-I	≤20	14.9, 17.0, 18.1, 18.3, 18.5, 19.8, 19.9, 20.0
TH-II	20.1-25	20.1, 20.4, 20.5, 21.6, 23.9, 23.5, 23.9
TH-III	25.1-29.9	26.9, 27.1, 27.2, 27.7, 28.0, 28.5, 29.1, 29.4
TH-IV	≥30	30.3, 30.5, 31.1, 31.0, 31.9, 32.3,
Total replications for each temperature at harvest		25[TH-I], 21[TH-II], 21[TH-III], 18[TH-IV] = 85

Weather station

For local and precise measurement of the prevailing temperature of the harvesting events, a stand-alone portable weather station (HOBO U30-NRC-SYS-C; Onset, Hoskin Scientific, Saint-Laurent QC, Canada) was installed at each sampling site (Fig. 3). The readings for meteorological variables were recoded, on data sheets, for the specific time of sampling in addition to downloading time-series data from the datalogger of the weather station.

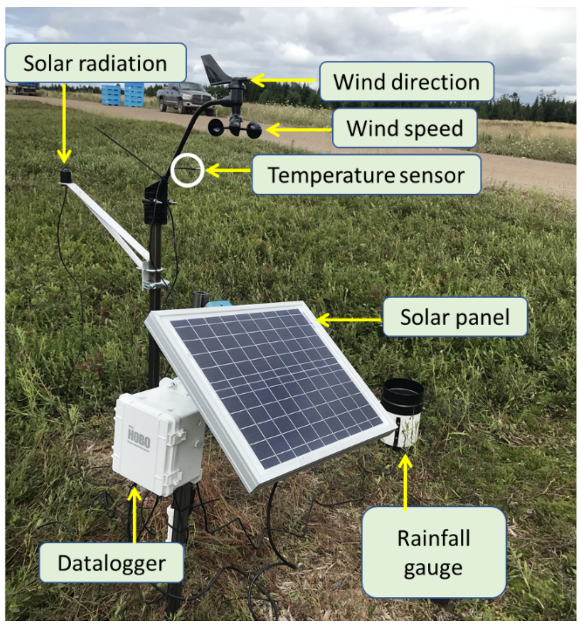

Figure 3: A portable weather station installed at the Middle Musquodoboit, NS field for real-time recording of the meteorological variables

Pre-harvest sampling temperature of fruit on the plant

A FLIR ONE (Oregon, US) thermal imaging camera was used to determine the temperature of the plot soil, berry surface, and plant leaves before each harvesting event (Fig. 4). The camera was operated via the FLIR ONE App (Version 4.2.0) of an IOS system. Temperature measurements were taken while the fruit was on the plant before its harvest (Fig. 4a) with the help of the thermal imaging camera (Fig. 4b). Screenshots of the soil and fruit temperature captured from the screen (Fig. 4c) with a zoomed-in close view are shown in Fig. 4d. Lower temperatures are shown in blue, and higher temperatures are displayed in red.

(a) (b) (c) (d)

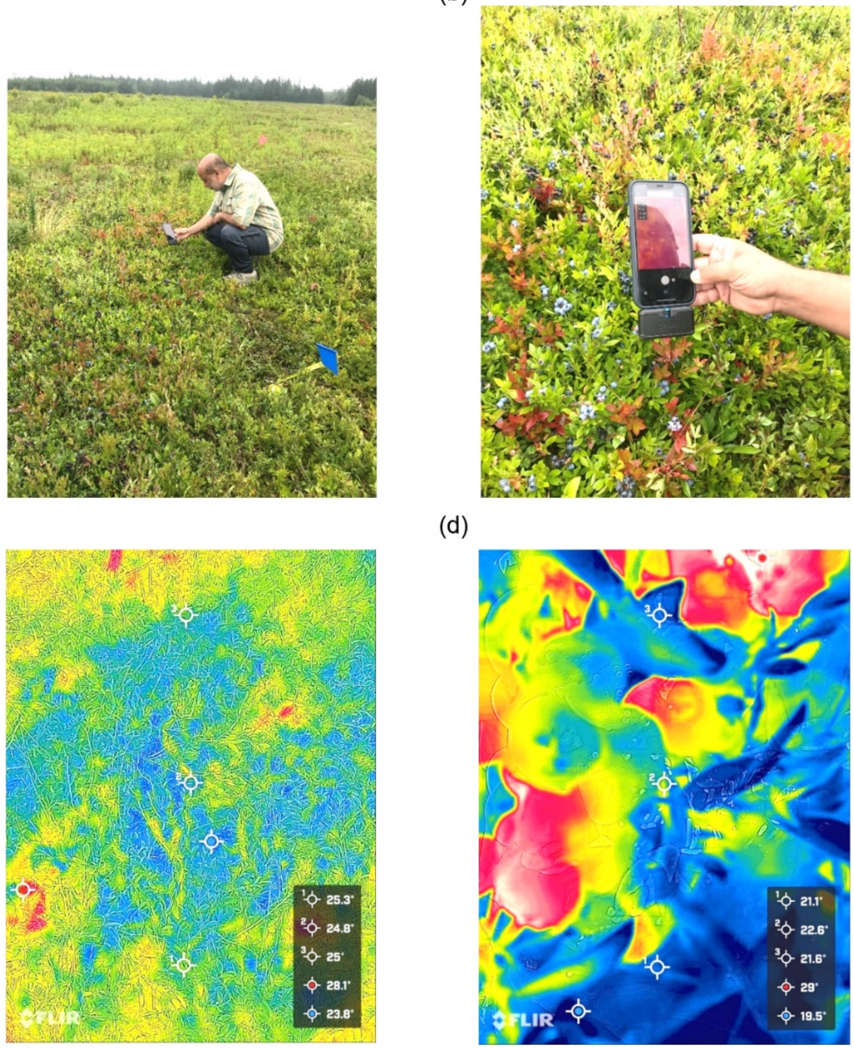

Figure 4: Measurement of berry temperature while the fruit was on the plant before its harvest (a) with the help of FLIR ONE thermal imaging camera connected with a smartphone (b). Screenshots of the soil and fruit temperature were captured from the phone screen (c) with a zoomed-in close view(d). Lower temperatures are shown in blue, and higher temperatures in red.

Post-sampling measurements

The harvested berries were immediately transferred to the temporary setups made for segregating the samples to the four components of harvest quality including i) good blueberries acceptable for fresh market, ii) bruised berries, iii) cut-split berries that were poor in quality due to badly ruptured skin, and iv) debris that comprised all foreign materials, such as plant stems, soil particles, and off-color small or shrunk berries. The individual components i, ii, iii, and iv segregated from the raw/composite harvest sample were carefully poured into an empty container that was zeroed on a battery-operated scale before weighing. Weights of individual components were then divided by the total weight of the raw sample and multiplied by 100 to obtain percent values of individual components.

Results and Discussion

Data collected was analyzed and results are discussed in this section to address the acceptable temperature range to harvest fields for maximizing fruit quality. The temperature at harvest was based on ambient air temperature. The mean temperature values for TH-I, TH-II, TH-III, and TH-IV were 17.5, 22.0, 27.3, and 31.8 °C, respectively (Table 2).

Table 2: Summary of the data of mean ambient air temperatures (°C) recorded during sampling intervals of temperature at

harvest TH-I (≤20 °C), TH-II (20.1-25 °C), TH-III (25.1-29.9 °C), and TH-IV (≥30 °C).

Temperature events	T_{min}-T_{max}	T_{mean}±SD
TH-I	14.9-20.0	**17.5**±3.61
TH-II	20.1-23.9	**22.0**±2.69
TH-III	25.5-29.1	**27.3**±2.55
TH-IV	30.3-32.3	**31.3**±1.41

The results of one-way ANOVA for the difference in percent means of ambient air temperature, fruit surface temperature, berry plant leaf temperature, and soil surface temperature during four temperatures at harvest were significantly different during the four events of temperature at harvest (P≤0.05). The importance of ambient air temperature or temperature at harvest thus becomes important to explore for determining the range of temperature at harvest considered the best to harvest fields for maximizing fruit quality. The mean plant leaf, soil surface, and fruit temperatures significantly increased with the increase in mean ambient air temperature during the four temperatures at harvest (Fig. 5; P≤0.05). The fruit surface temperature was always greater than ambient air temperature during all events of TH, whereas the leaf and soil temperatures were lower than ambient air temperature during the first two temperatures at harvest (i.e., TH-I and TH-II) and vice versa at TH-III and TH-IV.

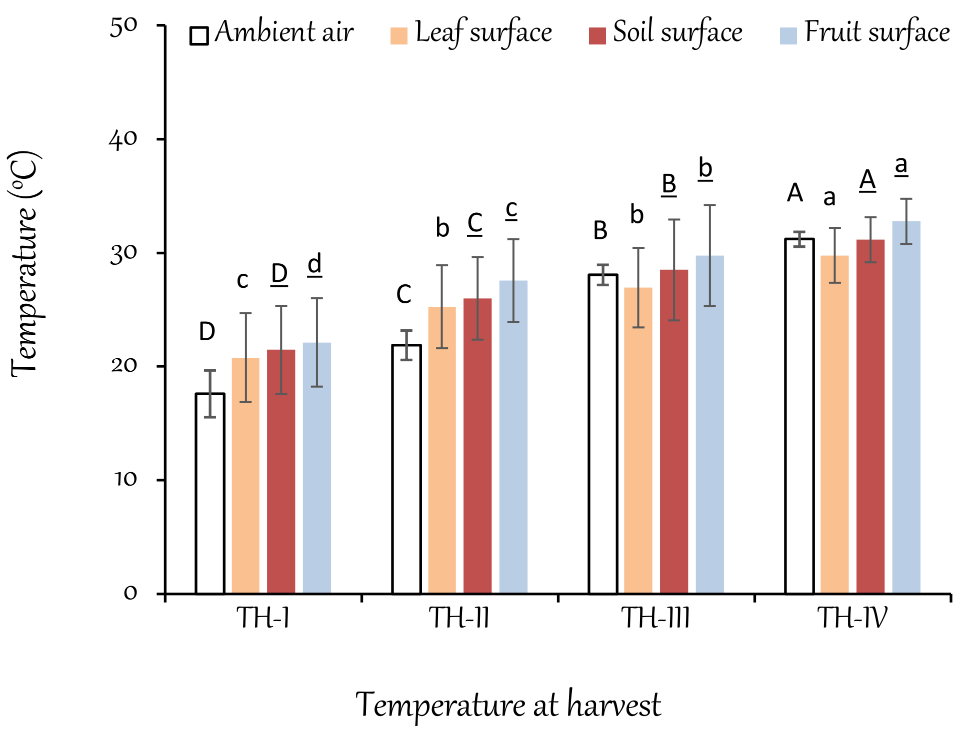

Figure 5: Mean temperature values (°C) and standard deviations from the means for ambient air, leaf surface, soil surface, and berry surface measured during replications of harvesting of four temperatures at harvest (TH-I to TH-IV). The respective significantly different means have been separated and labeled with Fishers' Least Significant Difference (LSD) letters (lower and upper cases with and without underlines) for their significant difference among the four temperatures at harvest.

The relationship between sunlight exposure and the temperature of fruit clusters is important to berry composition and metabolism (Spayd et al., 2002). Bergqvist et al. (2001) who studied the separation of sunlight and temperature effects on the composition of merlot berries (*Vitis vinifera* cv.), suggested that to achieve maximum color development in warm regions, prolonged exposure of clusters to sunlight should be avoided. Millar (1972) in his study of the thermal regime of grapevine, showed that berry temperatures paralleled the diurnal solar radiation curve. This means that the differences in temperature between ambient air and the exposed fruits increase as solar radiation increases and wind speed decreases, as one might expect from heat transfer principles. Smart and Sinclair (1976) indicated that solar radiation and wind velocity were the two most important determinants of fruit temperature: during the day shortwave radiation was the primary source of fruit warming and convection was the primary source of heat transfer away from the cluster.

The optimum temperature for berry harvest was determined by measuring the effects of temperature at harvest on fruit quality components including good berries, bruised berries, cut-split berries, and debris. Results of one-way ANOVA for the effects of temperature at harvest on the selected quality components of the harvest samples were calculated for mechanical harvester data. The temperature at harvest had a significant effect on all quality components of the harvest samples except for debris ($P \leq 0.05$). The mean percent of good berries decreased with an increase in temperature at harvest except for TH-I, the mean percent values of the other fruit quality components including bruised berries, cut-split berries, and debris significantly increased with an increase in temperature at harvest. Results of the analysis of mechanical harvester samples revealed that the acceptable temperature for harvesting the good quality berries with this method was ≤20 °C. Mechanical harvesting produced the highest percentage (80.5%) of good berries during TH-I which was statistically different and significantly greater than the percent means of good berries produced during TH-II (73.2%), TH-III (68.9%), and TH-IV (59.5%) (Fig. 6). This trend was reflected in the effect of temperature at harvest on the production of bruised and cut-split berries during TH-IV that had significantly different and higher production of bruised (17.1%) and cut-split berries (17.3%) that were statistically different and greater than the berries produced during TH-I (7.10%). There was no significant effect of temperature at harvest on debris produced by mechanical harvester during TH-I to TH-IV ($P > 0.05$).

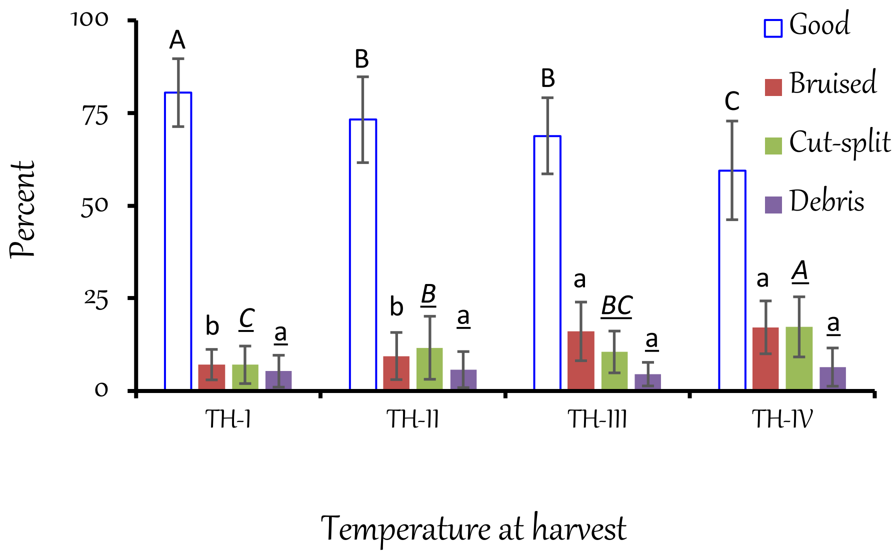

Figure 6: Percent means of berry quality components plotted against four temperatures at harvest (TH-I to TH-IV) for mechanical harvester samples. The percent means have been separated and labeled by standard error bars and Fishers' LSD letters (A, a, *A*, and a) for their significant difference at four temperatures at harvest. The means with similar respective LSD letters (i.e., upper and lower case regular, and/or underlined italic letters) are not significantly from one another.

About 60-80% of good berries collected from the harvest samples reflect 20-40% shrinkage, which seems to be practically on the higher end. The possible reason for this high percent shrink can be the strict rules followed for placing all berries with sensible slight soft skin or light bruises in the category of bruised berries. The other reason may be the effect of temperature on berry quality. Presumably, berries with slight soft skins or light bruises are allowed through cleaning/processing lines. Practically, all such berries are not discarded, but they have a valuable consumption for their uses in making yogurt, juices, or milkshakes as less than 10% of berries are consumed fresh, and the rest are sold frozen or in the forms of their value-added products.

Cost analysis showed a significantly different and higher income while harvesting at temperature

≤ 20 °C than harvesting at > 20 °C when considering the sale of solely good quality berries (Fig. 3). The field price income decreased by 8.08, 13.5, and 28.8% with harvesting at higher temperatures than 20 °C, i.e., TH-II (20.1-25 °C), TH-III (25.1-29.9 °C), and TH-IV (≥ 30 °C), respectively. This resulted in calculated losses of 721, 1,112, and 2,254 $/ha for harvesting and selling berries at TH-II, TH-III, and TH-IV, respectively than at TH-I.

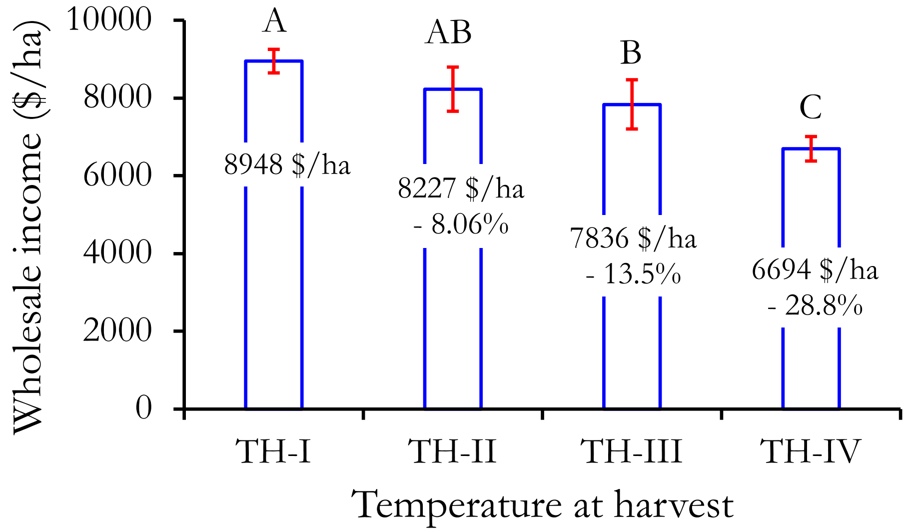

Figure 3: Decrease in income and percent decrease in the income of farmers for selling good berries, harvested at four temperatures at harvest including TH-I (≤ 20 °C), TH-II (20.1-25 °C), TH-III (25.1-29.9 °C), and TH-IV (≥ 30 °C) to processors at a market rate of 1.76 $/ha. The mean income values have been separated and labeled by standard error bars and Fishers' Least Significant Difference (LSD) letters (A, B, and C) for their significant difference among temperatures at harvest. The means with similar and/or shared LSD letters (i.e., A and AB) are not significantly from each other.

Conclusion

The project activities were performed in commercial wild blueberry fields of Nova Scotia in August 2021. The projective objective was to determine the effect of temperature during harvesting on wild blueberry fruit quality. The goal of this project was to aid wild blueberry farmers, processors, and stakeholders in making informed decisions about favorable harvesting conditions to maintain optimum fruit quality when harvesting wild blueberries for the fresh market. The temperature at harvest had four levels comprising TH-I, TH-II, TH-III, and TH-IV to represent temperature ranges of ≤20, 20.1-25, 25.1-29.9, and ≥30 °C, respectively. About 20-40% shrinkage was calculated and increased with an increase in temperature at harvest. This seemingly high shrinkage can be due to the strict rules followed for placing all berries with sensible slight soft skin or slight bruises in the category of bruised berries. The other reason may be the effect of temperature on berry quality. Presumably, berries with slight soft skins or light bruises are allowed through cleaning/processing lines. Practically, all such berries are not discarded, but they have a valuable consumption for their uses in making yogurt, juices, or milkshakes as less than 10% of berries are consumed fresh, and the rest are sold frozen or in the forms of their value-added products. A cost analysis reflected that the calculated income decreased by 721, 1,112, and 2,254 $/ha for harvesting and selling berries at TH-II (20.1-25 °C), TH-III (25.1-29.9 °C), and TH-IV (≥ 30 °C), respectively than at TH-I (≤ 20 °C).

Further investigations are recommended for evaluating different combinations of methods of and temperatures at harvest and their effects on chemical components, i.e., nutritious value, of the harvested/stored berries of a variety of species grown in various parts of Canada. It would also be interesting to explore if the yield of a field (because of dense or sparce canopies) also contributes to the effects of temperature at harvest on the harvest quality.

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