2025

ASSESSING THE IMPACT OF RISING TEMPERATURE ON BLUEBERRY PRODUCTION: EVALUATING THE ADAPATBILITY OF MITIGATION AND ADAPTATION STRATEGIES IN BRITISH COLUMBIA, CANADA

SHUJIE CAO

MASTER OF LAND AND WATER SYSTEMS—THE UNIVERSITY OF BRITISH COLUMBIA

1. Executive Summary

British Columbia is a leading producer of highbush blueberries in Canada, contributing significantly to both the domestic agricultural economy and the international fruit market. However, the effects of climate change, most notably rising temperatures, pose increasing threats to the sustainability, productivity, and quality of blueberry cultivation in the province. This report examined the physiological, ecological, and economic impacts of extreme heat on blueberry production and evaluated a range of mitigation and adaptation strategies, with a focus on practical implementation for BC growers.

Highbush blueberries are especially sensitive to heat stress throughout their development stages. From dormancy and bud break in late winter to flowering, fruit set, and ripening in the summer, elevated temperatures can disrupt plant physiology and negatively affect fruit yield and quality. Specific impacts include premature de-acclimation, reduced pollen viability, shortened pollination windows, softening and shriveling of berries, and increased susceptibility to pests and diseases. Late-season heat further complicates farm operations by compressing harvest windows and increasing post-harvest decay risk.

Data reviewed in this report confirm a significant decline in yield across major blueberry-producing regions due to extreme heat. In 2023, for example, the United States reported a yield decrease of 86 kg per acre, and Canada experienced a 10.12% reduction in national production compared to the previous year. Peru saw even more dramatic losses, attributed to compounding climate anomalies, including flooding and prolonged high temperatures. Multiple studies link these outcomes to climate-driven increases in average and peak temperatures, which affect both above- and below-ground plant functions.

One of the central challenges identified is the limited research and funding directed toward soil health under heat stress. While most climate adaptation strategies focus on plant canopy protection, the effects of elevated temperatures on microbial activity, enzyme function, and water availability in the root zone are equally important. Drought conditions, which often coincide with high temperatures, further exacerbate plant stress, particularly in row crops like blueberries that have limited canopy coverage and low soil shading.

To respond to these threats, the report evaluated a variety of pre-harvest and post-harvest strategies. These included: micro-sprinkler systems, protective plant sprays, low-tech greenhouses, improved irrigation practices, reflective tarps, in-field cooling units, and cultivar selection for heat tolerance. Each strategy was assessed based on key decision-making criteria: effectiveness in mitigating heat damage, financial feasibility, ease of adoption, side effects (e.g., pest and disease pressure), and scalability.

Among the pre-harvest options, micro-sprinkler systems emerge as one of the most promising strategies for BC growers. These systems provide evaporative cooling at the plant canopy level while using significantly less water than overhead sprinklers. They can be integrated with existing drip irrigation systems, which are widely adopted in BC, allowing for cost-effective retrofitting. Trials have shown that micro-sprinklers can reduce fruit surface temperatures, prevent sunburn, and increase berry weight. However, added humidity from misting may elevate pest and disease risk, requiring improved monitoring and integrated pest management (IPM) measures. Financially, the capital cost ranges from approximately $858 to $3,435 CAD per acre, depending on system complexity. Despite these considerations, the system offers a strong balance of effectiveness, scalability, and yield benefit, particularly in fields most vulnerable to heat.

In addition, low-tech greenhouses offer a longer-term, infrastructure-based alternative for pre-harvest heat protection. These structures provide physical coverage and partial climate control, helping to moderate temperature, light intensity, and wind exposure. Low-tech greenhouses offer greater consistency in protecting crops from both short-term heat spikes and seasonal climate variability. Low-tech greenhouses also reduce exposure to direct sunlight without introducing the added humidity associated with mist-based systems, lowering the risk of fungal disease and certain pests. Although not yet widely adopted for blueberries in BC, these structures are well-suited for incremental or high-value deployment, making them a viable investment for growers seeking long-term climate resilience.

Post-harvest, blueberries are highly vulnerable to quality degradation if exposed to ambient heat between harvest and cooling. Immediate post-harvest protection is therefore essential to preserve fruit texture, flavor, and shelf life. Among the evaluated strategies, reflective tarps are identified as the most accessible and cost-effective solution. These tarps reduce sun exposure and heat accumulation by maintaining a cooler microenvironment over harvested berries stored in trays, bins, or pallets. Field trials in British Columbia confirm that reflective tarps significantly reduce berry weight loss and softening. Their low cost, ease of use, and scalability make them especially suitable for farms of all sizes. Unlike mobile cooling systems or nighttime harvesting, which face practical limitations in BC due to labor and packhouse availability, reflective tarps offer immediate benefits with minimal investment or operational disruption.

The report also considered longer-term approaches, such as cultivar selection for heat tolerance. While advances in breeding hold promise for developing heat-resilient varieties, the typical 15–20-year development cycle limits their short-term applicability. Therefore, while cultivar improvement should remain a strategic research focus, more immediate measures are needed to protect current production systems.

In conclusion, this report recommends a layered approach to climate adaptation in BC's blueberry sector. During the growing season, micro-sprinkler systems provide a highly effective, water-efficient method for cooling plants and reducing heat-related yield loss. For growers able to invest in infrastructure, low-tech greenhouses offer additional environmental control and long-term stability. Post-harvest, reflective tarps present an inexpensive and reliable way to preserve fruit quality and minimize losses during transport and processing. By adopting a combination of these strategies, blueberry producers in British Columbia can enhance their resilience to climate variability, protect their economic returns, and maintain the province's strong position in domestic and global fruit markets.

2. Introduction

Blueberries (Vaccinium spp.) have emerged as one of the most commercially important fruit crops globally, known for their health benefits and versatility in fresh and processed markets (*Blueberry | Description, Types, Nutrition, Cultivation, & Facts | Britannica*, 2025; *Why BC Blueberries? | BC Blueberry Council*, n.d.). With rising consumer demand for nutrient-dense foods, global production has expanded significantly over the past few decades, led by regions such as North America, Peru, Chile, and Mexico. Canada, particularly British Columbia (BC), plays a central role in this industry—BC is the nation's top producer of highbush blueberries, while lowbush (wild) varieties dominate in the eastern provinces (A. and A.-F. Canada, 2024).

Highbush blueberries (*Vaccinium corymbosum* L.) are a cultivated species characterized by taller shrubs and larger fruit compared to lowbush blueberries (*Vaccinium angustifolium* Ait.), which are typically wild. Although lowbush blueberries produce smaller berries, their higher skin-to-pulp ratio leads to greater concentrations of sugar, antioxidants, and fiber per fruit ("Did You Know There Are Two Types of Blueberries?," n.d.; *Highbush Blueberry Vs Lowbush Blueberry*, 2024). However, the mineral content between the two types remains relatively similar ("Did You Know There Are Two Types of Blueberries?," n.d.; *Highbush Blueberry Vs Lowbush Blueberry*, 2024; Lachowicz-Wiśniewska et al., 2024). Highbush blueberries are less perishable and more durable during packing and shipping, making them well-suited for the fresh retail market. As a result, the majority of highbush blueberries are sold fresh. In contrast, lowbush blueberries, which are more delicate, are primarily used for processing and freezing (Government of Canada, 2011).

(Picture source: https://gardenerspath.com/plants/fruit/grow-lowbush-blueberries/; https://backyardberryplants.com/product/talisman-highbush-organic-blueberry-plant/)

Figure 2. Physiological comparison between lowbush (left) and highbush blueberry plants.

Despite the growth in blueberry demand, recent years have seen notable declines in blueberry yields across several major producing countries, with climate change—particularly increasing temperature—being one of the significant contributors. Various strategies have been developed over the years to address this issue; however, heat continues to pose a significant threat, as reflected in the ongoing decline in yields over the past few years. This study assessed the impact of rising temperatures on BC highbush blueberry production and to evaluate the adaptability of mitigation and adaptation strategies for application in BC, Canada.

2.1 Blueberry Production in US, Canada, and Peru

Highbush blueberries are perennial flowering plants and the most widely cultivated species within the *Vaccinium* genus and *Cyanococcus* subgenus. They thrive in slightly acidic, organic-rich sandy loam soils but are also adaptable to a variety of soil types, including peat, silt loam, and clay loam (Agriculture and Agri-food Canada, 2025; Padmanabhan et al., 2016; Raditic & Bartges, 2014). Often referred to as a "natural health package," highbush blueberries are rich in bioactive compounds such as antioxidants, vitamin C, polyphenols, and flavonoids. These compounds are associated with a range of health benefits, including anti-inflammatory and antioxidative properties, and have been linked to reduced neurodegeneration, improved bone health, lowering blood cholesterol, and anti-diabetic effects (Naderi et al., 2018; Raditic & Bartges, 2014; Rashidinejad, 2020; Shamsizadeh et al., 2017).

Blueberry cultivation dates back to the early 1900s, with the first commercial harvest taking place in 1916 following collaborative research efforts by scientists in New Jersey, USA (United States Department of Agriculture, 2021). Since then, production has expanded significantly, especially from 2010 to 2019, positioning the United States, Canada, and Peru as leading producers. According to data from the United States Department of Agriculture and Agriculture and Agri-Food Canada, the U.S. produced over 281,953 metric tons of blueberries in 2022, while Canada produced 185,773 metric tons. Together, these two countries accounted for approximately 38% of the global blueberry production, which totaled 1,228,569 metric tons in 2022. (A. and A.-F. Canada, 2024; USDA Economic Research Service, 2023). Outside of North America, Peru stands out as a leading producer of blueberries, yielding 261,450 metric tons in 2022—ranking just behind Canada in global production (IBO - State of the Blueberry Industry Report, n.d.).

The state of Washington is recognized as one of the top blueberry-producing regions in the United States, due to its favorable climate and soil conditions. Western Washington's humid, mild maritime climate provides ample precipitation (760 to 1500 mm annually) and experiences few instances of extreme heat or cold (4 to 15 ºC year round)—conditions that are highly conducive to blueberry cultivation (DeVetter et al., 2015). As stated, blueberries prefer slightly acidic soils with a pH between 4.5 and 5.5. Frequent rainfall in the region contributes to the natural leaching of cations, resulting in naturally acidic soils ideal for blueberry growth. In contrast, eastern Washington presents more challenging conditions, often requiring significant soil amendments and management practices to support commercial blueberry production (DeVetter et al., 2015).

Similarly, British Columbia features a moderate climate that supports optimal blueberry production. During the growing season, warm days combined with cool nights promote favorable fruit development and enhance flavor quality. Additionally, the province's naturally fertile and acidic soils provide ideal conditions for blueberry cultivation. These factors collectively position British Columbia as the leading producer of highbush blueberries in Canada (BC Blueberry Council, n.d.). Within BC, the major production regions include Abbotsford, Richmond, Pitt Meadows, and Surrey (*Agriculture | City of Abbotsford*, 2025; *Agriculture in Richmond - City of Richmond, BC*, n.d.; *Farm Markets*, n.d.; City of Pitt Meadows, 2023).

Blueberries are consumed locally, distributed across provinces for domestic markets, and exported globally, playing a key role in the agricultural economy. In Canada, they represent the country's top fruit export. In 2022, a total of 131,556 metric tons—combining both highbush and lowbush varieties—were exported to markets including the United States, Japan, New Zealand, and China, generating over CAD 600,000 in revenue (A. and A.-F. Canada, 2024). As the country's primary producer of highbush blueberries, British Columbia plays a crucial role in supporting the national agricultural economy.

Table 2.1. Blueberry fields distribution and acreage in British Columbia (Source: Reports and Websites of City of Abbotsford, 2025; City of Richmond; City of Pitt Meadows, 2023; The Chilliwack Progress, 2015; Surrey Farms).

Region	Acreage (× 0.4 ha.)
Abbotsford	6410
Pitt Meadows	3299
Richmond	1416
Chilliwack	>1000
Surrey	~600

2.2 Industry Challenges Brought by Rising Temperature

Elevated temperatures can influence both the growth of blueberry plants and the postharvest preservation of fruit quality. The effects of heat stress vary depending on the specific growth stage, including overwintering, bud break, flowering, and fruit development, with each stage exhibiting differing levels of sensitivity to temperature fluctuations.

2.2.1 Overwintering

Blueberry crop hardiness during winter is closely linked to the concentration of raffinose—a sugar compound that plays a key role in stabilizing plant cells under cold stress, such as frost events. However, elevated temperatures have been shown to reduce raffinose levels, thereby increasing the crop's vulnerability to environmental fluctuations and winter injury (Deslauriers et al., 2021). Additionally, blueberries enter a state of dormancy during the winter, which is essential for conserving energy and preparing for vigorous growth in the following season. Warmer than normal winter temperatures can disrupt this dormancy process, potentially resulting in weak or uneven bud development in spring. In more extreme cases, elevated winter temperatures may prevent dormancy altogether, leaving plants vulnerable to damage from cold snaps, frost, and other adverse winter events (Strik, 2018).

2.2.2 Bud Break

Blueberries transition out of dormancy and initiate flowering bud development through a temperature-regulated process known as de-acclimation. Elevated temperatures can accelerate this process, potentially leading to premature bud break before environmental conditions have stabilized. As a result, the early-developing buds become highly susceptible to damage from late-season frosts and temperature fluctuations (Strik, 2018). Since flowers develop from flowering buds, damage at this stage can substantially reduce the number of flowers and fruit that form later in the season. This often leads to lower fruit quality and a notable decline in overall yield.

(Picture source: https://blogs.cornell.edu/berrytool/berry-pests/blueberries-frost-damage/)

Figure 2.2.2(a). Frost damage on blueberry blossom.

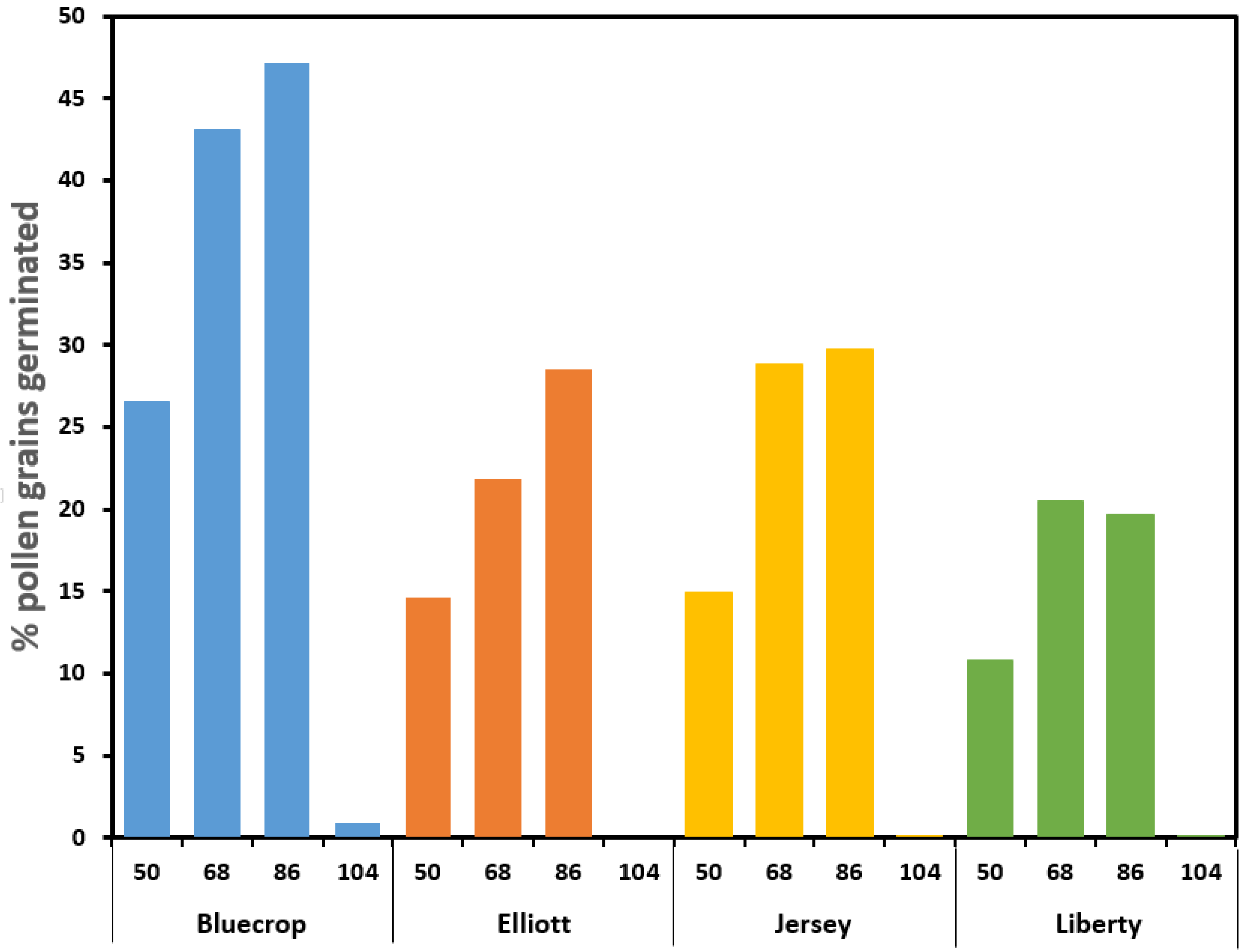
(Picture source: https://site.caes.uga.edu/blueberry/2015/02/freeze-damage-to-blueberry-buds/)

Figure 2.2.2(b). Freeze damage on blueberry buds.

2.2.3 Flowering and Pollination

Floral bud development is particularly sensitive to elevated temperatures, with pollen production and quality most affected during the bud swell stage. Exposure to extreme heat (37.5 °C) can result in a 39% reduction in fruit set. In addition to reducing pollen quantity, high temperatures also impair its nutritional composition, most notably by decreasing protein content. This degradation not only affects fertilization success but also has ecological implications; studies have shown that bees experience a sevenfold increase in mortality when consuming pollen produced under heat stress compared to pollen developed at standard temperatures (25 °C), due to an unbalanced pollen diet (Walters et al., 2025). A pollen diet with reduced protein content can lead to significant reproductive and developmental issues in pollinators. These include impaired ovarian and egg development, delayed nest initiation, and in more severe cases, the complete suppression of brood production. Such impacts can ultimately threaten pollinator populations and the pollination services essential for blueberry yield (Walters et al., 2025).

High temperatures also shorten the effective pollination period by reducing pollen viability and accelerating floral senescence (BC Agriculture & Food Climate Action Initiative, 2019). At temperatures above 35 °C, pollen germination and tube growth are significantly inhibited, often preventing successful fertilization before the ovules degrade. Simultaneously, elevated respiration rates in female flowers accelerate their aging, further narrowing the window for successful pollination and increasing the risk of poor fruit set (*Hot Weather Causing Rapid Blueberry Bloom*, 2020).



(Picture source: https://www.canr.msu.edu/news/effects-of-extreme-heat-on-blueberry-pollination)

Figure 2.2.3. Germination rates of highbush blueberry pollen at 50 ºF, 68 ºF, 86 ºF, and 104 ºF, respective to 4 cultivars of blueberries. Germination is a vital process in pollen growth and ovary fertilization, largely affecting the quality of pollination.

2.2.4 Fruit Development and Ripening

During the fruit development stage, elevated temperatures can negatively impact multiple aspects of blueberry quality, ultimately reducing marketable yield. Heat stress has been associated with declines in berry firmness, size, and flavor, and can also cause sunburn, which results in visible scalding on the fruit surface (BC Agriculture & Food Climate Action Initiative, 2019; *Blueberry Fruit Set, Development and Ripening*, n.d.). Studies have shown that excessive sun exposure often results in berry softening and shriveling (Yang et al., 2019). High temperatures accelerate transpiration and increase moisture loss from the berries, leading to reduced water content, firmness, and overall fruit size. In terms of flavor, heat can hinder photosynthetic efficiency by degrading key enzymes, which in turn limits the synthesis and accumulation of carbohydrates. This reduction affects the soluble solids content, an important determinant of sweetness and flavor in blueberries (*Blueberry Fruit Set, Development and Ripening*, n.d.). Additionally, fruit necrosis, spotting, and poor coloration, may also occur during berry development under heat stress, further contributing to unmarketable yields (Yang et al., 2019).

From a farm management perspective, elevated temperatures can compress the ripening period, leading to overlapping harvest times across different fields or varieties. This overlap increases the complexity of labor scheduling and intensifies labor demands within a shorter timeframe. When harvest timing is not well-aligned with berry maturity, it often results in yield loss and diminished fruit quality, as overripe or sun-damaged berries may no longer meet market standards (BC Agriculture & Food Climate Action Initiative, 2019).

2.2.5 Post Harvest

Postharvest conditions play a critical role in preserving blueberry quality for market. Storage temperature is a key determinant of postharvest shelf life, with delayed cooling after harvest identified as one of the most significant factors contributing to reduced marketable yield. Exposure to high temperatures after harvest accelerates both berry and pathogen metabolism, leading to increased moisture loss and a higher risk of decay, softening, and weight reduction. Prompt and adequate cooling is therefore essential for maintaining fruit quality and extending shelf life (Paniagua et al., 2014).

2.2.6 Pests and Diseases

In addition to its effects on plant growth and fruit quality, high temperature also increases pressure from pests and diseases. Table 2.2.6 outlines the major pests and diseases affecting blueberry production, with blueberry scorch virus and spotted wing drosophila (SWD) identified as two of the most serious threats (Agriculture and Agri-food Canada, 2025). While the direct effects of extreme heat on the activity and infestation patterns of viruses and pests remain not fully understood, high temperatures are known to weaken plant defenses, potentially increasing susceptibility to these threats. Additionally, the use of cooling practices such as misting—while beneficial for mitigating heat stress, can elevate humidity levels around the crop, inadvertently creating favorable conditions for pests like SWD and for the development of fungal diseases (BC Agriculture & Food Climate Action Initiative, 2019).

(Picture source: https://www.bcblueberry.com/bc-blueberry-council/resources/pest-and-disease-identification/swd-spotted-wing-drosophila)

Figure 2.2.6. SWD and the mushy berry they cause.

Table 2.2.6. Occurrence of Major Insect and Mite Pests, and Diseases of Blueberries in British Columbia (Source: 2023 Crop Profile for Highbush Blueberry in Canada by Agriculture and Agri-food Canada, 2025).

Pest Name	Occurrence in BC
Insect and Mite Pests	
Blueberry Aphid	
Blueberry Gall Midge / Cranberry Tipworm	
Bruce Spanworm	
Leafroller, Obliquebanded	
Spotted-wing Drosophila	
Weevil, Black Vine	
Weevil, Clay-colored	
Weevil, Obscure	
Weevil, Rough Strawberry	

Weevil, Strawberry Root	
Winter Moth	
Diseases	
Alternaria Fruit Rot	
Anthracnose Fruit Rot	
Bacterial Blight	
Blueberry Scorch Virus	
Blueberry Shock Virus	
Botrytis Blight and Fruit Rot	
Godronia Canker	
Mummy Berry	
Phomopsis Canker	
Widespread yearly occurrence with high pest pressure.	
Widespread yearly occurrence with moderate pest pressure OR localized yearly occurrence with high pest pressure OR widespread sporadic occurrence with high pest pressure.	

*Refer to Appendix 1 for more information regarding pests and diseases.

2.2.7 Drought Pressure

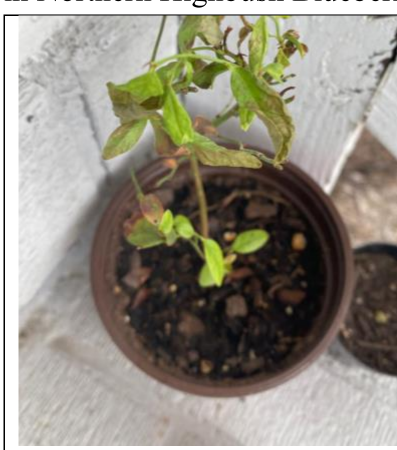
Drought stress in blueberries, often intensified by high temperatures, results from increased evapotranspiration, reduced water uptake and transport efficiency, and limited water availability. Blueberry plants are particularly vulnerable to drought early in the season, during periods of active shoot growth and development. While mature plants exhibit greater structural resilience, water stress becomes critical again during fruit development, often leading to soft, shriveled berries that fall below market quality standards (Longstroth, 2012). The plant's physiological response to drought across different growth stages is illustrated in Table 2.2.7. This issue places additional pressure on farm irrigation systems and overall water management.

2.2.8 Stress on Soil

Soil plays a critical role in supporting plant growth through its biological activity and regulation of water availability. These functions directly influence key aspects of plant development, including leaf size, plant height, chlorophyll content, stem diameter, and overall vigor (Chukwudi et al., 2021). Studies have shown that extreme heat can significantly inhibit soil enzyme activity and lead to substantial reductions in microbial biomass and fungal abundance. This disruption negatively impacts soil health and nutrient cycling. Notably, croplands are more susceptible to these heat-induced changes compared to permanent grasslands, due to croplands' generally lower abundance and diversity of microbial community (Riah-Anglet et al., 2015). With regard to water availability, elevated temperatures increase evaporation rates, often resulting in above-normal moisture loss from both soil and plant surfaces. This can lead to drought conditions and water deficits, which place additional stress on plants by limiting their ability to uptake sufficient water for physiological functions and growth. This heat stress is particularly pronounced in row crops such as blueberries, which have limited capacity for canopy evaporative cooling through transpiration. Row crops' relatively low canopy-to-soil surface area ratio results in reduced shading and moisture retention, increasing soil exposure to direct sunlight, making them more vulnerable to elevated temperatures and associated water stress (Costa et al., 2019).

In addition, a significant research gap exists concerning the impact of rising temperatures on the soil ecosystem in BC blueberry production specifically. This gap is largely due to limited funding from provincial sources and the perception that belowground effects have a comparatively smaller influence on yield and quality than aboveground plant responses. As a result, the role of soil health in long-term resilience to heat stress remains underexplored (D. Geesing, personal communication, 2025).

Table 2.2.7. Common Drought Responses of Blueberries (Source: Drought Stress Symptoms in Blueberries by M. Longstroth, 2012; Critical Temperatures and Heating Times for Fruit Damage in Northern Highbush Blueberry by F. H. Yang et al., 2019)

 (https://greg.app/blueberry-wilting/)	 (https://www.canr.msu.edu/uploads/files/Blueberry%20Drought%20Symptoms.pdf)	 (https://blogs.cornell.edu/berrytool/berry-pests/blueberries-drought-stress/)
Wilting shoots from temporary water deficit.	Marginal leaf burn.	Brunt dead shoot tip.

<table>
<tr>
<td>
(https://www.researchgate.net/publication/337775591_Critical_Temperatures_and_Heating_Times_for_Fruit_Damage_in_Northern_Highbush_Blueberry)</td>
<td>
(https://www.researchgate.net/publication/337775591_Critical_Temperatures_and_Heating_Times_for_Fruit_Damage_in_Northern_Highbush_Blueberry)</td>
<td>
(https://www.researchgate.net/publication/337775591_Critical_Temperatures_and_Heating_Times_for_Fruit_Damage_in_Northern_Highbush_Blueberry)</td>
</tr>
<tr>
<td colspan="2">Necrosis in green and ripe fruits.</td>
<td>Fruit spotting.</td>
</tr>
<tr>
<td colspan="3"></td>
</tr>
<tr>
<td>
(https://www.researchgate.net/publication/337775591_Critical_Temperatures_and_Heating_Times_for_Fruit_Damage_in_Northern_Highbush_Blueberry)</td>
<td>
(https://www.researchgate.net/publication/337775591_Critical_Temperatures_and_Heating_Times_for_Fruit_Damage_in_Northern_Highbush_Blueberry)</td>
<td>
(https://www.researchgate.net/publication/337775591_Critical_Temperatures_and_Heating_Times_for_Fruit_Damage_in_Northern_Highbush_Blueberry)</td>
</tr>
<tr>
<td colspan="2">Shriveling of green and ripe fruits.</td>
<td>Poor fruit coloration.</td>
</tr>
<tr>
<td colspan="3"></td>
</tr>
</table>

(https://www.canr.msu.edu/uploads/files/Blueberry%20Drought%20Symptoms.pdf)

Severe, large-scale burnt damage that will significantly impact yield for future years.

3. Mitigation and Adaptation Strategies for Managing Rising Temperatures in Blueberry Production, and Their Adaptability to BC Blueberry Industry.

To address the challenges posed by rising temperatures and the associated economic losses, a range of mitigation and adaptation strategies have been explored, tested, and implemented within the blueberry industry. These strategies include the use of in-field cooling systems, improvements in irrigation efficiency, adjustments to harvest scheduling, enhanced post-harvest handling practices, and breeding or selecting cultivars with improved heat tolerance (BC Agriculture & Food Climate Action Initiative, 2019; Gumbrewicz, 2021; Lobos & Hancock, 2015; Yang et al., 2020).

3.1 In-Field Cooling Systems

One of the most commonly known in-field cooling methods is sprinkler or micro-sprinkler irrigation systems. These systems rely on evaporative cooling, where the evaporation of water absorbs heat, thereby reducing both plant surface and ambient air temperatures (BC Agriculture & Food Climate Action Initiative, 2019; Yang et al., 2020). This approach has shown promising results in reducing crop canopy temperatures, nearly eliminating heat-related damage and increasing berry weight by an average of 10%. However, increased humidity from these cooling methods can create favorable conditions for insect pests and fungal diseases, posing additional management challenges (BC Agriculture & Food Climate Action Initiative, 2019; Yang et al., 2020). In addition, the concentration of soluble solids (sugars) in the berries tends to decrease slightly under these conditions, which may have an impact on fruit flavor. Compared to sprinklers, micro-sprinklers have proven equally effective as sprinklers in cooling, while using considerably less water (Yang et al., 2020).

In British Columbia, most blueberry farms have transitioned from overhead to drip irrigation systems to conserve water and fertigate individual plants precisely (BC Agricultural Climate Action Research Network, 2022). A combined approach, using drip irrigation for water delivery and micro-sprinklers for cooling, has been shown to provide optimal results by avoiding excessive soil and canopy wetness. Successful implementations of such dual systems have been reported also in Oregon, USA. However, growers in British Columbia have expressed hesitation about investing in sprinkler systems due to uncertainty surrounding the future frequency of extreme heat events and the substantial investment associated with installing or retrofitting the necessary infrastructure (BC Agricultural Climate Action Research Network, 2022). Additionally, overhead irrigation systems are generally incompatible with machine harvesting, introducing more complications in farm operation (BC Agriculture & Food Climate Action Initiative, 2019).

Other in-field cooling methods include the use of plant coatings and foliar sprays that create a reflective barrier on leaf and berry surfaces to reduce heat absorption and evaporation, as well as improve plant performance under extreme temperatures. Some producers in the Fraser Valley have experimented with these products, but their effectiveness, along with potential impacts on plant health and berry quality, remains uncertain. Further research is needed to better understand the benefits and limitations of these treatments under local growing conditions (BC Agricultural Climate Action Research Network, 2022; BC Agriculture & Food Climate Action Initiative, 2019).

(Picture source: https://msfruitextension.wordpress.com/2012/03/19/blueberry-irrigation-methods/; https://extension.uga.edu/publications/detail.html?number=B1504&title=low-volume-irrigation-systems-for-blueberry-with-chemigation-and-fertigation-suggestions)

Figure 3.1.1. Drip line (left) and micro-sprinkler (right) in blueberry production.

3.2 Protected Farming

In addition to sprinkler cooling systems and plant sprays, both considered forms of protected farming, other infrastructure options like low-tech greenhouses can also be explored for blueberry production. Compared to open-field cultivation, low-tech greenhouses offer a moderate level of environmental control, including regulation of temperature, light, and humidity through features such as ventilation systems, basic cooling devices, and insulation layers (Drake, 2023). These structures can provide a buffer against extreme weather conditions and help maintain more stable growing environments during vulnerable stages of blueberries. Additionally, low-tech greenhouses are generally more feasible for growers compared to high-tech alternatives. While high-tech greenhouses offer greater precision in controlling growing conditions, they also require significantly higher financial investment. In contrast, low-tech greenhouses are more cost-effective and offer greater flexibility, making them a more accessible and practical option for many blueberry producers (S. Loewen, personal communication, 2025)

It is important to note that protective measures should be implemented when temperatures reach 32 °C during the green berry stage and 35 °C during the blue berry stage. This is because the wax layer on the berry surface, an essential component for heat protection, is typically thinner in the early stages of development, making berries more vulnerable to heat stress at that time (BC Agricultural Climate Action Research Network, 2022).

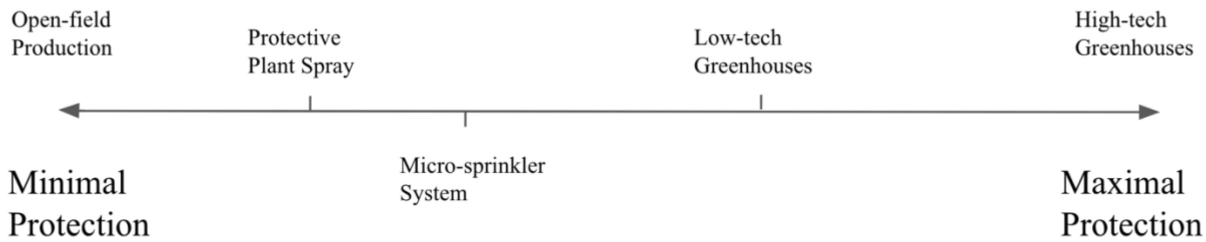


Figure 3.2.1. The qualitative spectrum of protection levels of different farming strategies.

(Picture source: https://greenhouse6.en.made-in-china.com/product/QnJRLzmSziUr/China-10X20-Transparent-Hydroponic-Automatic-Blueberry-Shade-Net-Garden-Netting-Greenhouse-for-Sale.html)

Figure 3.2.2. Low-tech greenhouses that can ventilate, apply air condition, and provide shading.

3.3 Improvements in Irrigation Efficiency

The majority of blueberry producers in British Columbia have transitioned from sprinkler systems to drip irrigation, which offers greater water-use efficiency by minimizing evaporation (BC Agriculture & Food Climate Action Initiative, 2019). Drip irrigation is effective in managing drought stress associated with extreme temperatures, delivering water directly to the root zone with minimal waste. While it does not provide the cooling benefits of sprinkler systems, it remains a reliable method for mitigating drought-related damage under heat stress conditions.

3.4 Adjustments to Harvesting Scheduling

Blueberries are also particularly vulnerable to heat damage during the period between harvest and cooling. Exposure to direct sunlight during the day can significantly reduce fruit quality. As a mitigation strategy, harvesting at night or early in the morning—ideally before 10:00 a.m.—has been recommended (BC Agriculture & Food Climate Action Initiative, 2019). This timing not only helps preserve berry quality by avoiding heat stress, but also facilitates faster harvesting, as berries detach more easily from the plants under cooler conditions. Additionally, it offers a more comfortable and efficient working environment for laborers. In Washington State and Oregon, nighttime harvesting is widely practiced by grape, apple, and melon growers. This approach is supported by packhouses that operate around the clock, allowing for seamless integration between harvesting and processing. As a result, overall efficiency is significantly improved, and fruit quality is better preserved during periods of high daytime temperatures.

However, in British Columbia, limited nighttime labor availability and the closure of berry processing facilities at night present practical challenges. These limitations reduce the feasibility of nighttime harvesting and can result in delays between harvest and cooling (BC Agriculture & Food Climate Action Initiative, 2019).

(Picture source: https://root24farms.com/how-we-grow-harvest-blueberries/)

Figure 3.4.1. Workers harvesting blueberries during nighttime.

3.5 Enhancement in Post-harvest Handling

Effective post-harvest handling is essential for preserving blueberry quality under extreme heat conditions. Key strategies include minimizing heat exposure and reducing the time berries remain in the field after harvest. Prompt transfer to shaded or cooled environments is critical. Portable in-field cooling systems, ranging from small units to larger setups can be powered by generators and moved throughout the field as needed. These systems help rapidly lower fruit temperature, reducing the risk of softening, decay, and moisture loss immediately after harvest (Figure 3.4.1). In addition, stationary in-barn cooling systems, such as refrigerated units and walk-in coolers, provide a controlled environment for temporarily storing berries before they are transported to packhouses or processing facilities (BC Agriculture & Food Climate Action Initiative, 2019). Together, in-field and in-barn cooling systems help maintain berry quality during the vulnerable post-harvest period.

In British Columbia, in-field cooling systems are not as widely adopted as in regions like Washington and California, largely due to the smaller scale of blueberry production. The cost and logistical requirements of implementing mobile cooling units may not be economically feasible for many BC growers, particularly those operating smaller or medium-sized farms (BC Agriculture & Food Climate Action Initiative, 2019).

(Picture source: https://www.storeitcold.com/mobile-guide/)

(Picture source: https://www.igrowpreowned.com/igrownews/a-mobile-post-harvest-pre-cooling-system-for-post-harvest-pre-cooling-at-grow-sites)

Figure 3.5.1. (a)(b) Small-scale mobile in-field cooling system; (c) Large-scale mobile in-field cooling system.

In addition to mechanical solutions like cooling systems, physical methods can also play a valuable role in reducing berry exposure to direct sunlight. Reflective tarps, constructed from heavy-duty durable materials, offer effective protection for harvested berries stored in trays, flats, or pallets. They have shown promising results in field trials conducted in British Columbia, effective in maintaining stable, cool, and moist conditions throughout the day, and significantly reduced berry weight loss during post-harvest handling (Climate & Agriculture Initiative BC, 2021). Available in a variety of sizes, weights, and designs, these tarps can be easily adapted to suit different farm setups and operational needs, making them a practical and flexible solution for field heat mitigation. Despite the reflective tarps' limitation in the performance under different weather conditions, these outcomes highlight their potential as a practical, low-cost solution for protecting fruit quality under extreme heat conditions. Figure 3.4.2 demonstrates reflective tarps in use under different scenarios.

(Picture Source: https://bcclimatechangeadaptation.ca/app/uploads/FV10-Project-Report-Managing-Reflective-Tarps-Blueberry-Industry-2021.pdf)

Figure 3.5.2. Reflective tarps are used on different containers in multiple scenarios.

3.6 Breeding and Genetic Selection for Heat-tolerant Cultivars

Research has identified oxidative stress as one of the severe physiological impacts of heat on highbush blueberry plants. This stress results from the accumulation of reactive oxygen species, which attack unsaturated fatty acids in cell membranes, ultimately leading to loss of membrane integrity and protein degradation or malfunction (Yu et al., 2016). The expression levels of antioxidative and protein-repairing genes are crucial in determining a plant's tolerance to heat stress (Yu et al., 2016). Consequently, one promising direction in breeding and genetic modification can be the selection of cultivars with higher expression of these genes, aiming to reduce oxidative damage and enhance heat resilience in highbush blueberries.

The BC Berry Breeding Program, led by the BC Blueberry Council, is actively working to strengthen the profitability and resilience of the province's blueberry sector by improving traits such as local adaptation, yield, fruit quality, and tolerance to heat and drought stress (*Breeding Program | BC Blueberry Council*, n.d.). However, due to the complexity of plant breeding, it typically takes 15 to 20 years from the initial selection of a trait to the commercial release of a new cultivar (*Breeding Program | BC Blueberry Council*, n.d.). This timeline ensures stable genetic expression and minimizes unintended impacts on other phenotypic traits, examined via thorough research experiments and field trials.

While long-term breeding efforts are ongoing, growers may consider adopting existing cultivars with demonstrated heat tolerance. Certain northern highbush blueberry cultivars—such as 'Jersey', 'Elliott', and 'Bluecrop'—have been shown to perform better under high temperatures compared to some southern cultivars. This improved heat tolerance is partly attributed to their ability to develop a thickened waxy cuticle in response to elevated temperatures, which helps reduce water loss and protect against heat-related stress (Yang et al., 2019; Yu et al., 2016).

Table 3. Qualitative Comparison among the Strategies

		Financial Feasibility	Ease of Adoption	Ease of Pest/Disease Control in Comparison to No Treatment	Effectiveness in Heat Damage Mitigation	Net Impact on Fruit Quality	Scalability
Pre-Harvest	Sprinkler / Micro-sprinkler Systems	Low	Low-Medium	Low	High	Positive-medium (if pest and diseases are managed well)	Medium
	Protective Plant Spray	High	High	Uncertain	Uncertain	Uncertain	High
	Low-tech Greenhouses	Low	Medium	Medium	Medium-High	Positive-high	Medium
Post-Harvest	Harvesting Schedule Adjustment	Medium	Medium	No Effect	Medium	Positive-medium	Medium
	In-field Post-harvest Cooling	Medium (small scale); Low (large scale)	Medium	No Effect	High	Positive-high	Medium
	Reflective Tarps	High	High	No Effect	Medium	Positive-high	High
	Cultivar Selection	Medium	Low (established farms); medium (new farms)	No Effect	High	Positive-high	Low (established farms); high (new farms)

4. Financial Evaluation of the Strategies

All the cost are in Canadian dollars adjusted for inflation rate of 3.5%.

Table 4.1. The Capital Costs and Operation Estimation of Adopting Sprinkler / Micro-sprinkler Systems.

		Cost Estimate
Capital Costs	Equipment	$858-3435 per acre (0.4 ha.)
	Installation Labor	$17.85 per hour per worker
	Updates and Adjustments of Farm Operation	As needed
Operation Costs	Additional Water	Water licence reapplication if water usage exceeds 92,000 m^3per year. Application fee $250 + annual water rental fee
	Additional Power	kWh × rate × hours per year Rate varies based on farm scale.
	Maintenance	As needed

Information Source: (Canada, 2015; *General Service Business Rates*, n.d.; Government of British Columbia, 2021; Stanford & Panuska, 2018)

Table 4.2. Cost Estimation of Protective Plant Spray.

		Cost Estimate
Product Cost		$1.48-4.44 per acre (0.4ha.)
Operation Cost	Application Labor	$17.85 per hour per worker

*For detailed calculation please refer to Appendix II. Costs are variable with product types and application rates.

Information Source: (Canada, 2015; Novasource Tessenderlo Group, n.d.)

Table 4.3. Cost Estimation of Low-tech Greenhouse.

		Cost Estimate
Capital Costs	Equipment (Greenhouses, Cooling Device, Ventilation)	$45,000 per greenhouse of 25' × 98' × 12.5' (if purchasing fully ready-made greenhouses. It can be much cheaper to build them up using existing materials.)
	Installation Labor	$17.85 per hour per worker
	Updates and Adjustments of Farm Operation	As needed
Operation Costs	Additional Power	kWh × rate × hours per year Rate varies based on farm scale.
	Plastic Maintenance	As needed

Information Source: (Canada, 2015; *General Service Business Rates*, n.d.; *Planta Greenhouses Kits - DIY Backyard and Commercial Greenhouse Kits*, n.d.)

Table 4.4. Change in Labor Cost of Harvesting at Night.

	Daytime	Nighttime with shift premium
Wages	$17.85 per hour per worker	$19.57 per hour per worker

*Shift premium during nighttime is not mandatory by law.

Information Source: (BC Public Service, n.d.)

Table 4.5. Capital and Operation Cost Estimation of In-Field Post-Harvest Cooling Device.

		Cost Estimate
Capital Costs	Equipment	$331,898 (large scale); $6146 (small scale)
	Installation Labor	$17.85 per hour per worker
	Updates and Adjustments of Farm Operation	As needed
Operation Costs	Additional Power	kWh × rate × hours per year Rate varies based on farm scale.
	Operation Labor	$23.00 per hour per operator

Information Source: (BC Agriculture & Food Climate Action Initiative, 2019; Canada, n.d.)

Table 4.6. Cost Estimate of Reflective Tarps.

		Cost Estimate
Product Cost		\$2.46-6.15 per m^2
Operation Cost	Application and Maintenance Labor	\$17.85 per hour per worker

Information Source: (BC Agriculture & Food Climate Action Initiative, 2019)

Table 4.7. Cost Estimation for Cultivar Selection.

Cultivar	Estimated Cost Per Pot	Estimated Cost Per 100 Pots
Jersey	\$21.99	\$1,100
Elliott	\$18.99	\$1,100
Bluecrop	\$18.99	\$1,100

Information Source: (*Blueberry Plants (Commercial) – Nourse Farms*, n.d.; *Blueberry Plants from Stark Bro's*, n.d.)

5. Conclusion and Recommendation

The highbush blueberry industry in British Columbia plays a vital role in the Province's agricultural economy and Canada's fruit export sector. However, rising temperatures, driven by climate change, have introduced severe challenges that span all phases of blueberry production, from overwintering and bud break to flowering, fruit development, and post-harvest handling. This project has comprehensively evaluated the physiological impacts of heat stress on blueberry plants, as well as pest and disease pressure, soil health degradation, and increased labor and irrigation demands. In response, a range of mitigation and adaptation strategies have been reviewed and analyzed for their effectiveness, feasibility, and adaptability to the unique conditions of blueberry farming in BC.

One of the most promising strategies during the growing season is the use of micro-sprinkler cooling systems, particularly when combined with drip irrigation. Micro-sprinklers operate on the principle of evaporative cooling, reducing plant surface temperature and ambient heat stress by dispersing fine water droplets. Compared to traditional sprinklers, micro-sprinklers consume significantly less water while offering comparable cooling performance. Empirical evidence demonstrates that this method can reduce fruit damage to nearly zero during extreme heat events and increase berry weight by approximately 10%. For regions like the Lower Fraser Valley, where most producers have already adopted drip irrigation, integrating micro-sprinklers into the existing infrastructure can be a practical and effective approach.

Despite its advantages, micro-sprinkler adoption in BC has been limited due to several concerns. The upfront investment for equipment and installation can range from $858 to $3,435 per acre (0.4ha.- and adjusted for inflation), a significant financial consideration for small and mid-sized farms. Moreover, the added humidity associated with misting systems can elevate the risk of fungal diseases and increase the prevalence of pests such as spotted wing drosophila (SWD), requiring integrated pest management (IPM) adjustments. Furthermore, these systems may not be compatible with mechanical harvesting setups, which some farms rely on to optimize labor efficiency.

That said, in evaluating all factors, including heat mitigation effectiveness (high), net fruit quality impact (positive if managed properly), scalability (medium), and pest control trade-offs (manageable through IPM)—the recommendation is to prioritize micro-sprinkler installation in fields that are most vulnerable to heat, especially during the green and blue berry stages where wax layer development is incomplete. This phased approach helps balance cost concerns with yield protection and allows farms to gradually scale up as climate trends and funding opportunities evolve.

Alternatively, low-tech greenhouses present a viable protected farming strategy for mitigating heat stress, especially in high-value or heat-sensitive fields. While the initial capital investment may be high, the cost can be dramatically reduced by recycling existing materials, and these structures offer broader environmental control, moderating not only temperature but also light intensity, wind exposure, and humidity. In regions experiencing frequent and prolonged heat events, low-tech greenhouses can provide consistent growing conditions, reduce the risk of sunburn, and extend the harvest window. They also avoid the elevated humidity associated with mist-based systems, thereby minimizing pest and disease pressure. For growers seeking a long-term, infrastructure-based solution to climate volatility, low-tech greenhouses offer a scalable and adaptable option. Although adoption may be more feasible on a smaller scale initially, phased implementation and potential cost-share programs could support wider use over time.

Post-harvest, blueberry fruit is highly susceptible to quality degradation if exposed to ambient field heat. Immediate cooling post-harvest is therefore essential to preserve texture, flavor, and weight.

Among the available options, the use of reflective tarps stands out as the most practical and accessible strategy for BC growers. Reflective tarps are simple, low-tech tools that provide shade and reduce direct heat exposure on harvested berries stored in trays or bins. Field trials conducted in British Columbia have shown that reflective tarps help maintain cool, moist conditions throughout the day and significantly reduce post-harvest berry weight loss. Their effectiveness, affordability, and ease of use make them ideal for small and medium-sized farms.

From a financial perspective, reflective tarps cost approximately $2.46 to $6.15 per square meter, with minimal maintenance and labor costs. Unlike mobile or stationary cooling systems, which may require generators, fuel, or additional energy infrastructure, reflective tarps do not demand ongoing operational inputs. Their high scalability, positive impact on fruit quality, zero side effects on pests or plant health, and low financial barrier to adoption position them as a cost-effective component of any post-harvest heat mitigation plan.

While strategies such as nighttime harvesting and mobile field cooling offer excellent technical benefits, they face limitations in British Columbia due to labor availability, packhouse operating hours, and cost constraints. Similarly, low-tech greenhouses present a viable longer-term solution for more intensive growers but may be financially out of reach for many producers at this time. Therefore, prioritizing adaptable, cost-effective solutions such as reflective tarps and micro-sprinklers allows for both immediate and strategic responses to rising temperature conditions.

In conclusion, addressing the growing threat of heat stress in BC blueberry production requires a layered, context-sensitive approach. During the growing phase, micro-sprinkler systems offer a strong return on investment in terms of fruit protection and yield stability, especially when integrated with existing drip irrigation infrastructure. For post-harvest handling, reflective tarps provide a simple yet powerful tool to preserve berry quality under field conditions without imposing high capital or operational costs. Both strategies are highly adaptable to the BC context and should be considered core components of heat resilience planning for blueberry growers. For agricultural policymakers, allocating additional resources to address the impacts of heat on blueberry production would be highly beneficial. Supporting research initiatives that focus on heat-related challenges—particularly underexplored areas such as soil health—and providing financial incentives for both research institutions and farmers implementing mitigation strategies would significantly strengthen the industry's resilience to climate change. As climate change continues to challenge the consistency and profitability of fruit production in BC, a proactive adoption of scientifically backed, field-tested solutions will be essential to sustain the industry’s long-term viability.

6. Appendix

Appendix I. Overview of Damage, Life Cycle, and Management Challenges of Major Insect and Mite Pests and Diseases Affecting Blueberries in British Columbia (Source: 2023 Crop Profile for Highbush Blueberry in Canada by Agriculture and Agri-food Canada, 2025).

Name	Damage	Life Cycle	Management Challenges
Insect and Mite Pests			
Blueberry Aphid	Feeds on shoots; transmits blueberry scorch virus.	Overwinters as eggs near buds; asexual reproduction in-season.	Needs pollinator-safe strategies; vector management critical.
Blueberry Gall Midge / Cranberry Tipworm	Larvae feed on buds, causing stunted growth and delayed maturity.	Several generations/years; larvae pupate in soil.	No resistant cultivars; monitoring and thresholds needed.
Bruce Spanworm	Feeds on blossoms and leaves; can defoliate plants.	Larvae feed spring; moths lay eggs in late fall.	Requires timing control with scouting and IPM-compatible insecticides.
Leafroller, Obliquebanded	Feeds on foliage and buds; contaminates harvested berries.	2 generations/year; larvae overwinter under bark.	Bee-safe treatments needed; pruning helps control.
Spotted-wing Drosophila	Larvae feed in fruit; causes rot and spoilage.	5+ generations/year; lays eggs in ripening fruit.	Needs resistance management and new control strategies.
Weevil, Black Vine / Clay-colored / Obscure / Rough Strawberry / Strawberry Root	Larvae damage roots; adults feed on foliage.	Adults lay eggs in soil; larvae feed underground.	Control difficult post-infestation; scouting not always reliable.
Winter Moth	Feeds on developing leaves and blossoms.	Larvae feed in spring; overwinter as eggs.	IPM-compatible control products required.
Diseases			
Alternaria Fruit Rot	Causes soft rot with green mold; leaf spotting.	Overwinters on debris; spreads via spores in moist weather.	New fungicide options and efficacy studies needed.
Anthracnose Fruit Rot	Causes sunken lesions and postharvest rot.	Overwinters on twigs; spreads by rain or harvest tools.	Fungicide resistance; need for preventative strategies.

Bacterial Blight	Kills shoots and flower buds; severe in new plantings.	Spreads in cool, wet weather via wounds.	Copper resistance present; alternative controls needed.
Blueberry Scorch Virus	Blights blossoms; reduces yield; plant may die.	Spread by aphids and infected cuttings.	Asymptomatic early stages hinder detection.
Blueberry Shock Virus	Kills flowers/shoots during bloom; no fruit for 1-4 years.	Spread by infected pollen, bees, and stock.	No cure; control via clean stock and bee management.
Botrytis Blight and Fruit Rot	Infects flowers, fruit, and stems; causes gray mold.	Overwinters in tissue; spreads in cool, humid conditions.	Fungicide resistance and moisture control critical.
Godronia Canker	Kills new stems; lowers yield.	Overwinters in stems; spreads by spores in rain.	No fungicides registered; reliant on pruning.
Mummy Berry	Shoots and berries wilt, drop, or dry.	Overwinters as mummified berries; spores infect buds/fruit.	Fungicide resistance risk; burying mummies crucial.
Phomopsis Canker	Girdles stems; causes dieback and shoot death.	Overwinters in stems; rain spreads spores.	Managed via pruning; no resistant varieties.

Appendix II. Calculation for cost of protective spray per acre.

According to the product label for Purshade, a crop solar protectant, the recommended mixing ratio is 0.25 L of Purshade per 3.8 L of water—equivalent to 6.6%. For small fruits, the suggested application rate ranges from 1 to 3 gallons per acre. The product is sold at a unit price of $49.80 USD per 25-pound container.

Purshade is applied at a rate of 1 to 3 US gallons per acre. Convert gallons to liters using the conversion:
1 gallon = 3.78541 liters

1 gallon = 3.78541 L

3 gallons = 11.35623 L

The product is mixed at a 6.6% concentration by weight, meaning: For every 100 L of solution, 6.6 kg of Purshade is required.

Therefore:

At 3.78541 L: Purshade needed = $3.78541 \times 0.066 = 0.2498$ kg

At 11.35623 L: Purshade needed = 11.35623 × 0.066 = 0.7495 kg

Product Cost per Kilogram (in CAD)

25 lb = 11.3398 kg

Unit cost (USD) = $49.80

Exchange rate: 1 USD = 1.35 CAD

Converted cost = $49.80 × 1.35 = $67.23 CAD per 25 lb

Cost per kg = $67.23 / 11.3398 = $5.93 CAD per kg

Multiply the quantity of Purshade needed by the cost per kilogram:

At 1 gallon per acre: 0.2498 kg × $5.93 = $1.48 CAD

At 3 gallons per acre: 0.7495 kg × $5.93 = $4.44 CAD

Reference

Special thanks to Leslie Lavkulich, Dieter Geesing, and Stan Loewen for their help, providing valuable information that contributes tremendously to this project.

Agriculture | City of Abbotsford. (2025, May 23). https://www.abbotsford.ca/business-development/agriculture

Agriculture and Agri-food Canada. (2025). *Crop Profile for Highbush Blueberry in Canada, 2023*. https://publications.gc.ca/collections/collection_2025/aac-aafc/A118-10-8-2023-eng.pdf

Agriculture in Richmond—City of Richmond, BC. (n.d.). Retrieved June 9, 2025, from https://www.richmond.ca/business-development/planning/agriculture-richmond.htm

BC Agricultural Climate Action Research Network (Director). (2022, June 1). *Heat damage, tolerance and mitigation in berries* [Video recording]. https://www.youtube.com/watch?v=QilC4D5J9eM

BC Agriculture & Food Climate Action Initiative. (2019). *State of Practices & Technologies Assessment for Managing Extreme Heat Impacts*. https://bcclimatechangeadaptation.ca/app/uploads/FV07-Managing-Extreme-Heat-2019-report.pdf

BC Blueberry Council. (n.d.). *What is a BC Blueberry*. https://www.bcblueberry.com/sites/default/files/inline-files/BCBC%20What%20is%20a%20BC%20Blueberry.pdf

BC Public Service. (n.d.). *Shift premiums—Province of British Columbia*. Province of British Columbia. Retrieved July 7, 2025, from https://www2.gov.bc.ca/gov/content/careers-myhr/all-employees/pay-benefits/salaries/overtime/shift-premiums

Blueberry | Description, Types, Nutrition, Cultivation, & Facts | Britannica. (2025, January 14). https://www.britannica.com/plant/blueberry-plant

Blueberry Fruit Set, Development and Ripening. (n.d.). Retrieved June 2, 2025, from https://extension.uga.edu/publications/detail.html?number=C1294&title=blueberry-fruit-set-development-and-ripening

Blueberry Plants (Commercial) – Nourse Farms. (n.d.). Retrieved July 7, 2025, from https://www.noursefarms.com/collections/blueberries-commercial?srsltid=AfmBOoo8ffvHnmOZmaVuHmV7hp3USVi-8a3qoDAZZdq7cR3Xj8zK13Mb

Blueberry Plants from Stark Bro's. (n.d.). Stark Bro's Nurseries & Orchards Co. Retrieved July 7, 2025, from https://www.starkbros.com/products/berry-plants/blueberry-plants

Breeding Program | BC Blueberry Council. (n.d.). Retrieved June 24, 2025, from https://www.bcblueberry.com/bc-blueberry-council/programs/research/breeding-program

Canada. (n.d.). *Farm Machinery Operator in Canada | Wages—Job Bank*. Retrieved July 7, 2025, from http://www.jobbank.gc.ca/explore_career/job_market_report/wage_occupation_report.xhtml

Canada. (2015, November 18). *Wages by commodity* [Program descriptions]. https://www.canada.ca/en/employment-social-development/services/foreign-workers/agricultural/agricultural-wages.html

Canada, A. and A.-F. (2024, July 22). *Statistical overview of the Canadian fruit industry, 2023*. https://agriculture.canada.ca/en/sector/horticulture/reports/statistical-overview-canadian-fruit-industry-2023

Chukwudi, U. P., Kutu, F. R., & Mavengahama, S. (2021). Influence of Heat Stress, Variations in Soil Type, and Soil Amendment on the Growth of Three Drought–Tolerant Maize Varieties. *Agronomy*, *11*(8), Article 8. https://doi.org/10.3390/agronomy11081485

City of Pitt Meadows. (2023, September). *Grown in Pitt Meadows: Our Agricultural Viability Strategy*. https://www.pittmeadows.ca/sites/default/files/2023-10/City%20of%20Pitt%20Meadows%20Draft%20Agricultural%20Plan_Oct%204.pdf

Climate & Agriculture Initiative BC. (2021). *Managing Extreme Heat with Reflective Tarps in the Blueberry Industry*. https://bcclimatechangeadaptation.ca/app/uploads/FV10-Project-Report-Managing-Reflective-Tarps-Blueberry-Industry-2021.pdf

Costa, J. M., Egipto, R., Sánchez-Virosta, A., Lopes, C. M., & Chaves, M. M. (2019). Canopy and soil thermal patterns to support water and heat stress management in vineyards. *Agricultural Water Management*, *216*, 484–496. https://doi.org/10.1016/j.agwat.2018.06.001

Deslauriers, A., Garcia, L., Charrier, G., Buttò, V., Pichette, A., & Paré, M. (2021). Cold acclimation and deacclimation in wild blueberry: Direct and indirect influence of environmental factors and non-structural carbohydrates. *Agricultural and Forest Meteorology*, *301–302*, 108349. https://doi.org/10.1016/j.agrformet.2021.108349

DeVetter, L. W., Granatstein, D., Kirby, E., & Brady, M. (2015). *Opportunities and Challenges of Organic Highbush Blueberry Production in Washington State*. https://doi.org/10.21273/HORTTECH.25.6.796

Did you know there are two types of blueberries? (n.d.). *Wild Blueberries*. Retrieved June 30, 2025, from https://wildblueberries.com/school_blog/did-you-know-there-are-two-types-of-blueberries/

Drake, A. (2023, October 24). Best Greenhouse Temperature Control Techniques to Help Your Plants Thrive All-Year Round. *Charley's Greenhouse*. https://charleysgreenhouses.com/news/best-greenhouse-temperature-control-techniques-to-help-your-plants-thrive-all-year-round/

Farm Markets. (n.d.). Surrey Farms. Retrieved June 9, 2025, from https://www.surreyfarms.ca/farm-markets

Geesing, D. (2025). *Personal Conversation. BC Ministry of Agriculture* [Personal communication].

General Service Business Rates. (n.d.). Retrieved July 7, 2025, from https://www.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/business-rates.html

Government of British Columbia. (2021). *Water Licences for Agriculture*. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/agricultural-land-and-environment/water/water_licences_for_agriculture.pdf

Government of Canada. (2011). *Canadian Blueberries—A True Taste of Nature*. https://publications.gc.ca/collections/collection_2011/agr/A15-11509-2011-eng.pdf

Gumbrewicz, R. (2021). *Adaptation Strategies for Wild Blueberry Growers in a Changing Climate: Mulching Effects on Crop Productivity and Fertility Effects on Blueberry Gall Midge*. https://digitalcommons.library.umaine.edu/etd/3501

Highbush Blueberry Vs Lowbush Blueberry: Key Differences Explained - Bumbee's. (2024, October 7). https://www.bumbees.com/highbush-blueberry-vs-lowbush-blueberry/

Hot weather causing rapid blueberry bloom. (2020, May 26). Blueberries. https://www.canr.msu.edu/news/hot-weather-causing-rapid-blueberry-bloom

IBO - State of the Blueberry Industry Report. (n.d.). Retrieved May 23, 2025, from https://agronometrics.com/ibo/sotir2022/South_America/PER

Lachowicz-Wiśniewska, S., Pratap-Singh, A., Ochmian, I., Kapusta, I., Kotowska, A., & Pluta, S. (2024). Biodiversity in nutrients and biological activities of 14 highbush blueberry (Vaccinium corymbosum L.) cultivars. *Scientific Reports*, *14*(1), 22063. https://doi.org/10.1038/s41598-024-71114-x

Lobos, G. A., & Hancock, J. F. (2015). Breeding blueberries for a changing global environment: A review. *Frontiers in Plant Science*, *6*, 782. https://doi.org/10.3389/fpls.2015.00782

Loewen, S. (2025). *Personal Conversation. TerraLink Horticulture Inc. 464 Riverside Road, Abbotsford, BC V2S7M1* [Personal communication].

Longstroth, M. (2012, July). *Drought Stress Symptoms in Blueberries*. https://www.canr.msu.edu/uploads/files/Blueberry%20Drought%20Symptoms.pdf

Naderi, A., Rezaei, S., Moussa, A., Levers, K., & Earnest, C. P. (2018). Fruit for sport. *Trends in Food Science & Technology*, *74*, 85–98. https://doi.org/10.1016/j.tifs.2018.02.013

Novasource Tessenderlo Group. (n.d.). *Purshade Solar Protectant Product Label*. https://morr.com/media/mageplaza/product_attachments/attachment_file/p/u/purshade_label.pdf

Padmanabhan, P., Correa-Betanzo, J., & Paliyath, G. (2016). Berries and Related Fruits. In B. Caballero, P. M. Finglas, & F. Toldrá (Eds.), *Encyclopedia of Food and Health* (pp. 364–371). Academic Press. https://doi.org/10.1016/B978-0-12-384947-2.00060-X

Paniagua, A. C., East, A. R., & Heyes, J. A. (2014). Interaction of temperature control deficiencies and atmosphere conditions during blueberry storage on quality outcomes. *Postharvest Biology and Technology*, *95*, 50–59. https://doi.org/10.1016/j.postharvbio.2014.04.006

Planta Greenhouses Kits—DIY Backyard and Commercial Greenhouse Kits. (n.d.). Planta Greenhouses Canada. Retrieved July 7, 2025, from https://plantagreenhouses.ca/

Raditic, D. M., & Bartges, J. W. (2014). 15—The Role of Chondroprotectants, Nutraceuticals, and Nutrition in Rehabilitation. In D. Millis & D. Levine (Eds.), *Canine Rehabilitation and Physical Therapy (Second Edition)* (pp. 254–276). W.B. Saunders. https://doi.org/10.1016/B978-1-4377-0309-2.00015-6

Rashidinejad, A. (2020). Chapter 29—Blueberries. In A. K. Jaiswal (Ed.), *Nutritional Composition and Antioxidant Properties of Fruits and Vegetables* (pp. 467–482). Academic Press. https://doi.org/10.1016/B978-0-12-812780-3.00029-5

Riah-Anglet, W., Trinsoutrot-Gattin, I., Martin-Laurent, F., Laroche-Ajzenberg, E., Norini, M.-P., Latour, X., & Laval, K. (2015). Soil microbial community structure and function relationships: A heat stress experiment. *Applied Soil Ecology*, *86*, 121–130. https://doi.org/10.1016/j.apsoil.2014.10.001

Shamsizadeh, A., Roohbakhsh, A., Ayoobi, F., & Moghaddamahmadi, A. (2017). Chapter 25—The Role of Natural Products in the Prevention and Treatment of Multiple Sclerosis. In R. R. Watson & W. D. S. Killgore (Eds.), *Nutrition and Lifestyle in Neurological Autoimmune Diseases* (pp. 249–260). Academic Press. https://doi.org/10.1016/B978-0-12-805298-3.00025-6

Stanford, S., & Panuska, J. (2018). *The Basis of Micro Irrigation*. https://hort.extension.wisc.edu/articles/the-basics-of-micro-irrigation/

Strik, B. (2018). How blueberry plants develop and grow. *Ag - Berries*. https://extension.oregonstate.edu/crop-production/berries/how-blueberry-plants-develop-grow

United States Department of Agriculture. (2021, October 21). *Blueberries Around the Globe – Past, Present, and Future*. https://www.fas.usda.gov/data/blueberries-around-globe-past-present-and-future

USDA Economic Research Service. (2023). *Fruit and Tree Nuts Yearbook Tables* [Dataset]. https://www.ers.usda.gov/data-products/fruit-and-tree-nuts-data/fruit-and-tree-nuts-yearbook-tables

Walters, J., Fisher, R., Sharkey, T. D., Isaacs, R., & Santiago, J. P. (2025). Extreme heat affects blueberry pollen nutrition, bee health, and plant reproduction. *Scientific Reports*, *15*(1), 6249. https://doi.org/10.1038/s41598-025-90676-y

Why BC Blueberries? | BC Blueberry Council. (n.d.). Retrieved February 19, 2025, from https://www.bcblueberry.com/bc-blueberry-council/why-bc-blueberries

Yang, F.-H., Bryla, D. R., Orr, S. T., Strik, B. C., & Zhao, Y. (2020). *Thermal Cooling with Sprinklers or Microsprinklers Reduces Heat Damage and Improves Fruit Quality in Northern Highbush Blueberry*. https://doi.org/10.21273/HORTSCI15119-20

Yang, F.-H., Bryla, D. R., & Strik, B. C. (2019). *Critical Temperatures and Heating Times for Fruit Damage in Northern Highbush Blueberry*. https://doi.org/10.21273/HORTSCI14427-19

Yu, K., Zhu, K., Ye, M., Zhao, Y., Chen, W., & Guo, W. (2016). Heat tolerance of highbush blueberry is related to the antioxidative enzymes and oxidative protein-repairing enzymes. *Scientia Horticulturae*, *198*, 36–43. https://doi.org/10.1016/j.scienta.2015.11.018