February 2023

Climate change impacts on Canada's food supply cold chain

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Key Messages

- Canada faces unique challenges to food supply cold chains that are expected to be exacerbated by climate change.
- As climate change is expected to challenge food production, there is a need to optimize the safety and quality of food that has already been harvested or processed.
- Increased ambient temperatures and increased frequency and severity of extreme weather and natural disasters can cause disruptions in food supply cold chains.
- Monitoring technologies are currently used to collect data throughout food supply cold chains, but are often not being used effectively to optimize food supply cold chains.
- Environmental health practitioners can play a key role in effective data collection and utilization as a means to increase the resiliency of food supply cold chains to warmer temperatures and natural disasters.

Introduction

Perishable foods, including fruits, vegetables, meat, fish, poultry, and dairy, are essential to the diets of Canadians. To maintain food safety and quality, perishables must be kept refrigerated or frozen during storage and distribution from their point of origin to the consumer, a process called the food supply cold chain (FSCC). A failure to maintain the proper temperature at any point during the FSCC can result in microbial growth, discoloration, bruising, or degradation of the product.

The effects of climate change increasingly impact populations in Canada and worldwide. Canadians have experienced greater frequency and severity of climate change-related events such as heat waves, wildfires, and floods. These events can disrupt the distribution of goods and cause supply shortages, such as during the unprecedented floods in British Columbia in November 2021, and wildfires in Newfoundland in the summer of 2022. Disruptions or changes in environmental conditions such as these may cause additional challenges in maintaining the integrity of the FSCC. In the absence of effective adaptation measures, disruption of the FSCC could lead to an increase in foodborne illnesses or reduce access to high-quality foods in areas impacted by severe weather events.

This document presents the findings of an evidence synthesis of academic and grey literature on the effects of climate change on the FSCC, and resulting impacts to food safety and quality. It highlights gaps in research and policy, provides examples of promising adaptation technologies and/or procedures, and discusses future directions for adapting and preparing FSCCs for challenges posed by climate change.

Background

Food safety and security

In Canada, an estimated four million people (one in eight) are affected by foodborne illness each year.[1] About 40% of these illnesses are caused by common foodborne bacteria, viruses, and parasites, such as norovirus, *Clostridium perfringens*, *Campylobacter spp*., and *Salmonella spp*. Temperature control of perishable foods is a key component of reducing the growth of microbiological causes of foodborne illness. However, foodborne illnesses are often unreported and uncharacterized, and around 60% of foodborne illnesses result from unknown causes.[1] Additionally, approximately 35% of food recalls in Canada each year are the result of microbiological contamination, which increase the risk of foodborne illness if the product is consumed.[2]

Temperature control also affects food quality. Food not kept at an adequate temperature is more likely to spoil and have a reduced shelf life, contributing to food loss and waste.[3] An estimated 35.5 million metric tons of food in Canada is wasted annually, and 32% of the waste is avoidable.[3] This amount of food waste is especially concerning in light of rising food prices and rates of food insecurity in Canada. In 2021, nearly 16% of Canadians experienced some level of food insecurity.[4]

The food supply cold chain

The process of maintaining temperature of a perishable food product from harvest or processing to the consumer is called the FSCC (see Table 1 for the stages of the FSCC). This process involves numerous cooling and refrigeration technologies as well as large-scale optimization of the supply chain in order to make sure that an adequate temperature is maintained through each stage. The FSCC is complex, with varying temperature needs for each product (see Table 2).

Table 1: Stages of the food supply cold chain.

Stage of the Food Supply Cold Chain	Description
Harvesting/Processing & Pre-cooling	Immediate cooling to bring temperature of product to an adequate range. Technologies used include room cooling, forced-air cooling, water or hydro cooling, ice cooling, and vacuum cooling.
Commercial Transport	Food is transported over long distances via plane, ship, truck, rail, or a combination. Depending on the food product and type of transport, refrigeration may be used.
Storage	Food is refrigerated, stored, and sorted to prepare for distribution.
Distribution	Food is transported relatively shorter distances to retail or restaurants. This is often done by refrigerated truck.
Retail	Food is kept in a refrigerated storage room or put out for display.
Consumer	Storage in domestic refrigerators or commercial (e.g., restaurant) refrigerators and freezers.

Note: This is a simplified representation of an FSCC, and some food products may go through all of these stages, skip some stages, or have additional steps added.

Table 2: Examples of optimal storage and transport temperatures for common food products in the food supply cold chain.

Optimal Storage & Transport Temperature	Examples of Common Food Products
Frozen (≤ -10 °C)	Some meats, fruits, vegetable juice concentrates, baked goods, ready-to-heat products
Cold (-9 °C to 2 °C)	Meat products, fish, dairy, low-temperature fruits and vegetables (e.g., apples, blueberries, carrots, lettuce)
Cool (2 °C to 15 °C)	Melons, pumpkins, tropical fruits, potatoes
Ambient (15 °C to 20 °C)	Bananas, cucumbers, grapefruit

Methodology

Literature search

The literature search was developed to answer the following research questions:

1. What are the current challenges facing the FSCC in Canada?
2. How is climate change expected to impact the FSCC?
3. What processes and technologies are currently in use or emerging that could be leveraged to mitigate the effects of climate change on the FSCC?
4. What are the practice and knowledge gaps related to climate change and the FSCC?

We searched academic and grey literature for information on the FSCC, refrigeration, food safety, food security, and climate change using the EBSCOhost databases (includes Medline, CIHAHL, Academic Search Complete, and ERIC), Google Scholar, and Google. Relevant English-language results were collected from January 2015 to May 2022. While the aim of the first two research questions is to better understand the Canadian context, articles from other countries were not excluded if they pertained to relevant climate change impacts or FSCC technologies and processes. Additional references were added via forward and backward chaining of the initial search results as well as supplementary searches as needed to expand on specific topic areas. For academic literature, both peer-reviewed and preprint sources were considered. For grey literature, we included reports and white papers from known public health, food safety, and academic institutions. We also included several reports from industry associations, such as the International Institute of Refrigeration, an independent intergovernmental association providing technical expertise in areas relating to refrigeration. Complete search terms and the full list of results are available upon request. Studies were selected for review if they addressed temperature control, the FSCC, perishable foods, food safety, food quality, food security, food temperature or quality monitoring, and various aspects of climate change. The studies were assessed by a single reviewer and the results were synthesized narratively.

Results

The current challenges facing the food supply cold chain in Canada

The FSCC is not equitably distributed across the world. Refrigeration technologies and processes are energy intensive and cost prohibitive in some countries with limited resources. In comparison, Canada has a well-developed FSCC that is able to provide temperature management to all perishable food where it is required. Despite this, disruptions or breaks in the FSCC are known to occur.[5] Of avoidable food losses in Canada, 5% occurs during distribution, 12% at retail, and 21% at the consumer stage. Insufficient temperature maintenance throughout the FSCC is believed to be a major contributor to these losses.[3]

It is important to understand the factors that may cause temperatures to fall outside of the acceptable range throughout the FSCC. Canada has several unique challenges in maintaining the FSCC. First, the geographic range that food travels within Canada is a major challenge in temperature maintenance. Canada has a large land mass with populations concentrated in urban centres spread across the country, and with additional communities spread throughout large rural and remote areas. Food destined for urban areas is primarily transported by road, while food destined for remote areas (and in particular, Northern communities) is transported by air.[6] In either case, transportation times for food in the FSCC are significantly longer in Canada compared with countries that have a smaller geographic area. For example, the total travel time for ready-to-eat lettuce moving through the FSCC in Canada was found to be 55 hours in winter and 22 hours in summer.[5] In comparison, the total transportation time for fresh cut vegetables in Belgium is four hours.[7] This challenge of geographic distance, while not insurmountable, means that the FSCC must be maintained for longer periods, leading to higher risks of disruptions. For Northern communities that rely on air travel for perishable food, the FSCC is even more susceptible. Planes used for food transport are often not equipped with refrigeration systems, so temperatures inside plane cargo holds can vary significantly depending on the ambient environmental conditions.[8]

Another challenge to Canada's FSCC is significant seasonal and regional weather variability. Canada's temperature can range from -40°C in winter to 40°C in summer. While failures in the FSCC can occur in both winter and summer, they occur more often in summer, despite shorter travel times.[5] Weather conditions during the winter may require alternative transportation routes, and may also put some foods at risk of cold damage if the temperature falls too low.[9]

Failures to maintain temperature during the summer are of particular concern to food safety. Recent research investigating the seasonality of foodborne illness outbreaks has shown that a number of pathogenic bacteria have a higher occurrence in summer than in winter,[10,11] and are affected by annual changes in weather conditions. In the case of *Campylobacter*, for example, the presence of the bacteria in chicken products at retail was significantly correlated with higher monthly average temperatures.[11] The detection of a foodborne pathogenic bacteria at retail (and not earlier in the FSCC) suggests that compromised temperature maintenance during the storage, transportation, or retail stages of the FSCC may be contributing to this increased risk.

Climate change impacts on the food supply cold chain

There is strong evidence that climate change will have adverse impacts on food safety and food security. However, much of this research is focussed on the direct impacts of climate change on the food supply. In contrast, there is less evidence on the effects of climate change on the safety and quality of food that has already been harvested or processed. In light of the known impacts of climate change on food production, it is necessary to optimize the safety and quality of the foods that make it to market. There is room for vast improvement in this area, as an estimated 11.2 million metric tons of food waste is avoidable and potentially edible food that could have made it to market, representing an approximate value of $50 billion dollars' worth of food.[3] There are relatively few studies that investigate this concept of optimizing food already harvested in the face of climate change, but the available research highlights the impact of climate change on existing vulnerabilities in the Canadian FSCC.

Increased temperatures

As discussed above, increased temperatures are correlated with increased failures in the FSCC.[5,9] Higher ambient temperatures make it more difficult and energy intensive to maintain cooling.[12] In climate models, Canada's average temperature is expected to increase 1.8°C to 6.3°C in the next century.[13] These changes will lead to the increased frequency, duration, and intensity of forecasted days over 30°C,[14] which may pose a greater risk to FSCCs that are not adequately prepared. However, increase in ambient temperatures will not be distributed evenly—Northern regions are expected to experience the greatest increase in temperature, far above the national average.[13] While Northern areas will experience fewer days over 30°C than other areas of Canada, they will experience temperatures that are dramatically warmer than the historical norm that local FSCCs may not be accustomed to. Northern communities are already at increased risk from failures in the FSCC, particularly due to air travel with unrefrigerated cargo holds. As such, this increased susceptibility due to dramatically warmer temperatures resulting from climate change is especially concerning.

While higher outdoor temperatures are a key factor in overall temperature maintenance throughout the FSCC, some aspects of the FSCC are particularly vulnerable. For example, pre-cooling is important to ensure that products retain their quality throughout the rest of the FSCC. During harvesting of fruits and vegetables, the product may initially be at a higher temperature than is required to maintain safety and quality.[15] Higher temperatures at this stage can lead to rapid loss of shelf life for perishable foods,[16] although the effects may not be evident until later in the FSCC. Inadequate pre-cooling has been shown to increase spoilage, reduce shelf life, and reduce the visual quality of food.[17] Pelletier et al.[18] studied the effects of ambient temperature during the harvesting and pre-cooling stage on the quality of strawberries at the retail stage. They found that delaying pre-cooling after harvest by four hours resulted in rapid decay of the strawberries, enough that the shipment would have to be discarded at the next stage of the FSCC (shipping).[18] The quality was reduced more for strawberries that had delayed pre-cooling than those that had been precooled immediately but to an inadequate temperature.[18] Additionally, the internal temperatures of strawberries on the tops of pallets after harvest exceeded the measured ambient temperatures, due to exposure to solar radiation.[18] Under increased average temperatures due to climate change, perishable foods may have higher temperatures at harvest and take longer to cool to an adequate temperature to maintain quality. It may also increase the risk that food is sent to the next stage of the FSCC with an inadequate internal temperature, which will reduce food quality down the line.

During transportation, higher temperatures have the potential to increase heat gain. As refrigerated trucks are often a closed system, while in operation, the risk of heat gain is typically lower. However, McKellar et al.[5] found that opening truck doors during deliveries to distribution centres or retail locations was a common cause of heat entry into the system, especially during summer months when there are a greater number of hot days. Other studies have noted that products placed at the back of trucks, near where doors are opened, are at greater risk of temperature abuse.[16,18] In contrast, once perishable food has arrived at a storage/distribution centre, evidence shows that adequate temperatures are largely maintained.[17]

Spotlight: Reefer trucks

A semi truck that carries a refrigerated trailer is called a "reefer truck." In Canada, most long-distance transport of perishable food is done by reefer trucks. Reefer trucks have an insulated cargo hold and have an active cooling system that blows cold air from the top of the trailer and pulls warm air down. Larger reefer trucks may have multi-compartment trailers that can be set to multiple temperatures. Most reefer trucks use hydrofluorocarbon (HFC) refrigerants; however, other technologies such as CO_2 refrigerants or cryogenic systems may be becoming more common.[19]

While a closed system, there has been significant variation detected within refrigerated trailers.[17] Pallets placed in the top centre of a refrigerated trailer benefit from the top flow of cool air from the reefer unit, while pallets placed near the edges may experience heat gain from outside ambient temperatures, solar heat gain, or warmth generated from the trucks tires.[17] Maintaining air circulation around the pallets can help improve these discrepancies.

It is important to note that reefer trucks aim to maintain the temperature of a product (whether cooled or frozen), not to cool it further. This is why adequate pre-cooling prior to transportation is essential to ensuring proper temperature throughout the entire FSCC.

Natural disasters and extreme weather

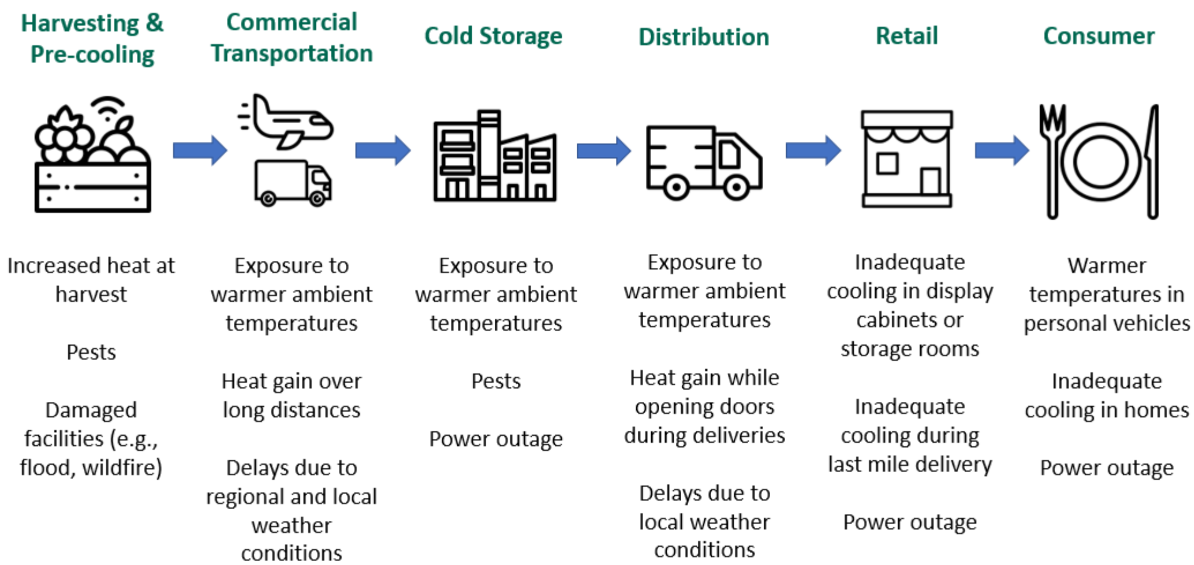
Canada, like other parts of the world, is expected to experience more numerous and severe natural disasters and extreme weather events due to climate change. Several regions have already experienced impacts to supply chains due to floods, wildfires, and extreme storms. While natural disasters and extreme weather pose similar challenges to food and other supply chains, the FSCC is particularly vulnerable due to its role in transporting perishable food.

Natural disasters and extreme weather can cause disruptions and delays to transportation routes. Around 90% of perishable food destined for Canadian consumers is transported by truck overland.[17] As these transportation routes can cover thousands of kilometres, there is a potential for regional events to affect the supply of perishable food throughout the country. In some instances, transport trucks may not be equipped to maintain temperature for the longer travel times it may take if a detour is required. Floods and wildfires may damage road infrastructure, which would require transportation routes to be altered.

Cooling is an energy-intensive process, so damage to facilities or power lines also has the potential to disrupt the FSCC. Floods and wildfires may directly damage facilities such as those used for pre-cooling or storage. Damages to power infrastructure may also affect facilities if no backup power is available, or the outage lasts beyond the backup power capacity. While less studied in Canada, the recent experiences of power outages in the United States during heat waves is also worthy of concern. With increased demand for mechanical cooling, it is possible that Canada may face similar restrictions on power usage that could affect facilities that need power to maintain the temperature of perishable food.

Temperature maintenance in retail settings and households has also been identified as a main challenge in the cold supply chain.[15] During heat waves, retail, restaurant, and domestic buildings that are not properly equipped for the increased temperature may be at higher risk of temperature abuse of perishable food. Consumer refrigerators are often set at temperatures higher than the recommended 4°C,[15,17] as consumers may lack awareness of the proper temperature or do not regularly verify their refrigerator's internal temperature. This may pose a food safety risk, especially during heat waves, as household refrigerators may not be equipped to handle higher ambient temperatures.

Figure 1: Expected impacts of climate change throughout the food supply cold chain.



Mitigation opportunities

The FSCC is an area of continual technological advancement. Optimization of the FSCC benefits companies involved in food production and retail because it can reduce costs related to food waste and energy use, and improve customer satisfaction.[20] As such, much research and development is being done that can be leveraged to help meet the challenges posed by climate change.

Improved monitoring technology is increasingly being used in FSCC applications. Temperature and climate sensors included on packaging can continually record temperatures and the amount of time spent at unsafe temperatures when they occur.[21] "Smart" packaging, using radiofrequency identification (RFID) technology, can be used to collect data with increased granularity, such as uniquely identifying each pallet or even individual food packages.[22] Packaging may also be designed to change colour if a temperature abuse occurs, to provide easy identification by workers throughout the FSCC,[22] as well as provide easy visual cues for consumers.[23]

Food monitoring data can collect a vast amount of information, such as the conditions that food is processed under, the presence of metabolites that indicate spoilage, and real-time geolocation. This type of data collection has already begun to expand throughout FSCC as the industry moves to increase traceability of food products. However, while these technologies are widely used to collect data, they are often not connected to an external source or to each other.[24] This represents a gap in efficient data utilization. There is increased research into the use of "Internet of Things" (IoT) technology in the FSCC as well as the development of "Big Data" systems that can effectively transform the vast amount of data collected into information that can assist decision-making.[24] For example, such a system could connect individual sensors to the internet to provide real-time data by email, text, or other audio and visual alerts so that temperature abuses can be identified immediately or even before they occur.[25] This type of data utilization could also be used to analyze long-term trends of FSCCs in various temperatures and transportation scenarios to identify optimizations. The effective use of data could also optimize future FSCCs, for example, by determining the ideal locations of new warehouses, distribution hubs, and storage facilities to minimize disruptions.[26] Real-time data could also be used at the consumer level to predict the expiration dates of current stock along with next shipment dates, which could assist stores in shifting out soon-to-be expired foods either through donations or by utilizing dynamic pricing of foods that are nearing their expiry date.[24]

Increased sustainability of refrigeration systems is another opportunity that has been adopted by industry involved in the FSCC. Refrigeration is an energy-intensive process. It is estimated that refrigeration accounts for 20% of global electricity consumption and 7.8% of global greenhouse gas emissions.[27] There is an increased awareness among industry of the impact of refrigeration in contributing to climate change, and a desire by many companies to reduce their environmental footprint in the name of corporate responsibility or to meet national greenhouse gas emission targets. Due to this, the industry is generally trending towards refrigerants with lower global warming potential (GWP).[19,28,29] More efficient cooling systems can also increase the capacity of the FSCC to maintain safe food temperatures during warmer ambient temperatures.[30] However, not all lower GWP refrigerants are more efficient than existing cooling technologies[31]—in which case, there is a need to engage with industry to ensure that changes in cooling technology also consider increased cooling efficiency, not just greenhouse gas emissions.

Changing cooling technologies may not be feasible for all companies or at all stages of the FSCC. However, gains in energy efficiency can also be made without changes in cooling technology. For example, one study showed how simply adding doors to display cabinets for perishable foods at retail stores significantly improved temperature maintenance.[32] It is also possible that improved insulation and heat-reflective materials can be applied throughout the FSCC, for example, in transport vehicles.[12] Significant improvements in temperature maintenance can also be achieved with improved equipment maintenance, such as cleaning compressors and ensuring seals are functioning properly.[12] Changes in procedures can also ensure that temperature maintenance is more effective, such as minimizing the number of times doors are opened,[9] or timing transport to occur at cooler times or on cooler days. Using technology to identify points of the FSCC that can be optimized in this way has the potential to result in improvements to the cold supply chain that are highly cost effective.

With respect to natural disasters and extreme weather, there is a lack of guidance on best practices for emergency planning and resilience that is specific to the FSCC. While each FSCC is unique and complex, there may be overarching practices for each stage of the FSCC that could address risks that are most likely. There may also be practices that could be adopted from emergency planning related to other risks to the supply chains that have recently been experienced, such as in 2020 during the COVID-19 response.[33] There is also a potential to incorporate technological tools, such as real-time monitoring, into emergency planning and response (for example, rerouting during a natural disaster).

Practice and knowledge gaps

In general, there is a dearth of research that specifically addresses climate change impacts and the FSCC. However, some conclusions can be drawn based on research relating to the FSCC and its known vulnerabilities in Canada. Based on this synthesis, there are both knowledge and practice gaps that must be addressed in order to fully understand and adapt to climate change impacts on the FSCC.

Knowledge gaps

It is clear from the literature that increased temperatures and increased frequency and severity of natural disasters and extreme weather will exacerbate existing vulnerabilities in FSCC. However, there is a lack of research that specifically explores the relationship between climate change and the FSCC. It is also possible that other impacts of climate change have not yet been associated with the FSCC. For example, Davis et al.[34] suggest that insect and rodent pests may become more frequent in cold storage facilities. However, no studies were found that characterized this risk for different food types; hence, further research is needed in this area.

Most studies included in this review examined a specific FSCC (i.e., for a particular product type to a particular destination). Typically, FSCCs are unique to each product and there is significant variability in the paths that each product takes throughout the FSCC. While each product is transported differently, there are consistent technologies and processes used throughout the FSCC that could be examined on a broader, more systemic level. For example, there is a need to identify specific processes and technologies at each stage of the FSCC that may be insufficient in terms of cooling capacity or resilience to natural disasters in the face of climate change. Conversely, it is not well understood which processes and technologies are sufficient to support adaptation.

A better understanding of these knowledge gaps is particularly needed for FSCCs that serve Canada’s Northern communities. The FSCC for Northern communities currently faces increased challenges due to the distance the products travel and the added complication of air transport, which often lacks refrigerated cargo capabilities. As Northern communities are expected to experience dramatic warming compared with their historical climate, these FSCCs are likely to become even more vulnerable and have increased cost pressures due to climate change.

Practice gaps

Despite the knowledge gaps, there is still opportunity to begin adapting the FSCC for the impacts of climate change. In order to do this there are several gaps that can be filled by environmental health practice in engaging with industry involved in the FSCC. There is a need to better understand industry's decision-making related to cooling processes and technologies. As discussed in this review, there may be common ground that could be useful, such as an industry desire to reduce climate impact and save costs related to energy usage. Environmental health practitioners could help raise awareness of the need to adapt FSCCs to climate change scenarios and support decision-making around cooling technologies and procedures.

There is an opportunity for environmental health practitioners to champion effective data collection and to encourage industry to adopt measurement practices for FSCC optimization. In particular, environmental health practitioners could advocate for the use of Big Data and IoT approaches to leverage data that may already be collected by companies involved in FSCCs. Improving data utilization can help to optimize FSCCs and may be particularly helpful in facing threats to FSCCs resulting from climate change. Having standardized data collection and measurement best practices could also help environmental health practitioners evaluate food safety at retail. The ability to access and interpret cold chain data for a particular food product could help environmental health practitioners identify food safety risks before products are sold to the consumer. To aid in these efforts, there is a need for knowledge synthesis to provide information and best practices for the collection, use, and interpretation of data in FSCCs to help guide environmental health practitioners in their decision-making relating to food safety and quality.

There is a need to better understand best practices for emergency planning and response for natural disasters that is specific to the FSCC. Environmental health practitioners have experience in emergency planning and response that could be applied towards determining practices that address the specific risks related to FSCC. Big Data and IoT approaches could also play a significant role in emergency planning decisions; however, at present there is a lack of guidance on how to use these technologies in emergency planning and response contexts.

Summary

The food supply cold chain is a critical concept for maintaining the safety and quality of perishable foods. Canada faces unique challenges in implementing FSCCs that can be exacerbated by climate change. In particular, increased ambient temperatures and an increased frequency and severity of natural disasters and extreme weather have the potential to impact the FSCC. This review discusses options for adapting to the impacts of climate change based on increasing energy efficiency and optimizing FSCC processes. There are also several key knowledge and practice gaps that are necessary to address in order to further mitigate the effects of climate change. While further research on this issue is needed, environmental health practitioners can play a key role in effective data collection advocating for improved data utilization in the food supply industry to mitigate future climate change effects to the FSCC.

Acknowledgements

The author would like to thank Michele Wiens (NCCEH) for literature search and referencing support, and Dr. Sarah Henderson (NCCEH) for their review of this document. The author would also like to acknowledge the helpful commentary provided by external reviewers during the development of this document: Dr. Sébastien Villeneuve (Agriculture and Agri-Food Canada) and Lorraine McIntyre (BC Centre for Disease Control).

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How to cite this document

ISBN: 978-1-988234-75-5

This document can be cited as: James K. Climate change impacts on Canada's food supply cold chain. National Collaborating Centre for Environmental Health (NCCEH). Vancouver, BC: NCCEH. 2023 Feb.

 Production of this document has been made possible through a financial contribution from the Public Health Agency of Canada to the National Collaborating Centre for Environmental Health.

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