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Identifying the impact of climate variables on biological and chemical contaminants of preharvest foods and their associated food safety risks: a scoping review protocol

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ABSTRACT

Background Foodborne and waterborne illnesses affect over four million Canadians annually and pose a preventable burden on the nation's healthcare system. Climate change can increase the risk of such illnesses by increasing the likelihood of exposure to contaminants. As climate change progresses, it is imperative to better understand its impact on the dissemination of foodborne and waterborne contaminants throughout the food system. Currently, there is limited, synthesised evidence for how future changes in Canada's climate may affect the risk of contamination of preharvest foods. The aim of this research is to collate and describe available information on effects of climate variables on biological and chemical contamination of preharvest foods in Canada. This information will contribute to improved understanding of climate change impacts and potential adaptation and mitigation strategies to increase climate resiliency in Canada's food system.

Methods A preliminary search of MEDLINE, Web of Science and Google was conducted to verify the absence of existing reviews and to inform the development of this review protocol. Information will be identified by searching four academic databases: MEDLINE via Ovid, AGRICultural OnLine Access (AGRICOLA), CAB International and Web of Science. This search will be supplemented by a targeted grey literature search. The search strategy includes index terms and keywords for Canada-relevant foodborne and waterborne pathogens and chemical contaminants, preharvest foods and climate change. Search results will be managed using Covidence during all phases of the review, conducted by two independent reviewers. Data will be extracted, synthesised and presented using graphical and tabular formats.

This scoping review protocol describes the process for retrieving a comprehensive set of evidence for how climate change variables may increase risk of biological or chemical contamination of preharvest foods in Canada. This review will provide decision-makers with a detailed understanding of climate variable-preharvest food-contaminant combinations using the best available evidence.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This will be the first scoping review to identify climate-sensitive foodborne and waterborne contaminants that affect Canada's preharvest food sector.
⇒ The search strategy will identify peer-reviewed literature, including case reports and conference proceedings as well as grey literature sources, including government and other organisation websites.
⇒ This review is limited to projected climate variables based on our current knowledge of climate change.

Ethics and dissemination Ethical considerations are not applicable to this protocol as scoping reviews conduct secondary data analysis that synthesises data from publicly available sources. The results from this review will be disseminated through a peer-reviewed publication and conference presentation.

BACKGROUND

Foodborne and waterborne illnesses pose a large but preventable burden on the health of Canadians. Annually, there are an estimated 4 000 000 episodes of foodborne illness in Canada, resulting in over 11 500 hospitalisations and 200 deaths.[1] Foodborne and waterborne illnesses are caused by exposure to pathogens, biological toxins or chemicals via consumption of contaminated food or water or contact with animals.[2] Most episodes of illness are self-limiting; however, certain individuals may experience more severe symptoms, resulting in hospitalisation, or rarely, death.

Climate change is an increasingly important determinant of human health that can act through direct and indirect mechanisms.[3] Growth, survival, abundance and range of foodborne and waterborne

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pathogens are intrinsically connected to changing climate variables including precipitation intensity and frequency, water temperature, air temperature and extreme weather events.[4] Thus, climate change represents a significant threat to national and provincial agri-food systems in Canada. The agri-food system in Canada consists of four major levels in which biological and chemical contaminants can be introduced: production, processing, distribution and consumption.[5] At the production level, preharvest food safety in a changing climate is especially important to understand as these commodities do not undergo extensive decontamination processes until further along the agri-food chain.[6] Thus, contamination of preharvest foods can pose a greater hazard to consumers compared with any other level, only to be further exacerbated by climate change. For example, elevated precipitation intensity can increase surface runoff of pesticides, fertilisers and manure, readily transporting pathogens and chemicals contaminating food and water sources.[3] Increased temperatures can introduce and establish pathogens in new production regions as well as stress livestock, increasing shedding of enteric pathogens and contamination of crops and the environment.[3] Ultimately, it is projected that climate change will increase the introduction of biological and chemical contaminants to food products, exacerbating food safety challenges and increasing incidence of foodborne and waterborne illnesses. In addition to these factors, there is limited data available detailing expected impacts of shifting climate variables on the range of distribution of biological and chemical contaminants in Canada's food system and how this will influence illness incidence. Therefore, it is necessary to investigate how different climate variables will alter food safety along the farm-to-fork continuum to better equip the agri-food system, healthcare system and decision-makers.

To our knowledge, there has not been a comprehensive synthesis of evidence for potential changes in the distribution and range of biological and chemical contaminants in Canada's agri-food system because of a changing climate. A preliminary search of MEDLINE, the Cochrane Database of Systematic Reviews and *JBI Evidence Synthesis* was conducted and no current or underway scoping reviews on the topic were identified. Therefore, the objective of this scoping review is to document the extent of the literature on the impact of climate change on the dissemination of biological and chemical contaminants in Canada's agri-food system, specifically focusing on preharvest foods as well as identify gaps in knowledge.

Review question

What are the effects of climate variables on biological and chemical contamination of preharvest foods in Canada?

Objectives

1. Identify if and how relevant climate variables influence the introduction of biological and chemical contaminants to preharvest foods in Canada.
2. Describe how projected climate-related food safety challenges at the preharvest level can impact the risk of foodborne and waterborne illnesses among Canadians.

METHODS

This protocol was designed in accordance with the Joanna Briggs Institute (JBI) methodology for scoping reviews and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews (PRISMA-ScR) guidelines.[7] This protocol is presented in accordance with the PRISMA-P checklist.[7]

This scoping review protocol is registered on Open Science Framework: https://osf.io/t45pd. It describes an ongoing study that started in April 2023 with a planned end date of December 2024.

Population, concept, context summary

Population

The proposed scoping review will include studies investigating climate-sensitive biological and chemical contaminants of preharvest foods that are projected to increase risk of foodborne and waterborne illnesses in the Canadian population.

Concept

The key concepts are foodborne pathogens, waterborne pathogens, chemical contaminants, preharvest foods and climate change. Preharvest foods were selected based on the 2016 Census statistical summary of Ontario agriculture and include both commodities and crops.[8]

Significant terms are defined as follows:

Foodborne contaminants: bacteria, viruses, parasites and toxins present in food that cause foodborne illness in humans via consumption of contaminated food.[9]

Waterborne contaminants: bacteria, viruses, parasites, single-celled eukaryotes and toxins present in water that cause waterborne illness in humans via consumption of contaminated water.[10]

Climate change: a long-term shift in average weather conditions in regions such as expected temperatures, precipitation patterns, wind patterns and extreme conditions.[11]

Preharvest food: a food commodity produced in a farm setting prior to crop or livestock products being sold.

Context

Published academic and grey literature, theses, conference proceedings, abstracts, case reports, and government documents published between 2003 and 2023, representing a 20-year publication window, will be included.

Patient and public involvement

None.

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Table 1 List of biological and chemical contaminants included in this scoping review

Biological or chemical contaminant	
Adenovirus	Lyngbya
Aflatoxin	Marine toxin
Aeromonas	Microcystis
Algal toxins	Mycotoxin
Amygdalin	Naegleria fowleri
Anabaena	Norovirus
Aphanizomenon	Okadaic acid
Astrovirus	Phormidium
Bacillus cereus	Planktothrix
Brevetoxin	Pseudomonas aeruginosa
Brucella	Rotavirus
Campylobacter	Salmonella
Ciguatoxin	Sapovirus
Clostridium botulinum	Saxitoxin
Cryptosporidium	Schistosoma
Cyanobacteria	Scombrotoxin
Cyclospora	Shigella
Cylindrospermopsin	Spirulina
Domoic acid	Staphylococcus aureus
Entamoeba histolytica	Tetrodotoxin
Escherichia coli	Toxoplasma
Giardiasis	Trichinella
Glycoalkaloid	Vibrio
Helicobacter pylori	Yersinia
Hepatitis A	
Hepatitis E	
Lectins	
Legionella	
Listeria	

Design

Inclusion and exclusion criteria

The inclusion criteria for the scoping review are:

- Observational or experimental research conducted in Canada-relevant climates that examines or evaluates an association between one or more climate variables and biological or chemical contamination of a preharvest food or water source.
- Climate variables include, but are not limited to, temperature, precipitation, drought, humidity and extreme weather conditions.
- Biological and chemical contaminants are limited to those relevant to Canada as identified by subject matter experts in the Public Health Agency of Canada and Health Canada (table 1).
- Preharvest foods are limited to those relevant to Ontario, Canada (table 2).

The exclusion criteria for the scoping review are:

- Articles written in a language other than English or French.
- Articles without full-text availability.
- Duplicates of articles.

Information sources

The proposed scoping review will consider published academic and grey primary research, abstracts, theses, case reports, conference proceedings and government reports. Specifically, we will search four academic databases: MEDLINE via Ovid, AGRICultural OnLine Access (AGRICOLA), CAB International and Web of Science. Grey literature will be identified by searching websites of Health Canada, the Ontario Ministry of Agriculture, Food and Rural Affairs, the Canadian Food Inspection Agency, the Food and Drug Administration and Environment and Climate Change Canada as well as ProQuest Dissertations & Theses and Google. The primary research study designs considered for inclusion will be descriptive and analytical observational studies, including prospective and retrospective cohort studies, case–control studies, cross-sectional studies, case series and individual case reports. In addition, modelling, experimental studies

Table 2 List of preharvest foods included in this scoping review

Preharvest food category	Commodity
Grain crops	Hay Soybean Grain corn Winter wheat Silage corn Barley Spring wheat Mixed grain Dry field bean Oat Fall rye Canola
Livestock and poultry	Dairy cattle Beef cattle Pork Pig Sheep Lamb Poultry Broiler Roaster Laying hen Pullet Turkeys
Fruit crops	Grape Apple Peach Strawberry Sour cherry Pear Raspberry Plum Sweet cherry
Vegetable crops	Sweet corn Potato Green pea Tomato Green bean Wax bean Carrot Pumpkin Squash Onion Cucumber Pepper Broccoli Cabbage Asparagus
Other	Irrigation water

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and risk assessment types of studies will be included. Grey literature will include government reports, conference proceedings, theses and abstracts.

Search strategy

The following search strategy will be implemented to retrieve published academic and grey literature from databases. A preliminary limited search of MEDLINE via PubMed, Web of Science and Google was executed to identify articles related to foodborne and waterborne biological and chemical contaminants, climate change, preharvest foods and combinations of these concepts. Various iterations of terms included: 'foodborne', food-borne', food borne', 'waterborne', 'water-borne' and 'water borne', separated by the 'OR' operator to ensure an inclusive retrieval of available literature. Using relevant retrieved articles, a comprehensive search strategy of index terms and keywords for MEDLINE via Ovid was generated and then refined through consultation with subject matter experts in agri-food and public health as well as reviewing select Government of Canada webpages (online supplemental tables 1–3). The search strategy will be adapted for each database and information source included in this scoping review.

Study/source of evidence selection

Search results will be collected and uploaded into Covidence, an online platform used for the reference screening process, full-text review and data extraction.[12] Duplicate articles will be removed.

Screening process

Citations will undergo two levels of screening. Citation titles and abstracts will first be screened against the eligibility criteria (level 1). The full text of relevant citations from level 1 will then be screened against the same criteria (level 2). Data from citations that pass level 1 and level 2 will then be independently extracted by two reviewers using an *a priori* data extraction form.

Defining agreement between reviewers

To determine the level of agreement between the two independent reviewers, we will use Cohen's kappa coefficient statistic (k). A k-value of 0.7 or higher will be considered as agreement between the reviewers. If the minimum level of agreement is not met at either level 1 or level 2, the independent reviewers will review and clarify eligibility criteria and its application. The full search process will be documented as a flowchart in accordance with the JBI methodology for scoping reviews and PRISMA-ScR guidelines.[7 13]

Level 1 screening (titles and abstracts)

A pilot test will be conducted by two independent reviewers prior to initiation of the level 1 screening process to ensure that eligibility criteria are clear. The two independent reviewers will screen the titles and abstracts of the first 50 articles, organised alphabetically in Covidence. The level of agreement will then be assessed. If sufficient agreement is attained (k ≥0.7), the reviewers will continue to screen all titles and abstracts. Citations meeting the eligibility criteria will progress to level 2. Disagreements will be resolved by discussion to reach consensus.

Level 2 screening (full text)

After completion of level 1 screening, the two reviewers will conduct a pilot test for level 2 screening. The reviewers will screen a set of 20 articles, assess inter-reviewer agreement and continue screening if sufficient agreement is attained (k ≥0.7). Disagreements will be resolved by discussion to reach consensus. At both level 1 and level 2, any remaining disagreements between the reviewers will be resolved by discussion with the principal investigator (LEG).

Data extraction and analysis

Data extraction will be conducted by two independent reviewers using a data extraction form (online supplemental table 4). The data extracted will include publication details such as title, authors, publication year, location of the study. In addition, details about the study findings will be documented such as the climate variables, preharvest foods, biological and/or chemical contaminants and any key findings relevant to the review questions.

A draft extraction tool will be modified and revised as necessary during the process of extracting data from each included source. Changes to the data extraction tool will be described in the scoping review. The data extraction form will be piloted by two independent reviewers using five of the included articles. Extracted data will be reviewed to ensure completeness and agreement. Data extraction of the remaining articles will then proceed. If appropriate, authors of papers will be contacted to request missing or additional data, where required. Disagreements will be resolved through discussion between the reviewers or with the principal investigator, if needed.

A flowchart will be used to map the screening process.[13] Results of individual citations will be reported in tabular format and then synthesised by climate variable and food-contaminant pair.

DISCUSSION

Food safety risks associated with climate change in Canada are not fully understood; however, risk of foodborne and waterborne illnesses is expected to increase and will have an estimated national impact of $30–62 billion by 2050.[1] To support the extensive and comprehensive identification and synthesis of information pertaining to the impact of climate change on foodborne and waterborne contaminants on preharvest foods in Canada's food system, this scoping review protocol describes our methodology to collect information on 53 biological and chemical contaminants, collectively. Subsequently, a scoping review will be written to convey findings and provide insight and understanding of contaminant transmission patterns

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under future climate variables in preharvest foods, filling some of the existing knowledge gaps.

An additional aim of this proposed scoping review is to inform possible future mitigation strategies to promote climate resilience in Canada's food system, minimising associated food safety risks to Canadians. Furthermore, the identified relationships between climate variables and contamination of preharvest foods can be incorporated into forecasting models to support our understanding of anticipated future impacts as well as explore the effects of mitigation strategies.

Publishing an *a priori* protocol supports transparency in the review process and helps to limit reporting bias. The methodologies discussed in this scoping review protocol use the widely accepted JBI approaches to map evidence and gaps in current research.[7] Testing of the outlined inclusion and exclusion criteria with two independent researchers will limit potential forms of bias related to study inclusion and random error.[14] Publication bias will be reduced by including both peer-reviewed and grey literature during our comprehensive assessment of available research and by contacting authors for full-text information that is not publicly available.[15]

This scoping review is limited to projected climate variables based on our current knowledge, meaning our research conclusions are subjected to modification with potential adaptations to these projections as more climate data become available over time. The search terms of this protocol include contaminants most relevant to Canada; however, we did not include all possible contaminants associated with foodborne and waterborne illnesses transmitted through preharvest foods that may be relevant in other contexts.

Long-term, anthropogenic shifts in climate variables require further understanding of their diverse impacts to inform evidence-based action. Raising awareness through research and effective knowledge mobilisation to stakeholders and decision-makers in Canada's agri-food system is needed to foster climate resiliency and safe food for Canadians.

Dissemination and ethics

This study will contribute to the identification of climate-sensitive foodborne and waterborne contaminants of preharvest foods in Canada. The results from this scoping review will guide future prioritisation of climate-sensitive preharvest food safety risks and inform subsequent mitigation and adaptation strategies.

The methodology of a scoping review involves the review and synthesis of data from publicly available sources, therefore ethics approval is not required.

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Contributors BZ, SM, GH and LEG contributed to the conceptualisation and design of the scoping review protocol. BZ wrote the manuscript with guidance from, VN, AP, IY and LEG, who contributed to the editing of the manuscript. The authors have read and approved the final manuscript. LEG is the guarantor.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

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Table 1: Search terms for major concepts and specific biological and chemical contaminants.

Concept/contaminant	**MeSH terms**	**Keywords and alternative names**
Foodborne disease	Exp foodborne diseases Gastroenteritis Food Safety	Foodborne disease? Foodborne illness* Foodborne infection? Food-borne disease? Food-borne illness* Food-borne infection? Food borne disease? Food borne illness* Food borne infection? Food safety Food poison* Gastroenteritis
Waterborne disease	Waterborne diseases	Waterborne disease? Waterborne illness* Waterborne infection? Water-borne disease? Water-borne illness* Water-borne infection? Water borne disease? Water borne illness* Water borne infection?
Contaminants	Food contamination Food quality Food safety	Food contaminant? Food contamination Food quality Contaminated food Food safety
Bacillus cereus	Bacillus cereus	Bacillus cereus
Brucella	Exp brucella Brucellosis	Brucella Brucellosis Cyprus fever Gibraltar fever Malta fever Rock fever Undulant fever
Campylobacter	Exp campylobacter Campylobacter infections	Campylobacteriosis Campylobacter*
Clostridium botulinum	Exp clostridium botulinum Clostridium perfringens Clostridium infections Botulism	Clostridium botulinum Botulism Clostridium perfringens Clostridium welchii Clostridial AND food*
Escherichia coli	Escherichia coli Enteropathogenic escherichia coli Enterotoxigenic escherichia coli	Escherichia coli Vtec Ehec Etec

	Exp shiga-toxigenic escherichia coli Enterobacteriaceae infections Dysentery, bacillary Escherichia coli infections Shiga toxin Escherichia coli O157 Enterohemorrhagic escherichia coli	Stec Shiga toxin*
Helicobacter pylori	Helicobacter infections Helicobacter pylori	Helicobacter pylori Campylobacter pylori* Helicobacter nemestrinae
Listeria	Exp listeria Listeriosis	Listeria Listeriosis
Salmonella	Exp salmonella Exp salmonella infections	Salmonella Salmonellosis Paratyphoid fever Typhoid Typhus Enteric fever Enteritidis Infantis Typhimurium Concord
Shigella	Exp shigella Dysentery, bacillary	Shigella Shigellosis Bacillary dysentery Shigella adj10 dysentery
Staphylococcus aureus	Exp staphylococcus aureus Staphylococcal infections Staphylococcal food poisoning	Staphylococcus aureus Staphylococcal AND food* Staph AND food*
Vibrio	Exp vibrio Exp vibrio infections Cholera	Vibrio Vibriosis Cholera Parahaemolyticus Vulnificus
Yersinia	Yersinia Yersinia enterocolitica Yersinia pseudotuberculosis Yersinia infections Yersinia pseudotuberculosis infections	Yersinia Yersiniosis
Aeromonas	Exp aeromonas	Aeromonas
Entamoeba histolytica	Entamoeba histolytica Amebiasis Dysentery, amebic Entamoebiasis	Entamoeba histolytica Amebiasis Amoebiasis

		Amebic adj10 (dysentery OR colitis) Amoebic adj10 (dysentery OR colitis) Entamoebiasis
Cryptosporidium	Exp cryptosporidium Cryptosporidiosis	Cryptosporidium Cryptosporidiosis
Cyclospora	Cyclospora Cyclosporiasis	Cyclospora Cyclosporiasis
Giardiasis	Exp giardia Giardiasis	Giardia Giardiasis Lambliasis
Legionella	Exp legionella Exp legionellosis	Legionella Legionellosis Legionnaire$ disease Pontiac fever
Toxoplasma	Toxoplasma Toxoplasmosis	Toxoplasmosis Toxoplasma
Trichinella	Exp trichinella Trichinellosis	Trichinella Trichinellosis Trichinelliasis Trichinosis
Adenovirus	Adenoviruses, human	Adenovirus
Astrovirus	Mamastrovirus Astroviridae infections	Astrovirus
Hepatitis A	Hepatitis A Exp hepatitis A virus	Hepatitis A
Hepatitis E	Hepatitis E Hepatitis E virus	Hepatitis E
Norovirus	Exp norovirus	Norovirus Norwalk virus
Rotavirus	Rotavirus Rotavirus infections	Rotavirus
Sapovirus	Sapovirus	Sapovirus Sapporo virus
Pseudomonas aeruginosa	Pseudomonas aeruginosa Pseudomonas infections	Pseudomonas aeruginosa Pseudomonas
Naegleria fowleri	Naegleria fowleri	Amebic meningoencephalitis Amoebic meningoencephalitis Naegleria fowleri
Schistosoma	Schistosoma Exp schistosomiasis	Schistosoma Schistosomiasis Bilharziasis Katayama fever Swimmer's itch Cercarial dermatitis

Cyanobacteria	Cyanobacteria Exp cyanobacteria toxins Anatoxin A	Cyanobacteria Cyanotoxin? Anatoxin-a
Aphanizomenon	Aphanizomenon	Aphanizomenon B-methylamino-l-alanine Bmaa
Cylindrospermopsin?	Cylindrospermopsis Cylindrospermopsin	Cylindrospermopsin? Cylindrospermopsine? Cylindrospermopsis 7-epi-cylindrospermopsin?
Lyngbya	Lyngbya Lyngbya toxins	Lyngbya Lyngbya toxin? Lyngbyatoxin? Plectonema
Microcystis	Microcystis Microcystins	Microcystis Microcystin?
Planktothrix	Planktothrix Oscillatoria	Planktothrix Oscillatoria
Phormidium	Phormidium	Phormidium
Anabaena		Anabaena Dolichospermum
Spirulina	Spirulina	Spirulina
Amygdalin	Amygdalin	Amygdalin Vitamin B17 Neoamygdalin Amygdaloside
Lectins	Plant lectins Phytohemagglutinins Wheat germ agglutinins	Lectins Haemagglutinin? Phytohemagglutinin? ((Kidney bean) adj3 (lectin?)) ((Wheat germ) adj3 (agglutinin? Or lectin?))
Mycotoxin	Exp mycotoxins Mycotoxicosis	Mycotoxin? (Fungal adj8 toxin?) Mycotoxicosis (Mushroom adj8 poison*)
Aflatoxin	Exp aflatoxins	Aflatoxin? Aflatoxicosis
Glycoalkaloid		Glycoalkaloid? Pyrrolizidine alkaloid?
Marine toxin	Marine toxins	Marine toxin? Marine biotoxin? Aquatic biotoxin? Aquatic toxin?
Ciguatoxin	Ciguatera poisoning Ciguatoxins	Ciguatoxin? Ciguatera fish poisoning Ciguatera

Saxitoxin	Shellfish poisoning Saxitoxin	Saxitoxin? Paralytic shellfish poison* Psp Shellfish poisoning
Okadaic acid	Okadaic acid	Okadaic acid? Dsp Ocadaic acid? Diarrhetic shellfish poison*
Domoic acid	Domoic acid	Domoic acid? Amnesiac shellfish poison* Asp
Brevetoxin	--	Brevetoxin? Neurotoxic shellfish poison*
Tetrodotoxin	Tetrodotoxin	Tetrodotoxin? Fugu toxin? Tarichatoxin? Tetradotoxin?
Algal toxins	Harmful algal bloom	Algal toxin? Algal bloom?
Scombrotoxin	Saurine	Scombrotoxin? Scombroid poison* Saurine

Table 2: Search terms for climate variables.

Concept	**MeSH terms**	**Keywords and alternative names**
Climate change	Climate change Greenhouse effect Greenhouse gases	Carbon emission? Climate change Climatic change Climate disaster Climate variability Climatic variability Environmental change Global warming Greenhouse effect Greenhouse gas* Planetary health Global environmental change?
Meteorological/climate factors	--	Atmospheric pressure Cold Cool* Extreme weather* Heat Humid* Ice Precipitation Rain*

		Season* Snow* Storm Temperature? Warm* Wind Ultraviolet radiation UV

Table 3: Search terms for preharvest foods.

Concept	**MeSH terms**	**Keywords and alternative names**
Grain crops		Hay Soybean? Grain corn Winter wheat Silage corn Barley Spring wheat Mixed grain? Dry field bean? Oat? Fall rye Canola
Livestock and poultry		Dairy cow? Dairy cattle Beef cow? Beef cattle Steer? Heifer? Calf* Pork Pig* Sheep Lamb? Poultry Broiler* Roaster* Laying hen? Pullet* Turkeys
Fruit crops		Grape? Apple? Peach* Strawberr* Sour cherr* Pear?

		Raspberr* Plum? Sweet cherr*
Vegetable crops		Sweet corn Potato* Green pea? Tomato* Green bean? Wax bean? Carrot? Pumpkin Squash Onion? Cucumber? Pepper? Broccoli Cabbage? Asparagus
Other		Irrigation water

Table 4: Data extraction form.

Publication information	Last Name of first author
	Year
	Title
Research location	Country
	Province/territory/state (if applicable)
Research information	Research objective(s)/question(s) of the study
	Study design
	Quantitative data collection (Y/N)
	Qualitative data collection (Y/N)
	Experimental data collection (Y/N)
Meteorological/climate variables	Temperature
	Precipitation
	UV Radiation
	Extreme heat events
	Extreme cold events
	Air quality
	Drought
	Flooding
	Wildfires
	Hurricanes
	Wildlife changes
	Freshwater conditions
	Ocean conditions

	Ice extent/stability/duration
	Coastal erosion
	Permafrost changes
	Other (describe)
Contaminant variables	Name of contaminant
	Is contaminant biological or chemical?
	If foodborne, what preharvest food(s)?
	Associated foodborne or waterborne illness(es)/ health outcomes
Methods and results	Data collection methods
	Data analysis methods
	Did the discussed climate variable(s) influence a contaminant + preharvest food association? (Y/N)
	Indicate the measure of association/ significance applied
	Indicate the direction of the measure of association/ significance
	Indicate the magnitude of the measure of association/significance
	Was a future projection modelled? (Y/N)
	If yes, describe the projected impacts.