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Flooding adversely affects fresh produce safety

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ABSTRACT

Flooding is the most recurring and common natural disaster affecting society, food security and the environment. Floodwater is known to be a carrier of biological, chemical and physical hazards affecting food safety during primary production and processing of fresh horticultural produce. Runoff from livestock, industrial, residential and sewage treatment areas into waterways and their overflow can contaminate agricultural water sources, production fields and post-harvest processing facilities. A transient increase in the population of faecal indicators such as *Escherichia coli* and the detection of environmental pathogens such as *Listeria monocytogenes* and *Salmonella* in produce, water, soil and processing facility are the short-term and most notable impacts of flooding, leading to a significant amount of food losses due to microbial contamination and potentially a rise in the foodborne illnesses among produce consumers. However, the long-term impacts of recurring flooding are far more severe and damaging due to the survival and persistence of microbial pathogens in soils, water sources and processing environments. This article focuses on how flooding can exacerbate the microbial food safety risks in the primary production and processing of fresh produce and briefly describes the management strategies.

Keywords: floodwater, foodborne pathogens, food safety, fresh produce, irrigation, natural disaster, post-harvest processing, soil and water contamination.

Flooding events have been a recurring natural disaster in Australia, causing significant economic damage to infrastructure, communities and the environment. With a reduction in average annual rainfall, the intensity and frequency of heavy rainfall in Australia is predicted to increase, leading to extreme weather events such as floods, cyclones, drought and temperature extremes.[1] In 2022, 47 flooding events were declared natural disasters as per the Australian disaster database (Australian Government Department of Home Affairs, see https://www.disasterassist.gov.au/find-a-disaster/australian-disasters, accessed 19 August 2023). The total costs of natural disasters in Australia in 2017 were estimated to be A$18 billion per year and forecasted to rise to $39 billion per year by 2050.[2] Flooding has been the most damaging natural disaster costing on an average $8.8 billion per year, which is approximately half the total costs of all natural disasters such as cyclone, hail, storm and bushfires. In addition to direct economic losses, flooding events can have significant effects on the food security and the occurrence and spread of foodborne diseases in the communities, whose economic impacts are currently unknown.

Extreme weather events such as flooding have been linked with foodborne and waterborne gastrointestinal illness outbreaks.[3] Fresh horticultural produce, generally grown in open fields, is more prone to extreme weather events, natural disasters and associated food safety risks. In Australia, dust storms were associated with *Listeria monocytogenes* outbreak caused by rockmelons in 2018. Similarly, flooding or runoff was speculated to be responsible for introducing toxic weed (*Datura stramonium*) seeds into spinach production field, leading to a large-scale intoxication outbreak in December 2022 caused by the contamination of bagged spinach leaves with weed leaves.[4] The increase in foodborne illness outbreaks related to fresh produce is a global concern with frequent implications of microbial contaminants such as Shiga-toxin *Escherichia coli* (STEC), *Salmonella* species and *L. monocytogenes* in these outbreaks. Natural disasters such as flooding can aggravate the distribution and transmission of microbial contaminants in agricultural production and processing systems.

Flooding events and associated hazards

Flooding can be broadly categorised into two types. The first type is linked to heavy rainfall leading to water accumulation in production fields and can affect microbial contamination of fresh produce through overland flows and splash transfer of pathogens from the soil onto the crops during rainfall.[5] In Finland, a *Cryptosporidium parvum* outbreak in 2012 was speculated to be caused by contaminated water splash from heavy rains onto frisee salad in the fields.[6] An increase in the detection of foodborne bacterial pathogens on fresh produce has been observed after heavy rainfall events in Australia (S. P. Singh, unpubl. data).

The second type of flooding, which is experienced as a natural disaster, is severe and involves large runoff and overflow from surface waters such as rivers, creeks, lakes and dams and enters into production fields and post-harvest processing facilities.[7] Floodwater can carry physical (e.g. wood, metal and glass), chemical (e.g. chemical residues, heavy metals, toxins, petroleum products) and biological (e.g. bacteria, viruses and parasites) hazards and transfer them into water sources, production fields and processing facilities (Fig. 1). The risks of contamination associated with flooding are significant when these operations are adjacent to livestock, industrial and residential areas. Floodwater mobilises pathogens from the environment such as sewage or septic overflow, runoff from livestock operations and compost yards, and industrial areas.

Flooding-induced microbial contamination during primary production and processing of fresh produce

The contamination of water sources poses a serious threat to the introduction and transmission of foodborne illness causing pathogens.[8] Agricultural water has been implicated in several foodborne illness outbreaks related to fresh produce, including *E. coli* O157:H7 outbreaks linked to romaine lettuce,[9] enterohemorrhagic *E. coli* in salad[10] and *Salmonella* Newport in tomatoes.[11] Floodwater carrying foodborne bacterial and viral pathogens and parasites can introduce these contaminants in water sources, growing crops, soils and processing facilities. The contamination of water sources, both surface and underground, can have short-term and long-term impacts on the pathogen transmission and persistence in the agricultural production and processing environments.[7]

Studies have shown that high faecal indicator pathogen loads are often detected in floodwater[12] and can contaminate agricultural water used for irrigation, foliar sprays and post-harvest operations.[8] Under normal circumstances, microbial quality of surface water varies considerably according to the season and location. For example, the *E. coli* population in the Australian Murray River water

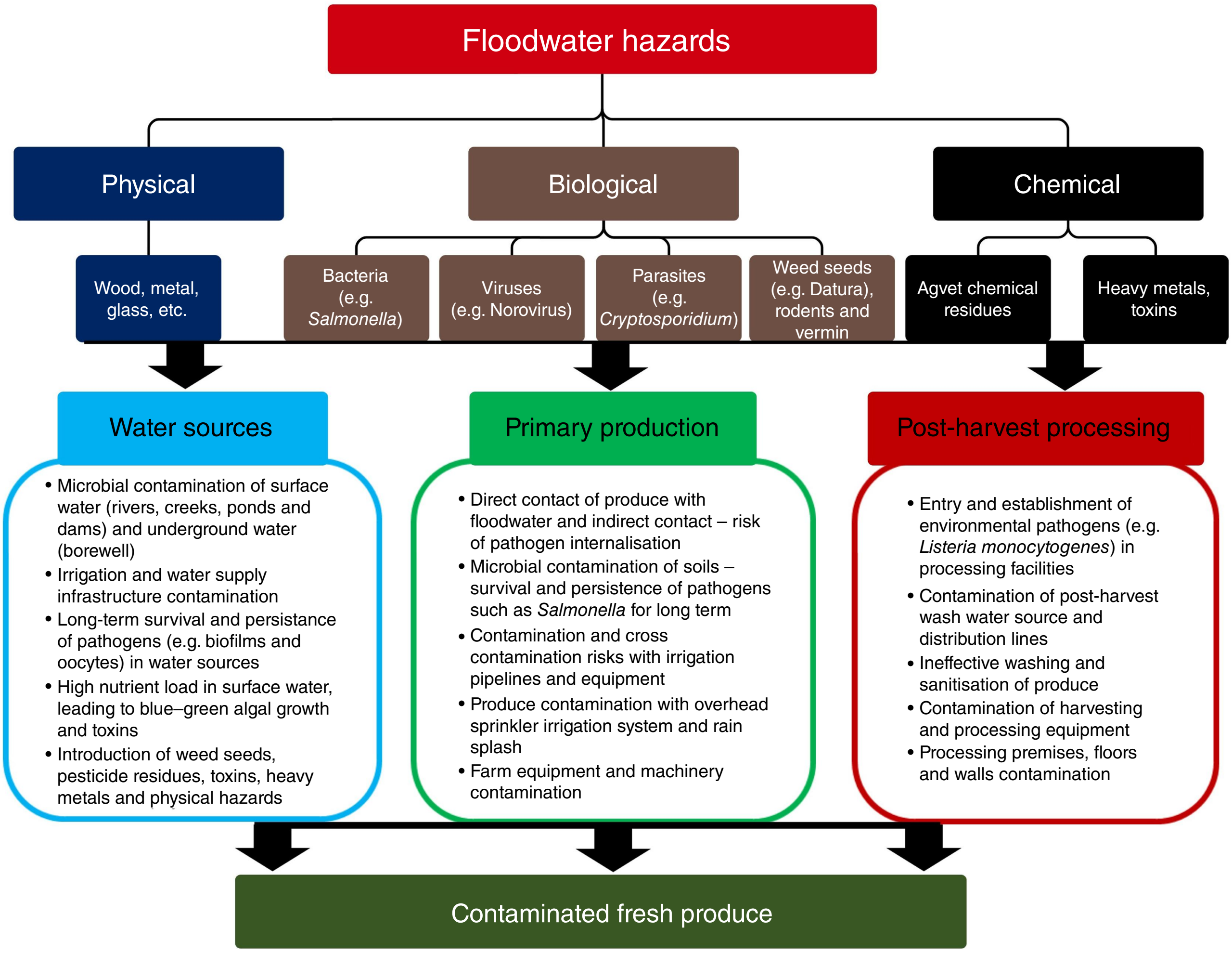

Fig. 1. Floodwater as a source and route of microbial contamination in fresh horticultural produce adjacent to livestock, industrial and residential areas.

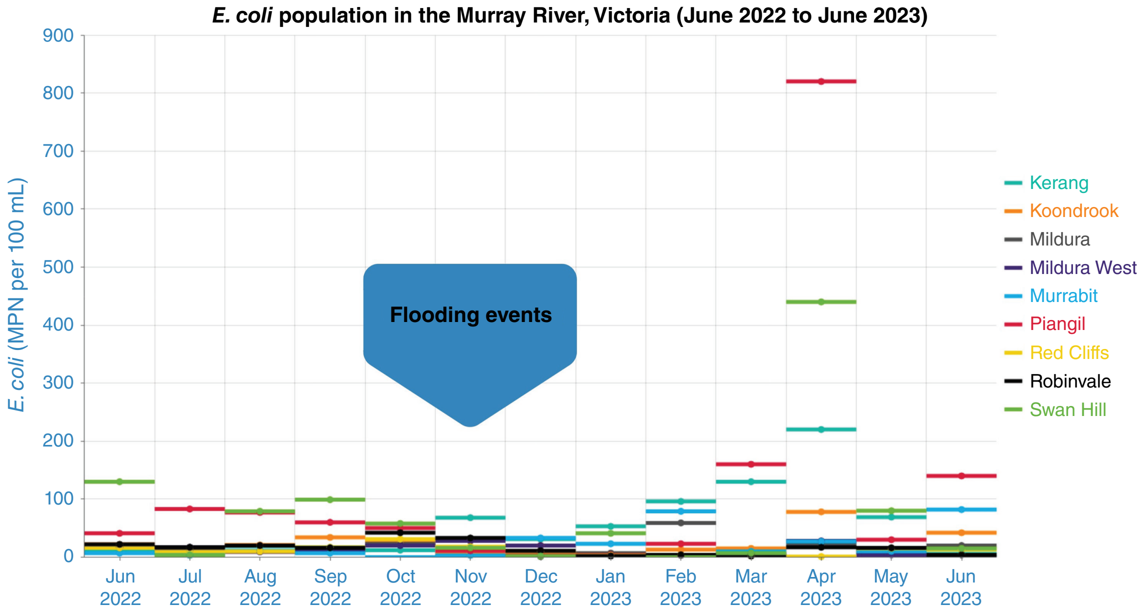

Fig. 2. *Escherichia coli* population in the Murray River water samples collected from multiple locations between June 2022 and June 2023 (Data source: Lower Murray Water, Victoria, Australia, see https://www.lmw.vic.gov.au/water-supply-and-services/water-quality-and-treatment/e-coli-river-water-reports/). The flooding events occurred between October and December 2022. MPN, most probable number.

samples collected from multiple locations in the Lower Murray region varied considerably between June 2022 and June 2023 (Fig. 2). The flooding in the region between October 2022 and January 2023 inconsistently increased the *E. coli* population at several locations. The highest *E. coli* population was recorded during April 2023 from Piangil, Kerang and Swan Hill locations, coinciding with the receding of floodwater (Fig. 2).

Microbial pathogens capable of forming biofilms and oocytes can persist in agricultural waters for weeks, increasing likelihood of their transmission.[13] Further to it, the contamination of agricultural water distribution systems (e.g. pumps, pipelines and sprinklers) can become a source of cross-contamination when water is used for irrigation, foliar application and post-harvest processing. The survival and persistence of these pathogens could be affected by several environmental factors such as solar radiation, organic load, as die off rates of these pathogens are highly variable and influenced by plethora of factors. In addition to microbial risks, high nutrient load in surface water sources (e.g. rivers, lakes and ponds) can also lead to the growth and multiplication of blue-green algae and thus production of associated toxins, making the water unfit for agricultural purposes.[14] These toxins can be absorbed or translocated in the plant system, rendering the fresh produce unsafe for human consumption. Therefore, the impact of flooding on microbial quality of agricultural water can have direct and indirect impacts ranging from short- to long-term.

Floodwater has strong potential to introduce bacterial and viral pathogens and parasites in production field soils. The persistence and survival of these pathogens varies considerably depending upon factors such as such as temperature, rainfall, solar radiation, soil pH, soil type, moisture, agronomic practices, nutrient availability, as well as soil biological interactions.[15] For example, abundance of the *Salmonella Typhimurium* in soils was reduced to the detection limit between 40 and 180 days, most of the *Salmonella* did not survive in soil for more than 90 days. Flooding and soil texture (content of sand) promote the decline rate of *Salmonella* in soils.[15] Similarly, foodborne viral pathogens get readily adsorbed on to fine-textured soils compared to coarse-textured soils. Sandy soils are relatively poor adsorbents of enteric viruses, whereas soils with clay content of 30–100% are excellent adsorbents.[16] The broader understanding and knowledge of die off rates of various microbial contaminants under variable conditions are unknown which limit the scientific basis of advice to growers regarding the post-flooding microbial hazards presents in the soil. Microbiological testing of soil for various target pathogen is thus the most reliable risk assessment method.

Floodwaters can contaminate agricultural equipment, packaging and storage facilities, and transportation vehicles. If these contaminated surfaces come into contact with fresh produce, cross-contamination can occur, leading to the spread of pathogens or chemicals from the floodwaters to the produce. This can happen during harvesting, processing, packing or transportation stages. Environmental pathogens such as *L. monocytogenes* and *Salmonella* can enter the processing facilities with produce itself, workers shoes, equipment and machinery. Contamination of produce-contact (e.g. conveyor belts, brushes) and non-contact surfaces (e.g. floors, walls) can lead to persistent contamination risks if their anchorage and harbourage remains unnoticed.

After a flood event, water used for post-harvest activities, such as washing, rinsing and cooling of fresh produce, can become contaminated. If this contaminated water is used during these processes, it can introduce pathogens or chemicals onto the produce, compromising its safety. Flooding can also lead to a loss of quality and reduced shelf life of fresh produce. Excessive moisture and prolonged exposure to water can cause physical damage, such as bruising, decay or mould growth, making the produce unsuitable for consumption.

Floodwater impacts on fresh produce safety – case studies

Spain

A study in Spain showed that irrigation water, soil and lettuce samples showed the presence of coliforms and *E. coli* when sampled 1 week after flooding.[7] However, bacterial population drastically decreased 3 weeks after the flooding. All three major foodborne bacterial pathogens (e.g. *Salmonella*, STEC and *L. monocytogenes*) were detected in lettuce samples after flooding. Salmonella was also detected in irrigation water and soil samples 1 week after the flooding. Similarly, another study in a greenhouse grown tomato crop, the presence of *E. coli* and *Salmonella* Newport was demonstrated in tomato samples during and after a flooding event in Mexico.[17]

Australia

After October to December 2022 floods in Victoria, a total of 86 samples (18 produce samples and 15 soil drags from production fields and 53 environmental samples from post-harvest processing facility) were collected from a fresh-produce farm located near Mildura, which was partially affected by flooding (S. P. Singh, unpubl. data). STEC was detected in a soil drag sample and on a produce sample from the flood-affected zone of the farm. Similarly, STEC was also detected on harvest bins and drains in the fruit receival area of processing facility, indicating the potential transmission of STEC from soil to produce to harvest bins to drains in the packing facility. *Salmonella* and *L. monocytogenes* were also detected on the non-contact produce surfaces (e.g. floors and drains) of the processing facility. In previous years (2021 and 2022) of food safety monitoring, no foodborne bacterial pathogens were detected on produce and environmental samples collected from this farm (S. P. Singh, unpubl. data). This case study highlights the potential of flooding events in introducing microbial contamination in the production fields and their transmission from field to processing facilities along with produce, harvesting and post-harvest equipment.

Management options

Post-flooding response

Educating growers and farm workers about flood-related risks and appropriate handling practices should be part of the preparedness for natural disasters. The flood-affected zones of the farm should be clearly identified and marked to restrict the potential transfer of microbial pathogens and produce from the affected zone to the clean zone. Once a flooding event has occurred, clear guidelines should be followed such as the United States Food and Drug Administration (US FDA) guidance on evaluating the safety of flood-affected food crops.[18]

Produce that has come in contact with flood water is considered adulterated and cannot be sold for human or animal consumption. If the crop comes in proximity to or is exposed to a lesser degree, a thorough risk-assessment should be conducted involving factors such as the floodwater hazards, type and stage of crop growth, degree and duration of crop exposure to floodwater and related conditions and likelihood for crops to absorb or internalise potential contaminants. Microbiological testing for faecal indicators and foodborne microbial pathogens should be the objective and integral part of food safety risk assessments.

Preharvest water should be subjected to microbial reduction strategies when the microbial load is intermediate (100–1000 colony-forming units per 100 mL). Electrolysis, ozone, UV and photocatalysis hold promise, either as single treatments with pre-treatments that remove suspended material or as combined treatments, with another chemical or physical treatment methods.[19]

Flood-affected fields should not be replanted for at least 30–60 days after the water recedes.[18] The waiting period for replanting are based on the known die off rates of pathogens and other factors such as temperature weather and soil type. Replanting with fresh produce crops such as leafy vegetables, herbs, melons and strawberries is not recommended. Crops with edible parts away from the soil and likely to be consumed after cooking or processing are more suitable for replanting.

The US FDA recommends the segregation of flood-affected crops from non-affected crops with a 30-foot (~9.1 m) buffer zone to prevent cross contamination between the flooded and non-flooded fields.[18] Conducting thorough risk assessments of flood-prone areas and implementing appropriate mitigation strategies are important strategies to manage flooding risks. Improving water and flood management systems, such as proper drainage and irrigation practices are critical. Enhancing hygiene practices during harvesting, processing and transportation of fresh produce along with regular testing and monitoring of water sources used in preharvest and post-harvest operation are among the practical management options.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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Biography

Dr Sukhvinder Pal (SP) Singh is a Senior Research Scientist at the NSW Department of Primary Industries. His research program is focused on enhancing food safety and traceability in the horticulture sector. His research group studies the sources and routes of microbial contamination in primary production and processing environments of fresh horticultural produce.