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Sanitisers in vegetable food safety

Gupta S, Fletcher GC, Woolf AB, Vanholsbeeck F, Swift S, Bremer P

October 2018















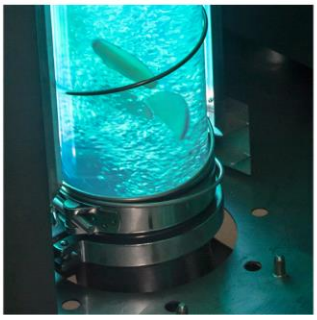


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EXECUTIVE SUMMARY

Sanitisers in vegetable food safety

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Disease outbreaks caused by pathogens on fresh produce (vegetables and fruits) have become common events that receive considerable media coverage, and can have economic impacts for the produce industries involved. An effective way to mitigate food safety risks in postharvest horticultural produce environments is firstly to understand the risk organisms (which are likely to vary by crop, location and season), and then to reduce microbial growth and prevent cross contamination. Sanitisers are an important tool in the horticultural food safety toolbox.

The Vegetable Research & Innovation (VR & I) Board wants to enhance the understanding of the current practices for use of sanitisers in the New Zealand vegetable industry. The New Zealand Institute for Plant and Food Research Limited (PFR) was asked to write a review on sanitisers in vegetable food safety which included:

- The results of a survey on sanitisers used by vegetable growers
- Efficacy and risks associated with sanitisers
- A summary of the microorganisms associated with vegetables that pose a risk to human health
- Allowable residues for domestic and international market acceptance
- A non-technical summary suitable for communication with vegetable product groups.

As today's consumers move towards safer, fresher and healthier choices in their daily diets, vegetables are becoming a more important "healthy" category than animal proteins, complex carbohydrates or sweeter alternatives such as fruits. Significantly, a desire for ready-to-eat or ready-to-cook products also means that minimal processing of vegetables (e.g. cutting, peeling and dicing) is an increasing practice, and this markedly increases food safety risk.

Bacteria (both pathogenic and non-pathogenic) and fungi can affect vegetable quality. Human pathogenic bacteria associated with produce can cause food recalls, outbreaks of illness, and even death. When used in appropriate concentrations and doses, sanitisers can improve product quality and reduce food safety risks.

As part of this review, a survey of sanitisers currently in use by vegetable growers in New Zealand was carried out. This showed a diverse range of sanitisers being used, including those based on chlorine (sodium or calcium hypochlorite), combined with bromine, chlorine dioxide, peroxyacetic acid, quaternary ammonium compounds and iodophors at various volumes and concentrations. Sanitisers were used for various reasons, including sanitising wash water, sanitising equipment and product contact surfaces, and sanitising hands. Most growers recognised the need for more information about the sanitisers, although producers were cognisant of the various regulations and guidelines relevant to the use of sanitisers.

The review provided comprehensive information on chemical sanitisers, organic alternatives, and novel and emerging biocides and sanitisers. It also provided detailed information on sanitiser efficacy and risks, including studies from New Zealand and Australia.

It is not possible to recommend one sanitiser that is suitable for all vegetables in all situations, and accepted for use in both domestic and export markets. Thus, this review includes recommendations to assist development of Good Operating Practice (GOP) guidelines for the New Zealand industry. At present only limited data are available for selecting suitable sanitisers for the different varieties of vegetables grown in New Zealand, so this review includes a section on knowledge gaps and recommendations for further research.

This review was based on published and non-published information. It includes a detailed search of scientific, regulatory and product literature, and draws on the extensive experience of PFR’s microbiology team.

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1 INTRODUCTION

Disease outbreaks caused by pathogens on fresh produce (vegetables and fruits) have become common events that receive considerable media coverage, and can have economic impacts for the produce industries involved . To address this issue, it is first necessary to evaluate various food safety risks that exist in the fruit- and vegetable-growing environments. The next step is to address these risks. One risk is cross contamination of fresh produce. Judicious use of sanitisers is a means of reducing its impact.

The Vegetable Research and Innovation (VR & I) Board want a better understanding of current practices for sanitiser use in the New Zealand vegetable industry.

The New Zealand Institute for Plant and Food Research Limited (PFR) was asked to write, in collaboration with researchers from the Universities of Otago and Auckland, a review on sanitisers focusing on the following areas:

- The results of a survey on sanitiser use by vegetable growers.
  This was carried out over a period of 3 months from the end of August to November 2017
- A summary of the microorganisms posing a risk to human health
- Efficacy and risks associated with sanitisers in use in New Zealand
- Allowable residues for domestic and international market acceptance
- A non-technical summary suitable for communication with vegetable product groups.

The overall purpose of this review is to provide the VR & I Board with relevant information to support the development of Good Operating Practice guidelines to manage sanitisers in postharvest horticultural produce environments.

Limitations

This review does not cover:

- All vegetables mentioned in the proposal request
- Experimental work carried out specifically for this project at PFR
- Alternative approaches to chemical sanitising agents (e.g. UV disinfection, ozonation, filtration/reverse osmosis)
- All plant pathogens.

The risks to vegetable food safety are numerous, and the use, misuse, overuse or using a sanitiser at too low a dose to be effective all need careful consideration. Vegetables that are generally consumed raw have caused human illness. According to research, leafy vegetables, salad vegetables and herbs are at high risk for causing food-borne illnesses (FAO/WHO 2008; Goodburn & Wallace 2013; Ramos et al. 2013). Examples of outbreak for fresh produce are numerous around the globe. (New Zealand Food safety 2018). From July 2016 to January 2016, one person died and 19 were hospitalised on after consuming packaged salads processed at Dole’s Springfield, Ohio, processing facility in the USA (CDC 2016). Another outbreak occurred in Canada in December 2017, because of contamination of Romaine lettuce with *Escherichia coli O157:H7*. As per the Public Health Agency of Canada, 21 individuals from three provinces were affected (CDC 2017).

Closer to home, in 2005, an outbreak of *Salmonella* Saintpaul, which affected at least 16 people in Auckland and the Waikato region, was associated with carrots from four farms and was the likely source of contamination (Neuwelt et al. 2006).

These incidents or outbreaks occur when human pathogens cross-contaminate vegetables. These might be bacteria such as *Listeria monocytogenes, Salmonella* spp*.,* Shiga-Toxigenic *Escherichia coli* (STEC), *Campylobacter* spp., *Aeromonas* spp*., Yersinia* spp*., Shigella* spp*., Clostridium botulinum, Clostridium perfringens, Bacillus cereus* and *Staphylococcus aureus*. The cause could also be viruses such as rotavirus, norovirus and hepatitis A, or parasites such as *Giardia lamblia, Cryptosporidium parvum*, *Cyclospora cayetanensis* and *Toxoplasma gondii*. All these pathogens are of concern to human health.

The use of molecular testing allows more powerful traceability of the outbreak strains. This means the microorganism can be traced back to where the cross contamination originally occurred, and the source of the exact offending organism identified. Alongside traceability, the food safety regulations are also becoming more stringent. Since January 2011, the US Food and Drug Administration (FDA 2011) Food Safety Modernization Act has been put into practice, and allows the FDA to focus on "stopping occurrence of food safety problems."

2 SANITISERS

2.1 An overview of sanitisers

A significant cause of postharvest losses of fresh vegetables is microbial contamination. While washing with water reduces the number of microorganisms attached to the surface of the produce by 1 or 2 logs (1 log reduction being a 10-fold reduction), it is also critical to understand that this water can actually be a source of cross-contamination. Therefore, adding a sanitiser to vegetable wash water is vital to effectively reduce risks in terms of product and human pathogens.

The US Environmental Protection Agency (EPA) defines a sanitiser as "an antimicrobial that reduces but does not necessarily eliminate all the microorganisms on a treated surface". Quantitative reduction in bacterial numbers does not mean complete removal. To be classified as a sanitiser, a product only needs to demonstrate a three log (or 99.9%) reduction of bacteria.

The inactivation/elimination or kill rates of the three processes are sterilisation (6–12 log kill) > disinfection (4–5 log kill) > sanitising (3 log kill).

For vegetables produced for human consumption, if any sanitiser is used in the wash water the following properties are necessary:

- It should be effective against target micro-organisms, i.e. human pathogens of interest and spoilage organisms. It should have a broad spectrum effect
- It should be safe for the users, living animals and the environment including with acceptable residue levels on food
- Relevant regulatory bodies should approve its use
- There should be sufficient supply
- It should not be prohibitively expensive
- It should be applicable to the product, e.g. gentle treatments for easily bruised produce
- It should be easy to use

The ideal sanitiser should not only reduce the bacterial load on products but also improve their shelf life, while not adversely affecting their visual appearance or other quality attributes. "Chemical-free" is also on the wish list. The effectiveness of these sanitisers could be evaluated by random testing of sample products for the presence of key organisms or just by viable counting. The level of sanitiser present in wash waters should also be readily monitored and preferably auto-dosed to maintain effective concentrations. Additionally, whether the sanitiser needs to be rinsed off after use, or not, is important because rinsing adds an extra processing step. Each additional step tends to slow processing and increase its complexity.

According to Delaquis (2004), chlorine-based sanitisers are popular in the fruit and vegetable industry as they cost less and are easy to use.

Chemical sanitisers can be grouped under four primary groups:

- Chlorine based: hypochlorite (Ca or Na), chlorine/bromine mixtures and chlorine dioxide
- Iodophors (iodine-based)
- Peroxyacetic acid sanitisers
- Quaternary ammonium compounds: QAC

The details of various sanitisers including their limitations are presented in Table 1. This table has been created with reference from (Gill 2011; Jennings et al. 2015; Velocity Chemicals 2015; Ramos et al. 2018 http://www.postharvest.net.au/postharvest-fundamentals/controlling-microbes/sanitisers-and-fungicides and https://www.sciencedirect.com/topics/neuroscience/quaternary-ammonium-compounds

Table 1. Chemical sanitisers and some other alternatives for treatment of vegetables: Mode of action, critical points, monitoring, costs, handling/general instructions and limitations *(information was gathered from published research only).*

Name	Mode of action	Critical points	Monitoring	Indicative price examples (all prices in NZD)	Handling/ General Instructions	Limitations
Chlorine (hypochlorite) Calcium hypochlorite (swimming pool chlorine) e.g. Ym-Fab Activ-8™ Sodium hypochlorite (household bleach)	Kills microbes by destroying microbe DNA	Needs high concentration of active chlorine (hypochlorous acid), e.g. 100 ppm. This requires the pH to be maintained between 6 and 7.5.	Test strips. Chlorine meters	10 kg for $59 = $5.9/kg (Splash™ Chlorine Granules)	It is important to monitor water quality, as it is not effective in water which has a high organic load. Corrodes most metal alloys and packing equipment Rinse step with potable water necessary after treatment Health concerns from carcinogenic chlorinated end-products that could be formed	High temperature reduces efficiency Does not kill spores, as their outer coat is resistant: bacterial spores and protozoan oocysts could be resistant Disinfection by-products (DBP) such as chorine vapours are formed. These are hazardous and have environmental impact. Efficacy reduced in presence of organic matter
Acidified sodium chlorite		Greater oxidising capacity than hypochlorous acid Greater solubility than sodium hypochlorite e.g. of effective concentration: 1200 ppm				Limited research conducted and limited information on production of disinfection by-product (DBP)
Chlorine dioxide e.g. Vibrex Hortiplus® Biowash	Kills bacteria, viruses and fungi by reacting with proteins and fatty acids	Higher potency than sodium hypochlorite Active at much lower concentrations than sodium hypochlorite – typically 10-20x lower, e.g. 10 ppm.	Redox probe	$341 for 20 L = $17.10/L (Vibrex Hortiplus) The stabilised chlorine dioxide tablet is expensive and	For treatment with ClO_2, ventilation of work area necessary Could be a risk to health if gas	Effectiveness decreases with increase in organic load in the water but can handle some organic load

		Much less corrosive than either ozone or chlorine and has short treatment time Major factors to consider are humidity, gas concentration, temperature and the actual exposure time. Inactivates *Escherichia coli O157:H7* and *Listeria monocytogenes*		unsuitable for large-scale use.	dissipates into atmosphere It must be generated onsite Has explosive properties, so needs to be handled with precaution Rinse step is necessary	At neutral pH it is more active than chlorine. Carcinogenic chlorinated end-products formed after chlorine dioxide use are less than those formed by chlorine.
Bromo chloro dimethyl hydrantoin (BCDMH) e.g. HarvestCide®	Microbes are killed steadily over an extended period of time. They attach to sulphurs in proteins which makes them inactive.	Sustained release effect Can work in slightly acidic solutions Requires relatively low concentration (e.g. 15 ppm) Environmentally friendly Approved by Food Standards Australia New Zealand (FSANZ) but little used outside New Zealand	Automatic dosing analyser	23 kg for $750 = $32.6/kg (HarvestCide Granules) 160 kg: $2582 = $16.10/kg (HarvestCide Gel)	Can stain some surfaces. Can cause tainting of end product Corrosive above 50ºC	Not effective against *Listeria* Bacterial spores are less affected.
Quarternary Ammonium compounds (QACs): benzethonium chloride, benzalkonium chloride, and cetylpyridinium chloride	Causes disruption of membranes and could also denature proteins Additionally, blocks microorganism's nutritional pathway so that nutritional intake is affected and they are starved	Heavy organic load and hard water can compromise effectiveness. and chelating agents could be added to counter these issues. Example of typical use concentration: 0.05-0.2% QAC.		5 L for $23 = $4.60/L (Kemsol Quat™ 2000 – Arrow Hygiene) 5 L for $20 = $4/L (Qualchem Q-Fresh™ Disinfectant – Arrow Hygiene)	Colourless, odourless, non-staining, less corrosive and relatively less toxic Works at different temperature and pH range	Not effective against spores and less effective in presence of organic matter Less useful at low pH More effective against fungi and Gram-positive bacteria than Gram-negative (*Salmonella* spp. and *Escherichia coli* are exceptions) Market access limited

Peroxyacetic acid (PAA) e.g. Tsunami 100™	Strong oxidising agent	Can work well in cooler temperatures (4ºC) especially when combined with stabilized hydrogen peroxide Effective against biofilms Active properties are unaffected by temperature changes and organic load in water at <80 ppm (the maximum permitted dose); it does not display corrosiveness. Disinfection by-products are not formed.	PAA test strips Automated analyser Sometimes difficult to monitor	225 kg for $923 = $4.10/kg 1100 kg for $4156 = $3.80/kg (PAA – Postharvest)	Environmentally friendly and less corrosive Concentrated peroxyacetic acid is a safety hazard. High concentrations damage produce and can shorten shelf life.	Deactivated by high pH and high temperature Less affected by organic load than hypochlorites Low antimicrobial efficacy for vegetables at permitted levels
odophors Iodine e.g. Ecolab Iodophor Multi™	Penetrates cell walls and oxidises a number of critical components	Provides broad spectrum protection against bacteria, yeasts and moulds e.g. Commonly used concentration: 25 ppm		Ecolab Iodophor Multi™ 200 L for $1277.99	Corrosive to metals Not affected by organic load	
Ozone		Has benefit of extending shelf life and can be used for shorter treatment times No harmful end products “Off-gassing” needs to be considered in relation to H&S Solubility in water is low. Typically 10 ppm	Usually monitored using a redox meter. Palintest could be used for monitoring ozone in water. Ozone meters could be used for monitoring ozone in air.	Main cost is capital. Initial cost of ozone equipment (c. $37,000), with associated costs ozone monitoring equipment in air and in water (c. NZ$1300 each)	Activity reduced in presence of organic load Corrosive to metal and equipment	Efficacy needs to be understood well If inhaled in high doses, could have health impact. Must be generated onsite
Electrolyzed water e.g. Envirolyte®		Environmentally friendly Considered organic		200L for $300 = $1.50/L Envirolyte		More data required on understanding efficacy

(Envirolyte Industries International Ltd)	e.g. Low-concentration electrolysed water (LcEW: 4 mg/L free available chlorine)	Alternatively can invest capital to purchase an onsite unit to generate it from common salt	Onsite generation generally required
Calcium-based solutions (calcium lactate)	Acts as antimicrobial agent Reduces postharvest decay May increase calcium content of final product May delay ageing and ripening of vegetables e.g. 3% calcium lactate solution	4 kg powder for $338 = $84.50/kg (calcium lactate)	Similarly to calcium chloride, there could be bitter or off-flavours. Limited antimicrobial activity
Hydrogen peroxide	Breaks down easily, no harmful by-products Higher temperatures could produce better reduction. e.g. Typical concentration used: (0.04–2%)	20 L for $75 = $3.80/L 217 L for $510 = $2.40/L (50% hydrogen peroxide)	More research required on understanding efficacy and market access
Organic acids (lactic acid, citric acid, tartaric acid etc.) e.g. Citrox 14T™	Generally recognised as safe (GRAS) compounds Environmentally friendly e.g. Pro-San L (0.66% citric acid, 0.036% SDS)	20 L drum for $260 = $10.50/L (Citrox Bioklenz™)	More data required on understanding efficacy and sensory quality e.g. flavour tainting Antimicrobial efficacy is dependent on the microorganism strain and acid type.

2.2 A survey on sanitisers in New Zealand vegetable industry (August – November 2017)

As part of an industry communication process, a survey was conducted to understand the current practises of sanitiser use in the New Zealand vegetable industry. A list of 37 vegetable growers was provided by the VR & I Board and the survey was sent by email and follow-up phone calls were made.

Of the 37 growers contacted, 19 responded to the survey. Eight of the 18 growers who did not respond were contacted by the VR & I Board member again but did not respond. Some growers who were contacted were worried about recording information and some said they never respond to surveys. Of the 19 growers who responded, 10 growers said they either do not wash their vegetables or do not use any chemical sanitisers. Nine growers who currently use sanitisers completed the survey. We did not intend to send out the survey to organic growers, however, when a follow-up phone call was made and we found out that the grower was organic, we offered to share our results with them. This uncovered some interesting responses.
One organic grower did not want to be informed about food safety risks, the sanitiser survey or associated documents. This response is concerning since the hazards associated with organic production could be similar to non-organic production. Sometimes the risk level might be elevated in organic crops as there are no chemical risk mitigation steps and the use of composts may pose additional risks. Hence, it is important that all vegetable growers have an understanding of the food safety risks associated with their crops and processing methods.

The following is a summary of the growers' responses to the questions we asked. The numbers in brackets indicate how many growers responded to the question.

2.2.1 Vegetables that receive postharvest treatment

Response: (9/9)

Question 1: Please list vegetable crops sold by your business that receive any kind of postharvest cutting, washing or misting treatment (excluding any product sold as a raw material to processing factories).

The vegetable crops were:

- beetroot (shredded)
- broccoli
- cabbage
- carrots
- citrus
- corn
- coriander (shredded)
- kale
- kumara
- leeks
- lettuce (multi leaf and iceberg)
- parsley
- peas
- potatoes
- onions
- radish
- salad greens
- silver beet
- spinach
- spring onion
- squash
- tomato

2.2.2 Reasons for sanitiser use

Response: (7/9)

Question 2: Please list the diseases that affect the postharvest shelf life of each of the vegetable crops you grow.

The answers to Question 2 are listed in Table 2:

Table 2. Major vegetable diseases that affect the postharvest shelf life of different vegetable crops.

Name of vegetable crop	Diseases
Carrots	*Sclerotinia* sp., soft rot caused by bacteria or untreated water, cavity spot, dry rot, root rot including violet root rot
Kumara (fresh)	*Rhizopus* rot Black rot
Onions	Black mould, basal rot, soft rot, neck rot, wet neck, *Botrytis* and *Fusarium* rot
Potatoes	Bacterial rot, soft rot, dry rot, black dot and infection in lenticels due to untreated water
Squash	Fruit rots: caused by *Botrytis* and *Sclerotinia*
Tomatoes	Lenticel infection due to untreated water

While some growers provided information about specific crop diseases, some growers did not record their answer to this question or said “no diseases”. Some growers replied that diseases varied according to the crop they grew, while others recorded that a number of crops were affected by one or two main diseases (e.g. downy mildew and *Cladisporium* sp. seen in spinach, silver beet, kale, radish, parsley, leeks, lettuce and onions).

2.2.3 Primary reasons for the New Zealand vegetable industry using sanitisers

Response: (8/9)

Question 3: What are the primary reasons you use a sanitiser?

The primary reasons were:

- To remove any bacteria or pathogens and reducing microbial load
- To manage microbiological hazards from human sources
- To manage cross contaminations of products
- To minimise the spread of fungi
- To clean and /or disinfect equipment and vegetable crop contact surfaces such as belts and the processing plant
- For water treatment
- To sterilise containers used for water
- To keep the product clean
- To extend the shelf life

2.2.4 Most important food safety risks in the postharvest produce environment

Response: (8/9)

Question 4: What food safety risks do you think exist in the postharvest horticulture produce environment?

The risks were:

- Inadequate information about effectiveness and safety of sanitisers that could be used on green vegetables
- Chemical hazards: high levels of residue from overuse of chemicals
- Microbiological hazards: bacterial risks: Pathogens (*Escherichia coli, Salmonella* spp*., S. aureus and L. monocytogenes*)
- Exposure to vegetable, soil and water pathogens
- Cross contamination including contamination of end-product due to product being washed with contaminated water
- Physical hazards: food poisoning, communicable disease, foreign object and choking
- Allergens
- Pests (i.e. rat or bird droppings).

2.2.5 Sanitisers currently in use

Response: (7/9)

Question 5: What sanitisers at what concentrations do you use for risk minimisation?

The sanitisers used by respondents are listed in Table 3.

Table 3. Sanitisers (including concentrations/dosage for use) being used by survey respondents working in the New Zealand vegetable industry.

Sanitisers	Concentrations
Calcium hypochlorite	3–10 ppm
Chlorine/Sodium hypochlorite	Residual level 2 ppm/ 250 mL in 400 L water 80 ppm
Geosil (silver/hydrogen peroxide active ingredients)	Not answered/ commercial instructions
Iso propyl alcohol	58%
Nylate® (a chlorine and bromine mix) spray	5–15 mg/L
Ozone	Not answered
Peroxyacetic acid	25–100ppm
Purell hand sanitiser (gel) alcohol based	Commercial concentration
Sutresan	Not answered
Supermix 2 (Quarternary ammonium compound)	1 pump concentrate per 1 L water (1:80)
Sodium hydrochlorite for carrot hydrocoolers	1–3 mg/L
Terminex® (chlorine dioxide)	Not answered

2.2.6 Sanitiser application form and time

Response: (8/9)

Question 6: When, where and how do you apply sanitisers to produce or to packing equipment?

Respondents' results are listed in Table 4.

Table 4. Sanitiser application form and time being used by survey respondents from the New Zealand vegetable industry.

Sanitiser application	Sanitiser application form and place and time
Sanitiser applied to final rinse of produce	Used in spray form: Tri-film spray for contact brushes as a step to stop transfer of fungus to grower bins
Sanitiser applied to packing equipment	Weekly application
	Sodium hypochlorite: Automatic dosing into waterline at washing
	Foam to scrub down all plants
	Supplier approved foaming equipment
	Iso propyl alcohol on packing belt daily
	Supermix 4 in foam machine daily
	Spectrasan floor, scrubber weekly
	Chlorine on floor weekly
	Auto dose dispenser to maintain level
Sanitiser applied to clean all product contact surfaces	Supermix 2: Depending on risk and the product, e.g. for carrots and peeled onions it is daily
Sanitiser in the autodosing system	Peroxyacetic acid
Sanitiser for staff to use in bathrooms on daily basis	Purell hand sanitiser
Sanitiser applied continuously in-line using oxidation reduction potential (ORP) eroder system and concentrations verified offline using chlorine and pH strips	Nylate
Sanitiser added to wash line water	Calcium hypochlorite and ozone

2.2.7 Procedure for the selection of sanitisers

Response: (7/9)

Question 7: How do you select/choose the sanitisers you use for a particular vegetable?

Selection of sanitisers included:

- Using the weekly microbial testing results which reflects the problem pathogens
- Choosing generic sanitiser, e.g. Chlorine or HarvestCide® (formerly Nylate®)
- Recommendations from chemical suppliers' advice and global (factory) information, e.g. for Quaternary ammonium sanitiser, using recommendations from the manufacturer
- Recommendations from other growers
- Using same sanitiser/ repeating (calcium (Ca) hypochlorite and ozone) for all produce
- Using the critical limits determined by validation trials, e.g. for usage of peroxyacetic acid.

2.2.8 Regulations/guidelines or standards applicable for sanitiser use on vegetable crops

Response: (7/9)

Question 8: What regulations/guidelines or standards does your business follow that are applicable to sanitiser use on vegetable crops in New Zealand?

The guidelines listed were:

- New Zealand Good Agricultural Practices (NZGAP)
- Manufacturers specifications: Material Safety Datasheet (MSDS), Australia New Zealand Food Authority (ANZFA) Application A393, Woolworths™ supplier excellence standards, Subway™ global standards
- New Zealand Food grade safety standards
- Food Acts 2014 and Food Regulations 2015
- Food Safety System Certification (FSSC22000)
- All sanitisers are checked to see if food grade safe at NZ standards before use
- Hazard Analysis and Critical Control Points (HACCP), Food safety program (FSP) and Ministry of Primary Industries (MPI) full control plan.

2.2.9 Yearly sanitiser use

Response: (6/9)

Question 9: Please indicate the approximate volume of each chemical sanitiser you use in a year?

The volume of each chemical sanitiser used by respondents is listed in Table 5. This does depend on the volume of produce that is processed by individual producers but a rough estimate is provided.

Table 5. Sanitiser volumes being used by survey respondents from the New Zealand vegetable industry.

Sanitiser Name	Approximate volume/year
Chlorine	12 L
Peroxyacetic acid	10,000 L
HarvestCide® (formerly Nylate®)	Approximately 100 kg granules per washing line
Shurfoam	1200 L
Sodium hypochlorite	8000 L
Spore Kill	20 L
Sutresan	2400 L
Supermix 2	3x 20 L containers of concentrate
Terminex	2400 L
Tri film	80 L
Quaternary ammonium sanitiser	7000 L

2.2.10 How long does the sanitiser stay effective

Response: (6/9)

Question 10: How long does your sanitiser stay effective in a) diluted (ready to use) form and b) concentrated (as purchased) form?

The respondents' answers were:

- Calcium hypochlorite stays effective until used
- Calcium hypochlorite/ozone mix: Unsure about effectiveness, replenish monthly
- Effectiveness of Sutresan varies from batch to batch
- Nylate® is effective for 24–72 h
- Purell stays effective for 3 years
- Sodium hypochlorite and Shurfoam stays effective for 10 days
- Supermix stays effective for approximately 1 year
- Terminex stays effective for 8 months.

One grower commented that Peroxyacetic acid does not lose its effectiveness as quickly as chlorine based sanitiser. The product is stable if stored correctly and the grower uses it immediately.

2.2.11 Sanitiser dosage

Response: (6/9)

Question 11: Do you a) monitor the dosage of sanitisers during the packing process? b) How do you do this?

The respondents answered as follows:

- Yes, by using monitoring equipment, e.g. monitoring using an automatic dosing system into waterline at washing, dispensed using an oxidation reduction potential (ORP) controller
- Yes, by regular testing and recording of results using pH strips and an electronic monitoring system. The CHEM02 chemical controller is calibrated annually.
- Yes, dosing checked manually
- Yes, dosing checked externally
- Not monitored, e.g. Supermix but used by approved trained handlers.

2.2.12 Factors influencing sanitiser choice

Response: (6/9)

Question 12: How important are the following factors in making your choice of sanitiser? (1=not important, 2=important, 3=very important)

- Effectiveness against food safety pathogens
- Effectiveness against produce decay organisms
- Safety of handling
- Environmental safety.

The answers to Question 12 are shown in Table 6.

Table 6: Criteria for choosing sanitiser (1=not important, 2=important, 3=very important) according to survey respondents from the New Zealand Vegetable Industry.

Name of Sanitiser	Effectiveness against food safety pathogens	Effectiveness against produce decay organisms	Safety of handling	Environmental safety
Calcium hypochlorite/ozone	3	1	3	3
Chlorine	3	3	3	3
Nylate®	3	3	2	2
Peroxyacetic acid	3	2	3	2
Sodium hypochlorite	3	3	3	3
Sutresan	3	3	3	1
Supermix 2	3	3	2	2
Terminex	3	3	3	1
Quaternary ammonium sanitiser	3	2	3	2

2.2.13 Sanitiser storage

Response: (7/9)

Question 13: Where and how do you store your sanitisers?

The storage of sanitisers is vital as some of them are hazardous chemicals in higher doses. When we asked where and how the vegetable growers store their sanitisers the answers ranged from stored in a separate building, chemical store rooms, locked shed, locked cupboard or stored separately in 200 L drums away from sunlight.

2.2.14 Method of preparation of sanitisers for application

Response: (7/9)

Question 14: How do you prepare the selected dose of your sanitisers?

Preparing sanitisers is carried out by both manual and automatic methods. Often an auto-dosing system using proportional dosing was used (e.g. for peroxyacetic acid, quaternary ammonium sanitiser and calcium hypochlorite/ozone. Manual preparation using standard operating procedures, Personal protective equipment (PPE) and MSDS from company standards and work safe New Zealand guidelines was also carried out (e.g. Nylate® and Supermix 2). For sanitisers, e.g. chlorine, sodium hypochlorite and foam measuring jugs and simple dosing pumps were also used. An automated foamer was used for Terminex and Sutresan.

2.2.15 Disposal method

Response: (6/9)

Question 15: How do you dispose of the sanitisers?

Sanitiser disposal occurred:

- By washing down the drain: e.g. for Terminex/Sutresan or calcium hypochlorite (breaks down after 24 hours)
- Rinsed to trade waste: e.g. for peroxyacetic acid or quaternary ammonium compounds
- By dilution in dirty wash water: e.g. for sodium hypochlorite
- Return for refills or through waste reclaim: e.g. for chlorine
- Disposed as advised by supplier: e.g. for Nylate® and Supermix 2.

2.2.16 Availability of information on sanitisers

Response: (8/9)

Question 16: Do you consider that you are well informed regarding the sanitisers in use or available for use in the New Zealand horticultural industry?

Of the eight respondents, three growers said they checked with their suppliers, while the remaining five were either unsure, thought it could be better or said that they did not feel well informed.

2.2.17 Interest in receiving more information about sanitisers

Response: (9/9)

Question 17: Would you be interested in obtaining a copy of a document outlining good operating practice guidelines to manage sanitisers in postharvest vegetable/horticulture produce environments?

All growers said they would be interested in such a document.

As a general comment, questionnaire communication with the vegetable growers and suppliers was time consuming, however, the information generated was valuable for the review.

3 MICROORGANISMS OF CONCERN FOR FOOD SAFETY

Vegetables can become contaminated on the farm, at the packhouse or at a retail level. This can be by direct contamination or through contact with contaminated soil or water, symptomatic and asymptomatic workers or by cross contamination with other food.

Some microorganisms of concern include:

- Bacteria such as *Aeromonas* spp., *Bacillus cereus, Clostridium botulinum, Clostridium perfringens, E. coli (pathogenic and non-pathogenic), L. monocytogenes Plesiomonas* spp., *Salmonella* spp., *Shigella* spp., *S. aureus, Vibrio cholerae* and *Yersinia enterocolitica*
- Viruses such as Hepatitis A, Rotavirus and Norovirus
- Parasites such as *Cryptosporidium parvum, Cyclospora cayetanensis, Giardia lamblia* and *Toxoplasma gondii.*

The various organisms that have caused food-borne outbreaks are shown in Table 7A. This table also includes information on the particular vegetable that was related to the outbreak.

Table 7A. Major vegetable pathogens associated with outbreaks: Table redrawn from Ramos et al. (2013) (excluding fruits).

Pathogen	Name	Product
Bacteria	*Clostridium botulinum*	Cabbage, carrots, garlic, pepper and potato
	Shiga-Toxigenic *Escherichia coli*	Alfalfa sprouts, cabbage, celery, coriander, lettuce and watercress
	Listeria monocytogenes	Bean sprouts, cabbage, cantaloupe, chicory, eggplant, lettuce, potatoes and radish
	Salmonella spp.	Alfalfa sprouts, artichokes, beet leaves, cabbage, cantaloupe, cauliflower, celery, eggplant, endive, fennel, green onions, lettuce, mung bean sprouts, mustard cress, pepper, salad greens, spinach and tomato
	Shigella spp.	Celery, green onions, lettuce, parsley and salad vegetables
	Staphylococcus aureus	Lettuce, parsley, radish, salad vegetables and seed sprouts
	Vibrio cholerae	Cabbage and coconut milk
	Yersinia enterocolitica	Carrots, cucumber, lettuce and tomatoes
Viruses	Hepatitis A and Norovirus	Lettuce, green onions, watercress
Protozoa	*Cryptosporidium* spp. *and Cyclospora* spp	Lettuce, green onions and onions

To understand the food safety risks associated with contamination and the consequences some of these bacterial pathogens are described in detail below:

Listeria monocytogenes

Listeria monocytogenes (Lake, 2005) is a hardy, salt-tolerant gram positive bacterium. Unlike most foodborne pathogens, it can survive and grow at temperatures below 1°C. It can also grow and persist in food-manufacturing environments where it forms biofilms that can protect it from sanitisers. The organism is common in the environment in many niches including soil and decaying vegetation. It is of little concern for healthy people but causes listeriosis in immunocompromised individuals including the elderly, unborn babies, those with HIV/AIDS or those on immune suppressing medication such as chemotherapy. It has high mortality rates typically between 15 and 30% of reported cases. High numbers of bacteria are usually required to cause illness. Several cases of *Listeria monocytogenes* contamination of fresh produce has been reported worldwide.

Salmonella

This bacterium can cause a self-limiting gastroenteritis (nausea, vomiting, diarrhoea, cramps and fever with symptoms lasting a couple of days) or typhoid (high fever, diarrhoea or constipation headache and lethargy). Typhoid is more serious with a death rate of up to 10% if not treated. After *Campylobacter* spp*.* it is the second highest cause of bacterial food-borne illness in New Zealand (MPI 2018).

Vegetables may be a common source of *Salmonella* spp*.* related illness. Vegetables may become contaminated from bird droppings, contaminated water or poor worker hygiene. In 1990 and 1993, 300 people in the USA, from four different states, were affected when fresh tomatoes were contaminated with *Salmonella* spp*.* (Wood et al. 1993).

Shigella

Shigella is not common in New Zealand (NMDHB 2017) *Shigella* causes gastroenteritis with watery diarrhoea (often containing blood, mucus and pus), fever, nausea and sometimes vomiting. Symptoms start 1–3 days after ingesting the bacteria and usually lasts 5–7 days. There is a high rate of person to person infection with affected people being infective for up to 4 weeks after the initial infection. Vegetables have been an important cause of outbreaks, including a large (886 cases) outbreak in the USA attributed to bruised over-ripe tomatoes (Reller 2006).

Escherichia coli

E. coli is naturally found in our gut and does not cause any problems but, like *Shigella*, a few strains can produce shigatoxin and are called shigatoxin-producing *E. coli* or STEC. There are seven important serotypes that have caused vegetable-associated outbreaks. For example, although most outbreaks of foodborne illness from vegetables are from those that are eaten raw, a large outbreak of a STEC infection (252 cases) was associated with potatoes and leeks contaminated with *E. coli* O157 (Launders 2016). In this outbreak people became infected through handling these vegetables and through cross contamination to other foods. One of the more recent outbreaks was in December 2017 when the Public Health Agency of Canada declared an outbreak of 21 STEC O157:H7 infections in three provinces linked to Romaine lettuce (CDC 2017b).

Yersinia

Three *Yersinia* species can be considered as human pathogens. They are *Yersinia enterocolitica, Yersinia pestis* and *Yersina pseudotuberculosis* (Ministry of Health 2017) *Yersinia pseudotuberculosis* caused New Zealand's largest outbreak of foodborne illness in 2014 with 334 cases, 65 of whom had to be hospitalised. Like *Listeria* spp., these bacteria are able to grow at refrigeration temperatures. The exact cause of the outbreak was not confirmed but it was likely to be lettuces and/or carrots (MPI 2014).

Apart from the pathogens, vegetables are also affected by spoilage microorganisms. Spoilage microorganisms include non-pathogenic bacteria. The number and type of spoilage microflora on vegetables is highly variable. Oliviera et al. (2010) and Zagory (1999) reported that raw vegetables after harvest harbour 10^3–10^9 colony forming units (CFU)/g of mesophilic bacteria. Although not the focus of this review, it is useful to note that as well as controlling human pathogens, sanitisers are also effective against spoilage bacteria and fungi. Thus, the sensible application of sanitisers can not only help assure food safety but can also contribute to enhanced product storage life.

The microorganisms that cause postharvest spoilage of fresh produce are summarised in table 7B. This table has been prepared with information from Buck et al 2003, Barth et al 2010, Snowden A.L (1991), http://www.postharvest.net.au/postharvest-fundamentals/controlling-microbes/spoilage-organisms/,
http://agriinfo.in/default.aspx?page=topic&superid=2&topicid=2046

and "A colour atlas of post-harvest diseases and disorders of fruits & vegetables". Volume 2:

Table 7B: Summary of microorganisms that cause postharvest spoilage of fresh produce.

Vegetable crop	Scientific name	Type of microorganism
Alfalfa sprout, asparagus, broccoli, cauliflower, celery, lettuce, pepper, spinach	*Aeromonas*	Bacteria
Apple, pear, broccoli, cabbage, carrot, cucumber, cauliflower, celery, lettuce head, lettuce leaf, onion, potato	*Erwinia* (Asian leafy, bean, potato bacterial soft rot, leafy vegetable soft rot)	Bacteria
Sweet potato	*Ceratocystis* (Sweet potato black rot)	Bacteria
Citrus, refrigerated fresh cut vegetable, broccoli, cabbage, carrot, lettuce head, lettuce leaf, mushroom, potato, tomato	*Pseudomonas* (bacterial spot)	Bacteria
Citrus, broccoli, cabbage, lettuce head, lettuce leaf, tomato	*Xanthomonas*	Bacteria
Peach	*Acidovorax*	Bacteria
Sweetcorn, cucumber, onion, potato, tomato, alfalfa sprout, cress sprout, mustard sprout, soybean sprout	*Bacillus*	Bacteria
Tomato	Lactic acid bacteria	Bacteria
Bean, broccoli, cabbage, carrots, cauliflower, eggplant, pea, pumpkin, squash, lettuce head, lettuce leaf, tomato	*Sclerotinia* (white rot, white mould, carrot water soft rot)	Fungi

Vegetable crop	Scientific name	Type of microorganism
Berries, grape, peach, pear, broccoli, carrot, cucumber, eggplant, pea, pumpkin, squash, sweetcorn, kumara, lettuce head, lettuce leaf, onion, shallot, tomato	*Botrytis* spp. (neck rot, grey mould)	Fungi
Apple, berries, peach	*Monilinia*	Fungi
Apple, berries, pear	*Mucor*	Fungi
Apple, banana, berries, citrus, cucumber, onion, tomato, bean, capsicum, eggplant, pumpkin, squash	*Collectotrichum (Anthracnose)*	Fungi
Apple, berries, citrus, peach, pear, cucumber, tomato	*Penicillium* (blue mould)	Fungi
Grape, peach, broccoli, cabbage, cucumber, potato, tomato	*Rhizopus*	Fungi
Berries, citrus, potato, tomato	*Phytophthora*	Fungi
Lettuce head, lettuce leaf, carrot, onion, tomato	*Geotrichum*	Fungi
Banana, pineapple, sweetcorn, cucumber, onion, potato, tomato, cabbage, capsicum, carrot, celery, potato, pumpkin, squash	*Fusarium* (soft rot, potato dry rot, leafy vegetable dry rot)	Fungi
Onion, sweet corn, tomato	*Aspergillus niger* (black rot)	Fungi
Cucumber, potato, bean, beetroot	*Pythium* (cottony rot)	Fungi
Asian leafy, broccoli, rocket, spinach	*Albugo candida* (white rust)	Oomycetes/ Fungi
Bean, broccoli, cabbage, capsicum, carrot, cauliflower, cucumber, eggplant, onion, pea, squash, sweet corn, sweet potato, tomato	*Alternaria* spp. (black rot)	Fungi
Asian leafy, lettuce, cabbage, cauliflower	*Pectobacterium* spp. (bacterial soft rot)	Bacteria
Bean, capsicum, carrot, cucumber, eggplant, pea, pumpkin, squash, sweet potato, tomato	*Rhizopus* spp. (storage rot, rhizopus rot)	Fungi
Carrot	*Thielaviopsis basicola* (black root rot)	Fungi

4 STUDIES ON SANITISERS: EFFICACY AND RISKS

A Google Scholar™ search on sanitiser efficacy and risk in horticulture returned more than 1200 entries which illustrated the importance of the problem. In this review we focussed on studies conducted in New Zealand. We did include one from Australia (Premier. 2013) as it was found to be very extensive compared to the more specific studies conducted in New Zealand. We found no current reviews performed in New Zealand or Australia. For the purpose of this review we looked at scientific papers where a range of sanitisers have been tested on vegetables under different conditions (e.g. temperature, organic matter load, pH and humidity).

The studies found in the scientific literature can be categorised as follows, with some studies falling into more than one categories:

A. Type of sanitisers

- Chemical-based such as chlorine
- Organic alternatives
- Combining sanitisers with other techniques such as UV radiation or heat.

B. Type of targets

- Total counts
- *Escherichia coli*
- *Salmonella* spp.
- *Listeria monocytogenes*
- Virus
- Extended shelf life.

C. Type of horticulture products on which the sanitisers have been tested.

We classified the studies by country (New Zealand or Australia) and then by type of sanitising method. For each study we considered the organism on which they were tested, what type of products were used and finally if any environmental influences were assessed for safe and efficient use of the sanitisers.

4.1 Studies in New Zealand

We found four studies carried out in New Zealand, mainly by commercial organisations but commissioned by grower associations.

A study carried out by Dowlut et al. (2013) focused on preventing the spread of *Pseudomonas syringae* pv. *actinidiae* (Psa). The study tested four types of sanitisers (Table 8) for efficacy against Psa biovar 3 on fruit and surfaces (wooden bin, plastic bin, metal and rubber).

Table 8. Sanitisers and active agents against *Pseudomonas syringae* pv. *actinidiae* (Psa) (Table replicated from Dowlut et al. 2013).

Products	Active ingredients
HarvestCide® -gel	Bromo-chloro-dimethyl- hydantoin
Nuron-Biosafe	Sodium hypochlorite
Citrox 14T	Citrus extract
Biowash	Chlorine dioxide

The test was carried out following a protocol used in previous studies where the efficacy was tested against exposure time (1 min, 2 min, 30 s and 10 s). They tested agar susceptibility and minimum lethal concentration in saline, as well as activity when organic matter is present or absent and pH effects (Dowlut et al. 2013). Many studies seem to overlook how environmental parameters affect sanitiser efficacy. For example, this study does not take into account temperature or humidity but they did test two modes of use, i.e. spraying and dipping.
A summary of their results can be found in Table 9.

Table 9. Summary of sanitisers effects against *Pseudomonas syringae* pv. *actinidiae* (Psa). NE=Not Effective; NS=Not sensitive; S=Sensitive, or time to effectiveness). Table replicated from Dowlut et al. (2013).

Summary			Sensitive to		Spray efficiency				Dip efficiency			
Product tested	Concentration	pH	pH	OM	Wood	Rubber	Metal	Plastic	Wood	Rubber	Metal	Plastic
HarvestCide® -gel	0.1%	5.5	NS	NS	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec
Nuron-Biosafe	0.1%	7.2	NS	NS	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec
Citrox 14T	1%	3.9	S	NS	1min	1min	30sec	1min	10sec	1min	30sec	1min
Biowash	1%	8.8	NS	S	1min	NE	NE	2min	2min	NE	1min	2min

Robertson (2003) and Bussell (2004) provided data on the efficacy of sanitising chemicals against two principal pathogens of New Zealand greenhouse tomatoes, the bacterium *Erwinia carotovora* (bacterial rot) and the fungus *Botrytis cinerea* (grey mould). An older study (Nederhoff 2000) assessed safe levels of hydrogen peroxide to control disease in soil-less systems. As no studies in New Zealand targeted food safety microorganisms, we looked at studies conducted in Australia.

4.2 Studies in Australia

The main sanitiser used in Australian horticulture is chlorine, as discussed in a review by Premier (2013). In this review, efficacy of sanitisers available in Australia effective against both pathogenic and non-pathogenic microorganisms, mainly leafy vegetables, were compared.

The review focussed on two type of chemicals:

- Peroxyacetic acid and acetic acid sanitisers
- Chlorine and chlorobromo sanitisers while looking at alternatives such as:
- Organic sanitisers derived from natural material
- New and emerging chemical free sanitiser technologies (such as electrified oxidising water)

As part of the study, leafy vegetables were treated with different sanitisers and shelf life was evaluated. The study found that for growers who wash vegetables on their on the farm, 100 ppm chlorine in water is appropriate. Chlorine was easy to use and cost effective, while at a marginally increased cost the chlorobromo sanitisers were also effective. The results of the study were shared with vegetable growers in Australia to highlight the importance of sanitising.

4.3 Studies on different types of sanitising methods

4.3.1 Direct comparison

Tan et al. (2015) tested six sanitisers on *Salmonella* spp. and natural microflora found on peeled turnips (Jicama). Acidified sodium chloride (ASC, 1200 ppm, 3 min), showed major effectivity when compared to acid electrolyzed water (AcEW, 5 min), chlorine (200 ppm, 3 min), cetylpyridinium chloride (CPC, 1%, 3 min), ozonated water (2 ppm, 5 min) and sodium dichloroisocyanurate (NaDCC, 150 ppm, 10 min). Acidified sodium chloride reduced *Salmonella* spp. by 4 $\log_{10}$ CFU for samples spiked between 10^4 and 10^5 CFU *Salmonella* spp. and reduced natural microflora by 2 $\log_{10}$ CFU.

4.3.2 Chlorine-based sanitisers: Chlorine (hypochlorite), chlorine dioxide and acidified sodium chlorite

The effectiveness of an antimicrobial product depends on the product surface structure, the microbial physiology and the treatment conditions (pH and temperature, for example).
It also depends on the chemical and physical state of the antimicrobial product. According to the Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables (1998), for fresh produce a suitable sanitiser treatment would be a 1–2 min exposure to 50–200 ppm chlorine at pH 6.0–7.5.

Chlorine dioxide (ClO_2) is effective against bacteria, viruses and is also registered as a fungicide. It has higher potency than sodium hypochlorite. A study by Banach et al. (2017) evaluated the efficacy of chlorine dioxide, sodium hypochlorite and a silver-copper solution for decreasing *Salmonella* Typhimurium and extended-spectrum beta-lactamase (ESBL) *Escherichia coli*. They also evaluated the impact that bacterial cell history (starved or non-starved) and water quality (potable, wash or organically loaded process water) had on sanitiser efficacy. They reported chlorine dioxide and sodium chloride were more effective than silver-copper solution for preventing cross-contamination in potable water.

A major finding was that in order to stop cross contamination, rather than treating the actual produce, treatment and disinfection of the wash water was of prime importance. A study by Hassenberg (2017), which investigated the efficacy of ClO_2 in the presence of organic matter and in relation to temperature changes, complements the study by Banach et al. (2017). This study focused on the chemical oxygen demand (COD) of wash water used to wash the vegetables. The COD of water is usually low in laboratory-based tests. Biocidal efficiency of ClO_2 is influenced by factors such as effluents, pH, temperature and organic matter load. The authors found that decreasing the temperature or increasing the organic matter content of processing water resulted in a pronounced increase in ClO_2 demand. As a result of these findings they recommended a second washing step after removing organic pollutants.

A study by Lee et al. (2004) tested the use of ClO_2 gas on foodborne pathogens on lettuce leaves. Rather than an aqueous solution, the gas was generated by a dry chemical sachet. Lettuce leaves were inoculated with a mixture of three bacterial strains, namely *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella* Typhimurium, and treated with ClO_2 gas for up to 3 h in a model gas cabinet at room temperature (22 +/- 2ºC). Post treatment, all survivors (including injured cells) were enumerated. The reductions were between 3.4 and 6.9 log depending on the species and the exposure time. The chlorine dioxide (ClO_2), gas sachet method achieved the desired effective kill without reducing visual quality. While the authors claim chlorine dioxide (ClO_2) gas sachets could enhance the microbial safety of lettuce when used during storage and transport to storage, it would be beneficial to test ClO_2 efficacy under varying conditions such as humidity.

A further study, from Sun et al. (2017) on grapefruit quality and safety, observed that in 24 h the microbial load decreases up to 1 log after treatment with controlled-release chlorine dioxide (ClO_2 gas. In this experiment, *Escherichia coli* or *Penicillium digitatum*, or natural *Xanthomonas citri* Citri **(***Xcc*) (fruits with citrus canker lesions), were inoculated on the fruit and then stored in boxes under commercial conditions. During incubation in a controlled chamber system, treatment was carried out using a dose equivalent to 0–60 $mg \cdot L^{-1}$ of pure ClO_2.The growth of *Penicillium digitatum* and *Escherichia coli* was completely inhibited with a dose of 5 mg/L in 24 hours. To eliminate *Xcc***,** a higher dose of 60 $mg \cdot L^{-1}$ was required. As part of the commercial scale simulation study, five treatments were performed: slower release, faster release, slower and faster release in combination (each containing 14.5 mg/L of pure ClO_2), double dose faster release (containing 29 mg/L ClO_2) and control using ClO_2 packets attached to top lids of commercially packaged 29 L citrus boxes. Evaluation of fruit quality was carried out either to match with normal storage and transportation times (10°C/6 weeks) or retail marketing (20°C/1 week). Yeast and moulds and total aerobic counts were reduced by 0.94 and 0.95 log CFU/g of fruit using the slower release treatment at standard dose. This was the best treatment microbiologically and from an overall quality aspect including sensory quality and visual quality. Peel browning was observed for higher doses.

Several studies included viruses as pathogens. Wengert et al. (2017) assessed the efficacy of a chlorine-based sanitiser against coliphage MS2 (used as a surrogate for pathogens that cause human disease) on fresh-cut Romaine lettuce during a simulated commercial production using a small-scale processing line. Their findings suggest that the currently recommended commercial production practices are unable to effectively decrease viruses once they have attached to leafy greens during commercial processing. Fuzawa et al. (2016) confirmed that leaf surface has an impact on the efficacy of sanitisers for Rotavirus inactivation.

4.3.3 Hydrogen peroxide

One study reported that at room temperature, hydrogen peroxide (0.04–1.25%) had efficacy comparable to 100–200 ppm chlorine (Olmez 2009). Higher temperatures (50–60°C) produced better reductions in microbial counts and better overall quality in another study (McWatters 2002).

4.3.4 Peroxyacetic acid

According to Neo et al (2013), the efficacy of peroxyacetic acid used on mung bean sprouts for reducing *Listeria monocytogenes, Salmonella* spp, Shiga toxigenic *Escherichia coli* and natural microflora was the same or slightly better than chlorine. When treated for 180 s, the inoculated pathogenic bacteria was reduced by 1.5 logs and 2.3 log for peroxyacetic acid at 70 ppm and chlorine at 170 ppm respectively (Shan Yu 2013). At 80 ppm in wash water (the maximum allowable concentration), less than 1.5 and only 1.7 log $_{10}$ CFU/g reductions were obtained for celery and fresh-cut cabbage respectively (Hilgren 200; Vandekinderen 2007) and 120 ppm was required to achieve a 1.2 log CFU/g reduction in microbial load (Vandekinderen 2007). Peroxyacetic acid is a good choice if it is necessary to use the sanitiser in cooler conditions since it can be used at refrigerated storage temperatures to directly kill bacteria. It is effective against *Listeria monocytogenes* in leafy greens and breaks down to acetic acid which slows the growth of *Listeria monocytogenes*.

Another major advantage of using peroxyacetic acid is that while treatment with hypochlorite and chlorine dioxide requires final rinsing in potable water, this is not necessary for peroxyacetic acid (Gombas 2017).

4.3.5 Quaternary ammonium compounds:

Listeria monocytogenes, Salmonella Typhimurium *and* Shiga toxigenic *Escherichia coli* were reduced by 1.56, 3.15 and 3.70 log $_{10}$ CFU/g in radish, cauliflower and broccoli when cetylpyridinium chloride was used at $5x10^3$ ppm. (Wang, 2001). Another study by Chaidez et al (2007) assessed the disinfectant activity of different doses of quaternary ammonium compounds in fresh produce wash water under different turbidity conditions and 2 contact times. They found quaternary ammonium compounds were effective against both *Staphylococcus aureus* and *Escherichia coli*. There was no effect of turbidity on reduction of *Staphylococcus aureus*, however higher reductions were obtained for *Escherichia coli* in lower turbidity (Chaidez et al, 2007).

4.3.6 Organic alternatives and other techniques

Organic acids

Organic acids include ascorbic acid, acetic acid, citric acid, lactic acid and tartaric acid, and are mostly generally recognised as safe (GRAS) compounds. Akbas (2007) found that microbial reductions for natural microflora was comparable to that of 100 ppm chlorine when fresh-cut iceberg lettuce was dipped in 0.5% lactic or citric acid for 2 min. In another study, a 15 min treatment with 2% acetic acid or 40% vinegar solution reduced CFU of *Yersinia enterocolitica* on parsley by 7 log_{10} CFU (Karapinar 1992). According to Ramos et al. (2013), however, for organic acids, antimicrobial efficacy could be low and is dependent on the microorganism strain and acid type. Sensory quality might also be affected due to the characteristic smell of organic acids and generally a significant reduction requires longer (5–15 min) exposure time (Olmez 2009).

Electrolyzed water

A study by Ding et al. (2015) looked at the effect of ultrasound and slightly acidic electrolyzed water (SAEW) on the microbiological quality of strawberries and tomatoes. The effect of the treatments was evaluated on available chlorine concentration (ACC), spectrophotometric characteristics, pH and oxidation reduction potential (ORP). It was found that ACC, ORP and pH of SAEW were not affected by a 10 min ultrasonic treatment. Ultrasound enhanced the bactericidal activity of SAEW. For strawberries and tomatoes, yeast and moulds and total aerobic bacteria were reduced by 1.29 and 1.50 and 1.29 and 1.77 log reductions respectively. However, while all other quality parameters remained the same, tomatoes demonstrated a reduction in firmness. This research indicates that SAEW in combination with ultrasound treatment could provide a suitable sanitization option, however more research is required to improve efficacy without losing quality.

Another non-chlorine technique is the use of a combination of low-concentration electrolysed water (LcEW; 4 mg/L free available chlorine) with mild heat (50°C). There are two types of electrolyzed water: acidic electrolyzed water/electrolyzed oxidising water (AEW) and neutral electrolysed water (NEW) (Ramos et al. 2013). According to Selma et al. (2008), bacteria (pathogenic and non-pathogenic) are affected by the strong bactericidal properties of AEW. In 2017, Liu et al. (2017) evaluated this combination on the safety and quality of fresh organic broccoli (*Brassica oleracea*). They observed a reduction in naturally occurring microorganisms and pathogens, including inoculated *Escherichia coli* O157:H7 and *Listeria monocytogenes* ($P < 0.05$). The general properties of broccoli such as antioxidant properties, the total phenolic levels and ferric reducing antioxidant power remained unchanged, however, the oxygen radical absorbance capacity of the treated broccoli was higher than that of the untreated control. In addition, mild heat treatment resulted in increased firmness. The increased firmness was attributed to changes in the pectin structure, including the assembly and dynamics of pectin. The results revealed that mild heat induced an antiparallel orientation and spontaneous aggregation of the pectin chains. This study demonstrated that LcEW combined with 50°C heat treatment was effective in reducing microbial counts on fresh organic broccoli without compromising the product quality (Liu et al. 2017).

A study by Tirawat et al. (2016) looking at the efficacy of acidic electrolyzed water (AEW) and lactic acid (LA) for mesophilic bacteria in sweet basil concluded that AEW was less effective than LA. LA was more efficient when combined with mild heat to disinfect sweet basil inoculated with *Salmonella* Typhimurium and *Escherichia coli*.

A more recent study by Trevisani et al. (2017) demonstrated the synergetic effect of Sodium dodecyl sulphate (SDS), lactic acid (LA and atmospheric cold plasma (ACP) on *Listeria monocytogenes* and verotoxin-producing *Escherichia coli* in red chicory, showing up to a 4 log reduction in pathogen loads. *Listeria monocytogenes* (Gram positive) required a longer washing/ exposure time than *Escherichia coli* (Gram negative) to achieve equivalent reductions in microbial counts. From this it could be concluded that the magnitude of cell damage depends on the cell membrane and cell wall structure of the microorganism. For red chicory, although ACP had some effects on odour and overall acceptability, combination treatments did not reduce sensory acceptability based on texture, colour or freshness. ACP and sanitisers in combination treatment form could be an important option to explore though research is required for optimising the treatment parameters.

Pyatkovskyy et al. (2017) studied the effectiveness of a commercial liquid sanitiser Pro-San L (0.66% citric acid, 0.036% SDS) alone and in combination with gaseous ozone against *Escherichia coli* on baby spinach. *Escherichia coli* O157:H7 was reduced by 3.9 log CFU/g using an effective combination treatment. This involved an initial spray application of Pro-San L followed by vacuum cooling and ozonation under pressure of 68.9 kPa (10 PSIG). The microbial load decreased to undetectable levels after 1 day when the spinach was stored long-term (3 days) after spraying with Pro-San and treated with gaseous ozone. The spinach leaves were damaged if the contact time with sanitisers was increased.

Ultraviolet-C (UV-C) light and ozone

A 2017 study by Gutiérrez et al. (2017) investigated microbiological quality, headspace gas composition, sensory attributes (colour, appearance, odour and decay) and chlorophyll a and b, total chlorophyll and total carotenoids for fresh-cut rocket treated with a combination of UV-C and gaseous ozone. They found, compared to a combination of gaseous ozone and chlorine treatments, a 20 kJ UV-C/m^2 treatment was superior after storage for 8 days at 5°C. The findings are promising for the use of this novel technology for fresh cut rocket.

A study on the integration of non-thermal UV-C treatment with a novel antimicrobial wash on whole tomato surfaces inoculated with three serotypes of *Salmonella* spp. (Mukhopadhyay 2015) found that inactivation efficacy of combined treatments varied widely depending on the sanitiser properties. Aqueous ozone (1 ppm) was the least effective, while a novel antimicrobial preparation 'HEN', formulated mixing hydrogen peroxide, Ethylenediaminetetraacetic acid (EDTA) and nisin, provided the best log reduction (4.71 ± 0.25 log CFU/fruit). Findings from this study suggest safe and effective postharvest intervention strategies are available to the produce industry as an alternative to current chlorine based wash.

Ozone is also considered to have strong antimicrobial activity. It is highly reactive and has high penetrability (Ramos et al. 2013). Ozone generation/production has lower running costs and it is GRAS. Ozone does not produce any hazardous disinfection by-products and decomposes into non-toxic products. Gaseous ozone is more effective against pathogenic and non-pathogenic microorganisms than aqueous ozone. However, gaseous ozone could be hazardous, toxic and reactive in this form (Picchioni 1996; Martin-Diana 2005; Anino 2006; Alexandre 2011).

Green tea extract, calcinated calcium and calcium-based solutions

Randazzo et al. (2017) showed that the antiviral activity of green tea extract (GTE) increased as pH increased. GTE showed complete inactivation of hepatitis A virus (HAV) and murine norovirus (MNV) in suspension at 37°C after overnight exposure. It also completely inactivated HAV at 25°C after similar time. GTE showed temperature, concentration and contact-time dependent response. For stainless steel and glass surfaces GTE was able to eliminate HAV and reduce MNV by 1.5 log count when the surface was treated with 10 mg/ml GTE for 30 min. Used at the same concentration, GTE was also found effective for lettuce and spinach in reducing bacterial count by 1.5 log after 30 min exposure. For controlling enteric viral contaminations for food and food contact surfaces GTE thus shows great prospects.

4.3.7 Novel and emerging biocides and sanitisers

Biocides, biocidal agents and new and alternative sanitisers

European legislation defines a biocide as “a chemical substance or microorganism intended to destroy, deter, render harmless, or exert a controlling effect on any harmful organism by chemical or biological means.”(EU Biocide Regulation 2012)(Wikipedia 2018).

The EPA however defines biocides as: "a diverse group of poisonous substances including preservatives, insecticides, disinfectants, and pesticides used for the control of organisms that are harmful to human or animal health or that cause damage to natural or manufactured products.”) (Wikipedia 2018)

Apart from biocides, a range of other biocidal agents are currently in use (Prado-Silva 2015). These include sodium dichloroisocyanurate, triclosan, benzalkonium chloride, cetylpyridinium chloride, chlorhexidine diacetate and trisodium phosphate (Maffei 2016; Suzuki 2016).

There are certain opportunities to include new biocidal treatments in the categories where:

- New chemical agents that have been approved for use, but have not yet been adopted
- New chemical agents that show promise in the laboratory, but have not yet been registered
- Combinations of chemical agents that show synergistic activity allowing the reduction in the levels used
- The combination of physical and chemical treatments
- Biological treatments, and the potential role for bacteriophage and probiotics.

However, in the course of time, resistance to biocides may appear. With regards to developing resistance, reports suggest that stepwise exposure to a series of biocides at sub-inhibitory concentrations could result in increased tolerance to biocides, or other biocides and antibiotics (Mavri 2016).

There have been studies on the positive effect of combination treatments such as dry-heat treatment (50°C) in combination with chemical treatments (1% oxalic acid, 0.03% phytic acid, 50% ethanol, electrolyzed acidic water, and electrolyzed alkaline water) for reducing *E. coli* O157 on alfalfa, radish, and broccoli and mung bean seeds (Bari 2009). Additional treatments such as mild heat, UV or ultrasound can also help the biocidal action of sanitiser. There is also the potential to use bacteriophages but this area of research was outside the scope of this review.

4.3.8 Conclusion

Most studies investigated sanitiser efficacy by either measuring the reduction in total counts or in the number of specific bacteria such as *Escherichia coli* or *Salmonella*. It is important when reviewing tests on sanitisers that the study takes into account the effect of environmental parameters that can change during treatment such as pH, temperature, humidity, or organic matter load. Effective sanitation should therefore consider these parameters when deciding on the exact procedure (sanitiser quantity and mode of delivery) to be used to handle the vegetables.

The temperature of the water used for washing and sanitising should be higher than the produce by 5–10°C to prevent water along with any contaminants being sucked inside the tissues of the produce (a process known as internalisation). (Agar 2015).

In general, effective product cleaning should always precede sanitation. To ensure the proper exposure of the bacteria to the sanitiser, the surface of equipment needs to be clean. If the water to which the sanitiser is added has major organic load, the sanitiser would combine with the organic load rather than the smaller bacteria (Schuler et al. 1986).

According to Premier (2013), aqueous solutions of chlorine dioxide or sodium hypochlorite are widely used. These are efficient sanitisers with a reduction of several log counts of bacteria species when used appropriately. Slow release chlorine dioxide gas offers extended shelf life to produce.

At present, “organic” treatments do not seem to offer efficient alternatives to chemical sanitisers except for the antiviral potential of GTE.

In conclusion, most studies agree that the main food safety risks to produce come from irrigation or wash water, followed by how the produce is handled postharvest (Mahajan 2017).

4.4 Human health and environmental risks associated with the use of sanitisers

A major issue facing all facilities is the potential for reactions between cleaning and sanitising products. Some highly reactive chemicals will produce toxic fumes when in contact with other cleaners. Most cleaning and sanitising products have one or more active chemical ingredient in them. Some of them might be more reactive than others and when they come in close contact, formation of toxic products could occur. An example would be mixing of basic and acidic cleaning chemicals.

The material safety datasheets (MSDS) provide detailed information for commercial cleaners and sanitisers. If using bleach as a sanitiser the surface area should be cleaned first. Appropriate ventilation should be available whenever using bleach for closed or confined spaces to avoid respiratory hazards. Studies and policies recognise that wash water should be treated before release (Fuzawa 2016). When ozone or ClO_2 is used in gaseous form it might pose a health and safety risk if the gas dissipates into atmosphere. It is better to use ClO_2 in a stabilised form, a salt-form in solution with bicarbonate. For bromochlorodimethylhydantoin (BCDMH), the breakdown product is dimethyl hydantoin (DMH). As per the FSANZ guidelines, the allowable daily intake of DMH is 0.025 mg/Kg of body weight which equates to 2 mg/kg of vegetables (Premier 2013) and an increased intake is not recommended. So this factor must be taken into consideration while choosing BCDMH. Use of excess chlorine for treatment of wastewater which has high total organic carbon content (TOC) (Fawell 2003) is also hazardous as this might produce high levels of trihalomethanes (THMs) and other carcinogenic disinfection by-products.

4.5 Risks and recommendations for coolers and cool storage

Best practice postharvest handling for nearly all vegetables involves cooling after harvest and maintaining temperatures to ensure optimum produce quality. Physical damage (cuts, bruising or crushing) will reduce quality by increasing rots (i.e. plant pathogens), but also lead to increased food safety concerns since damaged leaf juices or fruit juice provide substrates for pathogen growth (Food navigator 2016)Factors such as product integrity, pH and refrigeration are thus important in preventing contamination with pathogenic bacteria. In the produce industry cooling with cold air or water (hydrocooling) is common, and in some cases ice is used (e.g. for broccoli). Water and ice can lead to microbial contamination of produce if the microbiological quality of water is not managed. If the water is circulated or re-used to cool consecutive batches of vegetables this again can cause cross contamination. Management practises should include:

- Addition of antimicrobial chemicals in the water
- Microbial testing for water used for cooling and for making ice
- Adequate information about source and quality of ice
- The ice making, storage and transportation following microbiologically safe and sanitary conditions
- Changing water in hydrocoolers regularly
- Cleaning and sanitizing internal parts of the hydrocoolers
- Control of microbial loadings in chilling equipment (e.g. hydrocoolers and containers holding vegetables should be cleaned and sanitised regularly. Before cooling down produce all external contaminants e.g. soil, manures should be eliminated)
- Temperature control for water so that bacterial growth is inhibited.

See the Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits (1998) for more information.

4.6 Disposal

The current methods of disposal of sanitisers in New Zealand are recorded in Section 2.1.15. Some health and safety risks associated with the use of sanitisers has also been discussed in Section 4.4. Disposal is often based on:

- Visible organic contaminants,
- decreased concentration of the active compounds,
- Potential or measured formation of inactive or toxic secondary compounds or breakdown products.

Disposal of sanitisers is of major importance as often some of the sanitisers produce harmful disinfection by-products when they break down chemically after use. This has also been discussed under the ‘Limitations’ heading in Table 1. An example would be when chlorine is applied directly or in cases of hyper chlorination, formation of carcinogenic or halogenated breakdown products occur. Hence, disposal methods for these sanitisers need careful consideration. However, for some other sanitisers, such as chlorine dioxide and peroxyacetic acid, the end product are chloramines and trihalomethanes, and acetic acid and active oxygen, respectively. None of these present toxicity risks and or the risk of antimicrobial resistance from the microbes (Kim et al. 1999). The degradation product of ozone is oxygen and it is environmentally friendly (Khadre et al. 2007; Kim et al. 2007).

5 ALLOWABLE RESIDUES

As part of the review we attempted to gather information on allowable sanitiser residues on vegetables for domestic and International markets. There is a section on exporting fruits and vegetables from New Zealand in The Ministry of Primary Industries (MPI) website: Exporting Fruit and Vegetables. (MPI 2018). Available information on this site suggests that some vegetable crops such as garlic, leeks, potatoes, onions and shallots need additional requirements. There are diverse requirements, phytosanitary certificates or jurisdiction regulations/requirements depending on the importing countries. It should be noted that individual companies (e.g. supermarket chains) may have additional regulations that are more rigorous than the country regulations. Similar to Overseas Market Access Requirements (OMARs) for meat dairy and seafood, for fruits and vegetables there are Official Assurance Programmes (OAPs). However, the plant export OAP documents are password protected so the information is not easily accessible.

From an international perspective, to prepare a list of allowable residues, we would need to search each individual country or jurisdiction to find the approved legal uses and allowable residual levels for each chemical/product. This in itself is a major area to review and was deemed outside the scope of this project.

There is however, some information available in literature such as the fact that hypochlorite is banned in European countries. Apart from biocides some new and alternative sanitisers e.g. chlorine dioxide, hydrogen peroxide, peroxyacetic acid and ozone have been approved for use as sanitisers for fresh and minimally processed fruits and vegetables by the US Food and Drug Administration (Rico 2007), in addition to sodium hypochlorite (Bachelli 2013).

For ClO_2, within the European Union (EU), there are no regulations concerning ClO_2 application in fresh-cut produce washing (López-Gálvez, 2010). In the US, as long as the residual ClO_2 is below 3 ppm and treatment is followed by a potable rinse, the US FDA permits ClO_2 as an antimicrobial agent in the water used to wash fruit and vegetables. (FDA 2017).

Peroxyacetic acid is allowable at 80 ppm concentration in wash water for fruits and vegetables according to US Code of Federal Regulations (CFR 2007).

Overall, information on allowable residue of different sanitisers on vegetables for domestic and international markets was not easily available as a single document. However, the requirements for the New Zealand market are available. Section 1.3.3-4 and Schedule 18-2 of The Australia New Zealand Food standard 1.3.3 on processing aids lists chemicals that are generally permitted such as ethyl alcohol, isopropyl alcohol and potassium or sodium hydroxide (Food standard Australia New Zealand 2016).

The Australia New Zealand Food standard 2016 1.3.3, Section 1.3.3-9 provides information on water as a processing aid under the section: Bleaching, washing and peeling agents- various foods. This section states that “a substance may be used as a processing aid to perform the technological purpose of… a washing agent… for a food if the substance:

- Is used in relation to a food listed in the corresponding row of the table; and
- Is not present in the food at a level greater than the maximum permitted indicated in the corresponding row of the table (Australia New Zealand Food Standard 2016).”

The permitted concentrations are thus given as residues that are allowed in the food rather than the concentrations allowed in the water used for washing. The processing aid sanitisers for water from Schedule 18-6 (Permitted processing aids for water) are shown in Table 10.

Table 10. Permitted processing aids for water (Section 1.3.3-8, Australia New Zealand Food Standard 2016) (Table modified and redrawn to include only the sanitisers)

Substance	Maximum permitted level (mg/Kg)
Calcium hypochlorite	5 (available chlorine)
Chlorine	1 (available chlorine)
Ozone	Good manufacturing practices (GMP)

The processing aid sanitisers permitted for washing for various foods (Schedule 18-7) are tabulated in Table 11.

Table 11. Permitted bleaching, washing and peeling agents-various foods (Schedule 18-7: Australia New Zealand Food Standard 2016: Table modified and redrawn to include only the sanitisers).

Substance	Food	Maximum permitted level (mg/Kg)
Benzoyl peroxide	All foods	40 (measured as benzoic acid)
Bromo-chloro-dimethylhydantoin	All foods	1.0: (available chlorine) 1.0: (inorganic bromide) 2.0 (dimethylhydantoin)
Calcium hypochlorite	All foods	1.0: (available chlorine)
Chlorine	All foods	1.0: (available chlorine)
Chlorine dioxide	All foods	1.0: (available chlorine)
Hydrogen peroxide	All foods	5
Iodine	Fruits, vegetables and egg	GMP
Ozone	All foods	GMP
Peroxyacetic acid	All foods	GMP
Sodium chlorite	All foods	1.0: (available chlorine)
Sodium hypochlorite	All foods	1.0: (available chlorine)

"Sodium chlorite is permitted for use as an antimicrobial agent for meat, fish, fruit and vegetables. The maximum permitted level is the 'Limit of Determination' of chlorite, chlorate, chlorous acid and chlorine dioxide" (Permitted processing aids- various purposes (Section 1.3.3-11, Australia New Zealand Food Standard 2016).

According to Australia New Zealand Food Standard 1.3.3, only sanitisers listed in Tables 10 and 11 are permitted to be used for washing vegetables. Permission would have to be sought to use any novel chemical sanitisers.

6 NON-TECHNICAL SUMMARY

Disease outbreaks caused by pathogens on fresh produce (vegetables and fruits) have become frequent events worldwide, can receive considerable media coverage, and are affecting the economics of growing fruit and vegetable crops. An effective way to mitigate food safety risk in the postharvest horticultural produce environment is by reducing microbial growth and preventing cross contamination. This is possible by the judicious use of sanitisers.

The VR & I Board want to enhance the understanding of current practices for sanitiser use in the New Zealand vegetable industry and thus PFR was asked to review the role of sanitisers in vegetable food safety.

Bacteria (both pathogenic and non-pathogenic) and fungi can affect vegetable quality. Human pathogenic bacteria associated with produce can cause food recalls, outbreaks of illness and even death. When used in appropriate concentrations and doses, sanitisers can reduce this risk.

As part of the review, a survey of sanitisers currently in use by vegetable growers was carried out. This showed a diverse range of sanitisers being used, including those based on chlorine (sodium or calcium hypochlorite), chlorine combined with bromine, chlorine dioxide, peroxyacetic acid, ozone and quaternary ammonium compounds. These sanitisers were used for various reasons including sanitising wash water, equipment and product contact surfaces, and for sanitising hands. Most growers recognised the need for more information about the sanitisers although producers were generally cognisant of the various regulations and guidelines relevant to use of sanitisers.

The review provides information on chemical sanitisers, organic alternatives and novel and emerging biocides and sanitisers. It also includes information on sanitiser efficacy and risks including studies from New Zealand and Australia.

Other key points are:

- It is necessary to select suitable sanitisers for a particular produce and the production conditions
- The correct handling, storage and disposal of sanitisers is vital as sanitisers are mostly hazardous chemicals
- After use, most sanitisers need to be removed from produce and equipment surfaces by rinsing
- Sanitisers not properly removed may pose risks in terms of food safety. Domestic and international markets have varying rules in relation to residues which must be considered
- Product cleaning is required before applying sanitisers so that the organic load does not interfere with the active sanitising agent
- New sanitisers, or biocides or alternative methods for sanitising need careful consideration before being used in the vegetable industry.

7 IDENTIFICATION OF KNOWLEDGE GAPS AND RECOMMENDATIONS FOR FURTHER RESEARCH FOR SANITISERS IN NEW ZEALAND VEGETABLE INDUSTRY

At present limited data are available to allow selection of appropriate sanitisers for the different varieties of vegetables grown in New Zealand.

Often, the basis for the selection of a sanitiser is dependent only upon efficacy data generated overseas. This could be a potential issue, as there are effects of geographical locations, genetic diversity and environmental responses on the risks to vegetables and vegetable-packing facilities. One recommendation thus would be the initiation of a monitoring programme for New Zealand vegetable-packing facilities, to understand the actual risks in our vegetable-handling and packaging facility micro-environments. This would provide informed direction for best-practice and research for the New Zealand vegetable industry, rather than using International published data to determine risk. This could be carried out as a commercial research project, and would help to identify the key risk pathogens, and determine food safety hotspots in the vegetable packhouse environment. It would help in the determination of the “best” sanitiser for a particular produce/type of produce.

Each vegetable is unique, and the application and effects of sanitisers on different types of vegetables will differ. It is therefore important to match particular sanitisers with the best cleaning systems for each crop, rather than use a single generic sanitiser.

Where rots are commercially important, the effects that the presence of preharvest fungicides may have on the effectiveness of a sanitiser on a vegetable crop will need to be explored.

In the published literature, the vast majority of sanitiser efficacy studies have been carried out only under laboratory conditions. As the complexity of a vegetable-packaging facility can be enormous, with a variety of configurations and operational parameters, it is important to validate sanitisers under real-world conditions.

Consumer demands for safe and environmentally friendly sanitisers will become an increasingly important driving force in the selection of sanitisers for both the domestic and export markets. Currently, there is a lack of information on suitable alternative, more environmentally friendly sanitisers, their efficacy on a variety of produce, and their market acceptance. Alternative approaches to chemical sanitising agents (e.g. UV disinfection, ozonation, filtration/reverse osmosis) is in itself a large area of research. A review on efficacy for these processes should be undertaken.

Understanding vegetable food safety risks in relation to the current consumer food safety culture is an emerging area of research. Food safety familiarisation workshops to address knowledge gaps and thus provide information could assist the New Zealand vegetable industry to enhance overall consumer understanding.

Finally, a code of practice/best-practice guidelines for the New Zealand vegetable industry need to be put in place, which would include recommendations for choice of sanitiser (using the information in Table 1), their storage, use, disposal, and information on allowable residues for vegetable food safety associated with the use of sanitisers for a variety of crops. The current review could serve as background, with our suggested inputs. This would then become an important active working document for New Zealand vegetable producers.

The example of the recent *Listeria* crisis in the rockmelon industry in Australia provides a sobering reminder of the need to understand food safety of a crop, the appropriate response, and the economic and consumer confidence recovery. It is worth noting that horticultural industry investment in food safety is significantly higher in Australia than New Zealand.

8 RECOMMENDATIONS TO ASSIST DEVELOPMENT OF GOOD OPERATING PRACTICES (GOP) GUIDELINES

It is not possible to make generic recommendations of sanitisers that are suitable for all vegetables and accepted for use in both export and domestic markets. Based on an in-depth review of published information and our extensive expertise in the area of horticultural food safety, the authors' recommendations are as follows:

The VR & I Board or other suitable authorizing body should publish a list of sanitisers that are recommended for use in the New Zealand vegetable industry. The selection could be started from information provided in this review (particularly the information summarised in Table 1). This could form part of a code of practice for the entire New Zealand vegetable industry. This code of practice would include information on recommended choice/applications of sanitiser, dose, sanitiser disposal issues and the international regulatory environment, taking into account the manufacturers' recommendations for each of the sanitisers.

Other important aspects for GOP for sanitiser use would include:

- Water quality: If not from town supply, water quality should be monitored, including irrigation water, wash water, and water used to prepare sanitisers. Water quality assessments should initially be carried out throughout the year, especially focusing on periods of seasonal change. A regular monitoring programme in any high-risk seasons should be implemented.
- Minimising build-up of organic loads in wash water: Producers need to ensure that water containing sanitisers is dumped, or treated and recycled, when microbiological or organic loads increase. This is because the quality of water in which sanitisers are applied can greatly affect the efficacy of the sanitisers' ability to protect vegetable food safety. Because most vegetables are often grown near, or in the soil, this is a particular challenge. Special precautions should be taken for re-use of wash water. Where washing is used, multi-step washing is recommended, i.e. separate water bodies, with initial wash going to waste systems, and the separate final step containing a sanitiser.
- Monitoring and testing for sanitiser concentrations: During vegetable packing operations sanitiser concentrations in the wash water should be monitored regularly. Dose as well as disposal are significant, because most sanitisers in high doses are toxic chemicals.
- Proper labelling and storage of sanitisers: This should incorporate an understanding of the interactions between sanitisers, so that when used/stored in conjunction with one another, their effectivity and safety are maintained.

- A documented cleaning and sanitising regime: This is required for all vegetable packing facilities.
- An ongoing efficacy monitoring programme: The effectiveness of an implemented sanitation programme should be validated by a monitoring schedule, consisting of regular testing for target bacteria, fungi or indicators such as Adenosine triphosphate (ATP) in water, packhouse surfaces and product.
- New sanitisers, biocides and alternative sanitising agents: These should go through rigorous review before being included in the "acceptable sanitisers" category.
- Organic production: This also forms a part of the industry that aims to offer safe vegetables for consumers. Organic growers who do not use chemical sanitisers should use alternative sanitisers approved for organic use, or be able to provide detailed information on the safety of their systems and products.
- Food safety culture: A good basic training programme on food safety and hygiene practices is required for all vegetable workers and managers as an outreach/extension food safety programme. This training should include: understanding the principles and methods required for use, handling and storage of sanitisers and their use in effective cleaning and sanitation; reporting worker illness; knowledge of symptoms of infectious diseases; hand washing; use of appropriate personal protective equipment (PPE); covering cuts and wounds; and basic knowledge of the regulatory environment. Retention of information is as important as learning a process, so refresher courses should also be implemented. Training is required because knowledge gaps and lack of information/understanding could be major issues that could affect the overall process/performance.
- Hygienic equipment design for new construction is recommended, which would make cleaning and sanitising easier so that biofilm formation and build-up of microbial load within the packing facility could be more easily avoided. Where older facilities/construction exist, provision should be made for possible upgrades to enable proper cleaning and sanitising of the facility.

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