

Evaluation of vegetable washing chemicals

Robert Premier
Global F.S. Pty Ltd

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VG09086

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Evaluation of vegetable washing chemicals (VG09086)

Final report for HAL project

(June 2012)

Robert Premier

Global F.S. Pty Ltd

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Final report for HAL project VG09086

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Scope of the Report

This report presents the key findings and a summary of the work conducted in Victoria by the project team to evaluate various wash water treatments available to commercial vegetable growers to reduce the incidence of food borne illness and postharvest diseases.

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1. Media Summary

Vegetables, including leafy vegetables, are an important component of a healthy diet; they contain nutrients that are now known to be beneficial for the health of consumers. These nutrients are often referred to as phytochemicals or phytonutrients. They have a range of actions on the human body through their interaction at the cellular level. There is sufficient information in the literature to show that they protect consumers from heart disease, inflammation, cancer formation and many other chronic diseases. The anti cancer properties of phytonutrients can be due to a number of interactions, including the induction of phase I or II detoxification enzymes, modulation of phase I and other enzyme activities, antioxidant activity, electrophile scavenging activity, inhibition of nitrosation, and/or modulation of oncogene or protooncogene expression or function.

Health authorities are actively encouraging the consumption of vegetables through their 5 a day or 7 a day campaigns. This is having an effect on the consumption patterns in developed countries with consumers being more aware of the importance of vegetables in their diets.

There is however a perception that vegetables, and in particular leafy vegetables, can be the source of food poisoning outbreaks. This has in fact been an issue overseas in recent years, with severe outbreaks reported in the USA and Germany due to human pathogen contamination of vegetables. In Australia this has not been an issue, due mostly to the successful implementation of on-farm QA plans that growers must follow before they can sell their products to consumers through markets and supermarkets.

Part of the requirements of a good on-farm QA plan is the sanitary washing of vegetables, especially leafy vegetables, in water containing a sanitiser chemical. This sanitation step will reduce the levels of bacteria, including any contaminating human pathogens, and prevent cross contamination of produce during the washing stage.

In Australia there have been many chemicals available to growers, however growers do not have much independent information available regarding these chemicals.

This project has evaluated a number of chemicals and compared them in terms of efficacy, ease of use, cost and effects on the postharvest shelf life of leafy vegetables.

The results show that Chlorine, as used currently by growers, is still an efficient way to achieve the aims of the sanitation step. An emerging technology using electrified oxidizing water has however shown excellent results and could become a very useful tool for the sanitary washing of vegetables at on-farm level in the near future. The process would fulfil a chemical free washing claim and also be user friendly for the grower; it can be easily adapted to an automatic system with record of efficacy available for review by auditors of on-farm QA systems.

2. Technical Summary

The aim of this project was to compare the efficacy of sanitising chemicals available in Australia in reducing both spoilage and pathogenic microorganisms on vegetables, particularly leafy vegetables. Leafy vegetables are often consumed uncooked and hence the way that they are washed is critical in preventing food safety incidents at point of consumption. The comparison between sanitisers was done in a realistic commercial setting, using equipment already present on farm. The vegetables used in the testing were part of a normal harvest on that same farm. This project

- studied the efficacy of peroxyacetic acid and acetic acid sanitisers
- studied the efficacy of chlorine and chlorobromo sanitisers
- studied the efficacy of organic sanitisers derived from natural material

- studied the efficacy of new and emerging chemical free sanitiser technology
- studied the shelf life of leafy vegetables after treatment with a number of sanitisers.
- extended the knowledge to individual growers on the importance of the sanitation step
- supplied information to the vegetable industry on the correct ways to sanitise leafy vegetables in wash baths and hydro coolers.
- Washing vegetables in water containing 100 ppm of chlorine remains the most suitable system available to growers that wash on-farm at the moment. Chlorine has advantages in terms of efficacy, cost effectiveness and ease of handling. This is closely followed by Chlorobromo sanitisers, which are just as effective but have a slightly higher cost.

3. Key Outcomes and Conclusions

- Growers who produce leafy vegetables that are sold as pre-washed and ready to eat should consider using peroxyacetic acid based sanitisers. These sanitisers are however considerably more expensive and may contribute to a lower shelf life of the product.
- Growers who supply the organic market should consider an organic based sanitiser. Although the efficacy of these is not as good as Chlorine, Chlorobromo, or peroxyacetic acid sanitisers, they still show some level of efficacy and are better than acetic acid.
- In these trials electrified oxidised water, an emerging technology, was shown to have superior efficacy to any of the other products tested. Results also showed that product washed with electrified oxidised water had a longer shelf life.

4. Introduction

Washing of vegetables on-farm is a practice that is used routinely by vegetable growers in Australia. Vegetables need washing for three main reasons: 1) They need washing to remove dirt and dust so that they can be presented to the consumer in a visually appealing manner, 2) They need washing with sanitisers for postharvest treatment purposes so that postharvest plant diseases can be kept under control and thus increase vegetable shelf life and 3) They need washing with sanitisers for food safety purposes so that human pathogens that may be present on the surface of vegetables are not passed on to consumers.

The latter purpose is becoming more and more important as supermarkets, wholesalers and processors are pushing food safety down the line of supply to growers. Vegetable growers however have not kept up with developments in the area of sanitisers and most have not moved away from Chlorine solutions due to the fact that little or no independent information is filtering down to them in terms of new sanitisers. Chemical industry sales representatives are often the only source of information for the growers but this source of advice can be one-sided and skewed towards the product they sell.

In Australia, there have been projects to scientifically evaluate the efficacy of some new sanitisers; some of these have been funded by HAL in the past. The first of these was project VG97045 "New washing treatments for minimally processed vegetables". This project was carried out by the now defunct AIFSC and was skewed towards the processors of minimally processed vegetables and examined alternatives to Chlorine. One such alternative, which showed a lot of promise, was the use of silver and hydrogen peroxide. This combination showed enhanced bactericidal effect against both

spoilage and pathogenic microorganisms in washing trials with fresh-cut produce at bench and pilot scale. However the concept of using silver and hydrogen peroxide on food has not taken off. It has not been seen as a replacement for Chlorine in the fresh-cut industry and has not been extended to washing leafy vegetables on-farm. Since then, many other formats of washing chemicals have been developed but, again, most have not been fully scientifically evaluated. Another project that looked at this was VG99005 "Quality wash water for carrots and other vegetables". This project, using Ozone and Chlorine dioxide gas, was skewed towards root vegetables, concentrated on re-use of wash water and focused more on the postharvest disease area rather than food safety.

At the present time credible, independent evidence of the efficacy of currently available commercial sanitisers for use predominantly for food safety purposes is lacking in the vegetable industry. More importantly, leafy vegetable growers require this information urgently as there have been a number of overseas food safety outbreaks related to leafy vegetables in the last few years. These outbreaks have led quality assurance system managers to ask what is really known about the efficacy of the current vegetable washing sanitisers in Australia. With the concept of validation now being the buzz word in QA system auditing, the scrutiny of sanitisers will increase.

There are also other pressures resulting in leafy vegetable growers questioning the efficacy of the sanitiser they use, including the fact that there has been a negative response to the use of chlorine in some countries by consumers and regulators. In Australia for example, the organic industry does not allow the use of Chlorine. If organic vegetable growers want to wash leafy vegetables to reduce potential food safety issues, they really do not have credible sources of information to use in setting up a wash system for their products. In addition there is an urgent need to have an emergency plan in place in case Chlorine is banned for use with food in Australia or an export destination.

The sanitation step is becoming more and more important from a food safety perspective. Although there have not been any documented food poisoning outbreaks attributed to leafy vegetables in Australia in the past 10 years, the outbreaks that have occurred overseas have made the news headlines here. These outbreaks include the 2006 *E. coli* outbreak in bagged spinach in the USA, the Romaine lettuce outbreak in the USA in 2011 and the *E.coli* outbreak in Germany in the same year. This has lead to increased scrutiny of the food safety of leafy vegetables by supermarkets, wholesalers and processors within Australia. In addition, there have been numerous human pathogen detections during random testing of leafy vegetables by processors and supermarkets. These detections often lead to suspension of supply from a particular grower until samples show that they are clear of microbial contaminants. This has led to more growers washing leafy vegetables on-farm so as to reduce this risk to their business. There is no doubt that on-farm quality assurance programs such as Freshcare and SQF1000 have reduced this risk to growers, as it is these very programs that have focussed attention on washing systems and sanitisers used in the vegetable industry. As part of the external third party audits, growers need to show that they are maintaining adequate levels of available sanitiser in the wash tanks. This has proven difficult as most growers still use manual dipsticks (based on visual colour checks which are subjective) for testing.

A recent telephone survey conducted as part of this project showed that out of the 30 growers contacted, 27 were using Chlorine, with more than half of these using Calcium Hypochlorite and the rest using Sodium Hypochlorite. These two forms of Chlorination have advantages and disadvantages.

The growers who use Calcium Hypochlorite mostly do this by using tablets that dissolve slowly as water is passed over them. This system can produce huge levels of variability, depending on the flow of the water and on the way the tablets are made. In many cases, this leads to under chlorination, particularly if there is a large organic load (including soil) with the leafy vegetables.

The use of Sodium Hypochlorite on the other hand is easier for some growers as this is available in a liquid form, making it easy for automated dosing systems to add the required volume. An Oxidation Reduction probe can be used to regulate this addition, however these probes are not very accurate and must be checked by hand on a regular basis. This latter step is often overlooked by growers leading to over chlorination resulting in a Chlorine odour and the OH&S issues that are associated with people working in that environment. In addition to this, over-chlorination can lead to rust formation and corrosion of susceptible equipment.

For these reasons, the sanitation step can still be problematic for growers and hence they are continuously seeking a better solution.

5. Review of potential sanitisers to evaluate as part of project

Work by Behrsing *et al* (2000) shows that washing vegetables with potable water has the ability to reduce the levels of bacteria on the surface of the leaf by at least one log. The addition of 100 ppm of Chlorine only serves to further reduce the levels of bacteria on the leaf by less than an additional one log. Therefore the best that can be achieved with Chlorine is a reduction on the leaf of between one and two logs. However, the levels of bacteria in solution in wash water remaining after the washing step when using Chlorine are always close to the levels seen in potable water. The sanitiser then acts in two ways: 1) It further reduces the bacteria on the surface of the leafy vegetable (Beuchat and Ryu, 1997; Sapers, 2001) and 2) it stops cross contamination by killing most of the bacteria that wash off the leaf and into solution.

Both these points are important in deciding which sanitiser to use in the vegetable industry, especially the second point. High loads of pathogens can occur in small segments of the vegetable load being washed. These can occur for various reasons, including localised animal faeces contamination coming in from the field. If the water does not contain an active sanitiser, it is possible that cross contamination of the whole batch can occur. This has occurred in Australia previously when hydro-coolers have been used and the water did not contain an active sanitiser; the water spread the contamination throughout the entire vegetable load.

Currently, the most commonly used sanitiser in the vegetable industry is Chlorine, either in the form of Sodium Hypochlorite (NaClO) or Calcium Hypochlorite ($\text{Ca}(\text{ClO})_2$). The former is available as a liquid whereas the latter as a solid and is used as a granular additive to a stock solution or as a tablet (Brackett, 1987; Beuchat and Ryu, 1997). Many growers use Sodium Hypochlorite as it is easier to use.

There are however a growing number of alternatives that have recently emerged. Some of these have been used in the food industry for some years but have not been applied as a sanitiser in the fresh produce industry, whereas others have been specifically designed for use in the fresh produce industry.

This review summarises the chemical sanitisers that have been chosen to take part in the evaluation as required by project VG09086. The sanitisers were chosen because 1) they are easily available in Australia, 2) evidence exists that they work as a sanitiser, 3) they have the potential to be used in the vegetable industry and 4) they have the potential to offer some advantage to users in the vegetable industry.

5.1 Peroxyacetic Acid (PAA) containing sanitisers

Peroxyacetic Acid, or Peracetic acid as it is commonly referred to, is manufactured by reacting acetic acid with hydrogen peroxide, resulting in a highly stable PAA solution containing Peracetic acid and hydrogen peroxide. PAA has grown in popularity because of its effectiveness and environmental compatibility. Upon degradation, PAA breaks down into acetic acid (vinegar), water and oxygen.

One of the major advantages in using PAA is that it functions extremely well under cold conditions (4 °C) and unlike other sanitizers, does not experience cold temperature failure. For this reason, sanitization can be carried out on leafy vegetables that have been pre-cooled or in systems that use water to cool the vegetables, such as hydro-coolers.

PAA is registered with FSANZ as a sanitiser for use as a non-rinse washing aid. It is generally used at 50 to 150 ppm and is highly effective against a broad spectrum of bacteria and spores. It has been shown to be particularly effective against *Listeria monocytogenes*, the mechanism is by direct killing of bacteria but it also leaves a residue of acetic acid behind to slow down potential Listeria growth, effectively creating a lag phase for this bacterium on leafy vegetables.

The final major advantage is that it is available in Australia from a range of suppliers and comes with a number of different trade names, including Tsunami, Adoxysan, Summit and Proxitane so that technical support for growers is always available when using these products.

Some disadvantages of PAA are that it is more expensive to apply than hypochlorite and it is difficult to monitor; handheld test strips that show a colour change for PAA are still the best way to measure the levels in solution. Oxidation Reduction probes (ORP) are not sensitive enough to allow for the precise measurement of this oxidiser in solution. Another major disadvantage of this sanitiser is that if it is used at too high a concentration, it can cause damage to the tips of the leaf and it can shorten the shelf life of the produce.

5.2 Stabilised Chlorine Dioxide (ClO₂)

Chlorine Dioxide is usually a preformed gas which is then dispersed into solution. The problem with Chlorine Dioxide gas is that the agitation required to wash leafy vegetables usually causes the gas to come out of solution and dissipate into the atmosphere, potentially causing OH&S issues with operators. Only a few years ago a Chlorine Dioxide gas system installed in a vegetable farm near Melbourne caused the evacuation of the packing shed and the hospitalisation of staff (see appendix 2). However, there is now a safe alternative in the market as Stabilised Chlorine Dioxide. Stabilized Chlorine Dioxide differs structurally from Chlorine Dioxide gas and is very safe. Stabilized Chlorine Dioxide (SCD or Stabilized ClO₂, also known as Anthium Dioxide and Sodium Chlorite) is a salt form in solution with bicarbonate.

To make Stabilized Chlorine Dioxide, Chlorine Dioxide is taken and manufactured in a liquid state at high pH. Various Sodium Carbonate complexes are then added into the formulation, which link up with and bond to the Chlorine Dioxide to stabilize it. When this is placed in water, the Chlorine Dioxide gas is released. Stabilized Chlorine Dioxide is activated when it encounters bacteria although this is slower than acids and other inorganic substances.

Stabilized Chlorine Dioxide is registered with the US EPA (Environmental Protection Agency) as a bactericide, fungicide and antimicrobial agent. The FDA (Food and Drug Administration) and the USDA (United States Department of Agriculture) have approved the use of Stabilized Chlorine Dioxide

in food processing plants for sanitizing and controlling bacteria and mould. In Australia it is registered with FSANZ as a washing aid.

The major advantage of Chlorine Dioxide as a sanitiser are that it is 3 to 4 times as potent as sodium hypochlorite as a sanitising agent and is generally effective against all bacteria and viruses. It does not have the disadvantages that sodium hypochlorite has with respect to corrosion of susceptible metal surfaces. Another advantage is that the stabilised version comes in large tablets for ease of use and from a QA systems point of view it can be controlled and verified with ease by operators. Its main disadvantage is that it may pose OH&S issues if not used correctly and that it may be expensive if not impossible to use on large scale vegetable farms due to the quantity involved.

5.3 Oxidizing water (OW)

The use of OW is another way to inactivate microbes through a form of Chlorination (Izumi, 1999; Sapers, 2001). It differs from commonly used chlorine treatments in that the inactivating agent is generated directly in the water. There are conflicting claims as to where the technology has originated but most probably the technology was originally developed in Russia (Shtannikov et al. 1977).

Oxidizing water does not need special approvals in Australia for direct and indirect food contact applications and can be used as food washing aid without rinsing. Any chemical formed during the electrolysis step reverts back to the same chemicals that existed prior to electrolysis in due time. The process can be termed as chemical neutral as no chemicals are added and none are left behind after processing. The process can sometimes work better when small quantities of salt (NaCl) are added to the wash water but naturally existing salt and salts originating from the cut leaf are often sufficient to form the sanitising reactants.

Oxidizing water is created by the electrochemical disassociation of water and natural salts that may be present in solution as impurities between anode and cathode electrodes in a reaction cell. This process splits water into two separate streams, acidic (anode) and alkaline (cathode) water. OW from the anode stream has at least three antimicrobial properties that include low pH, as low as 2.5, high oxidation-reduction potential and a high level of free chlorine-based compounds (Park et al., 2001). The concentration of the chlorine compounds (usually 20 to 80 ppm) is influenced by the current (amps) of the OW generator. OW also contains a mixture of inorganic oxidants such as HClO, OCl⁻, Cl₂, and O₃, which are effective disinfectants (Yang et al., 2003). So the oxidants produced in the process of making OW combine into one effective sanitation step that has the ability to destroy microorganisms in a number of ways thus increasing the sanitation potential.

Oxidizing water has been used for inactivation of a wide variety of pathogenic and spoilage microorganisms, such as *E. coli* (including the O157:H7 strain), *Salmonella enteritidis*, *L. monocytogenes*, and *Campylobacter jejuni* (Park et al., 1999; Venkitanarayanan et al., 1999; Kim et al., 2000; Park et al., 2002; Fabrizio and Cutter, 2003). Several studies have shown that OW is effective at reducing pathogens and/or spoilage microorganisms associated with fresh fruits and vegetables (Izumi, 1999; Kim et al., 2000; Park et al., 2001).

The bactericidal activity of OW is quantitatively correlated to the free chlorine in the form of hypochlorous acid (HOCl) that forms in the solution. On the basis of chemical and spectroscopic data, Nakagawara and others (1998) concluded that the major component of acidic oxidising water is Cl₂/HOCl in chemical equilibrium at given pH values, for example, indications are that the major components are Cl₂ (at pH < 3), HOCl (at pH range 4 – 7), and ClO⁻ (at pH > 8.5). Some studies

have suggested that the very high ORP (oxidation-reduction potential) level of the anode water (> 1,100 mV) is a better indicator of bactericidal activity than pH (Kim *et al.*, 2000; Stevenson *et al.*, 2004). Thus, the concentration of HOCl is correlated to high ORP levels.

The effects of OW were evaluated in a study by Izumi (1999). The study focused on several fresh-cut vegetables, including some of which are normally found in fresh-cut salads (i.e. spinach, sliced carrots and sliced cucumbers). The researcher found that the Total Plate Counts (mesophilic aerobic bacteria) were reduced by 0.6 to 2.6 logs CFU/g when treated with oxidising water containing 15, 30, and 50 ppm available chlorine. The OW containing 50 ppm chlorine had the strongest bactericidal effect. This study noted that the effectiveness of oxidising water was the greatest with leafy vegetables (spinach leaves) which had the maximum surface area/unit weight of tissue among the tested fresh-cut vegetables. The observation that chemical sanitizer's effectiveness is influenced by the type and style of vegetables was also confirmed by Zhang and Faber (1996).

OW has been shown to be effective in reducing human pathogens including *E. coli* O157:H7, *L. monocytogenes*, and *S. Enteritidis*. In a study conducted by Venkitanarayanan *et al.* (1999), the effect of OW on the inactivation of *E. coli* O157:H7 and *L. monocytogenes* on the surface of plastic cutting boards was shown. They reported a reduction in the bacterial count > 5.0 log CFU/100 cm² and non detectable levels for *E. coli* O157:H7 and *L. monocytogenes* populations on cutting boards, respectively. Their second study (1999), focused on the efficacy of OW for inactivating *E. coli* O157:H7, *S. enteritidis*, and *L. monocytogenes* incubated at different times and temperatures. They reported that *E. coli* O157:H7, *S. enteritidis*, and *L. monocytogenes* were more rapidly inactivated at temperatures greater than 23°C.

A study by Koseki *et al.* (2001), demonstrated that washing lettuce with alkaline OW for 1 minute followed by decontamination with acidic OW water for 1 minute, reduced total aerobic bacteria by 1.7, 1.6, 1.0, and 1.1 logs CFU/g, respectively. Using the same treatment on cabbage, the research reported that total aerobic bacteria were reduced by 1.5, 1.5, 1.5, and 1.0 logs CFU/g, respectively. By contrast, when lettuce was soaked in acidic OW for 10 minutes the viable aerobic bacteria was reduced by 2 logs CFU/g (Koseki *et al.*, 2001). This study concluded that the alkaline OW increased the decontamination of microorganisms on the surface of lettuce leaves. Koseki *et al.* (2004) reported similar results.

Yang *et al.* (2003), reported similar results (2 log CFU/g reduction) when fresh-cut lettuce was treated with 300 ppm of OW at pH 7.0 and 30°C for 5 minutes; these results were also confirmed by Park *et al.* (2001). Swem *et al.* (2002) reported higher *E. coli* O157:H7 reductions (3.0 logs CFU/g) under the same treatment. However there was a difference in the treatments, Swem *et al.* (2002) treated the sample 30 min after inoculation, whereas Yang *et al.* (2003) treated the inoculated lettuce after 24 h of storage at 7°C. Using scanning microscopy, a bacterial film (a sticky and threadlike substance surrounding bacterial cells) was observed on the inoculated lettuce sample after 24 h storage. Therefore, biofilm formation affects the efficacy of OW. Park *et al.* (2001) reported a 2.65 log CFU per lettuce leaf reduction of *L. monocytogenes* inoculated on whole lettuce leaves after 3 minutes treatments. Yang *et al.* (2003) reported a 2.0 and 2.1 log CFU/g reduction when fresh-cut romaine lettuce was treated with 300 ppm OW at pH 7 and 30°C (of *Salmonella* Typhimurium and *L. monocytogenes*, respectively).

Oxidizing water in Australia

Electrified oxidizing water unit manufacturers in Australia are not easy to find. There is however a technology company that has been piloting an OW based unit to treat waste water. The company (Unipolar) claims that their technology (Unipolar® disinfection) is far more advanced than just OW. They claim an additional patent that improves the oxidising potential of their units. Unipolar is a patented electro-chemical technology to generate disinfectants that inactivate pathogens. According to literature supplied by Unipolar it is capable of a more than 4-log inactivation of bacteria and viruses; the technology is designed to take advantage of the compounds inherently present in water to produce a mix of strong oxidising agents, including chlorine, ozone, hydrogen peroxide and hydroxyl radicals. No chemicals are added to produce disinfectants, although the process benefits if there is some salt in the system.

The production of disinfectants at a molecular level and mixing within the cells brings pathogens in intimate contact with disinfectants to maximise their effectiveness.

All water passes through the cells so that all disinfectants formed during the electrolytic reaction start treating the water as soon as they are generated. Additionally, a pulsing current is used for the electrolysis, which is designed to weaken pathogens and make them more susceptible to the disinfectants. There are also significant residual chemicals in the water after treatment. Cl⁻ for example can be there at over 90ppm, levels sufficiently high to treat the surface of leafy vegetables.

The Unipolar water disinfection technology has been validated in accordance with the Department of Health Victoria guidelines (2010) to inactivate at least 4-log bacteria and viruses in waste water. These guidelines set a higher standard than the US EPA guidelines and 4-log inactivation is the highest credit that can be given to a treatment unit. The unit is claimed by the manufacturers to be safe with no hazardous chlorine or other chemicals added, avoiding the transport, storage and handling of hazardous materials. The system is designed to safely vent hydrogen produced by electrolysis.

One important point is that the whole process can be controlled by automation and the operator interface is simple, making it easy for operators to use the Unipolar equipment. Monitoring and control are based on measurement of residual free chlorine which is easy to record for QA purposes.

It has relatively low power consumption, typically 1.0–1.5 kWh/kL depending on the quality of the water and the level of disinfection required.

Maintenance is low cost and simple, regular electrode cleaning by reverse electrolysis is automated and does not require any chemicals or service water. The short cleaning cycle minimises loss of capacity. Titanium electrodes and PVC cells provide long life and easy maintenance. Individual cells are easily removed.

The modular design of the Unipolar cells allows them to be easily connected in series to enable higher doses of disinfectants in applications where there is a higher water demand. Typically, 4 to 8 Unipolar cells are connected in series to form a module. The capacity of a treatment plant is increased by simply adding more modules in parallel. The arrangement of the cells is compact to minimise the footprint of the installation. This is a system fully supported in Australia by the company with a number of service teams available to assist in the vegetable industry.

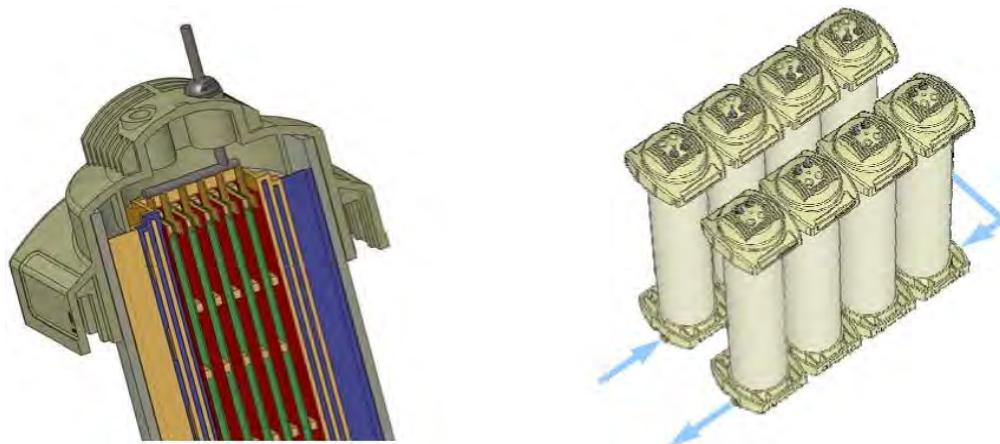


Figure 1. Diagram showing the Electrodes inside a Unipolar cell and a typical module of Unipolar cells (Ref; literature supplied by manufacturer).

5.4 Citrox

Citrox is a formulation of soluble bioflavonoids obtained from citrus fruits. The non-toxic and antimicrobial properties of natural bioflavonoids are well documented, and so these preparations have the potential for application to vegetable washing. This product is recommended by the Australian Organic Council as a washing product for organic vegetables. The core biotechnology of Citrox is the use of complex compounds which have been developed by a team of medical scientists as an antimicrobial for the treatment of oral disease. The key ingredients are flavonoids that are extracted through a specialised process from immature citrus fruits. The extracted flavonoids are combined with a number of natural acids (from fruit and vegetable origins) to produce the core active substances, which have a proven broad spectrum efficacy against harmful micro-organisms, fungi and yeast. A pamphlet published by the makers of Citrox claim inhibition of *E.coli*, *Candida*, *Staphylococcus*, *Salmonella* and *Enterococcus*

(<http://www.wysonghealth.net/products/documents/monographs/legacy/CITROX.pdf>)

Effectiveness of Antimicrobials

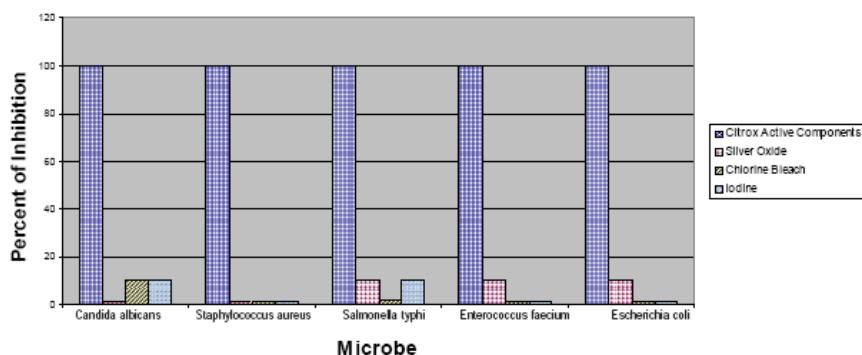


Figure 2; Inhibition of various microbes by the use of Citrox (Ref'
<http://www.wysonghealth.net/products/documents/monographs/legacy/CITROX.pdf>)

Work by S.J. Hooper *et al.* from Cardiff University in the UK has shown that Citrox is an efficient broad-spectrum antimicrobial agent with great potential for use in mouthwashes, playing a role in the maintenance of good oral hygiene.

They have shown that fourteen species of microorganism were selected, including bacteria associated with oral diseases, *Candida* species, and the bacterium *Clostridium difficile*, associated with diarrhoeal infection in hospitalised patients. They used *in vitro* tests to determine the efficacy of two Citrox formulations diluted to 0.007 and 8% v/v. Both Citrox formulations exhibited antimicrobial activity and significantly inhibited growth of all bacteria and yeasts at a working concentration of 1% v/v, however the contact time was not clear.

Citrox has been further developed for use in the washing of fruit and vegetables. Work done by Allende *et al.* (2008) showed that Citrox is just as effective as Chlorine for initial sanitation of leafy vegetables. However, work done by Lopez-Galvez *et al.* (2008) shows that Citrox is perhaps not as efficient as Chlorine in removing cross contaminating *E. coli* from the wash water.

The major advantages of Citrox as stated by the manufacturer are that it is 1) relatively stable at both low and high temperatures, 2) it works best at a pH between 2 and 8 (covering a range of levels found in farm waters), 3) it is manufactured from completely renewable resources, 4) it is effective in the presence of high organic matter loads, 5) it is claimed that it can break up biofilms, 6) it is easy to use and 7) it is completely non toxic and is approved by the Australian Organic Council. The disadvantages include the fact that it can be expensive and it cannot be monitored easily by automatic means (pH readings seem to be the only viable automatic monitoring available).

5.5 Aussan

Aussan is a new generation anti bacterial sanitiser/disinfectant derived from natural and organic ingredients. It is manufactured in Australia from specially selected bioflavonoids and organic acids, which have been derived from vegetables and fruit and give the chemical its efficacy. It is similar to Citrox but does not originate from immature citrus fruit. Aussan is a non toxic organic sanitiser that does not poison the organism but acts mechanistically, by destroying the cellular membrane of a microorganism (cell wall intrusion). All ingredients are carried in a food safe, naturally derived glycerine solvent which makes the active ingredients infinitely soluble in water.

It is a broad spectrum, natural antibacterial sanitiser that can be used in a wide range of industries including, but not limited to, food processing, pharmaceutical, water treatment, catering, medical, agriculture and livestock. When used for sanitising benches, equipment, etc., this powerful agent is claimed by company literature to destroy any bacteria that are present while leaving a non toxic residue that prevents bacteria from multiplying.

Aussan is described as a natural ingredient based sanitizing and preservation agent certified as an input for organic farming. Each ingredient used in the manufacture of Aussan-W4 has been evaluated against the requirements of FSANZ for use in the manufacturing, processing or handling of food. Aussan meets the requirements of FSANZ for use as a processing aid for most raw foods including uncooked crustaceans, fruit and vegetables, and poultry. Where further processing of food occurs such as cooking or preserving, Aussan may also be used as a food additive where required and under GMP, up to a concentration of 5 g/kg Test results supplied by the seller suggest that it can kill 99.86% of a test culture of *Pseudomonas aeruginosa* after a 10 minute exposure. It can also achieve a 99.99 % reduction in *Staphylococcus aureus* after a 10 minute exposure.

Aussan is not toxic to humans, plants or animals. Unlike many other sanitisers, Aussan is not washed from the surface it has sanitised, it remains on the surface and continues to sanitise until the bacteria/pathogen loading exceeds the volume of Aussan present. Other sanitisers and disinfectants must be washed away after use. This means they kill the bacteria, sterilise the surface and are washed away, leaving the surface ready for the next bacteria to arrive.

Advantages of Aussan include that is a wholly natural organic product. It has a broad-spectrum anti-microbial activity, which works against bacteria both gram positive and gram negative. It is non-mutagenic, non-carcinogenic, non-toxic, non-corrosive, non-tainting and non-volatile. It is claimed by

the manufacturer to have the ability to break down biofilm and its mechanism of action is by the destruction of the cell wall. It is stable at a wide range of pH levels from 2 to 12 and temperatures of up to 60°C. In fruit and vegetable processing and packing, it can be applied immediately after harvest for protection from human pathogens during picking, handling and transport. According to the manufacturer literature it is an excellent alternative to Chlorine and Peroxy acids in the washing of fruit and vegetables during processing operations as it provides safe and effective residual sanitizing, without the risk of damage to delicate foods and is not deactivated by common soils, so solutions last much longer.

5.6 CitroFresh

CitroFresh is marketed as a food wash and natural preservative and is derived from plant extracts. It can be used as a processing aid and as claimed by sales literature it reduces the risk of food poisoning by eliminating pathogenic micro-organisms

(http://www.citrolife.com.au/applications/fruit_and_vegetables). This in turn extends the shelf life and freshness of any fresh, raw, chilled and cooked foods, meats, poultry, fish and produce before packaging and distribution to retail outlets. The manufacturer claims that CitroFresh will keep produce fresh for up to 2-3 times longer than conventional methods, resulting in a very high reduction in spoilage. The product can be applied directly onto food products as a non-rinse sanitiser in either dipping baths, as a fog/mist or a spray. The ten benefits listed in sales brochures include:

1-Organic

2-Non-toxic

3-No harmful chemicals

4-Completely safe, does not invoke pathogen mutations

5-Kills 99.99% of germs

6-Effective against viruses, fungi and bacteria, including *Escherichia coli*, *Clostridium botulinum*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Salmonella choleraesuis*

7-Very effective against biofilms

8-Acts from pH 2 - 12 at temperatures up to 130°C

9-Non-rinse

10-Odourless and colourless: does not change colour or taste of any food

11-Easy to use and store

The major components of this product are citric acid, malic acid, bitter orange extract (bioflavonoid complex) and vegetable glycerine. The product has been shown to be effective at killing *Listeria monocytogenes*, *Salmonella* species and *E. coli* in literature provided by the manufacturer, however when reading this literature carefully the contact times were relatively long for some pathogens. The results of kill rates were also shown when a higher concentration of the product was used at 8%, which is much more than the dose recommended for use in vegetable washing at 2%. The product had many similarities with Aussan.

5.7 Acetic acid

Removal of pathogenic and spoilage bacteria from leafy vegetables by organic acids such as acetic acid have been studied. Acids are either naturally present as constituents of the food or are added to the product through formulation. The undissociated form of acetic acid is utilised to reduce microbial activity, a process which is highly dependable on pH. Nascimento *et al.* (2003) compared the results of sodium hypochlorite with seven different sanitizing solutions (vinegar at 6, 25, and 50 %; acetic acid at 2 and 4 %; peroxyacetic acid at 80 ppm; and sodium dichloroisocyanurate at 200 ppm). The statistical analysis of the results demonstrated that the effectiveness of all the sanitizing agents tested was equivalent to or higher than that for sodium hypochlorite at 200 ppm. The best results were achieved with 4% acetic acid, which reduced the initial aerobic mesophilic population by 3.93 log₁₀ CFU/g and reduced the mould and yeast population by 3.58 log₁₀ CFU/g. Nascimento *et al.* (2003) concluded that the results of the study demonstrated the effectiveness of acetic acid and vinegar as alternative sanitizing agents for the disinfection of fresh produce.

5.8 Nylate

Nylate, also known by the chemical name bromo-chlorodimethyl hydantoin (BCDMH), has been used for over 20 years and has full approvals from both the APVMA and FSANZ for use as a non rinse washing aid in the fruit and vegetable industry. Literature from the distributor states that it forms two extremely effective biocides in solution (hypochlorous acid (HOCl) and hypobromous acid (HOBr)), which have been shown to be effective against fungal and bacterial organisms, as well as a range of human pathogens, such as *Staphylococcus aureus* and *Salmonella kahla*, which pose risks to food safety.

The major advantage of BCDMH is that it is a stable compound, effective across a broad pH range and at much lower concentrations than Chlorine. Whilst Chlorine needs to be used at 100 ppm or more, BCDMH can be used at 5 to 10 ppm. It does however have one disadvantage; when (BCDMH) is hydrolysed, dimethylhydantoin (DMH) is formed as a by-product. Food Standards Australia and New Zealand recommends that the allowable daily intake (ADI) of DMH is 0.025 mg/kg of body weight, which is deemed to be equivalent to concentrations of DMH of 0.2 mg/kg of fruit and 2 mg/kg of vegetables. This always leaves a question mark over the safety of this product, even though it is unlikely that the allowable daily intake limits would ever be reached. The Organic industry has banned the use of BCDMH in washing vegetables.

5.9 Ozone

Ozone is a gas that has to be generated on site as it is very unstable. It is even more unstable in water and over very short periods of time it decomposes into oxygen. At 20 °C it decomposes very quickly with a half life of less than 30 minutes and hence it must be generated continuously (Khadre *et al.*, 2001). In water sources that contain a lot of organic as well as inorganic matter, the activity of ozone will decrease significantly. It is a colourless gas at normal temperatures and is over 3000 times more effective than chlorine oxidising capacity. This means that this sanitiser is very reactive and can corrode metal and other surfaces. It has a pungent smell and is readily detected by the human nose and can cause throat, eye and nose irritation even over short exposures (Guzel-Seydim *et al.*, 2003; Suslow, 1997). It is unlikely that this sanitiser will find extensive use on farms in Australia as it is extremely reactive and poses a significant OH&S risk.

5.10 Concluding commentary;

There are five groups of sanitisers that can be used in the vegetable industry

- a) Peroxyacetic acid sanitisers
- b) Chlorine sanitisers
- c) Organic sanitisers
- d) Gas based sanitisers
- e) Electrified Oxidizing water

The sanitisers described in this short review all have the potential to be used in the vegetable industry; they also have sufficient scientific evidence that they can actually reduce the levels of bacteria by at least one or two logs. With the exception of electrified oxidising water and Citrox, they are all available commercially at the time of publication of this report. Work done through this project tested all the sanitisers discussed in this report with the exception of Chlorine Dioxide and Ozone. Ozone was not evaluated as part of this project as it needs to be generated on site or purchased as a gas and is difficult to monitor. There was no availability of a processing shed capable of handling Ozone gas based sanitisers at the time of running this project. Chlorine dioxide was also not available for large scale wash tank experiments. A Chlorine dioxide washing system was trialled a number of

years ago for washing leafy vegetables. The system failed, gas escaped and the site had to be evacuated and some workers had to be taken to hospital (see appendix 2). As a result it was not evaluated in this study. A tablet that produces chlorine dioxide (Stabilised Chlorine Dioxide) when placed in water is available but it is not feasible in large scale washing systems due to cost. As part of this project, the author has negotiated with Unipolar to develop a small scale electrified water system suitable for evaluation in the vegetable industry.

This study reported on the efficacy of

- a) Peroxyacetic acid sanitisers (including Tsunami and Summit)
- b) Chlorine sanitisers (Calcium or Sodium Hypochlorite and Nylate)
- c) Organic sanitisers (Citrox, Aussan, CitroFresh and acetic acid)
- d) Electrified Oxidized water

6. Testing of sanitisers

6.1 General method

All sanitisers were used at the recommended dosage as stated in the accompanying literature or as stated by the supplier; all usage rates are described in the relevant section of the results. Baby spinach was chosen as the leafy vegetable product for the evaluation of the sanitisers as it is intended to be eaten uncooked, is usually very high in microbes and is contaminated with mud and soil. Additionally, most of the sanitisers were also tested with baby leaf lettuce (combination of red/green oak and coral lettuce leaf, rocket and other small leaf) as these are usually sold to be consumed uncooked.

Baths used ranged from 1000 to 2500 litre wash baths, depending on the location used for testing. Two locations were used, both situated on growers' properties on the eastern side of Melbourne and simulated actual washing steps used by the growers. Product was washed as per a commercial batch (usually up to 250 kg of leafy vegetables were washed at any one time in a recirculated wash bath, for the organic based sanitisers and the oxidising water experiments up to 120 kg batches were tested in the smaller wash baths), the contact time of which varied as the product was washed in a turbulent wash bath, but on average the product remained in contact with the sanitiser solution for approximately 45 seconds to two minutes.

Samples of both the product and the wash water were taken after washing produce in clean water (continuous replenishing) and after washing in water containing the sanitiser. These samples were tested in triplicate for total plate counts. Total plate counts or standard plate counts are a useful tool in determining efficacy of sanitisers. Samples were tested according to Australian Standards method (Standard plate count - AS 5013.1-2004, basically Pour plates of appropriate decimal dilutions were prepared using plate count agar and incubated aerobically at $30 \pm 1^\circ\text{C}$ for $72 \pm 2\text{ h}$). Samples of the products were kept for shelf life testing at 4°C before and after the wash step. *Fluorescent pseudomonads* were also measured but levels were too low to use as indicators for this project. The samples were evaluated for shelf life by visual examination for up to 18 days and checked at days 1, 5, 8, 12, 15 and 18; this was according to the quality scale as shown in appendix1. As a control every treatment was compared to water washing. Water washed produce lasted had a shelf life of 8 days unless otherwise stated.

Plot 1 shows the individual value plots of the percentage change in the baby leaf TPC between water and sanitiser washing. The results show that only four sanitisers managed to exceed the 90 % mark: these included Nylate at 5ppm, Chlorine at 100ppm, Summit at 100 ppm PAA, and some of the Adoxysan treated products. Very close to the 90% mark was Tsunami at 100 ppm PAA. A number of sanitisers did not make it to the 40% mark. These included Acetic acid at both concentrations tested, Citrox at 1% and some of the 2.5% Citrox treatments and one of the Proxitane treatments. Aussan was just on the border of the 40% mark. Overall, the best sanitisers were Chlorine and Nylate with the peroxyacetic acid sanitisers following closely behind. The organic sanitisers did not perform as well as the above mentioned sanitisers.

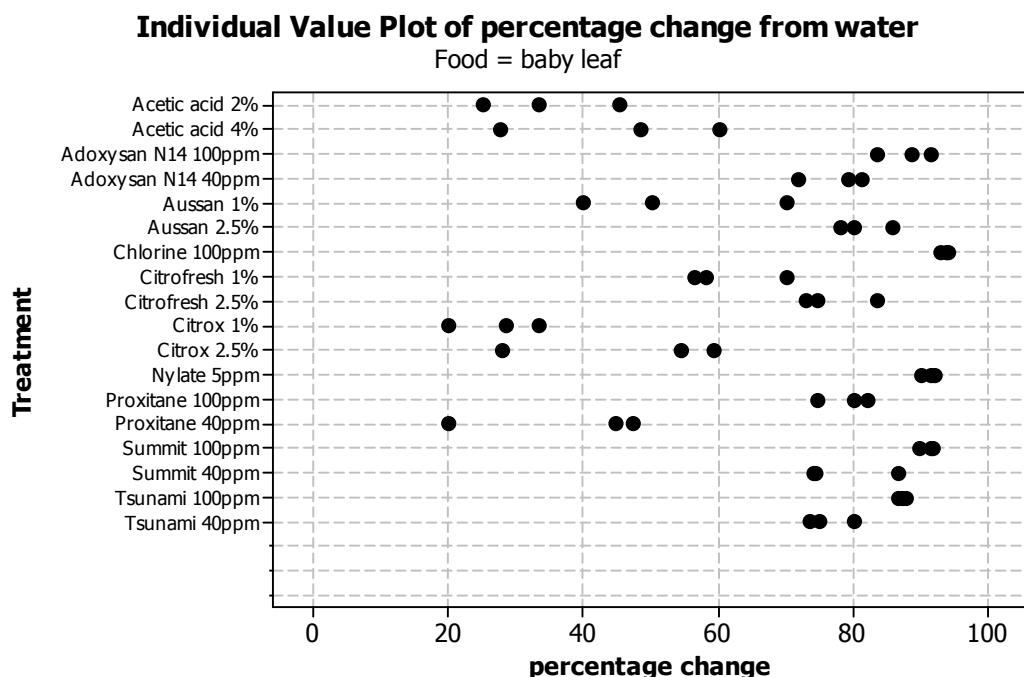


Figure 29; Graph of individual value plot (Plot 1) of % change from water for baby leaf (Unipolar disinfection not shown)

Results for washing spinach are shown in Plot 2. The individual value plots of the percentage change in the spinach TPC between water and sanitiser washing show that five sanitiser treatments managed to exceed the 90% mark. These include some of the Aussan at 2.5% v/v, Chlorine at 100ppm, Nylate at 5ppm, Summit at 100 ppm, and Tsunami at 100ppm. In this plot, the results for the Unipolar disinfected water are also shown. These are very close to the 100% mark, making them the most efficient sanitising treatment studied in this report, even exceeding that of Chlorine at 100 ppm. A number of sanitiser treatments did not meet the 40% mark, which included Citrox at 1% v/v, some of the Proxitane treatments at 40ppm PAA, Aussan at 1% v/v, both Acetic acid treatments and Tsunami at 40ppm PAA came close to the 40% mark.

Individual Value Plot of percentage change from water

Food = spinach

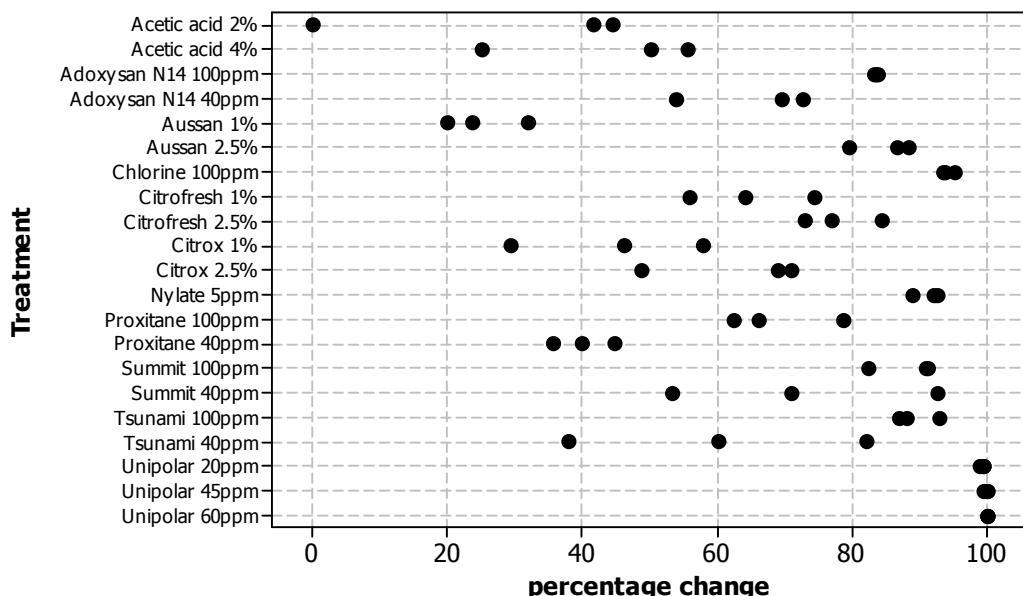


Figure 30; Graph of individual value plot (Plot 2) of % change from water for spinach

Washing in plain water alone gives a product which has a shelf life of 10 days for Spinach and 8 days for baby leaf (results not presented here but conducted as part of the shelf life trial). Discussions with growers suggest that there is an expectation that baby leaf and spinach reach a minimum shelf life of 12 days, something that is achievable with Chlorine washing. The sanitation step is also seen as a way to increase the shelf life of produce. Not all of the sanitising treatments however achieved this expectation, many only reached 8 days and one only managed to reach 5 days. The Peroxyacetic acid sanitisers mostly achieved 12 days shelf life when treated with 40 ppm of sanitiser. The shelf life decreased slightly to 8 days as the level of PAA sanitiser increased to 100ppm, with the exception of Proxitane, which only achieved a shelf life of 5 days when used at 100ppm PAA. Acetic acid at both the concentrations used in this study achieved a shelf life of 8 days with the exception of baby leaf treated with 4% v/v Acetic acid that only reached a 5 day shelf life. The organic sanitisers showed a variable shelf life: Citrox showed an 8 day shelf life when used at 1% v/v but the shelf life was reduced to 5 days when it was used at 2.5% v/v; Aussan showed a longer shelf life reaching 8 days even when used at 2.5% v/v.

CitroFresh showed the longest shelf life of 12 days when used at 1% v/v for baby leaf but with spinach, this shelf life was also achieved when used at both 1% and 2.5% v/v.

Chlorine and Nylate also showed a shelf life of 12 days but the real surprise was the shelf life observed with the Unipolar sanitised water, showing a shelf life of up to 15 days with treatments at settings one and two.

8. General Discussion

The levels of TPC in leafy vegetables can be extremely variable and can change from field to field and from planting to planting. However, CFU's are often used by most auditors of a HACCP plan to verify the sanitation step. The auditors look for a two log reduction in bacteria after the sanitation step. This has been relatively hard to achieve in all cases so auditors accept a one log reduction as evidence that the sanitation step has worked. In reality, what the auditors should also be looking for is the elimination of bacteria left behind in the wash water.

There is no doubt that the levels left behind in the wash water are relatively low when the sanitiser used is Chlorine, Nylate or the Peracetic acid sanitisers. Acetic acid, on the other hand, does not effectively reduce bacteria in the wash water. The use of acetic acid is not wide spread in the vegetable industry. A small number of organic growers however have used it or are still using it. The results presented here show that Acetic acid when used at 2% and 4% v/v has little effect on the levels of bacteria on the surface of spinach and baby leaf. At 2% and 4% v/v the levels on the surfaces of the leaf were reduced at best by approximately 50%. This level of reduction would not satisfy current QA requirements for food safety. The levels of bacteria remaining in the wash water were also relatively high, again suggesting that Acetic acid does not meet the requirements of a sanitiser. The shelf life of the finished product was also compromised when using Acetic acid at both concentrations trialled. Spinach had no problems meeting an 8 day shelf life when washed at both concentrations. However, baby leaf only achieved a 5 day shelf life when it was washed with the 4% v/v solution of Acetic acid. With the 2% v/v solution it reached an 8 day shelf life.

The Peroxyacetic acid sanitisers all showed acceptable results, however it is important to note that there is a difference in the formulations of these products. This difference can have an effect on the efficacy of the sanitisers and on the shelf life of the product being sanitised. The level of peroxide is very different in Proxitane when compared to the other preparations. In addition to this, the level of Peroxyacetic acid is also much lower in this commercial preparation meaning that more of the solution needs to be used to achieve the desired PAA concentration in the wash bath. As a result of this, the level of peroxide in the wash bath increases thus affecting the shelf life of the product being sanitised. Overall however, the use of Peroxyacetic acid for washing leafy vegetables was shown to be satisfactory in terms of efficacy and shelf life. Their use in a recirculating wash bath with contact times of less than two minutes was shown to be satisfactory in a commercial situation. Continuous checking needs to take place by using test strips that measure PAA, something that can be expensive.

The organic sanitisers did not perform as well as some of the other sanitisers tested. These sanitisers are often used to wash produce destined for the organic market. The commercial use of these sanitisers is however restricted to small scale production. A disadvantage of these sanitisers is that their efficacy is not as good in killing bacteria when compared to some of the other sanitisers tested in this report, especially in solution and on the leaf. All the literature examined by the suppliers of these organic sanitisers make claims about 99.9% killing capacity against a number of pathogenic bacteria. It is only when one dwells on the conditions of the test that long contact times are noted. Some of these contact times exceed 45 minutes, something that cannot be achieved in a commercial situation when contact times of less than two minutes are essential. Another major disadvantage of these sanitisers is the fact that they cannot be used easily on a recirculating water bath as they have a tendency to foam. Additionally, checking for levels of sanitiser is extremely hard and they are more suitable for a batch washing system, making their use expensive.

The most suitable sanitisers still appear to be the Chlorine or Nylate based sanitisers. Both work in separate manners but have extremely good efficacy in wash baths. The chlorine system needs to be

pH monitored and should not exceed a pH of 7; for the trials conducted in this report, this was achieved with citric acid. Failure to adjust the pH of the wash bath could mean an ineffective sanitation step. Nylate does not need to be pH adjusted. Both sanitisers can be monitored in the wash baths with the use of test strips or Oxidation/Reduction probes.

The shelf life obtained when using these sanitisers was higher in most cases than that obtained when using other sanitisers. The major disadvantage of using Chlorine is perhaps the threat that Chlorine may be banned from food production as it has been in a number of countries, especially in Europe. Chlorine may react with organic material to form undesirable by-products such as Chloroforms and other tri-halomethanes, which may have carcinogenic potential. At high pH, chlorine reacts with organic nitrogen based material to produce Chloramines, again potential carcinogens.

Finally, a new process for washing vegetables is that used by the Unipolar water disinfection system. This system uses a current of electricity to split the salts present in the water to form sanitiser molecules that then act to sanitise leafy vegetables. The process is easy to use and can be incorporated easily into existing washing systems as they are found. A full commercial scale trial conducted on a grower property has shown that this system has a number of advantages over conventional sanitisers, including Chlorine. Firstly, it is automatic and continuously produces a set amount of sanitisers on a recycling system. Secondly, it records the level of sanitiser used in a continuous manner, thereby satisfying the QA requirements from a HACCP point of view. Thirdly, the shelf life of the sanitised product appears to be higher than the shelf life obtained when using other sanitisers. Finally, no chemicals need to be added to the process to achieve sanitation with the Unipolar system even though it could work better in the presence of low levels of salt.

9. Technology Transfer

A range of methods were used for technology transfer as part of this project, the most important one was direct discussions with a number of growers that have experienced issues related to washing their produce. Furthermore, some of the results from this study have been presented at a Victorian Vegetable Grower Association meeting. The results have also been presented to the Freshcare technical steering committee. It is hoped that the information gathered as part of this project will be presented as a Vege-Note in the vegetable industry. The results of this project will be used to further strengthen on-farm QA systems, including Freshcare and Salad GAP.

10. Project Evaluation

The information supplied to growers has led to a better understanding of what is available to them for washing. A lot of interest has been generated by growers with regards to the new technology trialled as part of this project, namely the Unipolar water disinfection system. Many growers have also expressed concerns that there are no plans in place should Chlorine based sanitisers be banned in the industry. This project has alleviated some of their concerns as they now know that there are alternatives available.

11. Conclusions

The washing of leafy vegetables is an important step to keep leafy vegetables safe for consumers. This step is normally part of a wider food safety plan that growers must maintain on their farms and hence is part of the QA system audited by third parties. Therefore, any sanitiser used for washing leafy vegetables must be capable of being monitored.

The use of Chlorine either as Calcium Hypochlorite or Sodium Hypochlorite is still the most effective way to sanitise leafy vegetables in Australia. There are however other sanitisers available that have similar efficacies as Chlorine, including Nylate and some of the Peroxyacetic acid sanitisers. These are however slightly more expensive to use but all of these can be monitored in solution either by hand (with the use of test strips) or some automated process including OR probes or PAA probes.

There are organic based sanitisers available for washing leafy vegetables in the organic industry, however these are not as effective as the non organic sanitisers and are difficult to monitor for the purposes of record keeping in QA food safety plans.

There is a newly available technology that uses oxidized water to sanitise vegetables that has the prospect of fulfilling the requirements for washing vegetables without the addition of harsh chemicals and is capable of exceeding a 2 log reduction in total plate counts. The use of gas based sanitisers in the vegetable industry is not recommended for a number of reasons, the most important one being OH&S.

The results of this study show that:

In terms of efficacy:

Oxidizing water>Chlorine/Nylate>Peroxyacetic acid sanitisers>Organic acid sanitisers>Acetic acid

In terms of running costs

Oxidising water<Chlorine< Acetic acid<Nylate<Peroxyacetic acid sanitisers<Organic acid

In terms of set up costs, Oxidising water is still an unknown.

12. Key Issues

- Chlorine based sanitisers are still the most cost effective and most suitable sanitisers that the vegetable industry can use to wash leafy vegetables.
- There are other sanitisers available that can be used to wash vegetables in case Chlorine is banned (as is the case in some overseas countries), which includes the Peroxyacetic acid sanitisers and Nylate.
- There is a very efficient sanitation process available that needs further evaluation which uses Oxidised water produced by passing a current through recirculated water from the wash baths. This system can be fully automated and can record every step of the washing process, thus fulfilling many of the requirements of an on-farm QA plan.