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Final Report

In-line approaches to control surface pests of concern from export citrus

Dr Lisa Jamieson
The New Zealand Institute for Plant and Food Research Ltd

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Level 8, 1 Chifley Square
Sydney NSW 2000
Tel: (02) 8295 2300
Fax: (02) 8295 2399

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Summary

Fuller's rose weevil (FRW) egg detections continue to limit access for Australian citrus exports to a number of Asian markets. High pressure washing (HPW) has the potential to decrease infestation rates by removing egg masses. Australian packhouses use standard HPW systems; however, their performance varies substantially. In New Zealand, new generation HPW machines have been developed to enhance removal of difficult-to-remove organisms. Research to reduce FRW egg viability using postharvest dips is being undertaken in the USA, and these dips may have the potential to be incorporated in to an in-line pest reduction system that includes pre-HPW dips and new HPW systems that remove already-low numbers of FRW eggs and render remaining eggs non-viable.

There were three objectives to the project and the outcomes of each are summarised below.

Objective 1: To assess various HPW systems currently in use and to identify the best system for FRW egg removal from oranges

From 23 to 25 September 2013 Allan Woolf, Simon Redpath, Peter Taverner and Andrew Harty visited five Australian citrus packhouses of varying sizes in the Riverland (South Australia) and Sunraysia (NW Victoria) regions of Australia to observe and assess commercial citrus HPW performance (Redpath et al. 2014).

All citrus HPWs visited in Australia used a system similar to the standard rows of nozzles over a brush or roller bed with straight nozzles. Although the HPWs all used were similar, there was a great deal of variability among the HPW setup conditions in terms of pressure, distance, nozzles and filtration, with no standardisation of operating conditions. A generic 'Best-practice user manual for Citrus high pressure washers' was compiled to assist with lifting the performance of the current washing systems.

Objective 2: To determine whether selected pre-HPW dips can enhance FRW egg removal rates by HPW and/or reduce FRW egg viability

In the first year, trials were conducted to determine the impact of postharvest dip treatments (containing Prospect® oil, sodium hypochlorite, organosilicone and/or acetic acid) on the viability of FRW eggs and to determine if these pre-HPW dips enhanced removal of FRW eggs during HPW (Jamieson et al. 2014).

There is potential to increase FRW egg removal rates from the current ≈6% removal to ≈20–50% removal, along with reducing egg viability, by using postharvest dips containing Prospect oil followed by HPW systems.

In the second year trials were conducted to determine the impact of postharvest dip treatments (containing Prospect oil, sodium hypochlorite, malic acid, lactic acid, acetic acid, citric acid) on the viability of FRW eggs and to determine if these pre-HPW dips enhanced removal of FRW eggs during HPW (Page-Weir et al. 2015).

Although effective at removing FRW egg batches and reducing viability, using high rates of food acid (10%) with high rates of Prospect oil is not recommended because of fruit quality and sanitiser stability issues encountered during these trials. Low rates of food acid (1%) with a low rate of Prospect oil did not enhance FRW removal or reduce viability enough to warrant recommendation. Investigating an intermediate concentration of food acid and trials to determine which is the most suitable for citrus packhouses is warranted, but could not be completed in this project because of resource constraints such as availability of FRW, navel oranges, time and funds.

Objective 3: To determine the potential effects of dip compounds on the performance of sanitisers and postharvest decay

Trials were conducted in Australia to evaluate the impact of food acids and Prospect oil dips on the activity of sanitisers (Page-Weir et al. 2015). High rates of food acid (10%) and Prospect (3%) resulted in rapid loss of sanitiser activity and rates of both had to be reduced to improve compatibility.

Recommendations

We recommend that citrus packhouses use the procedures set out in the 'Best-practice user manual for citrus high pressure washers' (Woolf et al. 2015) to improve the pest removal efficacy of their HPW systems. For those packhouses building new HPW units, we recommend a rotating HPW system to enhance removal of FRW eggs, and other postharvest pests.

Further research is warranted to:

- Determine if low rate (~4%) acids + Prospect oil (1–0.5%) dips can enhance FRW egg removal and reduce egg viability and the impact of these on fruit quality, sanitizer performance and postharvest decay.
- Investigate the efficacy of applying heated dips (50–55^{o}C) with and without low rates of acids + Prospect oil.
- Determine if a fungicide is required for an effective postharvest dip treatment that reduces the risk of viable FRW eggs infesting fruit and maintains fruit quality.

Keywords

High pressure washing; insect removal; Fuller's rose weevil; postharvest dip; Prospect oil; food acids

Introduction

Fuller's rose weevil (FRW, *Naupactus cervinus*) is a quarantine pest in China, Korea and Taiwan. The presence of FRW eggs on Australian citrus is impeding market access growth in these key Asian markets. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs; this has reduced the number of shipments rejected during pre- or post-shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets.

High pressure washing (HPW) has the potential to decrease infestation rates further. Australian packhouses use standard HPW systems; however, their performance varies substantially. In New Zealand, new generation HPW machines have been developed to enhance removal of difficult-to-remove organisms.

In Australia and New Zealand, postharvest dips have been tested to enhance the removal of difficult-to-remove pests and/or to reduce the viability of pests (Taverner & Bailey 1995; Taverner & Cunningham 2000; Taverner & Perry 2009) (Rogers et al. unpublished data). In Australia Prospect®, a food-grade oil registered for postharvest treatment of pests on citrus, showed the most potential to enhance removal of FRW eggs. In addition, sodium and calcium hypochlorite at high rates can dissolve FRW egg adhesive, and at low rates, can act as an irritant, causing rapid egg hatch (Baker et al. 2013; Taverner 2007).

Food acids were considered after preliminary testing by the United States Department of Agriculture, Agricultural Research Service (USDA – ARS) indicated good mortality of FRW eggs using heated (40ºC) mixtures of acetic acid and Spray Aide® (acid surfactant) (Spenser Walse, pers. comm.). The USDA conducted further testing on malic acid, citric acid and lactic acid in 2014.

Hot water dips have been proposed as quarantine treatments for pests on citrus. Gould & McGuire (2000) found a 20-min 49°C hot water dip effective at killing mealybug and other arthropods sheltered under the calyx of limes. Limes were undamaged at 49°C but showed softening and damage at 52°C, suggesting that an effective pest treatment was close to the damage threshold of limes. Jessup et al. (1993) dipped FRW-egg infested Valencia oranges in hot water dips for shorter periods, without obvious fruit damage. However, 7-min 52°C dips resulted in only ~60% mortality of FRW eggs. To date, hot water treatments have not been adopted by citrus packers to control quarantine pests. Attaining high efficacy with shorter dip times and, consequently, reducing the risk of fruit damage, is likely to improve commercial adoption.

One approach is to pre-treat field bins of harvested oranges with food acid and Prospect® dips to assist the removal FRW eggs before high pressure washing. The treatment also aims to reduce egg hatch. However, there is a risk that unsanitised dips will result in higher decay rates (Taverner & Bailey 1995a). Although FRW control is the primary focus, it is important that any dip treatment does not compromise postharvest disease control.

Chlorine-releasing compounds, such as sodium and calcium hypochlorite, are commonly used to reduce microbes in water but are most active in mildly alkaline conditions (Suslow 2001). Peracetic acid (PAA) is used to sanitise water in acidic conditions (Mehmet 2004). Various chemicals can be combined in water, but not all combinations are compatible. Kanitis et al. (2008) assessed the stability of various sanitisers and the efficacy of a range of postharvest fungicides to provide effective combinations for use in citrus packing lines. A similar approach can be attempted to optimise combinations of food acids, Prospect and sanitisers.

This report summarises the main findings from research carried out in a two year project from October 2013 to September 2015.

The main objectives of the project were to:

- To assess various HPW systems currently in use and to identify the best system for FRW egg removal from oranges

- To determine whether selected pre-HPW dips can enhance FRW egg removal rates by HPW and/or reduce FRW egg viability

- To determine the potential effects of dip compounds on the performance of sanitisers and postharvest decay.

Methodology

Objective 1: To assess various HPW systems currently in use and to identify the best system for FRW egg removal from oranges

The first stage of this objective was to visit packhouses in the Riverland (South Australia) and Sunraysia (NW Victoria) regions of Australia and assess the performance of their HPW systems (Redpath et al. 2014) (Appendix 1). From 23–25 September 2013 Allan Woolf, Simon Redpath, Peter Taverner and Andrew Harty visited five Australian citrus packhouses of varying sizes with in-line HPW systems to:

- View and discuss current HPW systems used in Australia, to gain a better understanding of the scales of operation and issues with which the packhouse staff contend
- Assess the operational performance of the HPWs by making a range of measurements including pressure, flow rate, nozzles type, distance from nozzles, nozzle orientation, and dwell time
- Assess the removal efficacy of the HPWs by putting Navel oranges covered with a kaolin clay/glue mix through each HPW to determine standard industry removal rates; this gives an approximation of contaminant removal efficiency but is not meant to correlate fully with FRW removal
- Discuss current FRW in-orchard control methods, at-harvest infestation rates, target infestation rates, and the standard of compliance data required
- Discuss the potential of new washing systems (equipment details, e.g. size of pumps, throughput, number of fruit/hour, water filtration).

The second stage of this objective was to assess the removal efficacy of commercial and experimental HPW systems in New Zealand by examining the removal of paint and/or FRW eggs from oranges (Jamieson et al. 2014) (Appendix 2). The removal of paint and/or FRW eggs was tested on three types of washers. The first type was a standard row HPW system with rows of nozzles pointing straight down over a roller or brush bed operating at 90–120 psi with oranges under the washer for 15–20 seconds. The second type was a three-nozzle HPW system which treated single fruit which rotated for 1–2 seconds under three nozzles (one from 75 mm above and two at 45° angles, 100 mm to the side) operating at 600 or 850 psi. The third type was a rotating HPW system where fruit were singulated and passed under 1–2 rotating wands for 1–2 s twice. The wands had six nozzles (nozzle distance 110 mm) and water pressure was ~300 psi with a hold-down single nozzle situated just before the rotating wand.

A third stage of this objective was to compile a "Best-practice user manual for citrus high pressure washers" outlining procedures to optimise the capability of HPW systems (Woolf et al. 2015) (Appendix 3).

Objective 2: To determine whether selected pre-HPW dips can enhance FRW egg removal rates by HPW and/or reduce FRW egg viability

Field collected adult FRW were maintained within a laboratory colony on citrus leaves. Adult FRW tended to only be available in suitable numbers from January until March. For experiments adults were caged on oranges to lay eggs beneath the calyx for treatment. It was difficult to synchronise the availability of FRW adults in the field and good quality oranges. Wax paper within colony boxes provided egg rafts on paper for determining their viability after postharvest dips.

In the first year, two trials were conducted to determine the impact of postharvest dip treatments containing Prospect oil, sodium hypochlorite, organosilicone and/or acetic acid (Table 1) on the viability of FRW eggs on wax paper and on oranges and to determine if these pre-HPW dips enhanced removal of FRW eggs during HPW (Jamieson et al. 2014) (Appendix 2).

Table 1. The amounts of postharvest (PH) Prospect® oil (PO), sodium hypochlorite (SH), saturate organisilicone (OS) and acetic acid (AA) in dipping treatments applied to Fullers rose weevil (FRW) eggs on wax paper and FRW eggs on oranges.

Trt #	Treatment	PH Prospect oil	Sodium hypochlorite	Saturate organosilicone	Acetic acid	pH
1	3%PO/0.02%SH	3%	0.02%	-	-	-
2	3%PO/1%SH	3%	1%	-	-	-
3	1%SH	-	1%	-	-	9.0
41	0.02%SH/0.05%OS/CA	-	0.02%	0.05%	-	8.1
51	1%SH/0.05%OS/CA	-	1%	0.05%	-	7.8
6	5%AA	-	-	-	5%	2.5
7	3%PO/5%AA	3%	-	-	5%	-
82	0.05%OS/5%AA/NaOH	-	-	0.05%	5%	4.0
9	Water dip control					5.4
10	Air control (no dip)					
113	0.05%OS/5%AA	-	-	0.05%	5%	2.5

[1]Treatments 4 and 5, ~30 mL of citric acid was added to bring the pH to 7–8.
[2]Treatment 8 (initial pH of 2.5) 50 mL of 0.1 M NaOH was added but only moved pH by 0.1. A further 100 mL of 10 M NaOH was added and increased pH by 1.4.
[3]Treatment 11 did not have NaOH added.

Additionally in year one a trial was also conducted in Australia to determine the baseline removal rates of FRW eggs from oranges on a commercial HPW at a standard speed (treatment time) and with a longer treatment time, as well with a pre-HPW dip (40°C, containing Prospect oil, sodium bicarbonate and sodium hypochlorite) (Jamieson et al. 2014).

In year two trials were conducted to determine the impact of postharvest dip treatments containing Prospect oil, sodium hypochlorite, malic or lactic acid (Table 2) on the viability of FRW eggs on wax paper and on oranges and to determine if these pre-HPW dips enhanced removal of FRW eggs during HPW (Page-Weir et al. 2015) (Appendix 4). Infested fruit were passed through two 'types' (rotating or standard row) of experimental HPW systems to determine the removal rates of FRW eggs from oranges after postharvest dipping.

Table 2. Details of dip treatments to control Fuller's rose weevil eggs on citrus, including concentrations of chemicals and time between dips and high pressure washing.

Treatment #	Postharvest dip combinations and concentrations	Time (h) between dipping and high pressure washing
1	10% malic acid + 3% Prospect® oil + 0.02% NaClO	24
2	10% lactic acid + 3% Prospect oil + 0.02% NaClO	24
3	3% Prospect oil + 0.02% NaClO	24
4	10% malic acid + 0.02% NaClO	24
5	10% lactic acid + 0.02% NaClO	24
6	0.02% NaClO	24
7	1% lactic acid + 0.5% Prospect oil + 0.02% NaClO	24
1 + rinse	10% malic acid + 3% Prospect oil + 0.02% NaClO	0
2 + rinse	10% lactic acid + 3% Prospect oil + 0.02% NaClO	0
7 + rinse	1% lactic acid + 0.5% Prospect oil + 0.02% NaClO	0

Because of the high rate of skin blemish (pitting) with both 10% lactic and 10% malic acids after 24 h of drying time before HPW, a small fruit quality trial was conducted with oranges with no FRW eggs (Page-Weir et al. 2015). The aim was to minimise skin blemish by reducing the time between dipping and HPW and adding a rinse after the postharvest dip. Fruit quality issues were still encountered after the 10% malic and 10% lactic acid 1-minute dips with a rinsing and less time between dipping and HPW. Therefore, a second trial using FRW eggs on wax paper was carried out to determine the effect of lower concentrations (1 or 4%) of malic and lactic acid 1-minute dips (Table 3) on FRW egg viability (Page-Weir et al. 2015).

Table 3. Details of dip treatments to determine the impact on the viability of Fuller's rose weevil eggs on wax paper.

Treatment #	Postharvest dips and concentrations
1	Air control
2	Water control
3	1% acetic acid
4	1% citric acid
5	1% lactic acid
6	1% malic acid
7	4% acetic acid
8	4% citric acid
9	4% lactic acid
10	4% malic acid

An additional trial was conducted in Australia to compare the removal and reduction in egg hatch using lactic acid, malic acid and Prospect at ambient or heated temperatures (Page-Weir et al. 2015).

Objective 3: To determine the potential effects of dip compounds on the performance of sanitisers and postharvest decay

Trials were conducted in Australia to evaluate the impact of food acids and Prospect oil dips on the activity of sanitiser activity (Page-Weir et al. 2015).

Outputs

Jamieson LE, Redpath SP, Page-Weir NEM, Griffin MJ, Chhagan A, Taverner P, Rogers D, Woolf AB. November 2014. In-line approaches to control FRW eggs on Australian citrus. A Plant & Food Research report prepared for: Horticulture Australia Ltd Citrus Australia. Milestone No. 103. Contract No. 30297. Job code: P/331031/01. PFR SPTS No. 10866. (Appendix 1).

Redpath SP, Woolf AB, Taverner P, Jamieson LE. June 2014. Identifying opportunities to enhance the removal of Fuller's rose weevil eggs from Australian citrus. A report prepared for: Horticulture Australia Limited, Project no. CT13010. Plant & Food Research Milestone No. 58255. Contract No. 30297. Job code: P/331031/01. SPTS No. 10092. (Appendix 2).

Woolf A, Jamieson L, Taverner P, Olsson S, Redpath S 2015. Best-practice user manual for Citrus high pressure washers. A Plant & Food Research report. SPTS No. 11171. (Appendix 3).

Page-Weir NEM, Griffin MJ, Redpath SP, Jamieson LE, Taverner PD, Leo AT, Chhagan A, Hawthorne AJ, Woolf AB 2015. In-line approaches to control FRW eggs on citrus – Year 2. A Plant & Food Research report. SPTS No. 12170. (Appendix 4).

Jamieson L, Woolf A, Redpath S, Page-Weir N, Chhagan A, Griffin M, Olsson S, Rogers D, Taverner P 2015. CT13010 In-line approaches to control surface pests of concern from export citrus. Proceedings of the Citrus Technical Forum and Field Day 16-17 March 2015, Mildura Arts Centre, Mildura, Victoria, Australia: 35. (Appendix 5)

Jamieson L, Woolf A, Redpath S, Page-Weir N, Chhagan A, Griffin M, Olsson S, Rogers D, Taverner P 2015. CT13010 In-line approaches to control surface pests of concern from export citrus. Presentation to the Post Harvest Seminar Session at the Citrus Technical Forum and Field Day 16-17 March 2015, Mildura Arts Centre, Mildura, Victoria, Australia. http://www.citrusaustralia.com.au/latest-news/citrus-technical-2015-forum-field-day-16-17-march-2015. (Appendix 6)

Woolf A, Redpath S, Olsson S, Taverner P, Jamieson L 2015. High pressure washers. Proceedings of the Citrus Technical Forum and Field Day 16-17 March 2015, Mildura Arts Centre, Mildura, Victoria, Australia: 36. (Appendix 7).

Woolf A, Redpath S, Olsson S, Taverner P, Jamieson L 2015. High pressure washers. Presentation to the Field Day at the Citrus Technical Forum and Field Day 16-17 March 2015, Mildura Arts Centre, Mildura, Victoria, Australia. (Appendix 8).

Outcomes

Objective 1: To assess various HPW systems currently in use and to identify the best system for FRW egg removal from oranges (Redpath et al. 2014)

All citrus HPWs visited in Australia used a standard row HPW system with rows of nozzles pointing straight down. This is composed of a bed of rotating brushes or rollers with an overhead gantry of 6–12 manifolds each with brass low-flow fan nozzles pointing directly downwards onto the fruit.

Most systems had the nozzles offset in each consecutive gantry to give maximum potential fruit coverage. Depending on the system, generally one to four pumps were used to run the various HPWs. Although the HPWs were all similar, there was a great deal of variability among the HPW setup conditions in terms of pressure, distance, nozzles and filtration, with no standardisation of operating conditions. The operational performance of HPWs was assessed by making measurements, observations and assessing the removal efficacy of the HPWs.

The set-up of the HPWs ranged between 33 and 225 nozzles set at 95–300 mm apart, operating at pressures of 130–170 psi at nozzle heights of 105–270 mm, with treatment times of 9–20 seconds and mean flow rates of 7.1–17.3 L/min and 15–25% of nozzles blocked. Paint removal efficacy ranged from 35 to 95% depending on packhouse and concentration of the paint applied to oranges. A generic HPW optimisation manual for the industry has the potential to be developed, and its use to lift the performance of the current washing systems.

A better understanding was achieved of the scales of the operations and issues with which the packhouse staff contend. There are two major issues that need to be considered when developing improvements to HPW for citrus in Australia. The first issue is dealing with the large quantities of debris, dirt and grit present on fruit which may result in the need to design adequately self-washing filters to filter out grit, enabling nozzles to last longer. The second issue is maintaining a high throughput of 900–2600 fruit per minute.

Several presentations were made to the packhouse managers and HPW operators on the potential of new washing systems to enhance market access for Australian citrus exports. Recommendations on improved operating practices have been provided, and possible modifications to designs suggested (Woolf et al. 2015).

An experimental standard row HPW with vertical nozzles resulted in higher paint removal rates (93–96%) (Jamieson et al. 2014) than observed on commercial Australia HPW systems, where paint removal ranged from 35 to 97% (Redpath et al. 2014). This was probably because there were no blocked nozzles or nozzles were orientated correctly. This showed the importance of regular monitoring of performance and maintenance of HPW systems. Removal of paint was a good indication of water impact over a fruit surface; however, it did not reflect the numbers of FRW egg batches removed. On experimental units, fewer than 5% of FRW egg batches were removed using the standard row HPW unit operating with either straight or angled nozzles. However, the new generation rotating nozzle HPW system resulted in egg batch removal rates of up to 20%. Additionally a longer dwell time under a commercial standard row HPW system in Australia also increased removal of FRW eggs (26% removal).

Overall one of the major outcomes for objective 1 was that an effective HPW system requires regular monitoring and maintenance. Therefore, the "Best-practice user manual for Citrus high pressure washers" was produced to assist packhouse operators with increasing the performance of their HPW (Woolf et al. 2015). The second major outcome for objective 1 was that the new generation rotating nozzle HPW increased the removal rate of FRW eggs. Therefore, if packhouses in Australia were considering new HPW systems, then a rotating nozzle HPW would be recommended.

Objective 2: To determine whether selected pre-HPW dips can enhance FRW egg removal rates by HPW and/or reduce FRW egg viability (Jamieson et al. 2014; Page-Weir et al. 2015)

At the end of year one trials there was an initial indication that dips with Prospect oil tended to increase removal rates to ≈46% and tended to reduce the viability of FRW eggs from ≈70% hatching down to ≈30–50% hatching, or from 10–40% hatching down to 0% hatching.

Results from year two research indicated that a postharvest dip with 10% lactic acid and 3% Prospect and leaving for 24 h followed by HPW with the rotating system resulted in the highest FRW egg removal rates, of 91%. A postharvest dip with 10% malic acid and 3% Prospect was also very effective at increasing removal of FRW eggs. However, fruit quality data indicated that 10% malic acid or 10% lactic acid dips caused an undesirable skin blemish in the form of pitting, which was exacerbated by Prospect oil. Therefore, the rates of lactic and malic acid was reduced to 1 or 4%. The viability of FRW eggs was reduced after treatment with 1 or 4% lactic, malic, acetic or citric acid dips.

Trials in Australia indicated that heated pre-wash dips at 40°C with 1% food acid and 1% Prospect oil and calcium hypochlorite did not improve egg mass removal or decrease the egg hatch compared with results from the same non-heated pre-wash dips.

There were concerns that using a high rate of Prospect oil (3%) could result in health and safety concerns in the packhouse due to slippery surfaces. Therefore it was recommended that the rate of Prospect oil be dropped to 0.5–1.0%. Further trials to test the efficacy of lower rates of food acids combined with lower rates of Prospect oil could not be completed in this project because of resource constraints such as availability of FRW, navel oranges, time and funds.

Objective 3: To determine the potential effects of dip compounds on the performance of sanitisers and postharvest decay (Page-Weir et al. 2015)

High rates of food acid (10%) and Prospect (3%) resulted in rapid loss of sanitiser activity and rates of both had to be reduced to improve compatibility.

In Australian trials fruit decay was rapid, with high rates of decay in control-treated fruit and 1% food acid-dipped fruit after 3 days at 20°C. There were no significant differences in decay between the food acid treatments at 1% with or without Prospect. After dipping in 4% food acid, decay on oranges was significantly lower in acetic acid-dipped fruit than in malic and lactic acid-dipped fruit. Presence or absence of Prospect did not influence decay. However, fruit in all treatments decayed (100%) after 7 days at 20°C, suggesting that acetic acid dips inhibited fungal growth 3 days after treatment but were not fungicidal 10 days after treatment. Fungicides were also added to a food acid mixture to improve decay control. A mixture of thiabendazole, malic acid, Prospect and calcium hypochlorite resulted in 100% mould control after 7 days. However, a mixture of imazalil, acetic acid, Prospect and calcium hypochlorite resulted in poor mould control (17.5%).

Evaluation and discussion

Fuller's rose weevil eggs are particularly difficult pests to remove and/or kill, with HPW egg removal results here being the lowest of any pest we have examined to date. The nature of the adults laying eggs under the calyx makes removal a challenge (i.e. the HPW water jets reaching the egg), and this location also protects some of the eggs from dip treatments. However, the aim of this project was to enhance removal of eggs from fruit and/or reduce egg viability, not to provide complete control, and we have achieved that, firstly by using a new generation rotating washer that enhances from ~5% removal using standard row HPW up to 20% removal of egg batches using the rotating HPW. Other research has found that rotating HPW systems can enhance removal of key pests such as mealybugs and scale insects (Woolf et al. 2012).

Secondly, egg batch removal after HPW increased with the use of 1-minute postharvest dips using high rates (10%) of food acids applied 24 h before HPW. The addition of 3% Prospect oil to lactic acid enhanced egg batch removal from 45% to 91% removal; however, dipping using 10% lactic acid or 10% malic acid and leaving for 24 h before HPW resulted in unacceptable rates of damage to the oranges. Fruit quality trials investigated reducing the time between dipping with lactic acid or malic acid and HPW, and included a rinse after dipping, which reduced damage but did not eliminate damage. The use of a lower rate dip of 1% lactic acid + 0.5% Prospect oil dip did not increase egg batch removal compared with that of eggs dipped in water or not dipped. The rate of lactic acid was reduced because of the fruit quality issues encountered. The rate of Prospect oil was lowered to reduce the amount of oil in a commercial packhouse for health and safety reasons, e.g. potential slip hazards.

Thirdly, we reduced the viability of FRW eggs on fruit from ~90% viability to 25–57% viability with the use of 1-minute postharvest dips containing 10% malic or lactic acid and 3% Prospect oil. Additional treatments containing 3% Prospect oil alone and the high and low rates of acid + Prospect oil treatments that were rinsed before HPW were also shown to be more effective at reducing egg viability than that of eggs on wax paper dipped in water. The effects of food acids (lactic, malic, citric and acetic acids) applied at 1 or 4% on FRW egg viability were compared. All treatments reduced egg viability compared with those of untreated and water-dipped eggs on wax paper. Further research is required to determine if low rates (1–4%) of acid + low rate Prospect oil (1.0–0.5%) dips can enhance FRW egg removal and reduce egg viability.

Previous work has indicated that higher water temperatures and longer exposure times are required to kill FRW eggs on infested fruit (Jessup et al. 1993). Prospect was expected to improve heat transfer by aiding flow of the solution under the orange calyx. Likewise, heat was expected to aid the chemical flow under the calyx. However, there was no decrease in egg hatch, suggesting that the solution did not penetrate fully under the calyx. In addition, 30-s 40°C water dips did not achieve significant egg mortality on wax paper (exposed) or infested fruit (sheltered). Higher temperatures are required to provide efficacy. Limited trials indicated very high mortality of exposed FRW eggs with 30-s 50°C water dips, and 100% control with 60°C or higher water dips (data not presented). Similar water temperatures and longer contact times would increase efficacy on infested fruit but may be more difficult to achieve in commercial citrus packing lines. Redpath et al. (2015) found that a 52.5°C hot water treatment for 2–3 minutes consistently achieved >90% mortality of mixed life stages of latania scale, onion thrips and diapausing larvae of apple leafcurling midge. Sixty to seventy percent of the most tolerant pest tested, obscure mealybug, were controlled by a 2–3 minute hot water treatment at 51–52.5°C (Redpath et al. 2015). A hot water treatment of 51°C for 2 minutes did not affect the quality of 'Royal Gala', 'Fuji' or

‘Braeburn’ apples (Redpath et al. 2015). Therefore, there is potential to control a range of pests on oranges with a heated (50–55°C) postharvest dip for 1–3 minutes.

Lower food acid rates (4%) improved stability of free chlorine except when Prospect (3%) was added. The free chlorine concentrations were more stable when both food acid and Prospect rates were reduced. Another sanitiser, peracetic acid (PAA), was more stable when added to food acids and Prospect. The reason for the difference was not investigated. Presumably, the PAA was more stable in the acid environment created by the food acid (Mehmet 2004), whereas chlorine would be lost as chlorine gas under similar acidic conditions (Suslow 2001). However, the reason for chlorine instability with Prospect is unclear. PAA may be a better choice for water sanitation than chlorine-releasing compounds. Lower rates of food acid and Prospect would be required to maintain chlorine stability. Regardless, the effects on FRW egg hatch and removal need to be considered for these options.

The fruit bioassays confirm that chlorine does not control decay on inoculated fruit. Unfortunately, the food acids did not provide any decay suppression at 1%, which is the rate that maintains some chlorine stability. At higher rates (4%), acetic acid suppressed fungal growth, reducing decay to 5% for up to 3 days after dipping. Acetic acid has been shown to be an effective fumigant on a range of fruits (Tripathi & Dubey 2004). Fruit were sealed in plastic bags after dipping and some acetic acid may remain to volatilise. It is unclear if acetic acid suppressed fungal growth by aqueous contact or fumigant action. If fumigant, dipped fruit may need to be held in airtight storage rooms. In any case, acetic acid only delays growth and a fungicide should be applied within 24–48 h of harvest (Wild & Spohr 1989). Alternatively, a fungicide could be added to the dip, which creates the potential for further interactions. This study suggests that thiabendazole is compatible with malic acid and Prospect. But imazalil was incompatible with acetic acid and Prospect. The effects of these fungicide mixtures on FRW eggs hatch and removal were not investigated.

Overall, it will be a challenge to optimise a compatible dip mixture to maximise the control of FRW eggs and still maintain decay control and overall fruit quality. Further work on heated solutions as part of a systems approach for the control of FRW may still be warranted. Australian citrus packers are moving towards short heated fungicide treatments, which provide the heating capacity for other uses. For FRW control, selecting higher temperatures and maintaining short dip times should increase FRW egg efficacy. However, the range of temperatures evaluated needs to consider the limitations of commercial practice and fruit safety. Prospect and/or other chemicals must aid penetration under the calyx and thus reduce the required dip times. Fungicides may need to be directly added to the dips unless acetic acid mixtures can provide short-term protection from decay. In all instances, the mixtures considered for further evaluation need to fulfil the primary requirement of FRW egg control. The effect on fruit quality needs to be considered concurrently with any FRW egg efficacy work.

Recommendations

We recommend that citrus packhouses use the procedures set out in the 'Best-practice user manual for Citrus high pressure washers' (Woolf et al. 2015) to improve the pest removal efficacy of their HPW system. For those packhouses building new HPW units, we recommend a rotating HPW system to enhance removal of FRW eggs, and other postharvest pests.

Further research is warranted to:

- Determine if low rate (~4%) acids + Prospect oil (1–0.5%) dips can enhance FRW egg removal and reduce egg viability and the impact of these on fruit quality, sanitizer performance and postharvest decay.

- Investigate the efficacy of applying heated dips (50–55^{o}C) with and without low rates of acids + Prospect oil.

- Determine if a fungicide is required for an effective postharvest dip treatment that reduces the risk of viable FRW eggs infesting fruit and maintains fruit quality.

Scientific refereed publications

None to report.

Intellectual property/commercialisation

No commercial IP generated.

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Appendices

Appendix 1

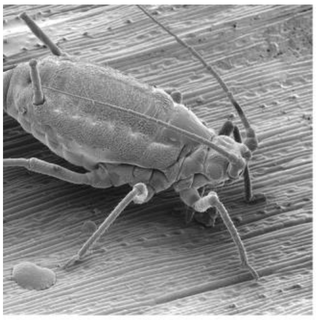
Redpath SP, Woolf AB, Taverner P, Jamieson LE. June 2014. Identifying opportunities to enhance the removal of Fuller's rose weevil eggs from Australian citrus. A report prepared for: Horticulture Australia Limited, Project no. CT13010. Plant & Food Research Milestone No. 58255. Contract No. 30297. Job code: P/331031/01. SPTS No. 10092.

PFR SPTS No 10092

Identifying opportunities to enhance the removal of Fuller's rose weevil eggs from Australian citrus

Redpath SP, Woolf AB, Taverner P, Jamieson LE

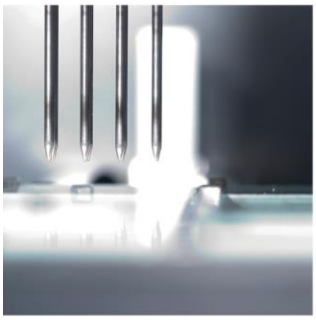
June 2014





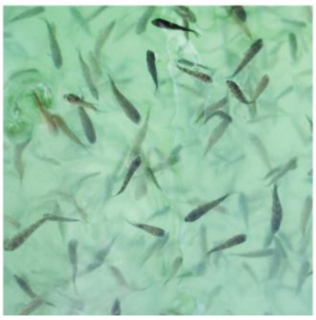
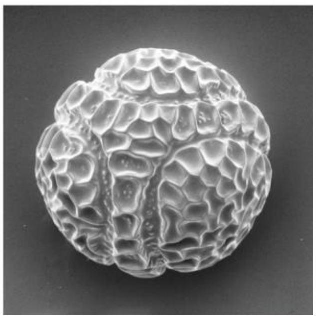










CONTENTS

EXECUTIVE SUMMARY

Identifying opportunities to enhance the removal of Fuller's rose weevil eggs from Australian citrus

Redpath SP[1], Woolf AB[1], Taverner P[2], Jamieson LE[1]
Plant & Food Research, [1]Mt Albert;
[2]South Australia Research Development Institute, Adelaide, Australia

June 2014

The Australian citrus industry is planning on expanding into profitable Asian markets i.e. China, Korea and Thailand. Fuller's rose weevil (FRW) is a quarantine pest in China, Korea and Thailand, and citrus red scale (CRS) has emerged as a quarantine issue for Korea and China. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs; this has reduced the number of shipments rejected during pre- or post-shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets. A combination of field-based and postharvest treatments, i.e. high pressure washing (HPW), has the potential to provide a systems approach capable of reducing the risk of FRW eggs being present on export citrus, therefore increasing export volumes to FRW-sensitive markets.

There have been significant developments in postharvest 'in-line' HPW pest removal systems in New Zealand over the last 5–10 years. New HPW systems are removing more difficult-to-remove pests than old HPWs. Old HPWs are operating in Australian packhouses to wash citrus; however, FRW egg removal rates are low.

As a first stage of a project to investigate a proof-of-concept approach to develop more effective postharvest 'in-line' systems to reduce viability and/or remove FRW eggs from Navel oranges, two PFR staff visited the Riverland (South Australia) and Sunraysia (NW Victoria) regions of Australia on 23–25 September 2013.

The aims of this stage of the project were to visit Australian citrus packhouses of varying sizes with in-line HPW systems to:

- View and discuss current HPW systems used in Australia, to gain a better understanding of the scales of operation and issues with which the packhouse staff contend
- Assess the operational performance of the HPWs by making a range of measurements including pressure, flow rate, nozzles type, distance from nozzles, nozzle orientation, and dwell time
- Assess the removal efficacy of the HPWs by putting Navel oranges covered with a kaolin clay/glue mix through each HPW to determine standard industry removal rates. This gives an approximation of contaminant removal efficiency but is not meant to correlate fully with FRW removal

- Discuss current FRW in-orchard control methods, at-harvest infestation rates, target infestation rates, and the standard of compliance data required
- Discuss the potential of new washing systems (equipment details e.g. size of pumps, throughput, number of fruit/hour, water filtration).

Results and conclusions

All citrus HPWs visited in Australia used a system similar to the Honiball system with straight nozzles. This is composed of a bed of rotating brushes with an overhead gantry of 6–12 manifolds each with brass low-flow fan nozzles pointing directly downwards onto the fruit. Most systems had the nozzles offset in each consecutive gantry to give maximum potential fruit coverage. Depending on the system, generally one to four pumps were used to run the various HPWs. Although the HPWs all used were similar, there was a great deal of variability among the HPW setup conditions in terms of pressure, distance, nozzles and filtration, with no standardisation of operating conditions. The operational performance of HPWs was assessed by making measurements, observations and assessing the removal efficacy of the HPWs. The set up of the HPWs ranged between 33 and 225 nozzles set at 95–300 mm apart, operating at pressures of 130–170 psi at nozzle heights of 105-270 mm, with treatment times of 9–20 seconds and mean flow rates of 7.1–17.3 L/min and 15-25% of nozzles blocked. Paint removal efficacy ranged from 35 to 95% depending on packhouse and concentration of the paint applied to oranges. A generic high pressure washing optimisation manual for the industry has the potential to be developed, and its use to lift the performance of the current washing systems.

A better understanding was achieved of the scales of the operations and issues with which the packhouse staff contend. Two major Issues that need to be considered when developing improvements to HPW for citrus in Australia are firstly, dealing with the large quantities of debris, dirt and grit present on fruit which may result in the need to design adequately self-washing filters to filter out grit, enabling nozzles to last longer; and secondly, maintaining a high throughput of 900–2600 fruit per minute.

Several presentations were made to the packhouse managers and HPW operators on the potential of new washing systems to enhance market access for Australian citrus exports. Recommendations on improved operating practices have been provided, and possible modifications to designs suggested. However, it appears unlikely that, even with significant modifications, the current washers will achieve adequate phytosanitary outcomes i.e. high removal of FRW eggs. Two novel higher pressure systems (that involve singulated fruit) should be tested to determine FRW egg removal.

Orchard FRW egg infestation rates can range from very low up to 25% of fruit infested depending on time of season, year and control methods used in the orchard. Orchard control methods can reduce egg infestation rates from 23% of fruit infested down to 0–4.3%. The rate of FRW egg removal from a commercial citrus HPW (10 booms each fitted with 23 nozzles) operating at 160 psi for a 24-s dwell time was estimated at between 5 and 20% (Taverner et al. 2007). There is potential to improve and standardise citrus HPWs to increase removal rates; however, moving towards a singulated system such as Compac® or Fruit Sortling System (FSS) was required in New Zealand to improve removal of difficult organisms significantly.

It is likely that a combination of field control measures to reduce infestation to below a threshold and a postharvest dip + HPW system that removes higher numbers than HPWs are currently achieving will be a solution for increasing the pass rates of citrus inspections for accessing FRW-sensitive markets. The most suitable system for citrus will need to be determined based on fruit tolerances, removal of FRW eggs, throughput and economic cost/benefits. Therefore, a proof-of-concept approach with stop/go stages was followed.

Future research

Future research for this project will focus on:

- Investigating the paint and FRW egg removal efficacy of Compac and FSS HPWs and comparing this with paint and FRW egg removal by Honiball HPWs
- Determining the impact of postharvest dips on FRW egg removal and viability
- Developing of a generic high pressure washing optimisation manual for the industry to lift the performance of the current and future washing systems.

For further information please contact:

Lisa Jamieson
The New Zealand Institute for Plant & Food Research Ltd
Plant & Food Research, Private Bag 92169
Mt Albert, Auckland
NEW ZEALAND
Tel: +64-9-9257284
Fax: +64-21-2268284
Email: Lisa.Jamieson@plantandfood.co.nz

1 INTRODUCTION

Australia's close proximity to a growing middle-class in Asia is an opportunity for the Australian citrus industry to expand into profitable markets. For example, the most recent citrus strategic plan lists the development of the South Korean market to 10,000 tonnes annually as a key performance indicator (Anon. 2011). This outcome is being impeded by the interception of quarantine pests, in particular, the interception of Fuller's rose weevil (FRW, *Naupactus cervinus* (= *Asynonychus cervinus*)) eggs and, more recently, Californian red scale (CRS, *Aonidiella aurantii*). FRW is a quarantine pest in China, Korea and Thailand, and CRS has emerged as a quarantine issue for Korea and China. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs (Baker et al. 2011; Baker & Crisp 2012); this has reduced the number of shipments rejected during pre- or post-shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets. New fumigants are being considered for the management of a range of pests, including FRW; however, the development of fumigation protocols acceptable to overseas markets is a long-term strategy. In the interim, new approaches are required to increase volumes exported into these important markets. A combination of field-based and postharvest treatments has the potential to provide a systems approach capable of reducing the risk of FRW eggs being present on export citrus, therefore increasing export volumes to FRW-sensitive markets.

There have been significant developments in high pressure washing (HPW) pest removal systems in New Zealand over the last 5–10 years. New HPW systems are removing more difficult-to-remove pests than old HPWs (Woolf et al. unpublished data, Rogers et al. unpublished data). These new systems do not rely on random movements of fruit to enable a targeted 'hit'; they treat each individual fruit for 1-2 seconds to ensure that the fruit has received full coverage. Three high pressure washing systems are currently being used commercially in NZ New Zealand One is based on the old-style 'descalers' (Honiball system), with rows of nozzles above a roller bed of fruit (Honiball et al. 1979; Jamieson et al. 2010; Whiting et al. 1998a, b; Woolf et al. 2009). This Honiball system is similar to the current citrus washers in Australia; however, in New Zealand we are investigating the use of angled nozzles to increase fruit movement under the nozzles, thereby increasing the chance of a direct hit to the area of interest (e.g. calyx of fruit). The second is a more targeted singulated three-nozzle system (FSS system, McDonald 1999; Jamieson et al. 2000; Whiting et al. 1998a, b). The third is also a singulated system with rotating nozzles to achieve coverage (Compac system, Rogers et al. unpublished data; Woolf et al. unpublished data).

In Australia and New Zealand, postharvest dips have been tested to enhance the removal of difficult-to-remove pests and/or reduce the viability of pests (Rogers et al. unpublished data; Taverner & Bailey 1995; Taverner & Cunningham 2000; Taverner & Perry 2009). In Australia Prospect®, a food-grade oil treatment showed the most potential to enhance removal of FRW eggs. In addition, sodium and calcium hypochlorite at high rates can dissolve FRW egg adhesive, and at low rates, can act as an irritant, causing rapid egg hatch (Taverner 2007; Baker et al. 2013).

As a first step of a project to investigate a proof-of-concept approach to develop more effective 'in-line systems to reduce viability and/or remove FRW eggs from Navel oranges, two PFR staff visited the Riverland (South Australia) and Sunraysia (NW Victoria) regions of Australia on 23–25 September 2013. The combined South Australian and Victorian citrus industries make up approximately 82% of the country's citrus export industry, and Australia's total citrus exports are worth around $A300 million to all markets.

2 AIM

The aims of this part of the project were to visit five Australian citrus packhouses of varying sizes with in-line HPW systems to:

- View and discuss current HPW systems used in Australia to gain a better understanding of the scales of operation and issues with which the packhouse staff contend
- Assess the operational performance of the HPWs by making a range of measurements including pressure, flow rate, nozzles type, distance from nozzles, nozzle orientation, and dwell time
- Assess the removal efficacy of the HPWs by putting Navel oranges covered with a kaolin clay/glue mix through each HPW to determine standard industry removal rates. This gives an approximation of contaminant removal efficiency but is not meant to correlate fully with FRW removal
- Discuss current FRW in-orchard control methods, at-harvest infestation rates, target infestation rates, and the standard of compliance data required
- Discuss the potential of new washing systems (equipment details e.g. size of pumps, throughput, number of fruit/hour, water filtration).

3 MATERIALS AND METHODS

Peter Taverner from South Australian Research and Development Institute (SARDI) selected five sites to cover a wide range of both small and large packhouses in South Australia and North West Victoria. Both Peter and Andrew Harty (Citrus Australia) acted as facilitators between PFR staff and packhouse staff. PFR staff carried out a series of measurements on a range of parameters on each HPW system in each packhouse. These included:

- Flow rate, pump pressure, throughput
- Dimensions/type of HPW unit and filtration unit
- Nozzle orientation, type, spacing and number
- Removal efficacy of PVA- and kaolin-painted Navel oranges.

3.1 Nozzle flow rate

The flow rate of 10 randomly selected nozzles was measured to determine if there had been significant wear or blockage. While complete blockage of nozzles is easy to note visually, partial blockage can be difficult to see and flow rate is one way to determine this.

The fruit conveyor was generally turned off and water turned on at standard pressure and running conditions. One end of a PVC pipe was placed over a nozzle and the other end of the pipe held over a graduated measuring container (e.g. 5-L jug). A timer (set on "count up") was used to time how many seconds it took to fill to a certain volume (Figure 1). To convert the time (in seconds) to litres per minute, the following formula was used:
$(v/t) \times 60$ = flow rate (litres/minute), where v = volume collected (litres) and t = time to fill (seconds)
Measuring flow rate was difficult at some packhouses because of substances such as silt, fruit pulp, chemicals in the HPW water causing froth. In these instances an unknown volume was timed, the froth allowed to settle, and the volume then recorded.

Figure 1. Measuring flow rate in a High Pressure Washing (HPW) system for citrus. Three simple tools are required to do this: flexible pipe, measuring container (~5 L) and a timer (count-up). Note the frothing of the water in the container, necessitating settling after measurement to determine the volume.

3.2 Nozzle distance, orientation and water pressure

Fruit size varies; therefore, nozzle height was measured from the nozzle to a tennis ball which was used to represent a standard object. An old tennis ball (i.e. with minimal hair) was placed between the brushes and the distance from the nozzle to the tennis ball measured along the angle of the water jet using a small ruler (trimmed so that the "start" was 0 mm). Distances between nozzles were also noted to determine total area of the HPW unit.

Nozzle orientation was also noted as this can affect the efficiency of any HPW system. Nozzles not pointing in the right direction or angled incorrectly can all have a negative impact on pest and dirt removal. Erroneous nozzle orientation can also damage HPW equipment such as brushes, rollers and the nozzles themselves.

Water pressure was noted for each HPW at the pressure gauge closest to the nozzles.

3.3 Efficacy of contaminant removal

Measuring HPW pest removal efficacy involves the provision of large quantities of pest-infested fruit, in this case FRW eggs. However, this is expensive and often not feasible, and we consider that the removal of a non-toxic white paint is a practical substitute (which we have used in much of our New Zealand-based research). The method can be applied to any washer type. It can highlight 'dead spots' that the water jets are not reaching, but full paint removal should not be taken as a guarantee that the degree of impact is sufficient to remove the target pests – i.e. paint may be easier to remove than the target pest. Thus, this technique provides a relatively simple cost-effective means of examining water washer coverage over fruit.

Approximately forty fruit that had been dipped in a mixture of kaolin clay and PVA glue as a substitute for pest-infested fruit, were run over each of the HPWs at the speed and pressure of the packhouses normal setup for oranges. When dry, the proportion of each fruit with paint remaining was rated and the location of the paint was recorded (Figure 2). Because of fruit exclusion zones between the South Australian and Victorian borders, oranges were painted by different people. Hence we had paint with the standard mix of PVA glue and kaolin clay used previously in New Zealand on apples, and one batch of oranges with double the amount of PVA glue and kaolin clay. These are identified in the Results and Discussion section. Although the double mixture was a mistake, it seemed to stick to the fruit better than the standard formulation. The percentage of white paint removed from around the button, since this is the location of FRW eggs, and around the entire body of the fruit including the button, was recorded (CRS can be present anywhere on the fruit but generally in grooves).

Figure 2. "Painted fruit" used to visualise contaminant removal efficacy by High Pressure Washers, using a mixture of kaolin clay and PVA glue. The above fruit are an indication of the range of removal efficacy from packhouses visited.

3.4 Discussion with packhouse staff

To gain a broad understanding of how the high pressure washing machines were operating, a general discussion was undertaken with a range of staff members from each packhouse which generally included the packhouse manager, QC manager, engineer and/or primary operator of the washer
(as appropriate for each packhouse).

Topics covered in the discussions included:

- Details of the washer equipment: manufacturer, nozzles, water pump and pressures
- Throughput: feed rate, export versus local market bins/day
- Maintenance schedule: daily and seasonal
- Estimate of washer performance
- Problems identified.

Sometimes all of the above were not available at each packhouse because of circumstances such as staff availability and lack of historical records.

4 RESULTS

All water washers used a system similar to the Honiball system with straight nozzles. This is composed of a bed of rotating brushes with an overhead gantry of 6-12 manifolds each with brass low-flow fan nozzles (e.g. H 1/4U-SS-4015, Boquillas VeetJet®) pointing directly downwards onto the fruit. Most systems had the nozzles offset in each consecutive gantry to give maximum potential fruit coverage. Depending on the system, generally one to four pumps were used to run the various HPWs. A simple overview of the five systems is available in Table 1. The throughput required for citrus packhouses ranged from 900 to 2600 fruit per minute.

Table 1. Summary of measurements and issues noted on citrus high pressure washing units (HPWs) at five citrus packhouses in the Riverland and Sunraysia regions of Australia.

Pack-house	Size of trtmt area	No. nozzles	No. rows	No. nozzle /row	Nozzle position	Distance nozzles apart (mm)	Pressure at pump (psi)	Nozzle height (mm)	Trtmnt time (s)	Mean flow rate (min-max) (L/min)	Nozzle blockages (%)	Sweep bar	Filter system	Other comments
1	2.7 m^2	104	12	9-10	offset	190	130	120	16	8.37 (7.3 – 9.1)	25%	Yes	Yes self-cleaning coarse rotary system	Two units together inline, home built 15 y ago, 44 or 22 fruit/s for each unit. One pump
2	2.9 m^2	168	12	14	offset	130	140 (10 bar)	145	15.6	12.3 (11.7 – 12.9)	15%	No	Yes 3000 L coarse and fine	No prewash system in place, MAF RODA agrobiotic (Spain), 40 fruit/s. Four pumps
3	3.1 m^2	225	10	22-23	offset	95	Gauge not working	105-110	20	7.05 (6.3 – 8)	unknown (not changed in 7 years)	Yes	Yes 1850 L angled fine mesh	Pressure controlled by gate valves at each manifold, manufacturer 'Spit Water', 15 fruit/s. One pump
4	2.0 m^2	150	10	15	?	100	160-170	150-155	15.2	17.3 (14.7 – 18.6)	22%	Yes – only used to clear fruit at end of shift	Yes, 2000 L coarse and fine	Two separate prewash systems in place. Locally manufactured, 30fruit/s. One pump
5	1.2 m^2	33	6	5-6	offset	300	No gauge	270	9	N/A	21%	No	None	Not really a HPW system, 15 fruit/s. One pump

4.1 Nozzles and configuration

Nozzles and their associated problems accounted for a large number of inefficiencies in all the systems observed. Some nozzles had not been changed for years, others were blocked, partially blocked, orientated wrong or interacting with (i.e. water jets hitting) one another. On average, 15–25% of nozzles inspected at all packhouses were either blocked or missing (Figure 3). It is observed and understood that because of silt/dirt/mud on the fruit that keeping nozzles unblocked is a very time-consuming exercise. However, as will be discussed later, a good filtration system is essential.

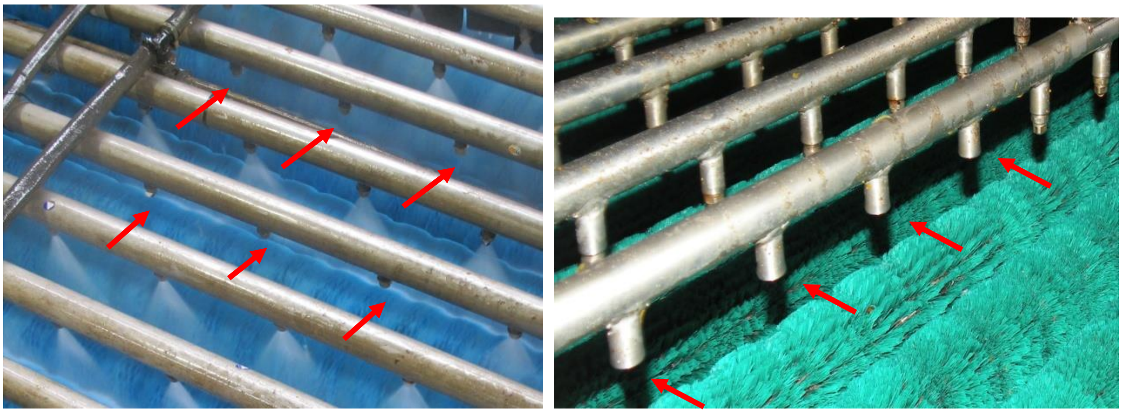


Figure 3. Completely blocked or missing nozzles in high pressure citrus washing systems.

There were no data recorded on partially blocked nozzles or ones that were orientated incorrectly, although the flow rates in Table 1 give an indication of where the partial blockages might be. However, just by visual observation there were a large percentage of nozzles that were not delivering a distinct fan-shaped jet of water to the fruit, and in one particular case, a large percentage were rotated so the spray fan was 90° to where it should be (Figure 4). Nozzles can be blocked or partially blocked for a number of reasons; these include nozzle wear, build up of debris, and filtration not working properly. Maintaining the filtration system and replacing nozzles is very important if high HPW pest removal efficacy is a priority.

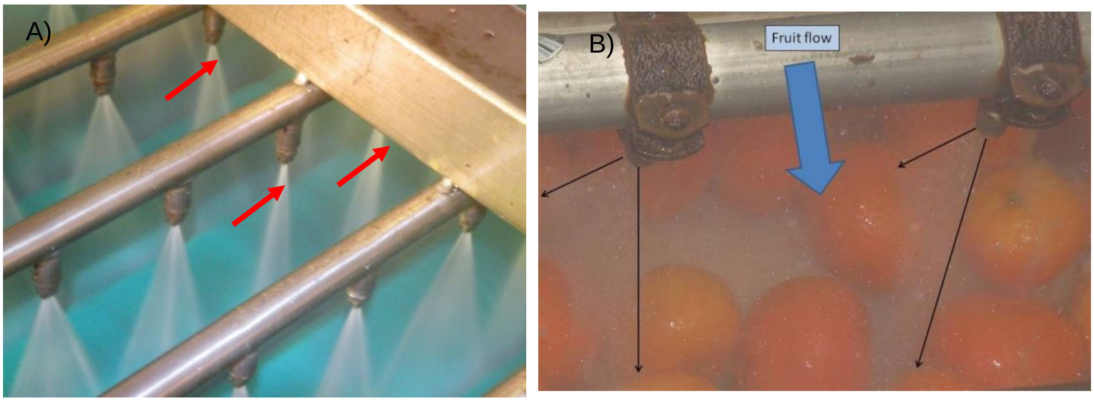


Figure 4. (A) Partially blocked nozzles in high pressure citrus washing systems not delivering a distinct 'fan' jet of water for maximum coverage. (B) Nozzles orientated incorrectly (rotated 90°) and only hitting a small fraction of the fruit (and also cause damage to the brushes).

4.2 Flow rates, pressures, heights, filtration systems

Flow rates were variable (Table 1) within each packhouse, but only a small sample of 10 nozzles were measured because of time constraints. Between packhouses, flow rates varied from an average of 7.1 to 17.3 L/min (Table 1). Nozzle wear was suspected given that many machines had not had their nozzles replaced recently or ever. Our experience is that significant wear occurs over even one season. This problem is greater in many growing areas in Australia where dust and dirt on fruit will lead to greater nozzle wear. A simple baseline set of data should be archived for each packhouse to refer to regularly, so that nozzle wear can be monitored. This would involve sampling flow rates from at least half the nozzles when all nozzles are new or unblocked, water is fresh, and the pump is working at the desired pressure.

Water pressure gauges were generally located at the pump, with no pressure gauges on or near the gantry. It is important that a gauge on the gantry is used so that pressure is measured as close to the nozzles as possible, since pressure (head) loss occurs along pipes, i.e. with distance. An increase in pressure on one gantry can indicate nozzle blockage, although small blockages and pressure differences are unlikely to be detected. A decrease in pressure (generally over a long time) suggests excessive nozzle wear. A pressure decrease may also indicate a lost nozzle, blocked pump inlet filters, or other pump problems. Water pressure measured in the packhouses ranged from approximately 130 to 170 psi for most systems. However, in one packhouse the gauge was not working and pressure to the gantry was controlled by a gate valve to each individual pipe. This is not an ideal situation because a uniform pressure cannot be applied across the treatment area. In another packhouse there was no pressure gauge and the water from the nozzles was very much like 'garden hose' pressure.

Between packhouses there was a wide range of distances measured from nozzle to tennis ball (105–270 mm, Table 1). Given that nozzle distance from fruit is a key factor influencing the removal efficacy of a given washer, the variation noted here is a significant issue that may need to be standardised. Only one HPW unit had an adjustable gantry to control height from the fruit. An adjustable gantry can be retrofitted and gives the packhouse the ability to optimise the washer, and to adjust the height for different sized fruit or other commodities.

Filter systems were generally not keeping up with the debris and silt present on the fruit. Most filtration systems consisted of a coarse mesh filter and some had a second fine mesh filter. At some packhouses it was observed that the filter system was letting through debris that could then potentially block nozzles, indicating that the mesh was not fine enough or that there was no fine mesh step after the coarse filter. Continuous cleaning and clearing of the filters was an issue, although at one packhouse an angled filter system that was continuously cleaned with a hose was more effective than other systems viewed.

4.3 Efficacy of contaminant removal

The use of a non-toxic white paint removed from the fruit was found to be inexpensive, rapid and simple to carry out. It highlighted 'dead spots' that the water jets were not reaching, and showed up a range of problems including blocked nozzles, poor nozzle orientation, water jet interaction, poor pressure and poor fruit rotation.

As mentioned earlier, because of fruit exclusion zones between the South Australian and Victorian borders, oranges were painted differently. Two packhouses received a double-strength mixture of PVA glue and kaolin clay painted on oranges, while the other three packhouses received single-strength. Figure 5 shows that the single-strength paint mixture used at Packhouses 3–5 was generally easier to remove than the double-strength mixture. Double-strength mixture was harder to remove, while more of the single-strength mixture often came off with the brushes before the HPW.

The assessment of paint removal consisted of concentrating on percentage removal around the button of the fruit, and also removal from the whole fruit including the button (Figures 5 and 6). Within a packhouse, there was not a vast amount of difference between the removal of paint from around the button of the fruit and that from the entire fruit body. An exception was at Packhouse 5 which overall had poor removal of paint; however, it tended to have a lower percentage removal of paint from the entire fruit than from around the button. Between packhouses, there appeared to be considerable differences in the percentage of paint removed. The biggest differences were attributed to double-strength paint being more difficult to remove than single-strength paint. Packhouse 4 had average paint removal efficacies from button and entire fruit body of 96.8% and 95.5%, respectively. This may appear to be a good result; however, this packhouse had incidences of single fruit scoring only 20–70% paint removal. Packhouse 5 had particularity poor removal of paint and this was more of a drench than an HPW system.

Figure 5. Examples of painted mixture not removed by the high pressure washer from around the button (left) and from the whole citrus fruit (right).

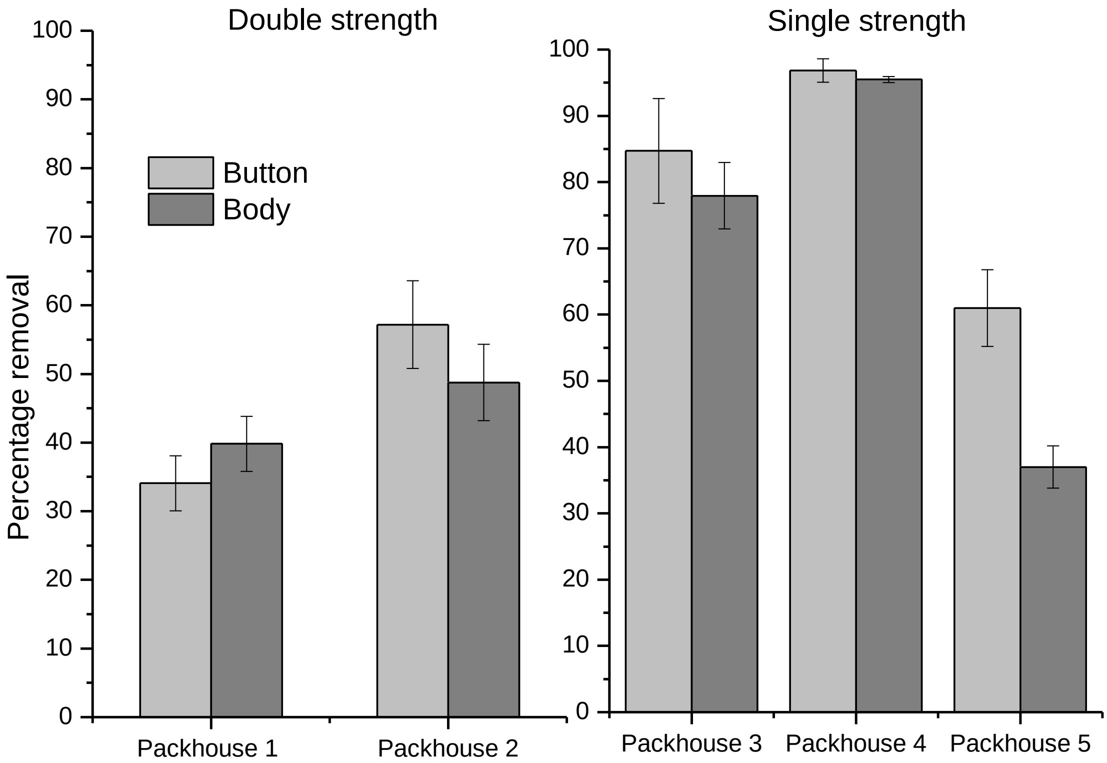


Figure 6. Mean percentage removal efficacy data of painted oranges run through five separate citrus packhouse high pressure washing (HPW) systems. Percentage removal assessments were made around the button area and on the whole body of the fruit (including the button). Single or double strength kaolin clay/PVA glue mixture was used in each packhouse.

5 GENERAL DISCUSSION

5.1 Degree of removal of FRW eggs required

For citrus exports, a sample of 600 citrus fruit are inspected and 10% of the calyces are lifted. To pass inspection, no eggs are to be found. Orchard infestations can range from low numbers up to 25% of fruit infested with FRW eggs depending on time of season, year and control methods used in the orchard (Andrew Harty, pers. comm.). For each 1 ha, 25 trees are inspected and infestation rates are 0 FRW to remain in the China export programme and 0.1 FRW adults per tree for export to Korea and Thailand. Current orchard control methods include skirting trees, minimising weed growth and insecticide trunk applications (estimated cost $A2000/ha (Andrew Harty, pers. comm.)). These can reduce infestation rates from 23% of fruit infested down to 0–4.3% of fruit with eggs detected in 240 fruit on the tree (Baker & Crisp 2012). Based on a compliance model (Jamieson et al. unpublished data): to be 95% confident passing inspection and in a worst-case scenario of 25% of fruit infested with one FRW egg mass, a HPW (in conjunction with a postharvest dip) that removed 98% of viable eggs would be required. More realistically, a combination of field control measures to reduce infestations to below 5% of fruit infested and a postharvest dip + HPW system that removed 90% would have potential for increasing the pass rates on inspections for accessing FRW-sensitive markets.

An indication of the rate of FRW egg removal from a commercial citrus HPW (10 booms each fitted with 23 nozzles), operating at 160 psi for a 24-s dwell time was estimated at between 5% and 20% removal of FRW eggs (Taverner et al. 2007). In the New Zealand situation using new HPWs (FSS system and Compac system), we have enhanced the removal of difficult-to-remove pests from 50% to ~90%.

Strategies we are proposing to investigate are in two broad categories; firstly, improving removal rates using modified HPWs or new HPWs, and secondly, using postharvest dips to enhance removal and/or reduce the viability of FRW eggs.

More detailed recommendations for improving the current citrus washers are outlined below and include regular maintenance such as checking for nozzle blockages, orientation, spray pattern, pressure drop, flow rates, installation of nozzles that are easy to replace, and improved filtration systems. Other improvements to the current system may include higher pressures, longer dwell times, more nozzles/rows, and angled nozzles to increase fruit movement under the HPW, therefore increasing the chance of hitting the calyx end.

New washers that treat single fruit such as the Compac or FSS washer described in the introduction which are used in the New Zealand apple and avocado industries may increase FRW egg removal from oranges. However, the location (often under the calyx) and adhesiveness of the egg masses makes high pest removal rates using HPW alone difficult. The combination of HPW with field control measures and postharvest dips to enhance removal and/or kill eggs will probably be required.

5.2 Recommendations for improvement of current washer

This survey of five citrus washers in Australia showed that, although they all used a similar principle (rows of nozzles over a brush bed), there was a great deal of variability between packhouses. Thus, there was a wide range of setup conditions in terms of pressure, distance and nozzles, with no standardisation of operating conditions. A generic high pressure washing optimisation manual for the industry has the potential to be developed and used to lift the performance of the current washing systems. The recommendations below could form the basis for inclusion in such a manual.

5.2.1 General observations

To ensure treatment is being carried out effectively, water pressure, fruit feed and movement, and general operation of the unit should be observed. Regular, careful inspection of the unit can highlight issues that might reduce the effectiveness of the machine, with serious economic consequences if phytosanitary obligations are violated.

Water pressure is an important factor and should be carefully monitored. While a pressure gauge is normally found at the pump outlet, it is critical that an accurate gauge be placed on each gantry and as close to the nozzles as practical, because pressure (head) loss occurs along pipes. We recommend at least two or three gauges for each washer.

The pressure gauges should be calibrated at the start of each season by comparison to a gauge known to be correct. Any changes in pressure in the season can be verified by swapping gauges. Having a spare new pressure gauge in stock allows for rapid changes and checks to be made. An increase in pressure on one gantry can indicate nozzle blockage, although small blockages and pressure differences are unlikely to be detected. A decrease in pressure (generally over a long time) suggests excessive nozzle wear. A pressure decrease may also indicate a lost nozzle, blocked pump inlet filters, or other pump problems.

Pressure gauges should be oil-filled or have other features that protect against vibration, especially if the pump is a piston type. When the pump is turned off, checking that the gauges read zero should be done regularly, because gauge wear or over-pressure can cause significant gauge errors.

5.2.2 Spray pattern

The spray pattern of nozzles should be regularly observed to check they are operating correctly. It is critical that the water jets are not blocked, are oriented correctly, and have a clear path to hitting the fruit. We have observed a range of problems including jets hitting one another, reduced spray fan, and completely wrong orientation (Figure 4). All these issues reduce the capacity of each unit to remove contaminants effectively. Incorrect orientation can rapidly lead to significant brush wear, as was detected at one packhouse.

5.2.3 Flow rate

The flow rate of each nozzle should be measured frequently to determine if there has been significant wear, blockage, and whether the nozzle type is correct. Flow rate is a key component of high pressure washing effectiveness since it plays a significant role in determining the impact of the droplets on the fruit, and thus the removal efficacy. Nozzles wear over time, particularly if water quality is poor, and nozzles may need replacing. A complete replacement every season is very likely to be required. While complete blockage of nozzles is easy to note visually, partial blockage can be surprisingly difficult to see, and flow rate is one way to determine this. Finally, when nozzles are replaced or cleaned, they must be replaced in the correct positions and delivery angle.

Each packhouse should construct a system that allows easy fitting of a water-collection pipe over the nozzle outlet. Flexible plastic hose or PVC pipe is commonly used. The first time flow rates are taken, it would be a prudent to number individual nozzles; this helps to make comparisons over time. We recommend that a simple diagram is developed with rows and nozzles labelled for easy reference.

5.2.4 Access to the washer

Ready access to the gantry and all nozzles is necessary, but was not easy on any HPW visited. Further to this, some washers had no walkways or ladders at all (and the washers were 1.5–2.5 m off the ground). This is a problem for operator safety, good maintenance, and for assessing washer performance. Improvements, or installation, of appropriate ladders and walkways is highly recommended. In addition, a system for lifting the nozzle gantry up and away from the conveyor would also be of benefit by making both the nozzles and conveyor more easily accessible. However, this would also require engineering of the supply piping.

5.2.5 Filtration and water quality

Filtration and water quality were issues at most packhouses visited. The lack of good filtration results in blocked and partially blocked nozzles from contaminants being re-circulated through the system. A series of coarse to very fine 'tray'-type filters is widely used when trying to remove large contaminants from the HPW water system. These tray-type filters can become clogged quickly and need to be constantly monitored and cleaned (Figure 7A). Use of "sloping" or angled filters with a waste drain at the bottom reduces the need to clean manually (Figure 8). However, the removal of fine contaminants such as silt, which is abundant on citrus in these regions, requires other filtration systems.

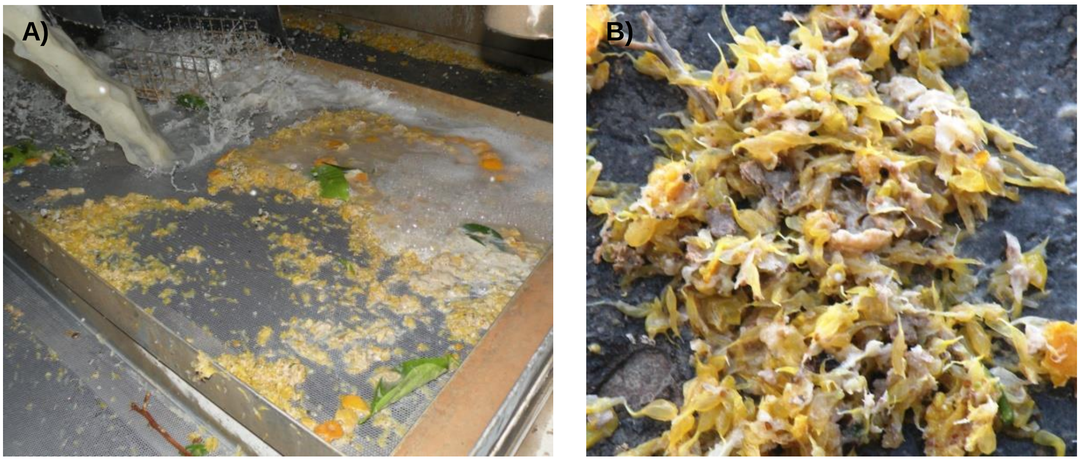


Figure 7. An example of a flat mesh type filter system in a high pressure citrus washer (A) and the nature of the material that blocks the filters (B) which is mostly fruit pulp from rotten fruit.

Figure 8. An example of angled filters trapping and depositing contaminants in a high pressure citrus washer.

In-line sediment cartridge filters do not appear to be used heavily, as they tend to become blocked quickly. One option to overcome this is to set up a baffle system in the filter tank to allow silt and dirt to settle out before the water is reticulated. The baffles would slow the flow of water back to the pump enough so water from the last baffle could pass through an in-line cartridge filter, allowing relatively clean water to flow through to the gantry. Alternatively a "cyclone"-type system could be of benefit.

There are other options for reducing contaminants in the HPW system. One is to have a separate prewash system. This helps to remove the majority of large debris such as leaves, stems, dirt and bird guano. This allows the HPW system to remove the fine particles left on the fruit. Also, staff pre-grading fruit before the HPW to remove soft/rotten/damaged fruit helps to eliminate fruit pulp going through the system (Figure 7). These short-term options would take much of the pressure off the filtration system. Another longer-term option would involve enhancing the filtration system. This can be done in many ways, i.e. more mesh filters, a series of in-line filters, or sand filters like those used in swimming pool applications.

It is important to maintain a high water quality and cleanliness to maximise washing effectiveness, fruit quality, to minimise fruit pathogens and food safety microorganisms.

Water hygiene is influenced by a range of factors, including the volume of fruit processed, cleanliness of the fruit (dust and dirt, bird guano, spray residues), volume of water in the system, water exchange rate, filter type and cleaning regime, and the use of sanitisers. These could all be monitored more diligently at all the packhouses we observed.

5.2.6 Cleaning of painted fruit

The aim of this is to check that the entire fruit surface is reached by the water jets. The rationale is mentioned earlier in section 2.4. Below are two possible ways of 'painting' fruit.

The PFR method: PVA and kaolin clay (Surround®)

A solution is made up of 4 g of PVA wood glue and 20 g of Surround® added to 100 mL of water. To achieve best results, mix the PVA with a small amount of water initially, then add the remainder of the water slowly with vigorous shaking until all dissolved (this takes some time). Finally, add the Surround and shake well to achieve a uniform solution. Frequent stirring of the solution is required, as settling occurs. Fruit are then dipped in the solution (one end at a time), allowed to dry partially on their sides (on newspaper or similar), then rolled over after an hour or so (to avoid pooling of solution at the base). After dipping, fruit should be allowed to dry for at least 2 days in an air-conditioned room at 20°C before being run through the HPW (Figure 9). Fruit should be kept dry until used for the washer tests, because exposure to dampness will make removal easier.

The face-paint method

Some packhouses report using non-toxic face paint, which can be obtained from many retail outlets. Again, standardising the means of application and drying is important.

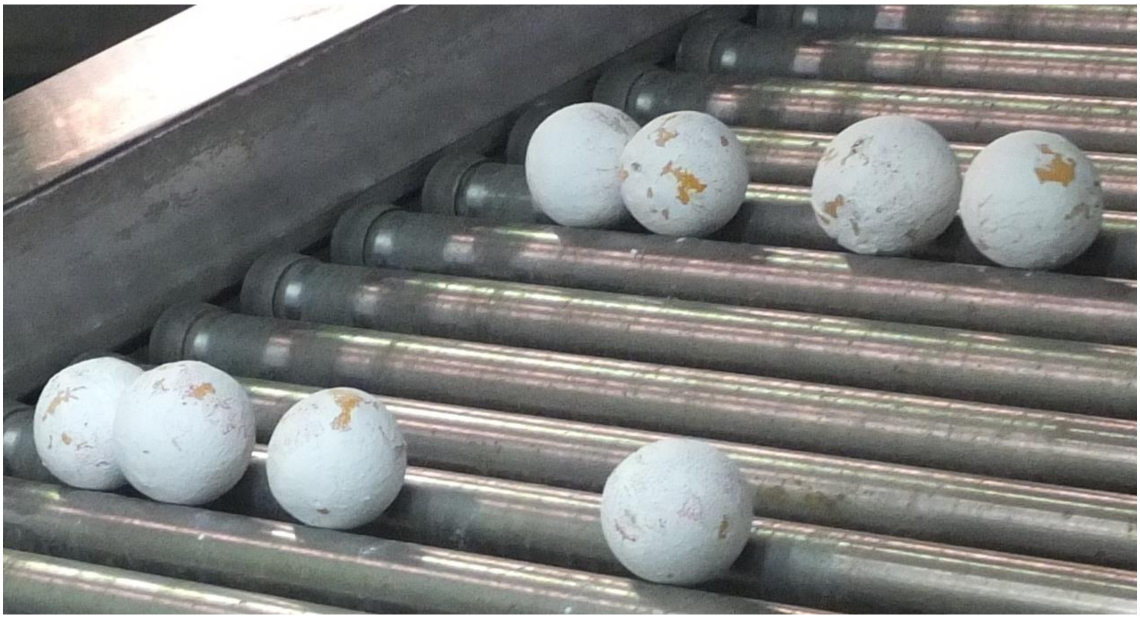


Figure 9. Painted (single-strength PVA/kaolin clay mixture) oranges ready to be put through a high pressure washing (HPW) system.

5.2.7 Nozzle height

It is important to measure nozzle height and distance from fruit periodically. A key factor in the effectiveness of high pressure washing is the distance between the nozzles and the fruit, because impact force declines exponentially with distance. If the distance is doubled, the impact is roughly four times less. As fruit size varies, a standard object needs to be used, and we have found an old tennis ball (with minimal hair) to be both useful and readily available. We did observe at one packhouse that an old hockey ball was a good substitute for an orange.

5.2.8 Personnel

Having a well-trained and diligent washer operator is likely to result in significant improvements. Consideration should be given to more training for this staff member and maintaining the same operator if at all possible over seasons. The significant investment in the machine and cost of running can be largely negated by poor operator skill and attentiveness. Consideration should also be given to instigating a regular meeting with the washer operator, site engineer, packhouse manager, and QC manager. Ensuring that there are clear lines of communication and responsibility will also improve effectiveness.

5.3 Changes to basic design of washer

From our observations, although the current citrus high pressure washers mostly had a similar fundamental design (i.e. a gantry over a rolling brush bed rows with multiple rows (manifolds) each with many downward-facing nozzles), there were significant differences in the setups. Such differences included the operating pressure and the nozzle type and number.

The current washers could, with some changes, be standardised, probably at a higher pressure and a high-flow type nozzle. This would probably result in increased pump capacity for most sites.

Other potential changes might be to change the angle of the washer nozzles (Figure 10). This is something we have examined in New Zealand, where we sought to improve removal of pests from the “ends” of fruit (i.e. where fruit tended to orient themselves sideways). This was done based on the hypothesis that the water jets were facing downwards and did not target the ends of the fruit as effectively. Our trials in New Zealand will examine this modification for citrus.

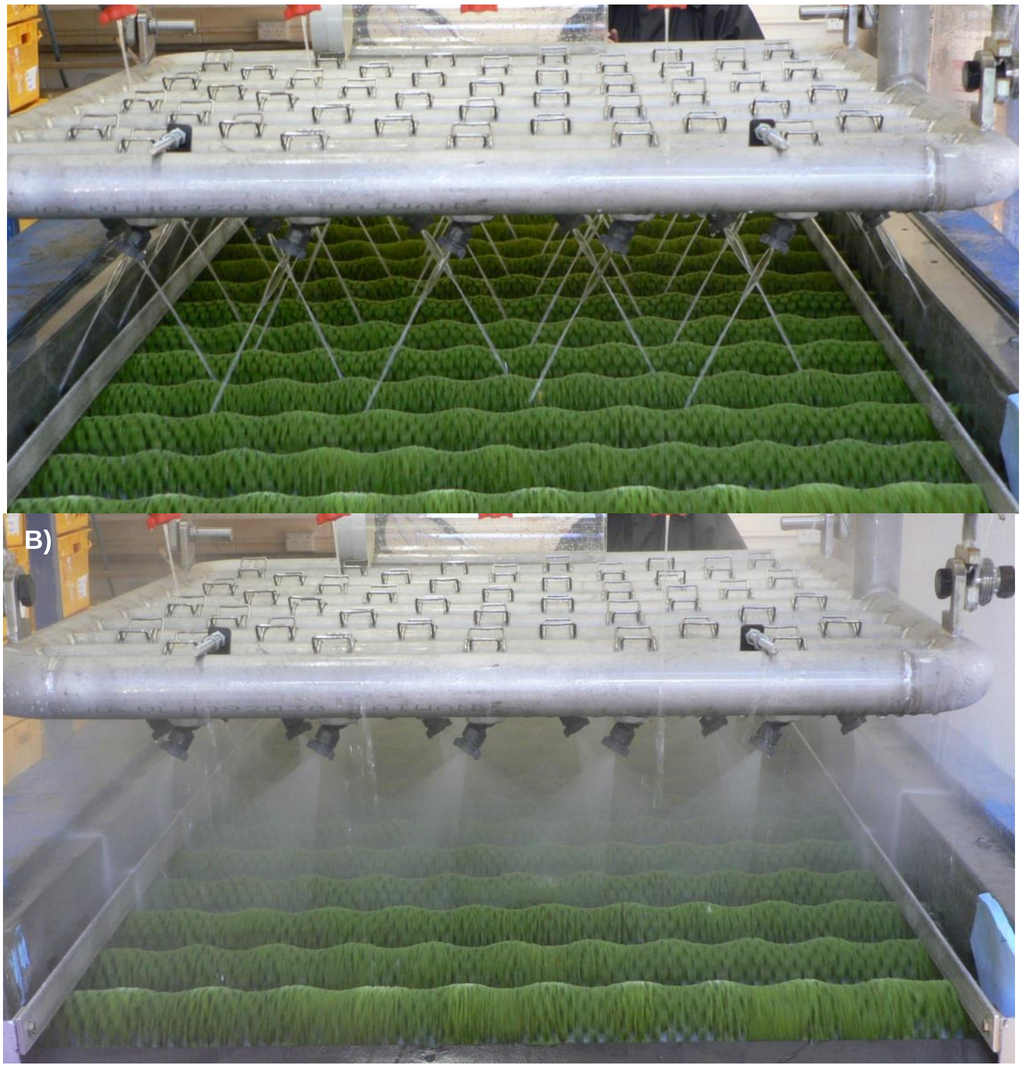


Figure 10. Angled nozzle system used in a high pressure fruit washer at Plant & Food Research (PFR) to improve removal of pests from apples and other crops. Each row of nozzles is oriented in opposite directions to facilitate fruit movement and target the sides of the fruit. A) Water jets during start-up (thus showing angles). B) Nozzles during standard operation.

5.4 New washer systems

Over the last 15 years New Zealand researchers, packhouses and engineering companies have worked with fruit industry bodies to develop novel high pressure washing systems. The fundamental drive for these innovations has been achieving very high rates of removal of the pests, to facilitate improved market access.

Two basic systems have been commercialised, mostly in the avocado industry. The two systems are a three-nozzle system developed by McDonald (1999), made up of two nozzles on each side at a 45° angle, and one nozzle at the top (Figure 11). This has a reciprocating action and has been commercialised by FSS (Fruit Sorting Systems, Tauranga) and modified by Apollo packhouse by moving the two side nozzles to a 90° angle. A rotary system was developed more recently, and is now sold by Compac®. This rotary system uses a "rotor" over each lane with four downward pointing arms that spin very rapidly around the fruit as fruit roll under the nozzles (Figure 12).

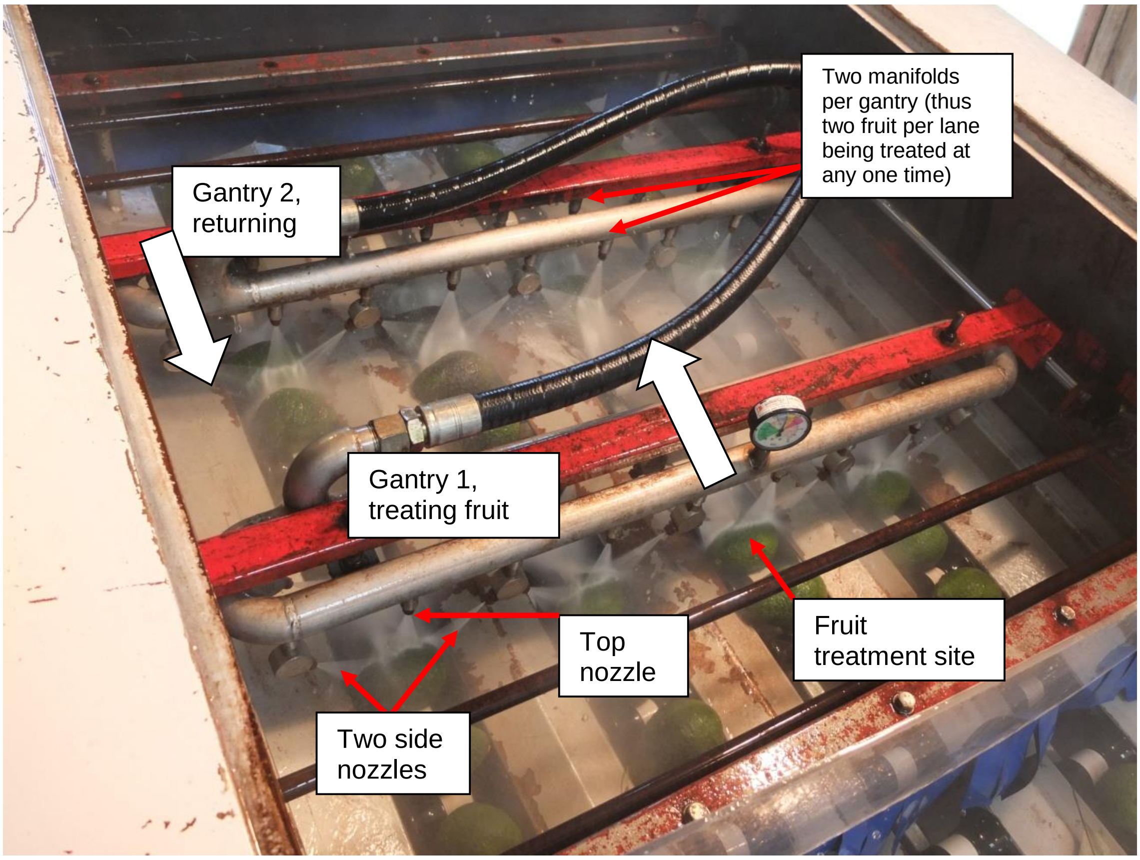


Figure 11. Three-nozzle high pressure fruit washing system commercialised by Compac® Fruit Sorting Systems (FSS) with two gantries, each with two manifolds and four lanes. This effectively results in 16 treatment sites, each with two 45°-angled nozzles and one top nozzle. Fruit are treated as the gantry follows the rotating fruit forward (Gantry 1 in the photograph above).

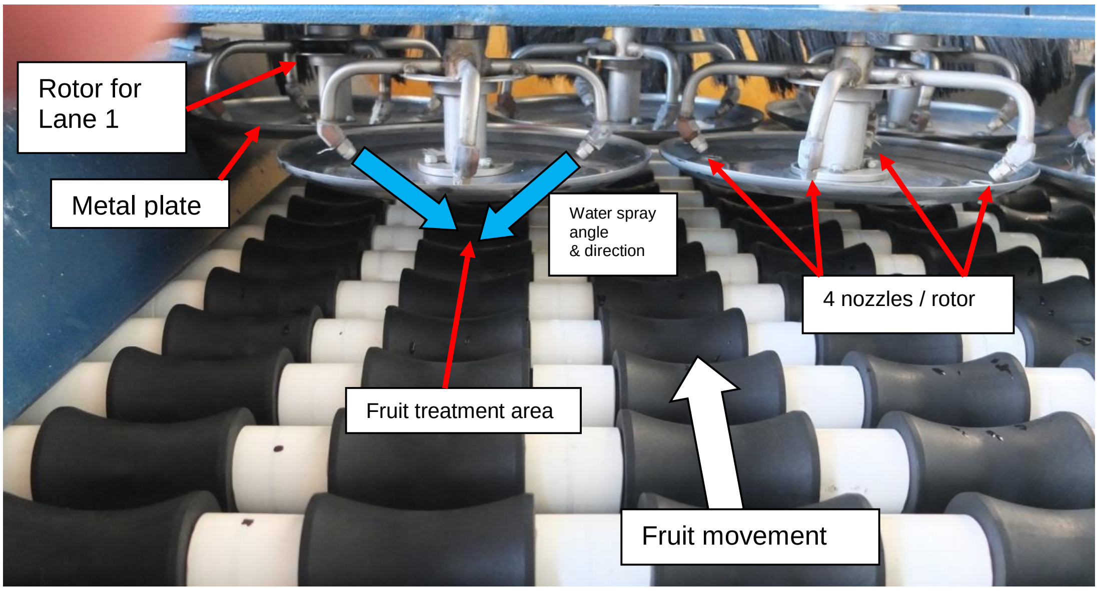


Figure 12. High pressure rotary fruit washer (Compac®). This washer involves a four-armed rotor over each lane that spins very rapidly around the fruit. The nozzles point down and inwards over the fruit as they roll along each lane.

These two systems rely on achieving high rates of cleaning by singulating fruit so that the treatment is carried out in a very controlled manner over a set of travelling rollers.

Because they use singulated fruit, these systems have lower throughput than the standard Honiball system (brush bed and overhead nozzles) (Table 2). These systems have recently been modified for apples, which being a spherical fruit needs a different system from an avocado which being more oval in shape, orients itself laterally on the rollers. In addition, avocados can tolerate very high pressures (900–1000 psi).

Thus, modifications of the above washers for apple have resulted in two commercial prototypes which have a higher throughput, with the Compac washer treating 1280–1600 fruit/min on an eight-lane washer (Figure 13). The FSS system was found to require longer treatment times for apples than for avocado, although improvements might be able to be achieved in oranges that were not possible in apples.

Table 2. Summary of approximate speed (fruit/min) and total throughput of two high pressure washer types for avocados and apples.

Washer type	Crop	Fruit/min	Lanes	Total throughput (fruit/min)
Compac ®	Avocado	100	6	~600
	Apple	160–200	8	1280–1600
FSS	Avocado	145	4	~ 580
	Apple	20-30	8	160-240

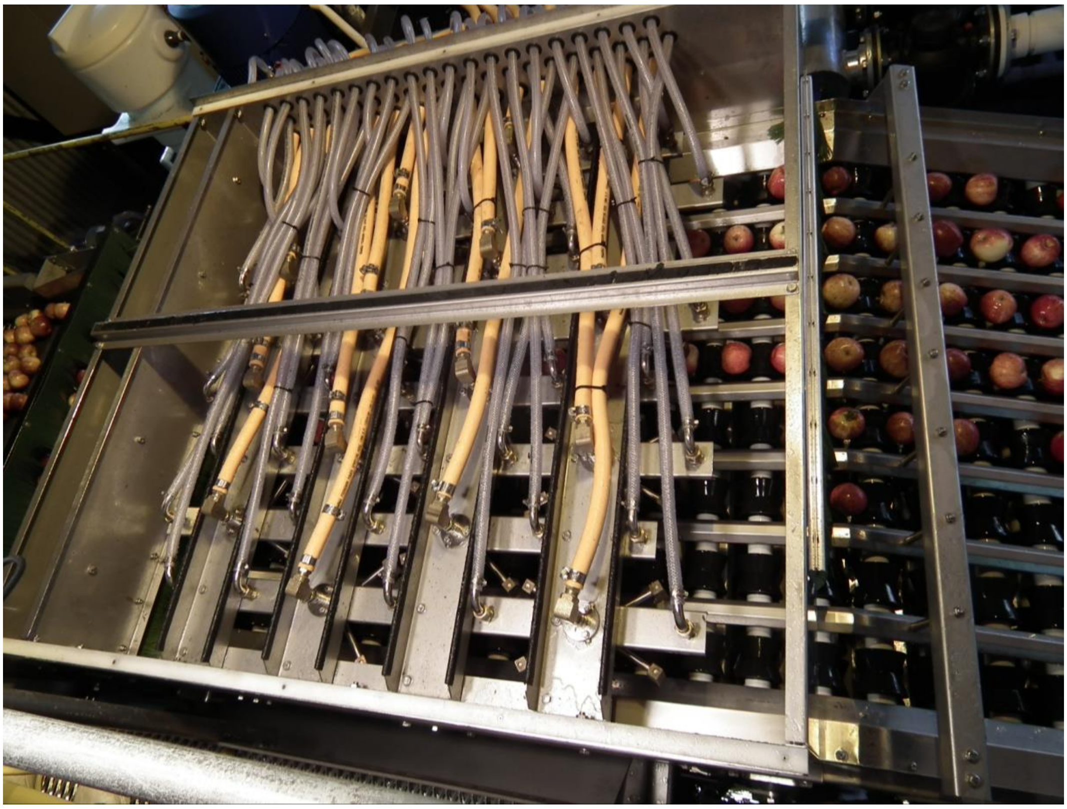


Figure 13. High pressure apple rotary washer (Compac®). This washer involves a six-armed rotor over each lane and has two rotors/lane.

6 CONCLUSIONS

This survey of five citrus washers in Australia showed that, although they all used a similar principle (rows of nozzles over a brush bed), there was a great deal of variability between packhouses. Thus, there was a wide range of setup conditions in terms of pressure, distance and nozzles, with no standardisation of operating conditions. The operational performance of HPWs was assessed by making measurements, observations and assessing the removal efficacy of the HPWs. The setup of the HPWs ranged from between 33 and 225 nozzles, set at 95–300 mm apart, operating at pressures of 130–170 psi, at a nozzle height of 105-270 mm, with a treatment time of 9–20 s and mean flow rates of 7.1 to 17.3 L/min and 15-25% of nozzles blocked. Paint removal efficacy ranged from 35% to 95% depending on the packhouse and the concentration of the paint applied to oranges.

A better understanding was achieved of the scales of the operations and issues with which the packhouse operation staff contend. Two major Issues that need to be considered when developing improvements to HPW for citrus in Australia are firstly, dealing with the large quantities of debris, dirt and grit present on fruit which may result in the need to design adequately self-washing filters to filter out grit, enabling nozzles to last longer; and secondly, maintaining a high throughput of 900–2600 fruit per minute.

Several presentations were made to the packhouse managers and HPW operators on the potential of new washing systems to enhance market access for Australian citrus exports. Recommendations on improved operating practices have been provided, and possible modifications to designs suggested. However, it appears unlikely that, even with significant modifications, the current washers will achieve adequate phytosanitary outcomes, i.e. high removal of FRW eggs. Two novel higher pressure systems (that involve singulated fruit) should be tested to determine FRW egg removal.

Orchard FRW egg infestation rates can range from very low up to 25% of fruit infested, depending on time of season, year, and control methods used in the orchard. Orchard control methods can reduce egg infestation rates from 23% of fruit infested down to 0–4.3%. The rate of FRW egg removal from a commercial citrus HPW (10 booms each fitted with 23 nozzles), operating at 160 psi for a 24-s dwell time, was estimated at between 5 and 20% (Taverner et al. 2007). There is potential to improve and standardise citrus HPWs to increase removal rates; however, moving towards a singulated system such as Compac or FSS was required in New Zealand to improve removal of difficult organisms significantly.

It is likely that a combination of field control measures to reduce infestation to below a threshold rate, and a postharvest dip + HPW system that removes higher numbers than HPWs are currently achieving, will be a solution for increasing the pass rates of citrus inspections for accessing FRW-sensitive markets. The most suitable system for citrus will need to be determined based on fruit tolerances, removal of FRW eggs, throughput and economic cost/benefits. Therefore, a proof-of-concept approach with decision points will be followed and is still in progress.

7 FUTURE RESEARCH

Future research will focus on:

- Investigating the paint and FRW egg removal efficacy of Compac and FSS HPWs and comparing this with paint and FRW egg removal by Honiball HPWs
- Determining the impact of postharvest dips on FRW egg removal and viability
- Scale up most promising treatment to a semi-commercial stage and test removal efficacies and fruit quality.

8 ACKNOWLEDGEMENTS

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DISCOVER. INNOVATE. GROW.

Appendix 2

Jamieson LE, Redpath SP, Page-Weir NEM, Griffin MJ, Chhagan A, Taverner P, Rogers D, Woolf AB. November 2014. In-line approaches to control FRW eggs on Australian citrus. A Plant & Food Research report prepared for: Horticulture Australia Ltd Citrus Australia. Milestone No. 103. Contract No. 30297. Job code: P/331031/01. SPTS No. 10866.

PFR SPTS No. 10866

In-line approaches to control FRW eggs on Australian citrus

Jamieson LE, Redpath SP, Page-Weir NEM, Griffin MJ, Chhagan A, Taverner P, Rogers D, Woolf AB

November 2014

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Executive summary

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[1]Plant & Food Research: [1]Auckland, [2]Hawkes Bay; [3]South Australian Research Development and Innovation, Adelaide

November 2014

Background

Fuller's rose weevil (FRW, *Asynonychus cervinus*) is a quarantine pest in China, Korea and Taiwan and the presence of FRW eggs on Australian citrus is impeding market access growth in these key Asian markets. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs; this has reduced the number of shipments rejected during pre or post shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets.

High pressure washing (HPW) has the potential to decrease infestation further. Australian packhouses use standard HPW systems; however, their performance varies substantially. In New Zealand, new-generation HPW machines have been developed to enhance removal of difficult-to-remove organisms. Research to reduce FRW egg viability using postharvest dips is being undertaken in the USA and these may have the potential to be incorporated into an inline pest reduction system that includes pre-HPW dips and new HPW systems that remove already-low numbers of FRW eggs and render remaining eggs non-viable. Here we report on the impact of experimental and commercial new-generation HPW systems in New Zealand on FRW egg removal and the impact of pre-HPW dips on both egg removal and viability.

Methods

Two trials were conducted on three 'types' (Honiball, Compac, three-nozzle) of experimental and three similar 'types' of commercial HPW systems, testing the removal of paint to determine overall coverage and removal around the button area of citrus fruit.

Two trials were conducted on two 'types' (Honiball, Compac) of experimental and two similar 'types' of commercial HPW systems to determine the removal rates of FRW eggs from oranges.

Two trials were conducted to determine the impact of 10 postharvest dip treatments (containing Prospect® oil, sodium hypochlorite, saturate organosilicone and/or acetic acid) on the viability of FRW eggs on wax paper and on oranges and to determine if these pre-HPW dips enhanced removal of FRW eggs during HPW.

A trial was conducted in Australia to determine the baseline removal rates of FRW eggs from oranges on a commercial HPW at a standard speed (treatment time) and with a longer treatment time, as well with a pre-HPW dip (40°C, containing Prospect oil, sodium bicarbonate and sodium hypochlorite).

Key results

- Unlike observations in Australia, where paint removal ranged from 35 to 97% (Redpath et al. 2014), the PFR Honiball HPW with vertical nozzles resulted in high paint removal rates (93-96%). This was probably because of correct setup, with no blocked nozzles or nozzles not orientated incorrectly. The angled nozzle system (33°and alternating rows) resulted in greater removal than vertical (straight down) nozzles with paint removal of 97-99.5%).
- A double pass on the experimental Compac HPW unit removed >90% paint from the button area where FRW eggs are laid; however, it was agreed that the rotor should have been lowered to improve coverage.
- Although well-set-up commercial Compac washers were removing over 90% of paint from the button area, this only equated to ≈20% removal of FRW.
- Therefore, removal of paint was a good indication of water impact over a fruit surface; however, it did not reflect the numbers of FRW egg batches removed.
- On experimental units, fewer than 5% of FRW egg batches were removed using the Honiball HPW unit operating with either straight or angled nozzles. However, use of the Compac HPW resulted in egg batch removal rates of up to 20%.
- Egg batch removal after HPW did not seem to increase consistently with the use of a pre-HPW dip compared with removal from fruit that were dipped in water alone. However, there was an initial indication that dips with Prospect oil tended to increase removal rates to ≈46% and tended to reduce the viability of FRW eggs from ≈70% hatching down to ≈30-50% hatching, or from 10-40% hatching down to 0% hatching. Further verification on fruit is required.

Conclusions

Although high rates of FRW egg removal were not achieved (>90% removal as reported with other pests), there is potential to increase FRW egg removal rates from the current ≈6% removal to ≈20-50% removal, along with reducing egg viability, by using postharvest dips followed by standard and new-generation Compac HPW systems. These inline pest reduction techniques along with pre-harvest control measures and ethyl formate (EF) fumigation and cool storage afterwards have the potential to achieve the high rates of protection required for FRW-sensitive markets in a residue-free manner.

Future work should focus on:

- Investigating the impact of malic acid/lactic acid/Prospect oil ambient temperature dips on FRW egg viability and the impact on egg removal following HPW 24 h after dipping
- Determining the impact of a combination of standard Honiball and Compac HPW on FRW egg removal and Navel orange quality
- Integrating the most effective postharvest dip + HPW treatment with pre-harvest control measures and fumigation and/or cool storage to quantify the efficacy of such a systems approach.

For further information please contact:

Lisa Jamieson
Plant & Food Research Auckland
Private Bag 92169
Auckland Mail Centre Auckland 1142
NEW ZEALAND
Tel: +64 9 925 7000; DDI: +64 9 925 7284; Fax: +64 9 925 7001
Email: Lisa.Jamieson@plantandfood.co.nz

1 Introduction

Fuller's rose weevil (FRW, *Asynonychus cervinus*) is a quarantine pest in China, Korea and Taiwan, and the presence of FRW eggs on Australian citrus is impeding market access growth in these key Asian markets. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs; this has reduced the number of shipments rejected during pre or post shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets. New fumigants are being considered for the management of a range of pests, including FRW. However, the development of fumigation protocols acceptable to overseas markets is a long-term strategy. In the interim, new approaches are required to increase volumes exported into these important markets. A combination of field-based and postharvest treatments has the potential to provide a systems approach capable of reducing the risk of FRW eggs being present on export citrus, and therefore increasing export volumes to FRW-sensitive markets.

There have been significant developments in high pressure washing (HPW) pest removal systems in New Zealand over the last 5-10 years. New HPW systems are removing more difficult-to-remove pests than old HPWs (Woolf et al. 2014; Rogers et al., unpublished data). These new systems do not rely on random movements of fruit to enable a targeted 'hit'. Instead, they wash each individual fruit for 1-2 s to ensure that the fruit has received full coverage. Three high pressure washing systems are currently being used commercially in New Zealand. One is based on the old style 'descalers' (Honiball system), with rows of nozzles above a roller bed of fruit (Honiball et al. 1979; Jamieson et al. 2010; Woolf et al. 2009). This Honiball system is similar to the current citrus washers in Australia. However, the use of angled nozzles is being trialled in New Zealand to increase fruit movement under the nozzles (Woolf et al. 2014). For citrus, this could increase the chance of a direct hit to the area of interest (e.g. calyx of fruit). The second washing system is a more targeted singulated system with three targeted nozzles (three-nozzle system; McDonald 1999; Jamieson et al. 2000; Whiting et al. 1998a, b). The third is also a singulated Compac® system, with rotating nozzles to achieve coverage (Compac system; Rogers et al., unpublished data; Woolf et al. 2014).

In Australia and New Zealand, postharvest dips have been tested to enhance the removal of difficult-to-remove pests and/or reduce the viability of pests (Rogers et al., unpublished data; Taverner & Bailey 1995; Taverner & Cunningham 2000; Taverner & Perry 2009). In Australia Prospect®, a food-grade oil treatment, showed the most potential to enhance removal of FRW eggs. In addition, sodium and calcium hypochlorite at high rates can dissolve FRW egg adhesive, and at low rates, can act as an irritant, causing rapid egg hatch (Taverner et al. 2007; Baker et al. 2013).

In September 2013, New Zealand and Australian researchers visited five citrus packhouses in South Australia/North West Victoria, which all had HPW systems similar to the Honiball system (Figure 1). The HPW set-up conditions observed varied in terms of pressure, distance, nozzles and filtration, with no standardisation of operating conditions. The set up of the HPWs ranged between 33 and 225 nozzles set at 95–300 mm apart, operating at pressures of 130–170 psi at nozzle heights of 105-270 mm, with treatment times of 9–20 s and mean flow rates of 7.1–17.3 L min^{-1}, and 15-25% of nozzles blocked. The removal of paint was used as a proxy for FRW egg removal and to determine the fruit coverage of the washing. Paint removal efficacy ranged from 35 to 95% depending on packhouse and concentration of the paint applied to oranges. A generic high pressure washing optimisation manual for the industry has the potential to be developed to lift the performance of the current washing systems.

The rate of FRW egg removal from a commercial citrus HPW (10 booms each fitted with 23 nozzles) operating at 160 psi for a 24-s dwell time was estimated at between 5 and 20% (Taverner et al. 2007). There is potential to improve and standardise citrus HPWs to increase removal rates; however, moving towards a singulated system such as Compac system was required in New Zealand to improve the removal of difficult organisms significantly (Rogers et al., unpublished data; Woolf et al. 2014). Two major Issues that need to be considered when developing improvements to HPW for citrus in Australia are firstly, dealing with the large quantities of debris, dirt and grit present on fruit, which may result in the need to design adequately self-washing filters to filter out grit, enabling nozzles to last longer; and secondly, maintaining a high throughput of 900–2600 fruit per minute.

This report summarises the results to date from trials carried out to enhance removal of paint (used as a proxy and determine fruit coverage of washing) and FRW egg batches from oranges using 'new generation' Compac and three-nozzle HPW systems, together with results from trials testing the efficacy of pre-HPW dips to enhance FRW egg removal and reduce FRW egg viability.

Figure 1. Measuring flow rate in a High Pressure Washing (HPW) system for citrus in Australia.

2 Aim

- To assess various HPW systems currently in use and to identify the best system for FRW egg removal from oranges
- To determine whether selected pre-HPW dips can enhance FRW egg removal rates by HPW and/or reduce FRW egg viability

3 Methods

Several trials were conducted at Plant & Food Research (PFR) Auckland, at packhouses in Hawke's Bay, at South Australian Research and Development Institute (SARDI) Adelaide and at a packhouse in South Australia, to determine the efficacy of various HPW systems and dips on the removal of FRW egg masses.

3.1 Fullers rose weevil collection and egg lay on wax paper or fruit

For Trials 1-6 (Sections 3.3 – 3.8) conducted in New Zealand, FRW adults (Figure 2) were collected from kiwifruit and apple orchards in Kerikeri, Te Puke and Motueka from December 2013 to June 2014. FRW adults were collected either by beating trees and collecting any fallen adults from white sheets beneath the tree, or by placing emergence traps around the trunk of the trees/vines to collect newly emerged adults moving from the soil into the plant canopy. Adults were sent to PFR Auckland and maintained on citrus leaves in large plastic 'fish' bins (60 x 38 x 23 cm; Figure 3) as described by Graeme Clare (PFR, unpublished data) at 20°C, 16:8 light:dark cycle. A small vial of water with a cotton wool wick was placed in each bin to provide moisture. The leaves and water vials were held above the base of the bin on a metal platform to allow air flow and to ensure any FRW frass accumulated in the base of the bin rather than on the leaves. Fresh leaves were added twice weekly and all live leaf material and FRW adults were transferred to a clean bin once a week. The amount of leaf material or number of vials of water was increased or decreased, dependent on the number of FRW in each bin, up to a maximum of 150 adults per bin. Bins were sealed by placing double-sided tape around the top edge and attaching a section of fine mesh fabric over the top of the bin.

To obtain FRW egg batches (Figure 4) on oranges, adults were placed in a ventilated cage attached to the button end of an orange (Figure 5) for three days and then removed and returned to a bin containing citrus leaves. Oranges with eggs present were stored at 5°C for up to four weeks before being treated and assessed for egg removal. Egg rafts on oranges for viability tests were stored at 9°C for up to 5 weeks before treatment. To obtain eggs on wax paper for viability testing of dips, folded wax paper was placed within the FRW rearing cages with citrus leaves for three days. Eggs on paper were then stored at 11°C for up to 6 weeks before being treated.

Figure 2: Fullers rose weevil adult.

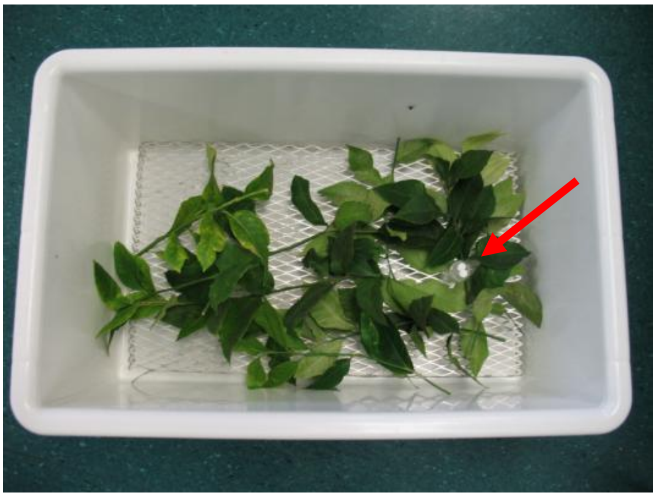

Figure 3: Fullers rose weevils were maintained on citrus leaves within a 'fish' bin. Arrow indicates small vial of water with cotton wicks.

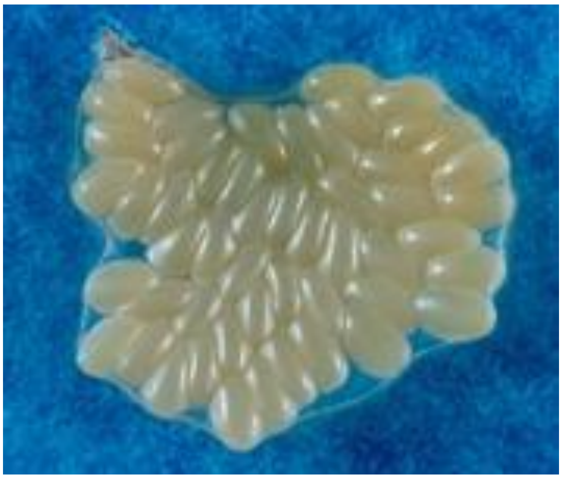

Figure 4: Fullers rose weevil egg batch.

Figure 5: Fullers rose weevil caged on to the button end of citrus fruit to lay eggs.

3.2 Painted and FRW-infested oranges

Where painted fruit were used as an indication of HPW efficacy, a single- or double-strength kaolin paint (Table 1) was applied to oranges (Figure 6). Polyvinyl acetate (PVA) glue and a small amount of water were mixed within a 1-L container to form a uniform suspension. More water, up to the required amount, was slowly added with thorough mixing with each new addition of water to the container. Once all the water and PVA had been mixed, the required amount of Surround® (a.i. kaolin clay) was added and mixed well. The mixture was poured into a 1-litre bucket and left to stand for 10 min to allow any trapped air to escape from the mixture and thus avoid bubbles and thinner coating of the 'paint' on the fruit surface. Fruit could either be painted with or dipped into the mixture. For these trials, one side of the orange was dipped into the kaolin mixture and placed paint side up, on 'Friday' trays and allowed to dry overnight at 20°C before dipping the other side (Figure 4). The fruit were then kept at 20°C with a dehumidifier for 24 hours to allow complete drying of the paint and for the mixture to bond well with the fruit surface before use in HPW.

Table 1. Kaolin clay paint applied to oranges and then used as an indication of high pressure washing efficacy.

Ingredients	Amount (single-strength)	Amount (double-strength)
PVA Glue	20 g	40 g
Water	500 mL	500 mL
Surround® (kaolin clay)	100 g	200 g

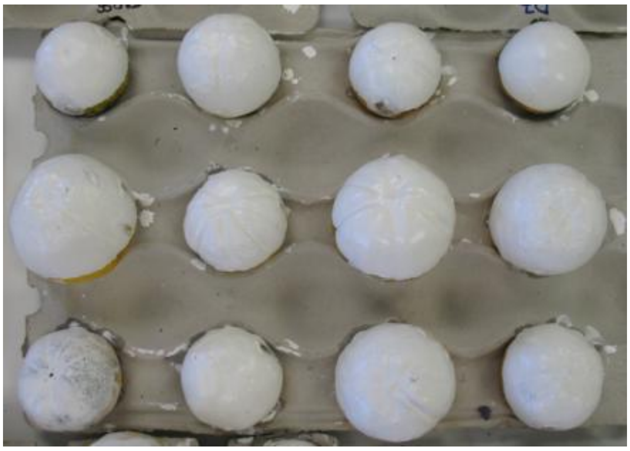

Figure 6: Oranges painted with a mix of kaolin clay and PVA.

3.3 Trial 1. Removal of paint from Navel oranges using prototype HPW systems in Auckland (December 2013)

Three bins (~3750 fruit) of juice grade Navel oranges arrived at PFR Auckland on 5 December 2013 from First Fresh (NZ) Ltd, Gisborne, were packed into boxes and stored at 5°C. The fruit were of very low quality, with sooty mould prevalent on most oranges (Figure 7). Single- and double-strength (PVA) paint was tested on these fruit and single-strength paint seemed to be removed too easily; therefore double-strength paint was used. Three days before treatment fruit were removed from cool storage and the next day half of each fruit was dipped in the mixture; the other half of each fruit was dipped the following day (as described in Section 2.2 above). On treatment day, painted fruit were either run over the experimental Honiball (Figure 8), Compac (Figure 9), or three-nozzle system (McDonald 1997, Figure 10) HPW machines. The Honiball system had eight rows of five or six nozzles per row alternating over a brush bed (nozzle height 150 mm straight and 175 mm with angled-nozzles) operating at pressures of 100 or 140 psi, respectively. Oranges were under the nozzles for approximately 20 s. Nozzles were tested pointing straight down or at alternating 33° angles for each row (Figure 8). For the Compac system, fruit were singulated and passed under a rotating wand for 1-2 s either once or twice (Figure 9). The wand had six nozzles (nozzle distance 110 mm) and water pressure was set at 200 or 300 psi. The three-nozzle system also had the fruit singulated, which then passed under three nozzles (one from 75 mm above and two at 45° angles, 100 mm to the side) operating at 600 or 850 psi (Figure 10). The HPW treatments were carried out on 11-16 December 2013. After each HPW treatment, fruit were passed through a drier for approximately 30 s. The drier unit comprised of an inline two-fan heater (45°C) set 250 mm above plastic bristle rollers (set at ~40 Hz).

A further trial was conducted in March 2014 to compare the removal of single-strength and double-strength paint. Three replicates of 30 Valencia orange fruit painted with single- or double-strength paint were run over the Honiball HPW unit in Auckland at 140 psi (the average pressure used in citrus washers in Australia; Redpath et al. 2014) with nozzles either pointing straight down or at a 33° angle (alternating directions for each -row).

Figure 7. Sooty mould on Navel oranges.

Figure 8. Honiball high pressure washing (HPW) machine in Auckland with angled nozzles.

Figure 9. Compac rotary high pressure washing (HPW) machine in Auckland.

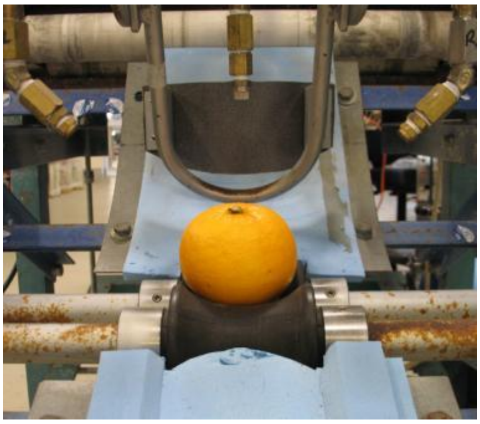

Figure 10. Three-nozzle high pressure washing (HPW) machine in Auckland.

Assessments were conducted 1-2 days after treatment by recording the percentage of fruit with paint left on for both the ‘whole’ fruit and around the ‘button’. Percentage paint removal values were then calculated.

3.4 Trial 2. Removal of paint from Valencia oranges using commercial HPW systems in Hawke’s Bay (February and April 2014)

Navel oranges were not available in February 2014; therefore three bins of ‘choice’ grade Valencia oranges were supplied from Gisborne. Valencia oranges were painted with both single- and double-strength paint to determine which strength to use. The double-strength paint had severe cracking (perhaps because of high humidity differences); therefore single-strength paint was used for trials to investigate the removal of paint from oranges using four commercial HPW systems. A brief description of each system tested follows.

3.4.1 Honiball Apollo HPW unit

The Honiball washer at Apollo Apples Ltd packhouse (Hawke’s Bay) (the standard washer system used by the apple industry) had two HPW systems each with16 rows of 12 nozzles (192 nozzles) off-set and pointing straight down (Figure 11). The nozzles were a quick release 40/15 nozzle and pressure was set at 92 psi. No nozzles were blocked and the height of the nozzle was 150 mm to the top of a tennis ball (as a substitute standard for a piece of fruit). During the peak season this packhouse expects to process 800-1000 bins (420 kg/bin) per day with the two washer units in operation. Water use was 120 m^3/h or 9-10 L/min/nozzle. The time for apples to pass under the nozzles was 30 s when tested in February (speed set at 50%) and 19-

26 s when tested in April. For sanitation, Tsunami® (a.i. peroxyacetic acid + hydrogen peroxide) was applied to the HPW water and there was a final heavy spray of four rows of ozone-treated water (4%) after the HPW. Fruit Handling Systems supplied this new unit, which was installed in 2013.

Figure 11. The Honiball high pressure washing (HPW) system at Apollo Apples Ltd in Hastings. Left: half the HPW area; High pressure nozzles are stainless (top) and the final lower pressure rinse (PVC pipework); top right: under the cover of a quarter of the HPW area; bottom right: close up of the nozzles washing apples.

3.4.2 Compac Mr Apple HPW unit

The Compac HPW unit at Mr Apple in Havelock North (Figure 12) had eight lanes each with two rotors with six nozzles and “hold-down” nozzles before each rotor, which assist with fruit stability. The rotor nozzles were stainless 15/10 and the hold-down nozzle was 65/30. A set of 96 rotor nozzles cost ~$NZ2K and there were 106 rotor nozzles required. The rotor operated at ~1000 rpm. The pressure at the gantry was set at 250 psi in February but was increased to 310 psi in April 2014. The unit processed 260 bins/day (410 kg/bin), compared with 700 bins/day for a standard Honiball-type HPW (at the Mr Apple Whakatu packhouse). HarvestCide® (formerly Nylate®) was used in the water (a.i. 1-bromo-3-chloro-5,5-dimethylhydantoin (BCDMH)) . Cup fill was ~60%. Compac installed the unit for the 2012 season, and the cost was estimated at $NZ250K, not including alterations to the filtration system.

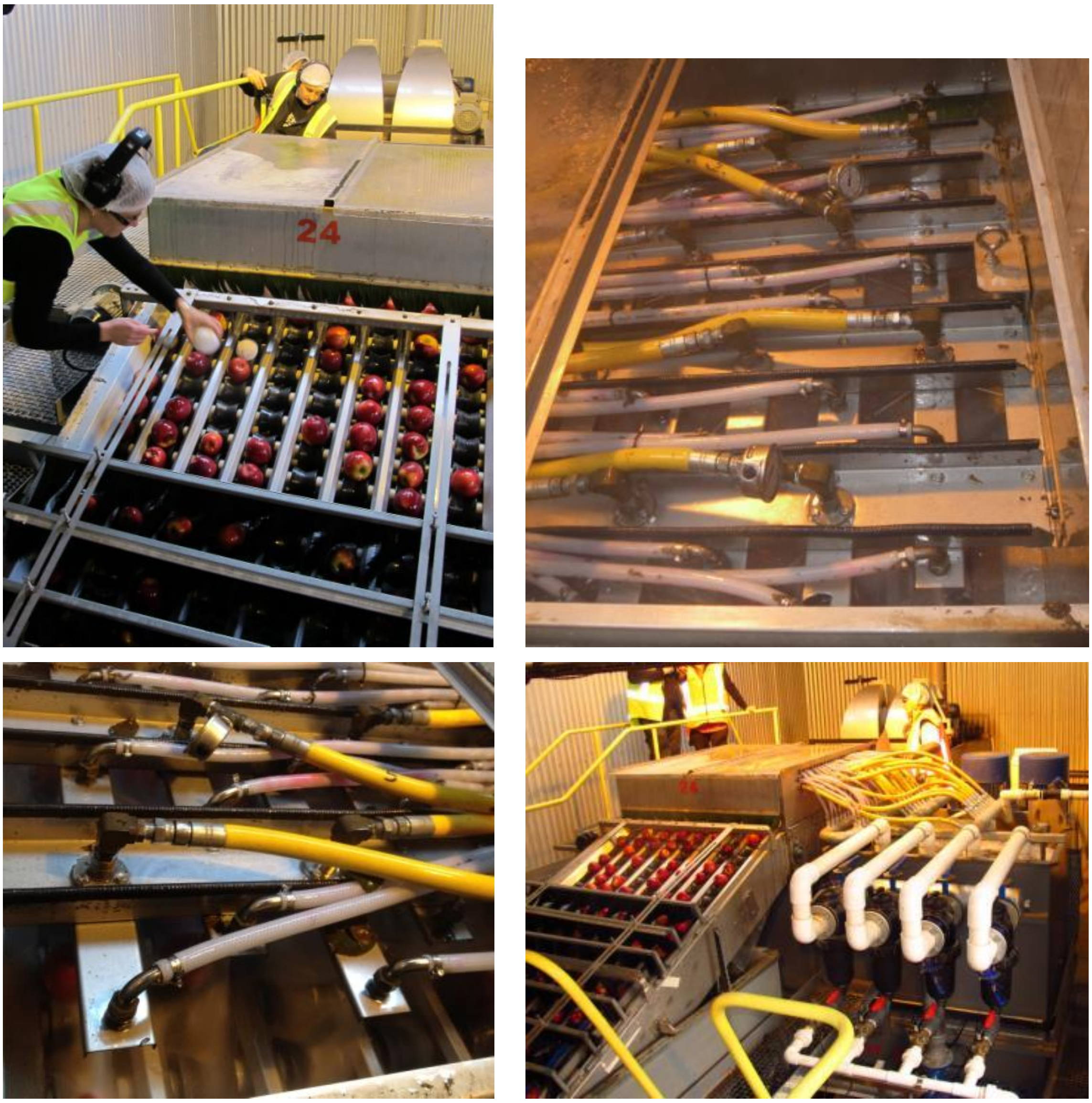

Figure 12. The Compac high pressure washing (HPW) system at Mr Apple in Havelock North. Top left: painted oranges entering the wash area; top right: Perspex cover lifted off the wash area showing hoses to rotating wash heads, each with six nozzles and hold-down nozzles; bottom left: close up of the rotating head washing apples; bottom right: the filtration system to the right of the washing area.

3.4.3 FSS-Apollo HPW unit

The FSS-Apollo unit has six lanes with reciprocating nozzle heads, resulting in each fruit being washed with two top nozzles and two side nozzles at a 90° angle to the top nozzle for 3 s (Figure 13). These modifications (i.e. two top nozzles) were made by Apollo because the standard three-nozzle system (one top and two 45° side nozzles) was not achieving adequate cleaning. The washer was set at 400 psi and flow rate is≈ 10.5 L/min/row. Throughput was estimated at 160-240 fruit per min; however, this washer was used after the Honiball washer and grading, therefore only for specific markets where higher phytosanitary standards are required.

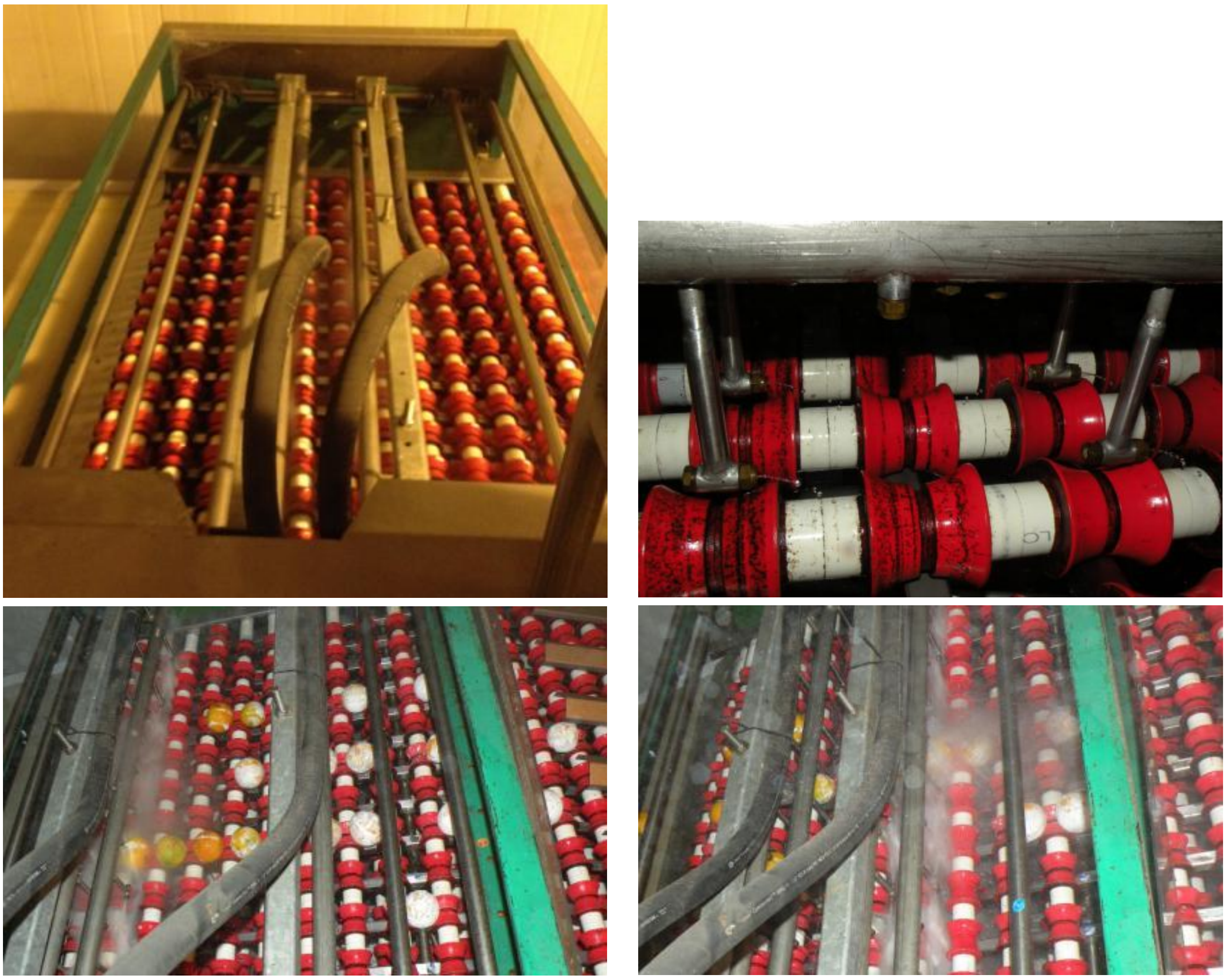

Figure 13. The FSS Apollo high pressure washing (HPW) system at Apollo Apples Ltd in Hastings. Top left: the washing area with the two reciprocating booms with nozzles that track the fruit as they wash; top right: close-up of a set of nozzles on a boom; bottom left: the left boom with nozzles tracking painted oranges; bottom right: the right boom with nozzles tracking painted oranges.

3.4.4 Compac Fruitpackers HPW unit

For the 2014 season, a second Compac HPW was installed in the Hawke’s Bay at Fruitpackers and was built by Fruit Handling Systems (FHS; a subsidiary of Compac based in Hawke’s Bay). This unit (Figure 14) was very similar to the Compac Mr Apple washer but had nine lanes and processed 30 bins/h (it was not running at full capacity at time of our visit). The washer was set to 300 psi and could comfortably achieve 390 psi. Cup loading was operating at 50-60%. This is a significant improvement, since the first Compac unit (installed at Mr Apple) was an improved filtration system with a 500-µm screen followed by a 200-µm screen (Figure 15). Water cleanliness was the highest we have observed so far in a commercial operation; this will reduce nozzle blockage and wear, and should improve general hygiene (both human and fruit pathogen).

Figure 14. The Compac high pressure washing (HPW) system at Fruitpackers, Whakatu. Top left: apples and painted oranges entering the wash area; top right: the wash area under covers; middle left: the wash area with covers off; middle right: close up of the rotating nozzle head with six nozzles; bottom left: view from underneath the nozzle heads; bottom right: view from above the nozzle heads.

Figure 15. The filtration system beneath the Compac high pressure washing (HPW) system at Fruitpackers, Whakatu.

3.4.5 Treatments and assessments

In February 2014 three replicates of 50 painted fruit were run through a commercial Honiball HPW system at Apollo Apples Ltd, set at a water pressure of 92 psi, and through the Compac HPW system at Mr Apple set at 250 psi (lanes 1, 2 and 3 tested). At Mr Apple, three replicates of 50 painted fruit were run through with two rotating heads operating and then another three replicates with only one rotating head operating

In April 2014 three replicates of ~30 painted fruit were run through the commercial FSS HPW at Apollo Apples Ltd set at a water pressure of 400 psi. Additionally, 30 painted fruit were run through the Compac HPW system at Mr Apple set at 310 psi, the Compac HPW system at Fruitpackers set at 300 psi, and also at a second higher pressure of 390 psi. At Fruitpackers it was noted that the nozzle orientation was incorrect (on the horizontal plane rather than the vertical) and this was corrected in lane 1 by adjusting to the vertical plane. Therefore, 30 painted fruit were run over lane 1 with nozzles in the correct orientation and another 30 over lane 2 with nozzles in the incorrect configuration, for comparison.

After treatment, fruit were transported back to PFR Havelock North, and placed on fibre trays in a 20°C room for drying. Paint removal was assessed the following day.

3.5 Trial 3. Removal of FRW eggs from Valencia oranges using experimental HPWs in Auckland (March 2014)

Valencia oranges infested with FRW eggs were obtained as described in Section 2.1. On 14 March 2014 three replicates of 30 egg-infested oranges were run over the Honiball Auckland HPW (140 psi with nozzles either pointing straight down or at a 33° angle and alternating directions for each row) or over the PFR experimental Compac HPW at 250, 350 or 450 psi. Eggs were laid on fruit between 2 February and 24 March 2014. Egg-infested oranges were randomly assigned to treatments. The Auckland three-nozzle experimental unit was not tested with FRW egg-infested fruit because paint removal data indicated that it did not perform as well as the Honiball and Compac HPW systems, there were inadequate numbers of FRW egg-infested fruit, and there were concerns with the very low throughput of an FSS system compared with the requirements of the Australian citrus industry.

3.6 Trial 4. Removal of FRW eggs from Valencia oranges using commercial HPW systems in Hawke’s Bay (April 2014)

Valencia oranges infested with FRW eggs were obtained as described in Section 2.1. On 2 or 16 April 2014, egg-infested oranges were run over the Honiball HPW unit at Apollo (90 psi), FSS-Apollo HPW unit at the Apollo packhouse (400 psi), the Compac HPW unit at Mr Apple (2 rotors at 310 psi), and the Compac HPW unit at Fruitpackers (380 psi; lanes 1, 2 or 3). As noted in Trial 2, the nozzles in lane 1 were adjusted to the correct vertical plane orientation. It was assumed that the other lanes would have been corrected after our visit, but FRW egg removal results indicate that this may have occurred after 16 April 2014. Therefore, we assume that lane 1 had the correct nozzle orientation and lanes 2 and 3 did not.

3.7 Trial 5. Viability of FRW eggs after dip bioassays in Auckland (May-July 2014)

On 8 May and 22 July 2014 FRW egg batches laid on wax paper (and stored at 11°C for 4 -12 weeks) were dipped for 1 min in one of the treatments outlined in Table 2. Dips were conducted in 20-L buckets with 10 L of solution. Eggs on wax paper were placed inside ventilated containers with fine mesh gauze at each end and agitated during treatment. After treatment, eggs on wax paper were left to dry and transferred to Petri dishes with filter paper, sealed with Parafilm® and placed at 20°C, 16:8 h light:dark. At 30-34 days after treatment, the numbers of larvae emerged from egg batches were recorded and the remaining eggs were dipped in 0.1% sodium hypochlorite for 10 min and rinsed three times with tap water to encourage hatching (Baker et al. 2010; Clare, unpublished data). Washed eggs were placed on a paper towel and left to dry for 20 min. After drying, batches were placed within a Petri dish lined with slightly damp filter paper and sealed with Parafilm. The numbers of emerged larvae were recorded weekly until no more larvae had emerged over a two-week period.

Table 2. The amounts of postharvest (PH) Prospect® oil (PO), sodium hypochlorite (SH), saturate organisilicone (OS) and acetic acid (AA) in dipping treatments applied to Fullers rose weevil (FRW) eggs on wax paper and FRW eggs on oranges.

Trt #	Treatment	PH Prospect oil	Sodium hypochlorite	Saturate organosilicone	Acetic acid	pH
1	3%PO/0.02%SH	3%	0.02%	-	-	-
2	3%PO/1%SH	3%	1%	-	-	-
3	1%SH	-	1%	-	-	9.0
4[1]	0.02%SH/0.05%OS/CA	-	0.02%	0.05%	-	8.1
5[1]	1%SH/0.05%OS/CA	-	1%	0.05%	-	7.8
6	5%AA	-	-	-	5%	2.5
7	3%PO/5%AA	3%	-	-	5%	-
8[2]	0.05%OS/5%AA/NaOH	-	-	0.05%	5%	4.0
9	Water dip control					5.4
10	Air control (no dip)					
11[3]	0.05%OS/5%AA	-	-	0.05%	5%	2.5

[1]Treatments 4 and 5, ~30 mL of citric acid was added to bring the pH to 7-8.
[2]Treatment 8 (initial pH of 2.5) 50 mL of 0.1M NaOH was added but only moved pH by 0.1. A further 100 mL of 10M NaOH was added and increased pH by 1.4.
[3]Treatment 11 did not have NaOH added.

3.8 Trial 6. Removal and viability of FRW eggs from oranges after dip bioassays and HPW in Auckland (May-July 2014)

On 8 May 2014, FRW-infested Valencia oranges were removed from cool storage, placed in mesh bags and dipped (10 L of solution in a 20-L bucket) with slight agitation in one of the treatments outlined in Table 2 (excluding Treatment 8, 17-20 oranges per treatment). Fruit were still cool when dipping and the oil treatments began to solidify on to the orange, coating it with a milky sludge.

On 19 June and 17 July 2014, FRW-infested new season Navel oranges (eggs laid over previous two weeks), were removed from cool storage the day before treatment. The oranges were placed in mesh bags and dipped with slight agitation in one of the treatments outlined in Table 2 (excluding Treatment 8, 20 oranges per treatment in June and 14 oranges per treatment in July).

After dipping, FRW egg-infested oranges were left for 1 h before being run through the Compac Auckland HPW unit at 350 psi (two passes, to mimic a commercial lane with two rotating heads). In May 2014, the hold-down nozzles before the rotor were not operating. In June and July 2014, the hold-down nozzles were operating and the height of the rotor was lowered by 20 mm to achieve better coverage of oranges. After HPW treatment the oranges were left to dry overnight at ambient temperature and the removal of FRW eggs from the button end was assessed the next day.

Fruit that were treated on 8 May 2014 were discarded after assessment as they had been stored at 5°C and there were concerns about FRW egg viability after cold temperature storage. Fruit that were treated on 19 June and 17 July 2014 were assessed and any remaining egg masses with buttons were cut off the oranges and placed in to Petri dishes and held for 31- 32 days to assess viability. After this time, any hatching was assessed and all excised button end sections with eggs were dipped in 0.1% sodium hypochlorite for 10 min and rinsed three times with tap water to encourage hatching. After drying, sections with egg batches were placed within a Petri dish lined with slightly damp filter paper and sealed with Parafilm. The numbers of emerged larvae were recorded weekly until no more larvae emerged over two consecutive weeks. Unhatched eggs were counted where possible, but care was taken not to cause physical damage to the egg rafts by removal from the calyx area, which often impeded complete count of eggs within a raft.

3.9 Trial 7. Removal of FRW eggs from commercial HPW in Australia

FRW were collected from citrus orchards in the Riverland, South Australia, in May and July 2014. Adults were held in Insect tents (Bugdorm 2120, 60 x 60 x 60 cm; Megaview Science, Taiwan) at 22°C (~60% RH) containing fresh citrus leaves and 10% honey solution.

Navel oranges selected for infestation had intact calyces with a small space between sepal tip and peel into which weevils could oviposit. Fruit were immersed for 5 min in dilute chlorine dioxide (= 5 ppm free chlorine) to inhibit fungal growth, then air-dried. Infestation was achieved by inverting small plastic cups (35 mL capacity; Hygienic Lily Ltd (Delisted)) containing one adult weevil over the calyx and securing with a rubber band. Fruit were inspected after three days. Fruit and weevils were replaced as required over a two-week period. Infested fruit were held at 5ºC until required and then evenly distributed among treatments by age.

Fruit infested with FRW eggs were either untreated or dipped in a heated (40°C) mixture of Prospect (4% vol/vol), sodium bicarbonate (2% wt/vol) and sodium hypochlorite (10,000 ppm free chlorine; determined by La Motte total chlorine test papers after serial dilution). After 24 hours, infested fruit were washed in a single pass on a commercial high pressure wash system in Riverland, South Australia. A summary of system measurements (Packhouse 4) are presented in Redpath et al. (2014). The HPW system was 10 rows each with 15 nozzles 100 mm apart and nozzles 150 mm high from a tennis ball. The pressure at the pump was ~160 psi, with a flow rate at the nozzles of ~17 L min^{-1}. Treatment dwell time was about 15 s for the first experiment and a second experiment was conducted using 30- and 60-s dwell times.

The washed fruit were assessed under a binocular microscope. Egg masses were counted after removing calyces.

3.10 Trial 8. Viability of FRW eggs after dip bioassays in Australia

Infested fruit were dipped in a heated 500 mL solution (1000 mL beaker) for 30 s. The solution temperature was maintained at 40°C by a water bath. The treatment consisted of Prospect Fruit

Treatment (Caltex Australia, Sydney NSW) mixed with either glacial acetic acid (Ace Chemicals, Adelaide SA) or citric acid (Ace Chemicals, Adelaide SA).

Initially, 15 fruit were dipped in 1% (vol/vol) Prospect mixed with either 1% (wt/vol) citric acid or 2.5% (vol/vol) acetic acid. All solutions where mixed vigorously before dipping. Fruit were allowed to air-dry on racks before being placed into trays. Egg masses were placed on Petri dishes and sealed in plastic bags with a damp sponge to maintain a high relative humidity. The sealed plastic bags were placed in an incubator at 25°C. Each egg mass was assessed weekly until all egg hatching had been completed (c. 30 days). Assessment involved recording the number of eggs that hatched. Two replicates were conducted. Further replicates were abandoned because of calyx senescence and excessive fungal development.

Subsequently, surface sanitised fruit were dipped in 4% (vol/vol) Prospect mixed with either 4% (wt/vol) citric acid or 4% (vol/vol) acetic acid. Control solutions contained reverse osmosis (RO) water only. After rinsing in water and air-drying, the infested fruit were placed in an incubator at 25°C. Each fruit was assessed weekly until all egg hatching had been completed (c. 30 days). Decayed fruit were removed from the incubator. Assessment involved recording the number of eggs that hatched. Further replicates were abandoned because of weevil death and lack of egg laying.

Final observations included assessment of the development of unhatched embryos. Fully developed embryos were those with a developed head capsule and body segmentation; otherwise embryos were classified as under-developed.

4 Results

4.1 Trial 1. Removal of paint from Navel oranges using prototype HPW systems in Auckland (December 2013)

Using the drier after HPW tended to confound the results by “buffing” areas of fruit and spreading a fine residue from brushes back onto the clean fruit. Drying is therefore not recommended for further paint removal trials.

The modified Honiball HPW unit with angled nozzles removed the most paint from around the whole fruit and the button area (Figure 16). From observations, paint removal was aided by the brush-bed as well as random direct hits from the nozzles. Unlike observations in Australia when paint removal ranged from 35 to 97% (Redpath et al. 2014), the PFR Honiball HPW with vertical nozzles resulted in high paint removal rates (93-96%). This was probably because of correct setup with no blocked nozzles or nozzles not orientated incorrectly. The angled nozzle system (33° and alternating rows) resulted in greater removal than vertical (straight down) nozzles with paint removal of 97-99.5%).

A double pass on the experimental Compac HPW unit removed >90% paint from the button area where FRW eggs were laid. General removal of paint from the whole fruit was lower; however, it was agreed that the rotor should have been lowered to improve coverage. Removal was better using a two-rotor system (simulating the standard Compac apple washer) at 200 or 300 psi compared with a single-rotor system at the same pressures.

The three-nozzle system resulted in poor removal of paint from both the whole fruit and around the button end of the fruit. However, the pump was cavitating, resulting in moments of reduced pressure that may have affected removal of paint. The pump was therefore fully serviced following this experiment.

Removal of single-strength and double-strength kaolin paint was similar when using the Honiball HPW unit at 140 psi (Figure 17). HPW was also effective at removing sooty mould from oranges (Figure 18).

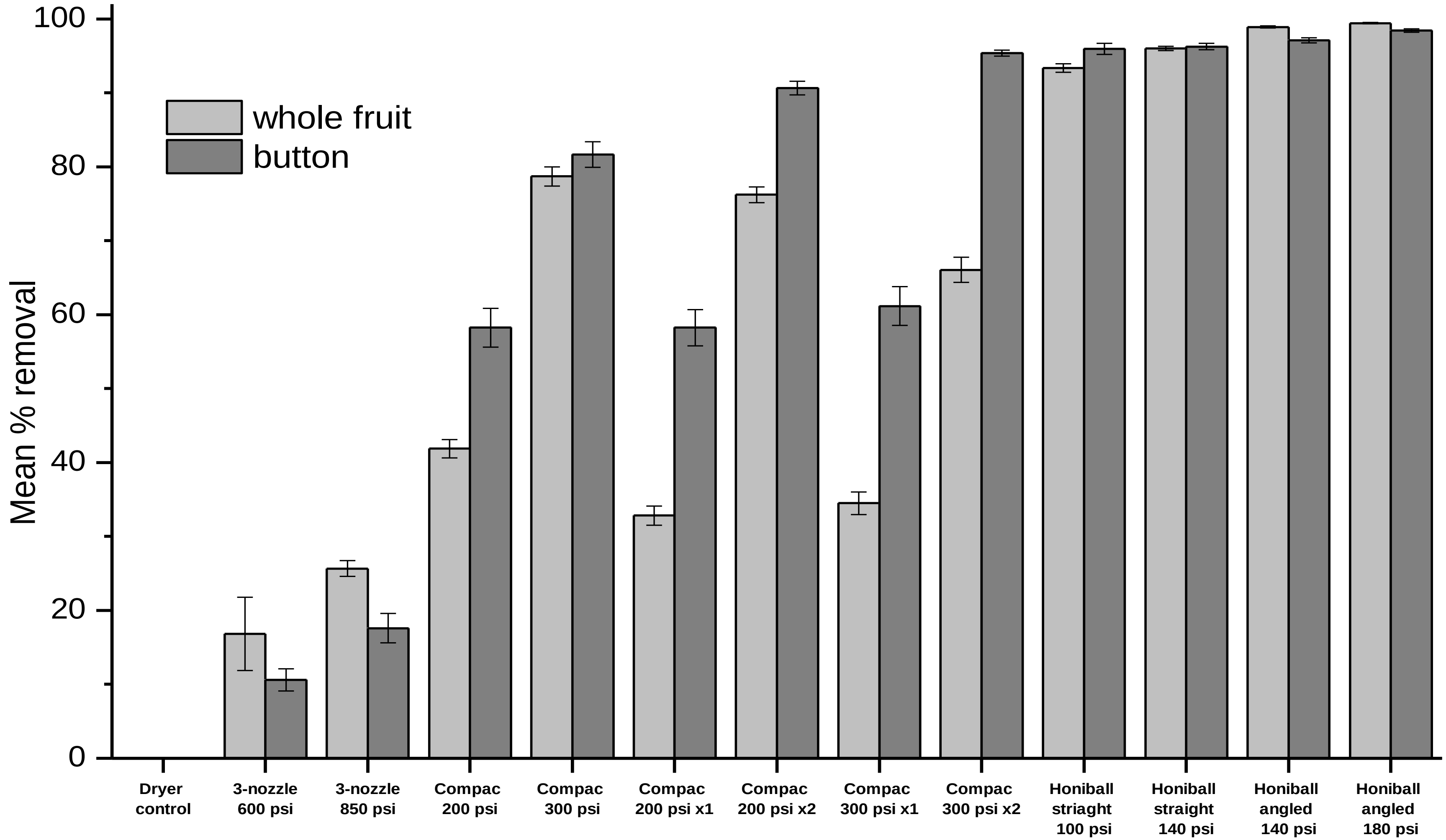

Figure 16. Mean percentage of paint (applied at double-strength) removed (± SE) from Navel oranges (juice quality) after treatment with prototype high pressure washing systems in Auckland + drying on. Note the pump on the Compac washer was cavitating, resulting in moments of reduced pressure.

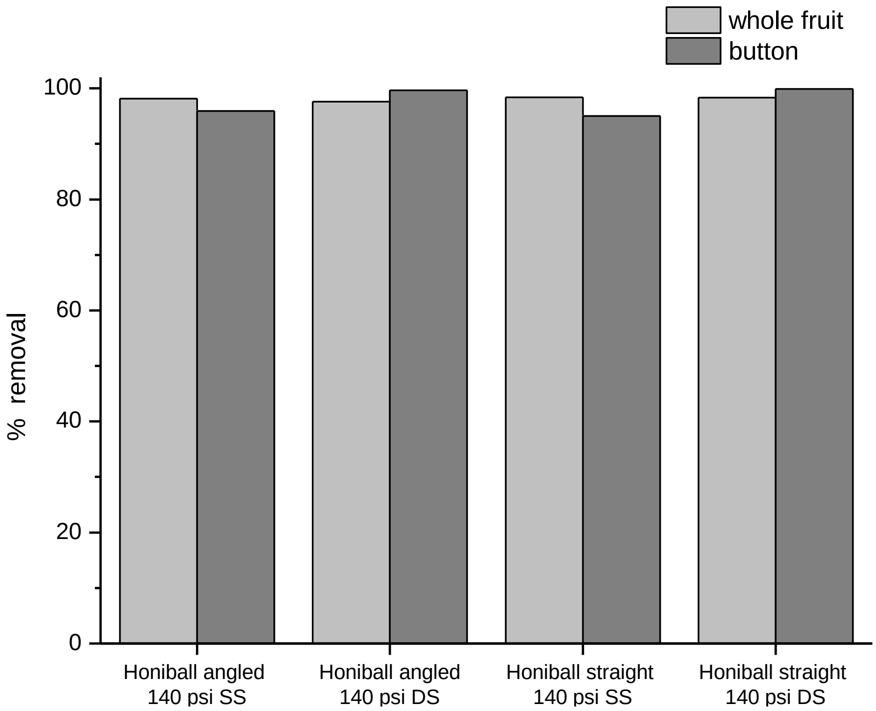

Figure 17. Percentage of paint removed from Valencia oranges (choice grade) with single (SS) or double-strength (DS) paint applications after treatment with prototype Honiball high pressure washing system in Auckland, with nozzles pointing straight down or on a 33° angle.

Figure 18. Sooty mould on citrus fruit before Honiball high pressure washing (HPW) treatment (left) and after.

4.2 Trial 2. Removal of paint from Valencia oranges using commercial HPW systems in Hawke's Bay (February and April 2014)

Removal of paint from around the whole orange and at the button end was the lowest using the commercial FSS Apollo HPW system (Figure 19).

The Honiball commercial unit removed over 90% of paint and the double-rotor Compac machines removed either similar amounts or more when operating at 250-310 psi at Mr Apple (Figure 19). At Fruitpackers, where the nozzles were incorrectly orientated horizontally (lane 2), rather than the correct orientation vertically (lane 1), paint removal was significantly lower, highlighting the importance of correct nozzle set-up. Overall, washing with the Compac washer in the lane with corrected nozzle orientation resulted in the best paint removal (Figure 19).

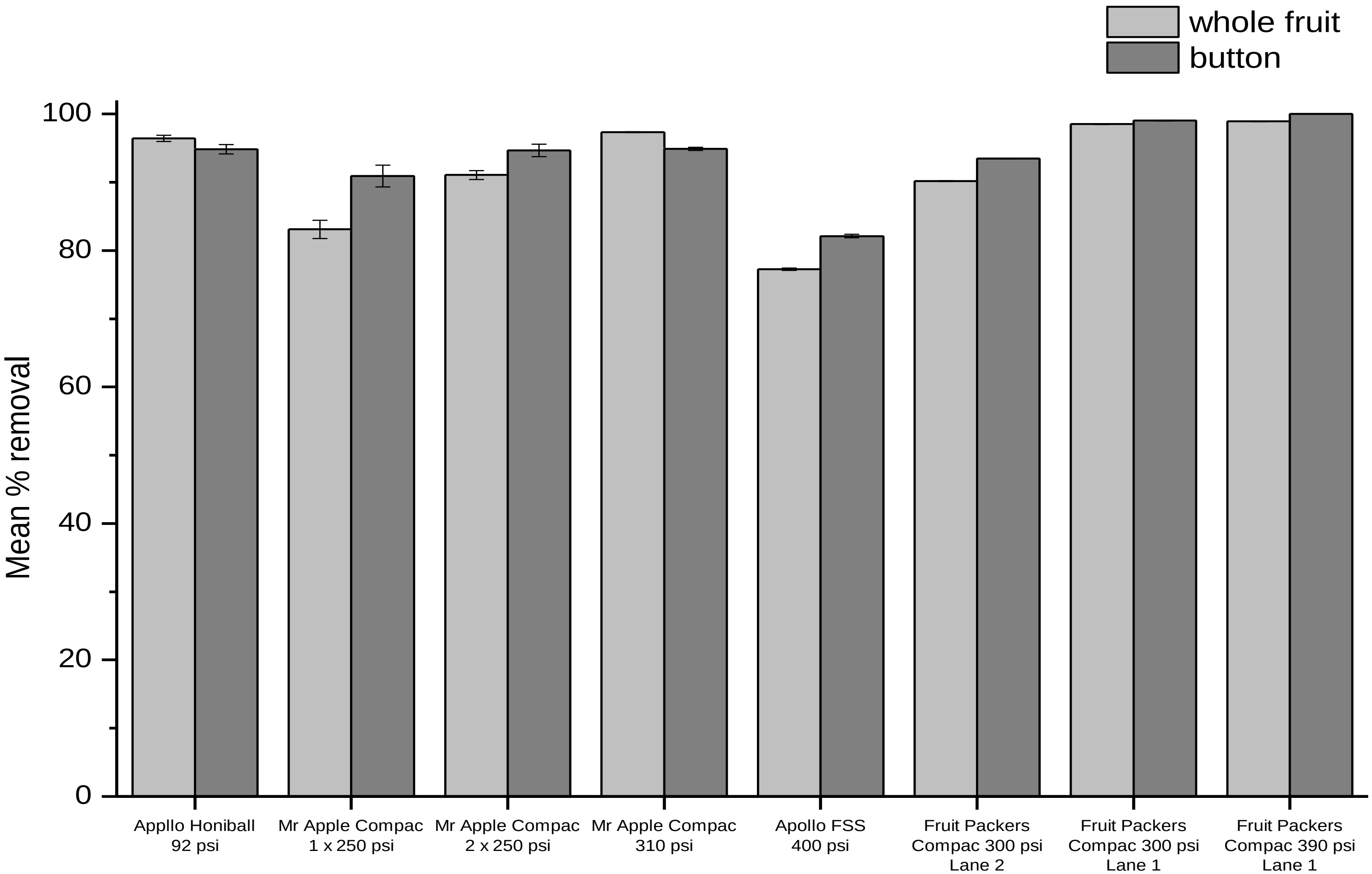

Figure 19. Mean percentage of paint (applied at single-strength) removed (± SE) from Valencia oranges (choice grade) after treatment with commercial high pressure washing systems in Hawke's Bay.

4.3 Trial 3. Removal of FRW eggs from Valencia oranges using experimental HPWs in Auckland (March 2014)

Less than 5% of FRW egg batches were removed using the Honiball HPW unit operating with either straight or angled nozzles (Figure 20). However, the Compac HPW operating at 250-450 psi resulted in egg batch removal rates of up to 20% at the highest pressure. The Valencia oranges had been stored; therefore some of the buttons were removed by the HPW treatment (up to 10%), which generally resulted in the egg batch being removed as well. Removing buttons from oranges does not decrease the marketability of fruit as long as the skin remains intact (Andrew Harty, pers. comm.).

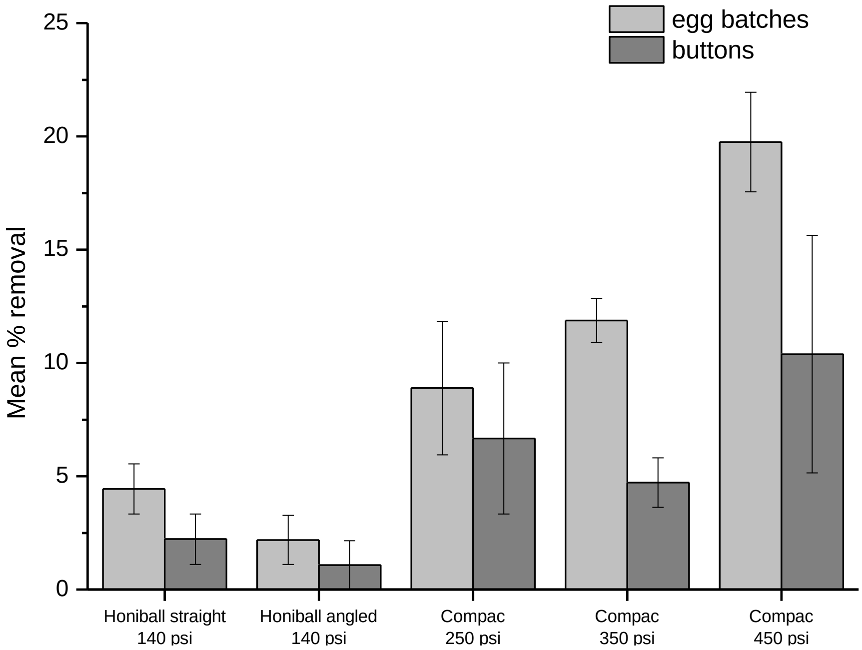

Figure 20. Percentage of Fullers rose weevil egg batches and buttons removed from Valencia oranges (choice grade) after treatment with experimental Honiball or Compac high pressure washing system in Auckland. N = 30

4.4 Trial 4. Removal of FRW eggs from Valencia oranges using commercial HPW systems in Hawke's Bay (March 2014)

Although the Honiball and Compac washers removed over 90% of paint from the button area, this only equated to 16-19% removal of FRW eggs where the machines were set up well (good pressure, correct nozzle orientation, no blockages etc.). Running FRW-infested fruit over lanes 2 and 3, where it had been observed that the nozzles were incorrectly orientated horizontally instead of vertically, showed the poor removal that is achieved when the nozzle direction is not optimised (Figure 21). This highlights the need for diligence in carefully observing the set-up of equipment.

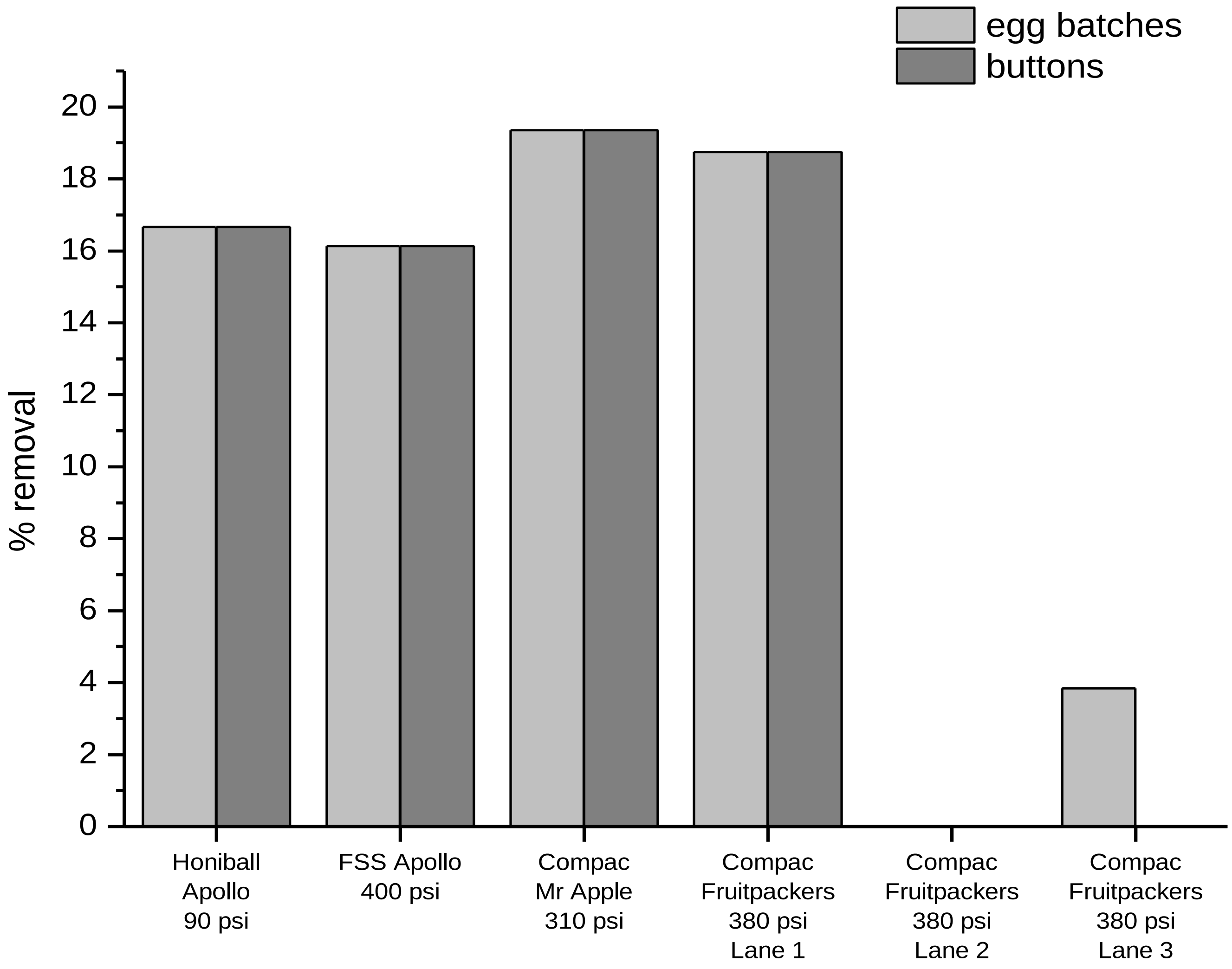

Figure 21. Percentage of Fullers rose weevil egg batches and buttons removed from Valencia oranges (choice grade) after treatment with commercial Honiball, Compac or FSS high pressure washing system in Hawke's Bay.

4.5 Trial 5. Viability of FRW eggs on wax paper after dip bioassays in Auckland (May-July 2014)

Egg batches laid on wax paper appeared to contain more eggs than those laid on oranges. This is probably because of the larger area between the folds of wax paper available for egg lay, compared with under the calyx area of an orange. In the May 2014 trial, 12 egg batches (that had been at 11°C for 33-68 days) were randomly assigned to each treatment and resulted in 322 – 578 FRW eggs being dipped per treatment. In the July 2014 trial, 17-20 egg batches (that had been at 11°C for 49-86 days) were randomly assigned to each treatment and resulted in 423-668 FRW eggs being dipped per treatment.

In the first experiment in May 2014 there was less than 50% hatch of FRW eggs from any treatment that included dips containing Prospect oil (Table 3). Treatment 1 (3% Prospect oil + 0.02% sodium hypochlorite) resulted in the lowest percentage hatch, of 29.8% (Table 3). Treatment 7 (3% Prospect oil + 5% acetic acid) and Treatment 2 (3% Prospect oil + 1% sodium hypochlorite) resulted in moderate hatch, between 41 and 49% respectively. All other treatments resulted in over 50% egg hatch. Both the water-only dip (Treatment 9) and the untreated control (Treatment 10) resulted in hatch rates of 70-71%.

In the second experiment in July 2014 overall egg hatch was lower (37% in the water-only dip and 8% in the untreated control). This was probably because the adults in the colony were ageing and laying fewer viable eggs; also, the eggs were stored for longer before treatment. No eggs hatched after being treated with dips containing Prospect oil (Treatments 1, 2 and 7), indicating (along with the May 2014 experimental results) that Prospect oil reduces egg viability rates.

Table 3. Total numbers of Fullers rose weevil eggs on wax paper treated with dips and numbers of larvae hatched 31-59 days after treatment.

		May 2014			July 2014			
Trt #	Treatment[1]	No. egg batches	Total	No. hatched	% hatch	Total	No. hatched	% hatch
1	3%PO/0.02%SH	12	322	96	29.8	423	0	0
2	3%PO/1%SH	12	353	175	49.6	615	0	0
3	1%SH	12	404	231	57.2	595	193	32.4
4	0.02%SH/0.05%OS/CA[2]	12	440	263	59.8	436	63	14.5
5	1%SH/0.05%OS/CA[2]	12	427	276	64.6	668	223	33.4
6	5%AA	12	495	280	56.6	461	97	21.0
7	3%PO/5%AA	12	410	171	41.7	610	0	0
8	0.05%OS/5%AA/NaOH[3]	12	449	280	62.4	-	-	-
9	Water dip control	12	395	280	70.9	567	208	36.7
10	Air control (no dip)	12	347	249	71.8	565	46	8.1
11	0.05%OS/5%AA	12	578	296	51.2	636	5	0.8

[1] Treatments contained postharvest (PH) Prospect® oil (PO), sodium hypochlorite (SH), saturate organisilicone (OS) and/or acetic acid (AA), or none of these (water dip and air controls)
[2]Treatments 4 and 5, ~30 mL of citric acid (CA) was added to bring the pH to 7-8.
[3]Treatment 8 (initial pH of 2.5) 50 mL of 0.1M NaOH was added but only moved pH by 0.1. A further 100 mL of 10M NaOH was added and increased pH by 1.4.

4.6 Trial 6. Removal and viability of FRW eggs on oranges after dip bioassays and HPW in Auckland (May-July 2014)

Removal of FRW egg batches often equated to removal of ‘buttons’ from the top of oranges (Table 4), although in some cases egg batches were removed while leaving the button intact. As noted above there is no concern about the absence of buttons from oranges as long as the skin remains intact.

Oranges that were dipped in either Treatment 1 (3% Prospect + 0.02% sodium hypochlorite) or Treatment 7 (3% Prospect oil + 5% acetic acid) before HPW, tended to have the highest average removal of FRW egg batches (between 46 and 47%) (Figure 22); however, there were no significant differences between treatments (P=0.477). No treatments tended to result in higher rates of FRW egg raft removal than the water-only dip (Treatment 9; Figure 22).

In terms of egg viability, there was no significant (P=0.817) difference between the percentage egg hatch from egg batches on treated and control (water dip or untreated) oranges (Table 5).

Table 4. Total number of Fullers rose weevil egg batches treated with dips and removal rates from oranges following high pressure washing (HPW) treatment.

Trt #	Treatment[1]	May (Valencia)			June (Navel)			July (Navel)		
		# egg batches treated	% egg batches removed	% buttons removed	# egg batches treated	% egg batches removed	% buttons removed	# egg batches treated	% egg batches removed	% buttons removed
1	3%PO/0.02%SH	17	35	35	20	50	15	14	57	57
2	3%PO/1%SH	19	16	26	20	30	10	13	62	54
3	1%SH	18	39	33	20	30	0	14	0	7
4	0.02%SH/0.05%OS/CA	19	47	37	20	45	5	14	29	21
5	1%SH/0.05%OS/CA	21	67	71	20	35	15	12	33	33
6	5%AA	21	10	5	20	50	20	13	54	46
7	3%PO/5%AA	21	71	71	20	15	5	13	54	23
8	0.05%OS/5%AA/NaOH	21	10	24	-					
9	Water dip control	19	37	53	20	30	15	13	54	38
10	Air control (no dip)	20	30	30	20	0	0	11	27	18
11	0.05%OS/5%AA	20	25	25	20	35	5	14	43	36

[1] Treatments contained postharvest (PH) Prospect® oil (PO), sodium hypochlorite (SH), saturate organisilicone (OS) and/or acetic acid (AA), or none of these (water dip and air controls)
[2]Treatments 4 and 5, ~30 mL of citric acid (CA) was added to bring the pH to 7-8.
[3]Treatment 8 (initial pH of 2.5) 50 mL of 0.1M NaOH was added but only moved pH by 0.1. A further 100 mL of 10M NaOH was added and increased pH by 1.4.

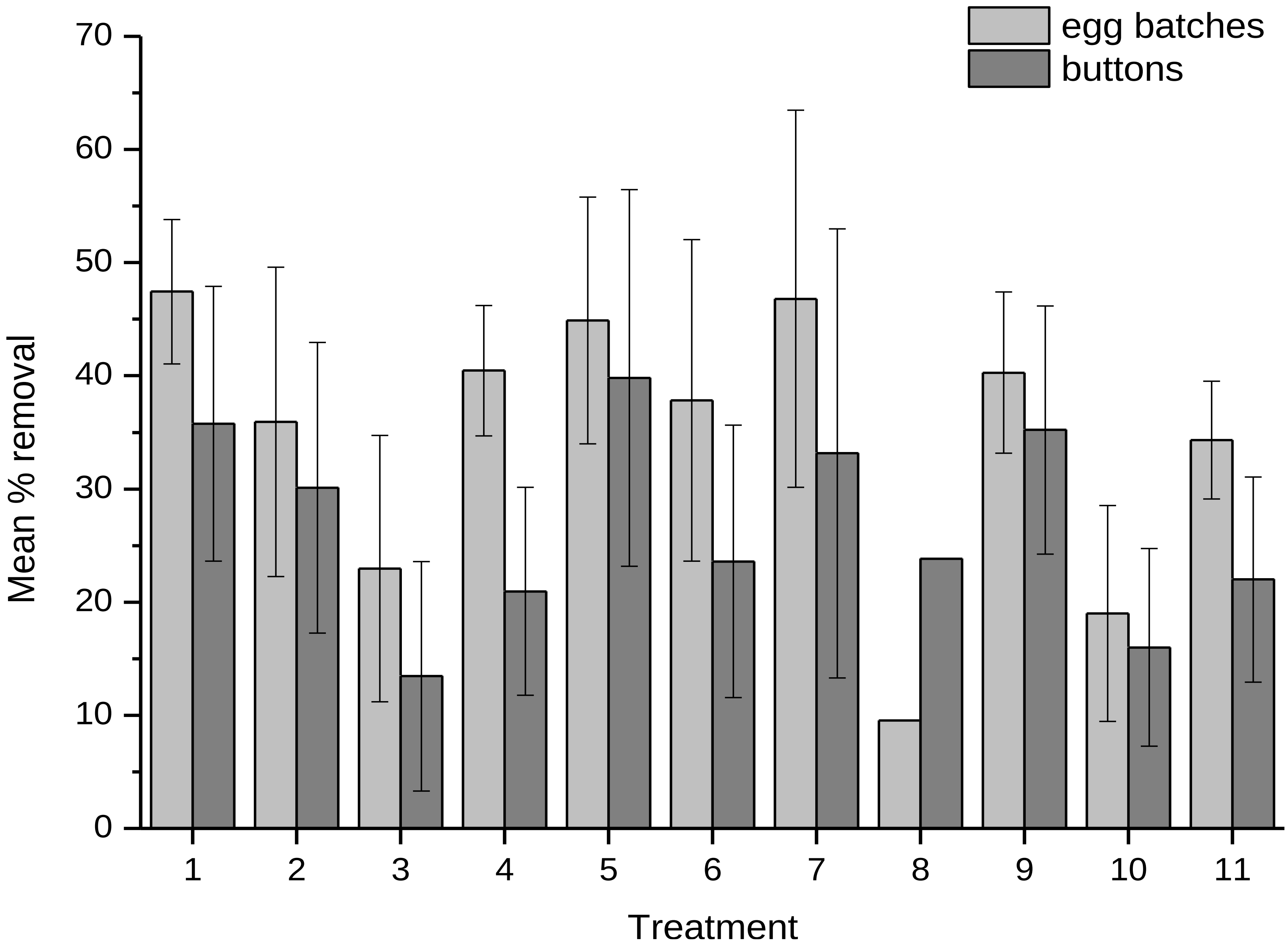

Figure 22. The mean percentage of Fullers rose weevil egg batches removed (± SE) from Navel and Valencia oranges on three occasions by high pressure washing following a one-minute dip. Vertical lines represent the standard errors of the mean. Treatment 8 was conducted on only one occasion.

Table 5. Total numbers of Fullers rose weevil eggs on oranges and % of eggs that hatched which were dipped and put through high pressure washing (HPW) on 19 June 2014 or 18 July 2014 and then the orange calyx removed and monitored for egg hatch 31-59 days after treatment.

Trt #	Treatment[1]	June 2014			July 2014		
		Total	No. hatched	% hatch	Total	No. hatched	% hatch
1	3%PO/0.02%SH	112	76	67.86	56	50	89.29
2	3%PO/1%SH	51	34	66.67	85	74	87.06
3	1%SH	94	64	68.09	91	83	91.21
4	0.02%SH/0.05%OS/CA	80	68	85.00	179	153	85.47
5	1%SH/0.05%OS/CA	63	52	82.54	113	98	86.73
6	5%AA	56	38	67.86	61	46	75.41
7	3%PO/0.05%OS	92	68	73.91	102	86	84.31
9	Water dip control	107	76	71.03	90	75	83.33
10	Air control (no dip)	175	157	89.71	114	100	87.72
11	0.05%OS/5%AA	29	24	82.76	67	48	71.64

[1] Treatments contained postharvest (PH) Prospect® oil (PO), sodium hypochlorite (SH), saturate organisilicone (OS) and/or acetic acid (AA), or none of these (water dip and air controls)
[2]Treatments 4 and 5, ~30 mL of citric acid (CA) was added to bring the pH to 7-8.
[3]Treatment 8 (initial pH of 2.5) 50 mL of 0.1M NaOH was added but only moved pH by 0.1. A further 100 mL of 10M NaOH was added and increased pH by 1.4.

4.7 Trial 7. Removal of FRW eggs from commercial HPW in Australia

The commercial HPW system of Packer 4 did not remove many FRW egg batches (Table 6). A pre-wash dip in heated Prospect, sodium bicarbonate and sodium hypochlorite increased the rate of egg batch removal. It was evident that some of the egg batches on dipped fruit were dislodged after washing but not removed. Egg viability was assessed 30 days after treatment. Egg hatch on untreated fruit was 88.8% compared with 40.4% on dipped fruit.

Table 6. Fullers rose weevil egg mass removal from dipped and undipped citrus fruit after a single pass on the high pressure washer of Packer D, washed 24 h after dipping.

Treatment	# Oranges	# Egg masses		% Egg mass removal	# Eggs remaining	# Eggs hatched	% Egg hatch
		Pre-Wash	Post-Wash				
Untreated	54	94	88	6.3%	215	191	88.8
Dipped[x]	52	91	75	17.6%	188	76	40.4

X = dipped in 40^{0}C solution of 4% Prospect® + 2% sodium bicarbonate + 10,000 ppm sodium hypochlorite

A subsequent experiment at Packer D using a longer dwell time (60 s) removed higher numbers of eggs on untreated fruit (Table 7). The dipped fruit were assessed after a single pass (30 s) and the rate of egg mass removal was similar to that with the longer dwell time on untreated fruit. The higher egg removal in this trial compared with that in the previous trial is likely to be because of the longer dwell time and a longer period exposed to the dip solution before washing. Because of unexpected delays, dipped fruit were washed 72 h after dipping rather than after 24 h. Higher pressures and/or longer dwell times on the existing system may further improve the rate of removal. However, it is unlikely to reach the 90-95% FRW egg removal target.

Table 7. Fullers rose weevil egg mass removal from dipped and undipped citrus fruit after the high pressure washer (HPW) treatment of Packer 4, washed 72 h after dipping.

Treatment	# Oranges	HPW Dwell Time (s)	# Egg masses		% Egg mass removal
			Pre-Wash	Post-Wash	
Untreated	48	60	65	48	26.2%
Dipped[x]	48	30	71	49	30.0%

X = dipped in 40°C solution of 4% Prospect® + 2% sodium bicarbonate + 10,000 ppm sodium hypochlorite

Egg viability was assessed 30 days after treatment. The egg hatch was highly variable but high in some egg masses in both treated and untreated batches (data not presented).

4.8 Trial 8. Viability of FRW eggs after dip bioassays in Australia

In initial experiments using excised calyces, the control egg viability and egg viability on treated fruit (1% Prospect mixed with either 1% citric acid or 2.5% acetic acid) were very high (~70-90%). The unhatched FRW embryos on both control and treated fruit were completely developed. This suggests that mortality occurred at least a week after treatment and the rates used were probably ineffective. After 2 weeks, the excised calyces were ‘brown’ and covered with saprophytic fungal hyphae. It is likely that these conditions were unsuitable for egg hatch.

Subsequent bioassays involved storing whole fruit in lower humidity to improve egg hatch conditions. The rates of Prospect, acetic acid and citric acid were increased to 4% each, which resulted in different oil-breaking responses. The Prospect and acetic acid mixture broke very quickly, resulting in a very oily orange surface. The Prospect and citric acid mixtures resulted in a Sorbolene®-type cream with some agitation. All fruit treated with Prospect mixtures required rinsing to remove excessive oil and cream.

Storing fruit in lower humidity reduced the saprophytic fungal growth, but fruit decay (green mould) was high in some treatments. The fruit treated in a 40°C water dip were all sound after 30 days of storage. The fruit treated with heated Prospect mixed with either acetic acid or citric acid had 38% (5/13 oranges) and 77% (10/13 oranges) decay, respectively. Prospect is a good adjuvant/carrier and increased mould can occur if dips are not sanitised. The acetic acid provides some sanitation but citric acid appears to be ineffective. A sanitiser may be necessary to avoid high decay rates on fruit treated in Prospect dips.

The FRW hatch was high in fruit treated in the 40°C water dip (Table 8). Prospect-treated fruit had lower hatch rates, and fewer egg mass numbers could be assessed because of high decay rates. The unhatched FRW embryos treated with the Prospect and acetic acid mixture were usually under developed. Some unhatched FRW embryos were well developed, usually the eggs closest to the inside of the calyx. Coverage is difficult to achieve on eggs laid deep under the calyx and these eggs typically survive longest. In the remaining treatment, all eggs dipped in Prospect and citric acid were unhatched and under developed. However, there were only three egg masses that could be assessed. This combination warrants further investigation, perhaps with an appropriate sanitiser added to reduce decay.

Table 8. Percentage hatch of Fuller rose weevil eggs on citrus fruit dipped in 40°C water or Prospect® (4%) with either acetic acid (4%) or citric acid (4%), 30 days after treatment.

Treatment	n	% Hatch (±SEM)
40°C; water	9	92.8 (±6.0)
40°C; 4% Prospect + 4% acetic acid	8	38.3 (±14.8)
40°C; 4% Prospect + 4% citric acid	3	0.0 (±0.0)

n = no. of infested citrus fruit assessed.

5 General discussion

Fullers rose weevil eggs are a particularly difficult pest to remove and/or kill, with HPW results here being the lowest for any pest we have examined to date. The nature of the laying under the calyx makes removal a challenge (i.e. the HPW water droplets reaching the egg), and this location also protects some of the eggs from dip treatments.

Results from the paint removal trials give a good indication of where the HPW jets are hitting the fruit and percentage coverage for general pest and contaminant removal (e.g. scale insects, sooty mould). The most effective paint removal HPWs were a well-set-up Honiball system or a Compac system with two rotor heads/lane. Although a good indication of impact over a fruit surface, the amount of paint removed does not reflect the numbers of FRW egg batches removed. We found that high amounts of paint could be removed but that significantly lower numbers of FRW eggs were removed.

Commercial HPW in Australia removed ≈6% FRW eggs and this could be increased to ≈ 26% with increased treatment duration (using a commercial system in Australia). The experimental and commercial Compac HPW double-rotor system removed ≈20% of FRW egg batches. Ultimately both the standard Honiball and Compac HPW systems could be used to wash citrus for high value markets. The throughput of the Compac washer is lower than that of a standard washer. However, if all fruit are washed using a well-set-up standard HPW (i.e. Honiball design), only fruit for selected FRW-sensitive markets would be directed to the Compac HPW. This targeted ‘two HPW system’ is used by one of the apple packhouses in New Zealand. Therefore, the combined FRW egg removal success of both these HPW systems used together should be investigated.

Egg batch removal after HPW did not seem to increase consistently with the use of pre-HPW dips compared with removal from fruit that were dipped in water alone. However, there was an initial indication that dips with Prospect oil tended to increase removal rates to ≈46% and tended to reduce the viability of FRW eggs from ≈70% hatching down to ≈30-50% hatching or from 10-40% hatching down to 0% hatching. Further verification on fruit is required. Researchers in the USA are also investigating the impact of postharvest dips on FRW egg viability and have reported that initial trials show that malic acid or lactic acid may have potential to reduce egg viability (Spencer Walse; Beth Mitcham, Veronique Bikoba pers. comm.). Walse used 10% malic acid (with Spray aid™ (1 vol:1 vol 10% malic acid) or 4.5% Prospect oil), which resulted in a severe discolouration of FRW eggs.

The reduction in egg viability by effective postharvest dips will rely on the active ingredients coming in direct contact with FRW eggs. This may prove difficult especially for eggs that are laid hard up against the calyx with other eggs surrounding them. Dipping agitation and/or “slickers” (detergents) to break down air bubbles and to drive the solution into the area where eggs are laid may be required, and even application via a HPW system, to ensure that eggs are exposed to the active ingredient.

Current postharvest FRW control research in the USA has shown that ethyl formate (EF, 2%) alone, EF followed by cool storage (CS), surfactant dip + EF + CS, acid dip (citric acid or acetic acid or quinic acid) + EF + CS all result in high mortality (but not complete control) of FRW eggs (Mitcham, unpublished). In Australia, a combined fumigation of EF + phosphine is being investigated to replace methyl bromide fumigation of citrus to Korea (Ren, unpublished data). Ultimately the control of FRW eggs will probably be via using a systems approach, with incremental increases in mortality/removal of FRW eggs from a range of both pre-harvest and postharvest control strategies until the required degree of protection, as defined by each market, is obtained. Postharvest dips and high pressure washing are likely to be included in that systems approach. The advantage of HPW is that it removes any evidence that the pest was there at all. The presence of dead pests can be an issue, as this relies on the inspectors' willingness and ability to record viability information.

Further research for this project should focus on defining the egg viability and removal response to malic acid/lactic acid/Prospect oil dips applied before HPW with standard and Compac systems. Asynchrony between the availability of FRW adults to lay eggs on oranges (available from February until April) and the availability of Navel oranges (available between June and November) have proven to be a challenge for this project. However, if initial trials using FRW eggs laid on Valencia oranges (harvested later than Navel oranges) can be used as a proxy to FRW eggs on Navel oranges, then trials on artificially and naturally infested Navel oranges during August-October 2015 to confirm efficacy can be undertaken. Confirmation trials in Australia will also be required, using commercial facilities.

6 Conclusions

Although high rates of FRW egg removal were not achieved (>90% removal as reported with other pests), there is potential to increase FRW egg removal rates from the current ≈6% removal to ≈20-50% removal, as well as with reducing egg viability by using postharvest dips followed by standard and new-generation Compac HPW systems. These inline pest reduction techniques, along with pre-harvest control measures beforehand and EF fumigation and cool storage afterwards, have the potential to achieve the high rates of protection required for FRW-sensitive markets in a residue-free manner.

7 Future work

Future work should focus on:

- Investigating the impact of malic acid/lactic acid/Prospect oil ambient temperature dips on FRW egg viability and the impact on egg removal after HPW 24 h after dipping
- Determining the impact of a combination of standard Honiball and Compac HPW on FRW egg removal and Navel orange quality
- Integrating the most effective postharvest dip + HPW treatment with pre-harvest control measures and fumigation and/or cool storage to quantify the efficacy of such a systems approach.

8 Acknowledgements

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Appendix 3

Woolf A, Jamieson L, Taverner P, Olsson S, Redpath S 2015. Best-practice user manual for Citrus high pressure washers. A Plant & Food Research report. SPTS No. 11171.

PFR SPTS No. 11171

Best-practice user manual for Citrus high pressure washers

Woolf A, Jamieson L, Taverner P, Olsson S, Redpath S

February 2015

Best-practice user manual for citrus high pressure washers

Best-practice user manual for Citrus high pressure washers

Woolf A, Jamieson L, Taverner P, Olsson S, Redpath S
Plant & Food Research, Auckland

February 2015

General introduction

High-pressure washing is an effective postharvest treatment for removal of insects and external contaminants. In order to maximise the effectiveness of these washers and minimise insect interceptions, the following procedures and tests have been developed and are recommended for use to detect operational problems with high pressure washing systems.

While there are differences in the specific design of citrus washers, the methods provided here provide tools to optimise washer capability. Some of these methods may not relate specifically to each individual washer, but they highlight key areas for all washers. If these procedures and suggestions are carried out regularly, the value of the significant capital investments and running costs of HPW systems will be recognised.

For further information please contact:

Allan Woolf
Plant & Food Research Auckland
Private Bag 92169
Auckland Mail Centre
Auckland 1142
NEW ZEALAND

Tel: +64 9 925 7000
DDI: +64 9 925 7267
Fax: +64 9 925 7001
Email: allan.woolf@plantandfood.co.nz

1 GENERAL OBSERVATIONS DURING OPERATION

1.1 What is this test for?

To ensure treatment is being carried out effectively by observing water pressure, fruit feed and movement, and general operation of the unit.

1.2 Why should we do this test?

Regular careful inspection of the unit can highlight issues that might reduce the effectiveness of the machine, with serious economic consequences if phytosanitary obligations are violated.

1.3 How to do this test?

Water pressure is an important factor and should be carefully monitored. While a pressure gauge is normally found at the pump outlet, it is best practice that an accurate gauge be placed on each gantry and as close to the nozzles as practical because pressure (head) loss occurs along pipes. We recommend at least two gauges for each washer (Figure 1).

The pressure gauges should be calibrated at the start of each season by comparison to a gauge known to be correct. Any changes in pressure in the season can be verified by swapping gauges (if more than one gauge is used). Having a spare new pressure gauge in stock allows for rapid changes and checks to be made. An increase in pressure on one gantry can indicate nozzle blockage, although small blockages and pressure differences are unlikely to be detected. A decrease in pressure (generally over a long time) suggests excessive nozzle wear.
A pressure decrease may also indicate a lost nozzle, blocked pump inlet filters or other pump problems.

Pressure gauges should be oil-filled or have other features that protect against vibration, especially if the pump is a piston type. When the pump is off, checking that the gauges read zero should be done regularly, because gauge wear or over-pressure can cause significant gauge errors.

Figure 1. Pressure gauge at the gantry, an important check on pressure in addition to a gauge at the pump.

Examine fruit loading onto the washer brushes. Is there excessive “doubling up” with two fruit in one position, i.e. on top of each other? This can lead to incorrect cleaning of the extra (non-aligned) fruit.

The machine may be designed to use different nozzle sizes in different locations, but the sizes can easily be confused, especially when removed for maintenance. Are the correct nozzles fitted in the right locations on the washer? Read the size numbers on the nozzles (possibly by removing them or using a digital optical inspection probe (as shown in Figure 2), or to observe that the spray angle is correct. We recommend packers convert to quick fit nozzles with a proven track record. ProMax® QuickJet® nozzles (e.g. QPTA-15-40) have proven to be effective for insect removal on apples in New Zealand. However, this may mean changes to pump capacity.

Figure 2. Example of simple inspection camera system (cost <$400). (These units are useful for a range of applications in a typical packhouse.)

The general cleanliness of the unit is also very important. The build up of organic matter on the gantry and HPW structure can lead to increased wear, and is also a food safety and general cleanliness concern. A simple hose down with a hand-held high pressure hose, or even a domestic water blaster, at the end of each day is recommended (Figure 4).

Figure 4. (A) An example of organic matter build up on the gantry of a HPW. **(B) A quick and easy remedy is to wash down with a domestic water blaster.**

2 SPRAY PATTERN

2.1 What is this test for?

To observe the spray pattern of nozzles to check they are operating correctly.

2.2 Why should we do this test?

It is critical that the water jets are not blocked or missing (Figure 5), are oriented correctly and have a clear path to hitting the fruit. We have observed a range of problems including jets hitting (interacting with) each other, nozzles rotated 90° (i.e. not operating laterally across the washer), blocked and partially blocked nozzles (Figure 6).

2.3 How to do this test?

Are any water jets hitting each other before they reach the fruit surface? For example, nozzles might interfere with each other above the fruit and thus reduce cleaning efficacy. Note: these observations must be made with fruit under the nozzles.

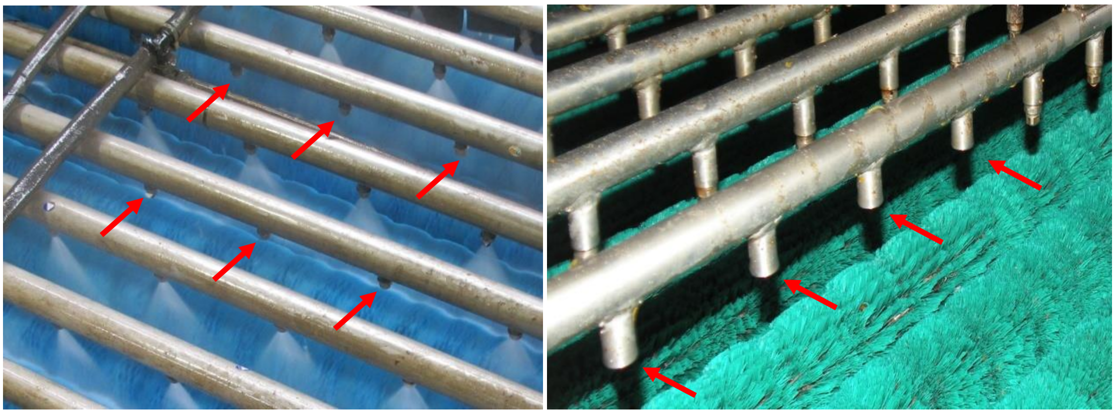

Figure 5. Completely blocked (A) or missing nozzles (B) in high pressure citrus washing systems.

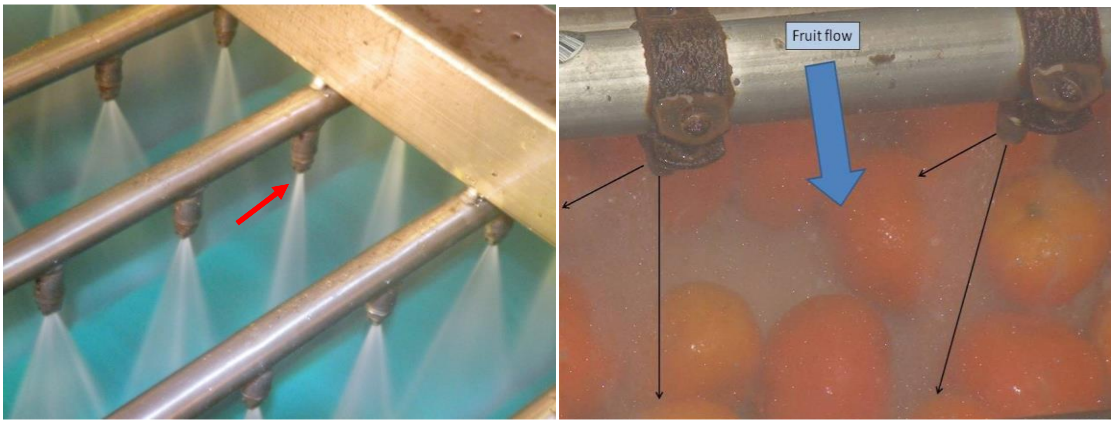

Figure 6. (A) Partially blocked nozzles in high pressure citrus washing systems not delivering a distinct 'fan' jet of water for maximum coverage. (B) Nozzles orientated incorrectly (rotated 90°, spray pattern indicated by arrows) and only hitting a small fraction of the fruit (this will also cause damage to the brush bed).

3 FLOW RATE

3.1 What is this test for?

To measure the flow rate of each nozzle to determine if there has been significant wear, or blockage, and whether the nozzle type is correct.

3.2 Why should we do this test?

Flow rate is a key component of high-pressure washing efficacy since it plays a significant role in determining the impact of the droplets on the fruit, and thus the removal efficacy. Nozzles wear over time, particularly if water quality is poor, and may need replacing. While complete blockage of nozzles is easy to note visually, partial blockage can be surprisingly difficult to see, and flow rate is an objective means to determine this. Finally, when nozzles are replaced or cleaned, they might be replaced in incorrect positions or at incorrect angles.

3.3 How to do this test?

Each packhouse should construct a system that allows easy fitting of a water-collection pipe over the nozzle outlet. Flexible plastic hose or PVC pipe is commonly used. Place one end of the pipe over each nozzle and place the other end of the pipe over a graduated measuring container (e.g. 5 L jug), and, using a timer (set on “countup”) time how many seconds it takes to fill to a reasonable volume (e.g. 1.5 L; Figure 7). This is a balance between achieving accuracy (short times will be less accurate) and having enough time to carry out the tests. Note the time and volume collected for each nozzle and repeat. Where foaming of the water occurs, simply remove the jug (after stopping the stopwatch), allow the foam / bubbles to subside, and read the volume of water delivered.

We have found this to take about 40 minutes. This is good point at which to note that having a system (e.g. a plan/diagram, or labelling system) for individually numbering the nozzles makes this work much easier and less prone to errors. Similarly, appropriate platforms / walkways that give good access to the washer unit are important here from both efficiency and health and safety perspectives.

To convert the time (in seconds) to litres per minute use the following formula:

Volume collected (in litres) x 60 = flow rate in litres/minute

Time to fill (in seconds).

Figure 7. Measuring flow rate. Time to fill to 1.5 L is measured for each nozzle.

Frequency: Measure flow rate weekly or at least monthly.

4 FRUIT ROTATIONS

4.1 What is this test for?

To measure the number of fruit rotations under the washing treatment.

4.2 Why should we do this test?

A key factor in removal efficacy is that fruit rotate freely under the nozzles. If a fruit does not rotate freely during the time it passes under the nozzles, there is a significant increase in the likelihood that contaminants will not be removed. However, a balancing factor is that the fruit must rotate in a stable manner under the nozzles. Different sized fruit will rotate more or less times during the treatment period.

4.3 How to do this test?

Using a medium fruit size, apply a dark line across/around the fruit using a permanent pen system (Figure 8). Marked fruit can be placed on the washer (laterally) and the number of rotations counted as the fruit passes under the washer nozzles while the washer is under normal operating conditions. Fruit on a brush bed system should rotate and turn quite randomly due to movement of the following fruit. Use of a spiral-cut brush system can help ensure fruit move left to right, which should improve removal efficacy.

Figure 8. Medium sized orange with black line marked across/around it for counting rotations on the brush bed.

Frequency: Measure monthly.

5 CLEANING OF PAINTED FRUIT

5.1 What is this test for?

Checking that the entire fruit surface is being clean by the water jets.

5.2 Why should we do this test?

The ultimate way to measure high-pressure water washer efficacy is to use the target insect, i.e. FRW egg rafts, scale insects. However, that is both technically challenging and very expensive to carry out. Therefore, we consider that achieving thorough removal of a non-toxic white paint is a reasonable substitute that has been found to be an effective tool to visualise issues.

The method can be applied to any washer type. It can detect dead spots that the water jets are not reaching, but full paint removal should not be taken as a guarantee that the level of impact is sufficient to remove the target insects – i.e. paint will generally be easier to remove.

5.3 How to do this test?

5.3.1 The "PFR method": PVA and Surround®

A solution is made up of 4 g of PVA wood glue and 20 g of Surround® (Kaolin clay, AgNova Technologies Pty Ltd, Box Hill, Victoria) added to 100 mL of water. To achieve best results, mix the PVA with a small amount of water initially, then add the remainder of the water slowly with vigorous shaking until all dissolved (this takes some time). Finally, add the Surround and shake well to achieve a uniform solution. Fruit are then dipped in the solution (one end at a time), allowed to partially dry on their sides (on newspaper or similar), then rolled over after an hour or so (to avoid a "pooling" of solution at the base). Frequent stirring of the solution is required as settling occurs. After dipping, fruit should be allowed to dry for at least 2 days in an air-conditioned room at 20°C (Figure 9). Fruit should be kept dry until used for the washer tests, because exposure to dampness or even high relative humidity will make removal easier.

Figure 9. Oranges dipped in PVA/Surround® mixture and dried and then run over the washer.

In the examples below (Figure 10), oranges were put through the washer, allowed to dry, and the level of paint remaining used to determine areas of the fruit that were not being adequately cleaned, and thus not impacted by water jets.

Note that runs using painted fruit should be carried out at the end of a treatment day and the washer brushes and tanks thoroughly cleaned so that no residues of paint/PVA, etc. remain.

Figure 10. These oranges pictured indicate a range of paint removal from one pass under a citrus HPW. Clearly there are efficacy issues with this unit.

6 NOZZLE HEIGHT

6.1 What is this test for?

To measure nozzle height and distance from fruit.

6.2 Why should we do this test?

A key factor in the effectiveness of high-pressure washing is the distance between the nozzles and the fruit, because impact force declines exponentially with distance. If the distance is doubled, the impact will be four times less. Measuring the height of the nozzle to the brush-bed roller can be challenging as the nozzles are generally setup to pass between the brushes (to minimise damage). Because fruit size varies, a standard object needs to be used, and we have found a tennis ball to be both useful and readily available.

1. Use an old tennis ball (i.e. with minimal hair) and place between the rollers immediately below the nozzle to be tested. For a moving brush-bed, the bed may need to be advanced to the correct location.
2. Using a small ruler (best trimmed so that the start is 0 mm) measure distance between the tennis ball and each nozzle (Figure 11).
3. Distance should be ~110 mm for the top nozzle.
4. Adjust gantry/nozzles as appropriate.

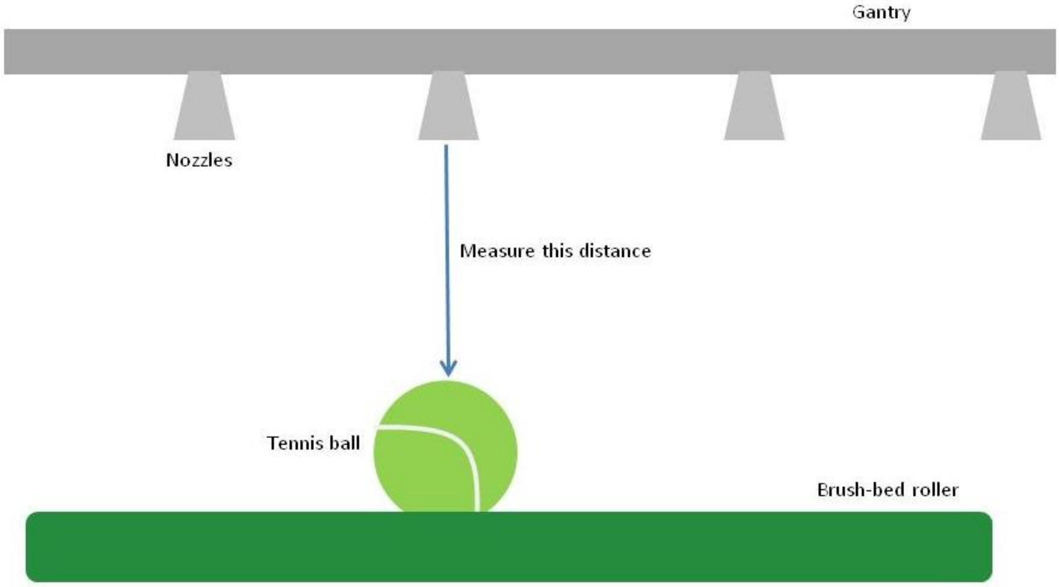

Figure 11. Diagram of how to check nozzle height (measuring distance from nozzle to a tennis ball) using a ruler.

7 WATER QUALITY/CLEANLINESS, AND FILTER MAINTENANCE

7.1 What is this test for?

Maintain a high level of water quality and cleanliness to maximise washing effectiveness, fruit quality, minimise fruit pathogens, and food safety.

7.2 Why should we do this test?

Water hygiene is influenced by a range of factors including the volume of fruit processed, cleanliness of the fruit (dust and dirt, bird guano, spray residues), volume of water in the system, water exchange rate, filter type and cleaning regime, and the use of sanitisers.

In terms of fruit rots, likely pathogens to build up in wash water include *Penicillium digitatum* and *P. italicum* (Green and Blue Mould) and *Geotrichum citri-auranti* (Sour rot). Use of sanitisers to minimise the build up of these spores is critical.

Potential sanitisers include, peracetic acid (Tsunami®), chlorine dioxide (Vibrex® Hortiplus), bromo-chloro products (Nylate®), calcium hypochlorite (Klorman®) and sodium hypochlorite (liquid pool chlorine). Using clean water that continually runs to waste would avoid most hygiene problems (assuming the water used is of high quality), but such volumes of water are generally either not available, too expensive or there are environmental limits on disposal.

The cleanliness of the wash water affects both the washer and the fruit. Sediments and small particulates will cause increased nozzle and pump wear, which will lead to changes to flow and pressure and reduce the effectiveness of the washer. Larger particles may cause partial or complete nozzle blockages. For citrus in Australia, the amount of dust on fruit results in significant contamination and buildup (Figure 12a), and when rotten fruit are processed fruit disintegrate resulting in large amounts of fruit material (Figure 12b).

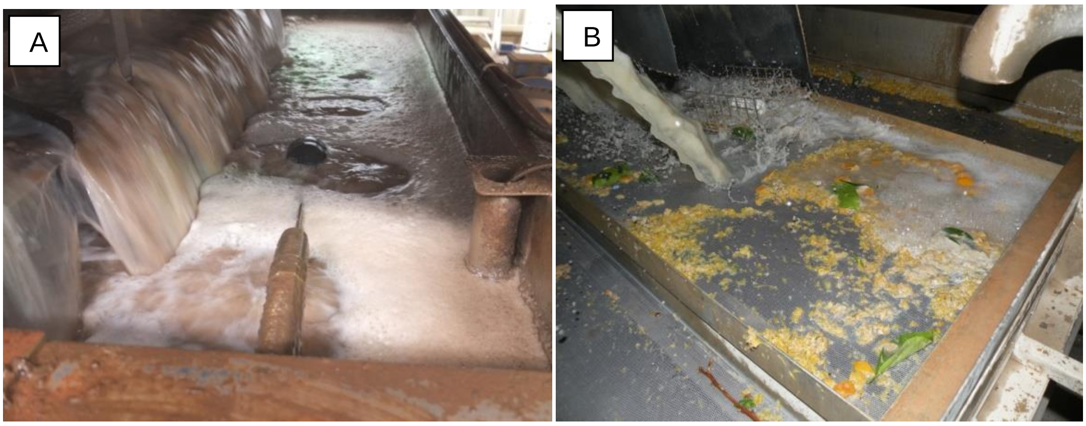

Figure 12. Challenges to water cleanliness: A. Dirt in the water tank. B. Rotten fruit that has disintegrated.

From a fruit perspective, not using a sanitiser will lead to increased levels of pathogenic fungi in the washer water system, and potentially to increased postharvest rots. A build-up in the washer system of agrichemicals (fungicides and pesticides) that are washed off the fruit could potentially cross contaminate fruit, and we therefore recommend using a final row of clean water rinse nozzles after the high pressure washing system (Figure 13).

Build-up of organic matter washed from fruit, particularly bird guano, poses a risk of proliferation of bacteria that are a risk to human health. Bacteria such as *Escherichia coli, Salmonella,* and *Listeria* are all potential risks and the effect of the German *E. coli* O157:H7 outbreak on the Spanish vegetable sector in 2011 is a sobering example of potential impacts of food safety scares. In that case considerable economic damage was done even though Spanish produce was subsequently found not to have caused the outbreak. Controlling the microbial quality of water will ensure that contamination of fruits does not occur that is especially important when those are eaten with no or little further processing.

7.3 How to do this test?

This area is too complex for a detailed system to be described here, but the following factors are important to consider in the management of water cleanliness.

- Fruit volume. More fruit means more organic matter and other contaminants entering the washer water.
- Fruit cleanliness. The amount of dust, rotten fruit, bird guano and spray residues will all influence water cleanliness. Proximity to animals (e.g. cattle) and practices such as use of manure as a fertiliser will increase the chance that wind-blown dirt may contain *E. coli* and other faecally transmitted pathogens. The presence of particulate matter and soluble organic compounds generally decreases the efficiency of sanitizers on the elimination of micro-organisms.
- Water volume in the washer system. A small volume of water in the washer's tanks and piping will result in a more rapid build-up of contaminants.
- Water exchanges and dumping. Periodic water dumping and hosing out of tanks (e.g. at lunchtime and at the end of the day) is recommended as best-practice. Any hard-to-clean parts of the tanks need to be eliminated or given special emphasis during cleaning. To facilitate very rapid refilling of the washer tanks (e.g. at lunch time and before the night shift), an additional clean-water storage tank with large outlet pipe system is effective. This can be achieved by a tank on a stand so that gravity feed through the large pipe results in a fill of 10–15 min maximum, thus allowing cleaning and refilling over a typical lunch break.

As recommended below for fruit cleaning, a "clean water rinse" after high pressure washing can be used as a way of continually adding clean water to the system (Figure 13). This water can also provide top-up and dilution of the main water system. Clean-water storage tanks with large outlet pipes will facilitate rapid refilling of the washer system. Since dust and dirt can be a real issue here in Australia due to the conditions citrus are grown in, another option is to install a light brush and pre-rinse system which will remove some contaminates before fruit reaches the main high pressure washing unit.

Figure 13. Oranges exposed to a clean water rinse after HPW.

- Sanitisers. There are a wide range of sanitiser systems available for use in high pressure washer and flume systems.. Products include, peracetic acid (Tsunami®), chlorine dioxide (Vibrex® Hortiplus), bromo-chloro products (Nylate®), calcium hypochlorite (Klorman®) and sodium hypochlorite (liquid pool chlorine).

Consideration needs to be given to the following:

- Ease of use and maintenance of effective concentration.
- Effect of organic matter and pH on the sanitiser. This is particularly a problem for hypochlorite products, which rapidly loses efficacy in the presence of organic matter and in alkaline conditions.
- Health and safety: chemical exposure risks during mixture preparation, and for grading and packing staff who may be handling fruit soon after the washer.
- Sanitiser cost – This should include operating costs. For instance, the cheapest (sodium hypochlorite) product may not require very high doses &/or high monitoring costs to have sufficient efficacy with a high organic load. If possible, a fixed inline dosing system is recommended to ensure that effective concentrations of the sanitiser are maintained at all times.
- If sand filters are used, a glass bead media should be used.
- Cartridge filters. These are used in most washing systems and are an important part of the cleaning system. It is recommended to use a dual cartridge filter system assembly with a bypass so that flow can be switched between cartridges during cleaning. This will allow more time to correctly service the unused filter while the machine remains running. Auto back flushing systems are preferable.
- Flat screen or mesh filters. Most washers use first a course mesh filter (3–4 mm diameter holes), followed by very fine mesh (e.g. “100–42” mesh (100 meshes/inch) made of 304 or 316 grade stainless steel). Generally flat “trays” of these filters can be removed and rinsed periodically (Figure 14). If possible having two of the fine filters allows for removal and cleaning while maintaining filtration.

Figure 14. An example of a flat mesh type filter system in a high pressure citrus washer (A) and the nature of the material that blocks the filters (B) which is mostly fruit pulp from rotten fruit.

- We recommend that consideration be given to regular commercial analysis of washer water quality. This should be done at a NATA accredited commercial testing facility such as Envirolab and DMG Microlabs. Measurements should include Total Plate Count / Aerobic Plate Count (TBC/APC) (preferably incubated at 15–25°C), yeasts and moulds, and thermo-tolerant coliforms (or E. coli) to assess the efficacy of the treatment process (sanitizers, etc.) and to indicate possible faecal contamination (which would indicate the risk of human pathogenic bacteria being present). Sampling should at least be made under worst case" conditions, i.e. at the end of a run before water is dumped. The sampling frequency would depend on the amount of work carried out (e.g. volume of fruits processed a day or a week) but should be sufficient to establish trends and to notice aberrant samples. Sampling should be randomized and any results above the normal should be traced back to consider their cause. When high counts are found, close attention should be paid to the next sampling period in case they are repeated.

8 ACCESS TO THE WASHER

Ready access to the gantry and all nozzles is necessary to ensure staff safety, but more significantly so that regular checking and maintenance can be carried out. Many high pressure washers are poorly equipped in this area and improvements, or installation, of appropriate ladders and walkways is highly recommended. In addition, a system for lifting the nozzle gantry up and away from the conveyor would also be of benefit by making both the nozzles and conveyor more easily accessible. However, this would also require engineering of the supply piping.

9 PERSONNEL

Having a well-trained and diligent high pressure washer operator is likely to result in significant improvements. Consideration should be given to more training for this staff member and maintaining the same operator if at all possible over seasons. The significant investment in the machine and cost of running can be largely negated by poor operator skill and attentiveness. Consideration should also be given to instigating a regular meeting with the washer operator, site engineer, pack house manager, QC manager and other relevant staff (e.g. exporter/marketer). Ensuring that there are clear lines of communication and responsibility will also improve effectiveness.

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Appendix 4

Page-Weir NEM, Griffin MJ, Redpath SP, Jamieson LE, Taverner PD, Leo AT, Chhagan A, Hawthorne AJ, Woolf AB 2015. In-line approaches to control FRW eggs on citrus – Year 2. . A Plant & Food Research report. SPTS No. 12170.

PFR SPTS No. 12170

In-line approaches to control Fuller’s rose weevil (FRW) eggs on citrus – year 2

Page-Weir NEM, Griffin MJ, Redpath SDP, Jamieson LE, Taverner PD, Leo AT, Chhagan A, Hawthorne AJ and Woolf AB

October 2015















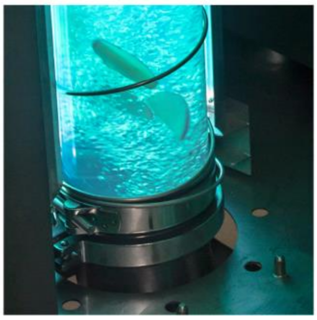


CONTENTS

EXECUTIVE SUMMARY

In-line approaches to control Fuller's rose weevil (FRW) eggs on citrus – year 2

Page-Weir NEM[1], Griffin MJ[1], Redpath SDP[1], Jamieson LE[1], Taverner PD[2], Leo AT[2], Chhagan A[1], Hawthorne AJ[1] and Woolf AB[1]

[1] Plant & Food Research: Private Bag 92169, Auckland Mail Centre, Auckland 1142,
[2] South Australian Research & Development Institute (SARDI), Waite Research Precinct, Waite Road, Urrbrae 5045, South Australia, Australia.

October 2015

Background

Fuller's rose weevil (FRW, *Naupactus cervinus*) is a quarantine pest in China, Korea and Taiwan and the presence of FRW eggs on Australian citrus is impeding market access growth in these key Asian markets. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs; this has reduced the number of shipments rejected during pre- or post-shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets.

High pressure washing (HPW) has the potential to decrease infestation rates further. Australian packhouses use standard HPW systems; however, their performance varies substantially. In New Zealand, new generation HPW machines have been developed to enhance removal of difficult-to-remove organisms. Research to reduce FRW egg viability using postharvest dips is being undertaken in the USA, and these may have the potential to be incorporated in to an in-line pest reduction system that includes pre-HPW dips and new HPW systems that remove already-low numbers of FRW eggs and render remaining eggs non-viable.

Methods

Field collected, adult Fuller's rose weevil (FRW) were maintained within a laboratory colony. Adults were caged on oranges to lay eggs beneath the calyx for treatment. Wax paper within colony boxes provided egg rafts on paper for laboratory dips.

Trials were conducted to determine the impact of seven postharvest dip treatments (containing Prospect® oil, sodium hypochlorite, malic or lactic acid) on the viability of FRW eggs on wax paper and on oranges and to determine if these pre-HPW dips enhanced removal of FRW eggs during HPW. Infested fruit were passed through two 'types' (rotating, standard row) of experimental HPW systems to determine the removal rates of FRW eggs from oranges after postharvest dipping.

Because of the high rate of skin blemish (pitting) with both 10% lactic and 10% malic acids after 24 h of drying time before HPW, a small fruit quality trial was conducted with oranges with no FRW eggs. The aim was to minimise skin blemish by reducing the time between dipping and

HPW and adding a rinse after the postharvest dip. Fruit quality issues were still encountered after the 10% malic and 10% lactic acid 1-minute dips with a rinsing and less time between dipping and HPW. Therefore, a second trial using FRW eggs on wax paper was carried out to determine the effect of lower concentrations (1 or 4%) of malic and lactic acid 1-minute dips on FRW egg viability.

Two trials were conducted in Australia, the first to compare the removal and reduction in egg hatch using lactic acid, malic acid and Prospect at ambient or heated temperatures. The second was to evaluate the decay and sanitiser compatibility with food acids and Prospect oil.

Key results

- Using a postharvest dip with 10% lactic acid and 3% Prospect and leaving for 24 h followed by HPW with the rotating system resulted in the highest egg removal rates, of 91%.
- The egg removal rate was reduced when the rates of lactic acid and Prospect oil were reduced to 1% and 0.05%, respectively.
- Of the egg rafts that remained on the fruit after washing, eggs treated with dips containing 10% malic acid + 3% Prospect oil,10% lactic acid + Prospect oil, left for 24 h and then passed over the rotating HPW had significantly lower hatch rates than those in the air and water controls. Eggs on wax paper, dipped in 10% malic acid + 3% Prospect oil or 10% lactic acid + 3% Prospect oil or 3% Prospect oil alone, had lower hatch rates than controls.
- All eggs on wax paper treated with acids at 1% or 4% resulted in significantly lower egg hatch than in the controls.
- Fruit quality data indicated that 10% malic acid or 10% lactic acid dips caused an undesirable skin blemish in the form of pitting, which was exacerbated by Prospect.
- Heated pre-wash dips at 40°C with 1% food acid and Prospect and calcium hypochlorite did not improve egg mass removal or decrease the egg hatch compared with results from the same non-heated pre-wash dips.
- High rates of food acid (10%) and Prospect (3%) resulted in rapid loss of sanitiser activity and rates of both had to be reduced to improve compatibility.

Conclusions

Although effective at removing FRW egg batches and reducing viability, using high rates of food acid (10%) with high rates of Prospect is not recommended because of fruit quality and sanitiser stability issues encountered during these trials. Low rates of food acid (1%) with a low rate of Prospect did not enhance FRW removal in reduce viability enough to warrant use. Investigating an intermediate concentration of food acid and trials to determine which is the most suitable for citrus packhouses is warranted, but could not be completed in this project because of resource constraints such as availability of FRW, navel oranges, time and funds.

We recommend that citrus packhouses move to a rotating high pressure washing system to enhance removal of FRW eggs, and potentially other pests such as red scale.

Further research is warranted to:

- Determine if low rate (~4%) acids + Prospect oil (0.05%) dips can enhance FRW egg removal and reduce egg viability, and to determine the impact of these on fruit quality, sanitizer performance and postharvest decay
- Investigate the efficacy of applying heated dips (50-55°C) with and without low rates of acids + Prospect oil
- Determine if a fungicide is required for an effective postharvest dip treatment that reduces the risk of viable FRW eggs infesting fruit while maintaining fruit quality.

For further information please contact:

Lisa Jamieson
Plant & Food Research Auckland
Private Bag 92169
Auckland Mail Centre
Auckland 1142
NEW ZEALAND

Tel: +64 9 925 7000
DDI: +64 -9-925 7284
Fax: +64 9 925 7001
Email: lisa.jamieson@plantandfood.co.nz

1 INTRODUCTION

Fuller's rose weevil (FRW, *Naupactus cervinus*) is a quarantine pest in China, Korea and Taiwan and the presence of FRW eggs on Australian citrus is impeding market access growth in these key Asian markets. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs; this has reduced the number of shipments rejected during pre- or post-shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets. New fumigants are being considered for the management of a range of pests, including FRW, but the development of fumigation protocols acceptable to overseas markets is a long-term strategy. In the interim, new approaches are required to increase volumes exported into these important markets. A combination of field-based and postharvest treatments has the potential to provide a systems approach capable of reducing the risk of FRW eggs being present on export citrus, therefore increasing export volumes to FRW-sensitive markets.

There have been significant developments in high pressure washing (HPW) pest removal systems in New Zealand over the last 5-10 years. New HPW systems are removing more difficult-to-remove pests than the old HPWs (Woolf et al. 2014; Rogers et al. unpublished data). These new systems do not rely on random movements of fruit to enable a targeted 'hit'. Instead, they wash each individual fruit for 1-2 s to ensure that the fruit has received full coverage. Three high pressure washing systems are currently being used commercially in New Zealand. One is based on the old style 'descalers' (standard row system), with rows of nozzles above a roller bed of fruit (Honiball et al. 1979; Jamieson et al. 2010; Woolf et al. 2009). This standard row system is similar to the current citrus washers in Australia. However, the use of angled nozzles is being trialled in New Zealand to increase fruit movement under the nozzles (Woolf et al. 2014). For citrus, this could increase the chance of a direct hit to the area of interest (e.g. the calyx of the fruit). The second is a more targeted singulated system with three targeted nozzles (three-nozzle system; McDonald 1999; Jamieson et al. 2000; Whiting et al. 1998a, b). The third is also a singulated rotating nozzle system to achieve coverage (Rogers et al. unpublished data; Woolf et al. 2014).

In September 2013, New Zealand and Australian researchers visited five citrus packhouses in South Australia/North West Victoria that all had HPW systems similar to the standard row system (Woolf et al., 2015). The HPW set-up conditions observed varied in terms of pressure, distance, nozzles and filtration, with no standardisation of operating conditions. The removal of paint was used as a proxy for FRW egg removal and to determine the fruit coverage of the washing. Paint removal efficacy ranged from 35 to 95% depending on packhouse and concentration of the paint applied to oranges.

During November 2013 - May 2014, testing was carried out in New Zealand using the Plant & Food Research (PFR) standard row HPW with vertical nozzles, resulting in high paint removal rates (93-96%). This was probably due to correct set-up and orientation of nozzles, with no blocked nozzles. The angled nozzle system (33°and alternating rows) resulted in greater removal than the vertical (straight down) nozzles did, with paint removal of 97-99.5%). Although the optimised commercial rotating washers were removing over 90% of paint from the button area, this equated only to ≈20% removal of FRW egg rafts. Therefore, removal of paint is a good indication of water impact over a fruit surface, but it does not reflect the numbers of FRW egg batches removed.

In Australia and New Zealand, postharvest dips have been tested to enhance the removal of difficult-to-remove pests and/or to reduce the viability of pests (Rogers et al. unpublished data; Taverner & Bailey 1995b; Taverner & Cunningham 2000; Taverner & Perry 2009). In Australia Prospect, a food-grade oil registered for postharvest treatment of pests on citrus, showed the most potential to enhance removal of FRW eggs. In addition, sodium and calcium hypochlorite at high rates can dissolve FRW egg adhesive, and at low rates, can act as an irritant, causing rapid egg hatch (Baker et al. 2013; Taverner et al. 2007).

Jamieson et al. (2014) reported that dips with Prospect oil tended to increase removal rates using a rotating HPW, from 20 to 46%. Prospect oil also tended to reduce the viability of FRW eggs laid by freshly collected adults, from ≈70% hatch down to ≈30-50% hatch; or for eggs laid by older adults maintained on citrus leaves, egg viability reduced from 10-40% hatch down to 0% hatch (Jamieson et al. 2014).

Food acids were considered after preliminary testing by the United States Department of Agriculture, Agricultural Research Service (USDA - ARS) indicated good mortality of FRW eggs using heated (40°C) mixtures of acetic acid and Spray Aide® (acid surfactant) (Spenser Walse, pers. comm.). The USDA conducted further testing on malic acid, citric acid and lactic acid in 2014.

Hot water dips have been proposed as quarantine treatments for pests on citrus. Gould & McGuire (2000) found a 20 min 49°C hot water dip effective at killing mealybug and other arthropods sheltered under the calyx of limes. Limes were undamaged at 49°C but showed softening and damage at 52°C, suggesting that an effective pest treatment was close to the damage threshold of limes. Jessup et al. (1993) dipped FRW-egg infested Valencia oranges in hot water dips for shorter periods, without obvious fruit damage. However, 7 min 52°C dips resulted in only ~60% mortality of FRW eggs. To date, hot water treatments have not been adopted by citrus packers to control quarantine pests. Attaining high efficacy with shorter dip times and, consequently, reducing the risk of fruit damage, are likely to improve commercial adoption.

Early work using hot water for decay control also found that effective treatments were close to the damage threshold of fruit (Eckert & Eaks 1989). However, short heated fungicide treatments (~30 s) have proven to be effective in controlling postharvest disease (Smilanick et al. 1997; Cabras et al. 1999) and are widely adopted.

It may also be possible to increase insecticidal efficacy by improving penetration of heated water under the calyx. Gould & McGuire (2000) argued that the difficulty in controlling insects was because the water did not penetrate under the calyx, leading to slower indirect heating. Prospect should penetrate more easily under the calyx, allowing faster heat transfer and providing some direct toxicity to the eggs (Taverner 1999). USDA-ARS work indicated good mortality against FRW eggs using heated food acid dips, with a surfactant.

One approach is to pre-treat field bins of harvested oranges with food acid and Prospect dips to assist the removal FRW eggs before high pressure washing. The treatment also aims to reduce egg hatch. However, there is a risk that unsanitised dips will result in higher decay rates (Taverner & Bailey 1995a). Although FRW control is the primary focus, it is important that any dip treatment does not compromise postharvest disease control.

Chlorine-releasing compounds, such as sodium and calcium hypochlorite, are commonly used to reduce microbes in water but are most active in mildly alkaline conditions (Suslow 2001). Peracetic acid (PAA) is used to sanitise water in acidic conditions (Mehmet 2004). Various chemicals can be combined in water, but not all combinations are compatible. Kanitis et al. (2008) assessed the stability of various sanitisers and the efficacy of a range of postharvest fungicides to provide effective combinations for use in citrus packing lines. A similar approach can be attempted to optimise combinations of food acids, Prospect and sanitisers.

This report outlines further research conducted into the removal and viability of FRW egg rafts treated with a range of postharvest dips, investigated in New Zealand. Results from trials in Australia testing heated dips using food acids and Prospect for the control of FRW eggs using exposed eggs and infested fruit (eggs under calyx) are also reported. The effects of food acids and Prospect on the performance of sanitisers and impact of postharvest decay were also tested.

2 AIMS

- To determine whether selected pre-HPW dips using food acids and Prospect oil can enhance FRW egg removal rates by HPW and/or reduce FRW egg viability
- To compare the efficacy of heated dips using food acids and Prospect oil with ambient temperature dips
- To determine the potential effects of dip compounds on the performance of sanitisers and postharvest decay

3 MATERIALS AND METHODS

3.1 Comparison of different postharvest dips to enhance removal or reduce viability of Fuller's rose weevil eggs – trials in New Zealand

3.1.1 Fuller's rose weevil collection, maintenance and egg lay on wax paper or fruit

Fuller's rose weevil (FRW) adults (Figure 1a) were collected from kiwifruit and apple orchards in Kerikeri, Te Puke and Motueka from November 2014 to April 2015. FRW adults were collected either by beating trees, collecting any fallen adults from white sheets beneath the tree, or by placing emergence traps around the trunk of the trees/vines to collect newly emerged adults moving from the soil into the plant canopy. Adults were sent to PFR Auckland and maintained on unsprayed citrus leaves in large plastic 'fish' bins (60 x 38 x 23 cm; Figure 1b) as described by Graeme Clare (PFR, unpublished data) at 20°C, 16:8 light:dark cycle. A small vial of water with a cottonwool wick was placed in each bin to provide moisture. The leaves and water vials were held above the base of the bin on a metal platform to allow airflow and to ensure any FRW frass accumulated in the base of the bin rather than on the leaves. Fresh leaves were added twice weekly and all live leaf material and FRW adults were transferred to a clean bin once a week. The amount of leaf material or number of vials of water was increased or decreased, depending on the number of FRW in each bin, up to a maximum of 150 adults per bin. Bins were sealed by placing double-sided tape around the top edge and attaching a section of fine mesh fabric over the top of the bin.

To obtain FRW egg batches on oranges, adults were placed in ventilated cages attached to the button end of an orange (Figure 1c) for three days and then removed and returned to a bin containing citrus leaves. Oranges with eggs (Figure 1d) present were stored at 5°C for 7 -14 days before being treated and assessed for egg removal. Egg rafts on oranges for viability tests were also stored at 5°C for 7-14 days before treatment. To obtain eggs on wax paper for viability testing of dips, folded wax paper was placed within the FRW rearing cages, amongst the citrus leaves, for three days. After three days, the wax papers were removed and any with egg batches were placed at 11°C for 7-14 days before being treated. Any eggs, on either fruit or wax paper that was more than 14 days old, were discarded.

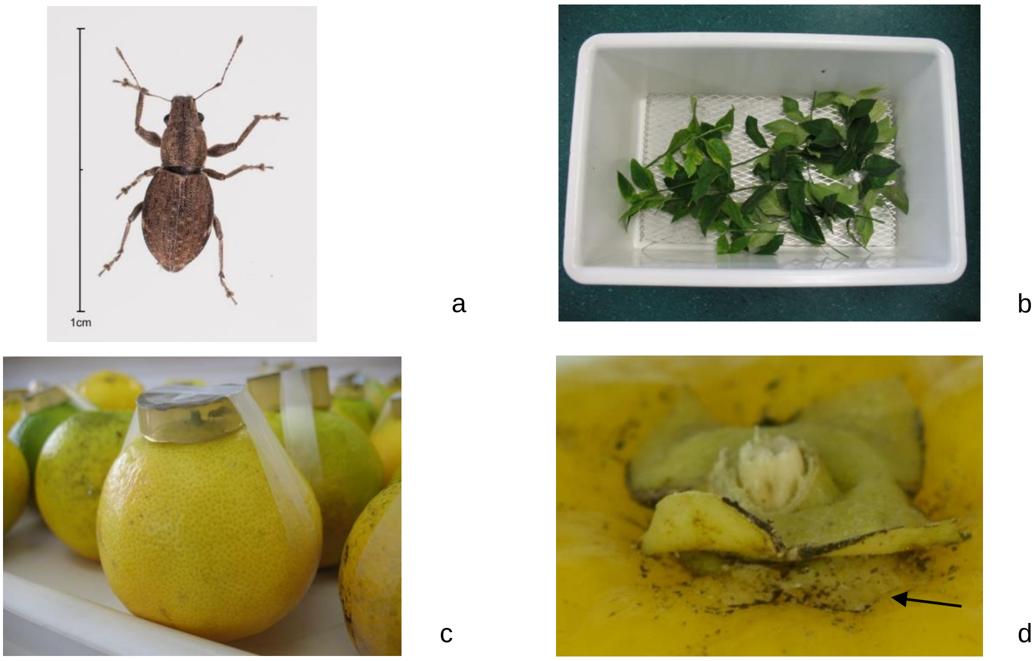

Figure 1: Fuller's rose weevil adult (a). Rearing container with citrus leaves on metal grid (b). Fuller's rose weevil adult caged onto the button/stem end of orange (c). Fuller's rose weevil eggs under the calyx of an orange (d).

3.1.2 Postharvest dipping and high pressure washing

Dipping and high pressure washing (HPW) trials were conducted using either New Zealand or imported USA navel oranges that were exposed to FRW adults for egg laying, as mentioned above. The dipping component consisted of a 5 L solution of each treatment mentioned in Table 1, poured into a 20 L bucket. For treatment, 1-7 infested oranges were dipped and slightly agitated in the solution for 1 min and then left in wire trays to drain/dry for 24 h before being passed over either the standard row or rotating nozzle HPW machines. Fruit in Treatments 1, 2 and 7 (rinse) were dipped and agitated in the solution for 1 min and then rinsed in 5 L of water for 1 min and then immediately passed over the standard row or rotating HPW machines. Dip, rinse and HPW treatments were used to minimise fruit quality issues that might occur with lactic and malic acids left on the fruit for 24 h.

To determine the effect of dipping alone on egg viability on fruit, egg-infested fruit (3-6 replicates of 6-12 infested oranges) were dipped with treatments listed in Table 1 and as described above and were not passed over a HPW system.

Table 1: Details of dip treatments to control Fuller's rose weevil eggs on citrus, including concentrations of chemicals and time between dips and high pressure washing.

Treatment #	Postharvest dip combinations and concentrations	Time (h) between dipping and high pressure washing
1	10% malic acid + 3% Prospect® oil + 0.02% NaClO	24
2	10% lactic acid + 3% Prospect oil + 0.02% NaClO	24
3	3% Prospect oil + 0.02% NaClO	24
4	10% malic acid + 0.02% NaClO	24
5	10% lactic acid + 0.02% NaClO	24
6	0.02% NaClO	24
7	1% lactic acid + 0.5% Prospect oil + 0.02% NaClO	24
1 + rinse	10% malic acid + 3% Prospect oil + 0.02% NaClO	0
2 + rinse	10% lactic acid + 3% Prospect oil + 0.02% NaClO	0
7 + rinse	1% lactic acid + 0.5% Prospect oil + 0.02% NaClO	0

Infested oranges previously treated with a postharvest dip were passed over either the experimental standard row (Figure 2) or rotating (Figure 3) HPW machines. The standard row system had eight rows of five or six nozzles per row alternating over a brush bed (nozzle height 150 mm pointed straight down), operating at a pressure of 120 psi. Oranges were under the nozzles for approximately 15 s. For the rotating system, fruit were singulated and passed under a rotating wand for 1-2 s twice. The wand had six nozzles (nozzle distance 110 mm) and water pressure was set at 300 psi with a hold-down single nozzle situated just before the rotating wand.

Figure 2: The experimental high pressure washing standard row system at Plant & Food Research, Mt Albert.

Figure 3: The experimental high pressure washing rotating system at Plant & Food Research, Mt Albert.

After treatment, fruit were dried at ambient temperatures for 24 h before being assessed for removal of egg rafts. Fruit numbers per replicate varied from 4 to 33 (average 15 fruit) during the trial period because of variability in the FRW egg-laying rates on the fruit, which declined as the FRW adults aged. Removal of eggs from fruit exposed to a postharvest dip before HPW treatment was compared with removal of eggs from fruit exposed to a water dip before HPW treatment, and with removal of eggs from fruit exposed to a HPW treatment only. There were 'air' and 'water' controls. There were three replicates of all treatments and controls.

3.1.3 Viability of Fuller's rose weevil eggs after dipping and high pressure washing

Egg rafts remaining on fruit after high pressure washing and eggs from fruit that were dipped and not passed over a HPW system were removed from the fruit and placed within labelled Petri dishes. Dishes were sealed using Parafilm® (Pechiney plastic packaging, Menasha, USA) closed and placed at 20°C, 16:8 light:dark. Dishes were checked on a weekly basis and any hatched larvae counted and removed. After 32 days, any remaining eggs were placed in a solution of 0.1% sodium hypochlorite for 10 min, then triple rinsed with water to encourage hatching. After drying, egg rafts were returned to Petri dishes and sealed with Parafilm. Dishes were checked weekly and any hatched larvae counted and removed for another 4 weeks, at which time a final count of any unhatched eggs was made.

3.1.4 Fruit quality trial

Because of the high rate of skin blemish (pitting) with both 10% lactic and 10% malic acids after 24 h drying time before HPW (Figure 4), a small fruit quality trial was conducted with oranges with no FRW eggs. The aim was to minimise skin blemish by reducing the time between dipping and HPW and adding a rinse after the postharvest dip. Percentages of malic and lactic acid (10%), Prospect oil (3%) and NaClO (0.02%) were the same as in Treatments 1 and 2 in

Table 1, and all treatments were passed over the rotating washer at 300 psi. All dips were for 1 min with agitation. One group of 15 oranges was dipped either malic or lactic acid, left for 1 h and then passed through the HPW machine. Another group of 15 oranges was dipped and then passed through the HPW machine a few minutes after dipping. The last group of 15 oranges were dipped and rinsed and then passed through the HPW machine a few minutes after dipping. Fruit were stored at 5°C for 20 days and then assessed using a rating scale of 0 – 3 with 0 = No blemish, 1 = slight blemish, 2 = moderate blemish and 3 = severe blemish. Blemish scores of 0 and 1 were classed as acceptable while scores of 2 and 3 were unacceptable.

A

B

Figure 4: Navel oranges dipped for 1 min in 10% malic acid (A) or lactic acid (B) + 3% Prospect® oil + 0.02% NaClO, then left to dry for 24 h and then high pressure washed with two passes on the rotating washer set at 300 psi. This damage is rated as severe blemish (rating = 3).

3.1.5 Dipping of eggs laid on wax paper

Two trials were conducted using FRW eggs laid on wax paper. The first trial examined the effect of the treatments listed in Table 1 on egg viability.

Fruit quality issues were encountered after the 10% malic and 10% lactic acid 1 minute dips, therefore a second trial using FRW eggs on wax paper was carried out to determine the effect of lower concentrations (1 or 4%) of malic and lactic acid 1 minute dips on FRW egg viability. The efficacy of dips using lower rates of malic and lactic acid against FRW eggs was also compared with the efficacy of citric and acetic acid 1 minute dips at the same low rates (1 & 4%).

In both the trials, prior to treatment, FRW eggs on wax paper were removed from 11°C and single batches of eggs were cut out from the sheets of wax paper (Figure 5). Between 5 and10 batches were assigned to each treatment and placed within a vented container (Figure 6). Vented containers had mesh both at the base and the lid, which allowed for the flow of liquid through the container.

Postharvest dips were mixed in a 1.5 L container and the mesh container containing the FRW eggs was dipped and agitated in the solution for 1 min. Eggs were then removed from the container and left to dry for c. 1 h before placing each treated egg batch into a separate Petri dish and sealing with Parafilm.

For the treatments with a rinse after dipping, containers with egg batches were drained of all liquid after the postharvest dip treatment and then immediately dipped and agitated for 1 min in water, after which time the eggs were removed and dried as described above. In the low acid rate trial, eggs on wax paper were not rinsed immediately after dipping.

Air controls remained on the bench at ambient temperature. Water controls were dipped for 1 min in 1.5 L of ambient tap water.

After postharvest dipping, the viability of egg rafts laid on wax paper were treated and assessed in the same way as described in Section 3.1.3.

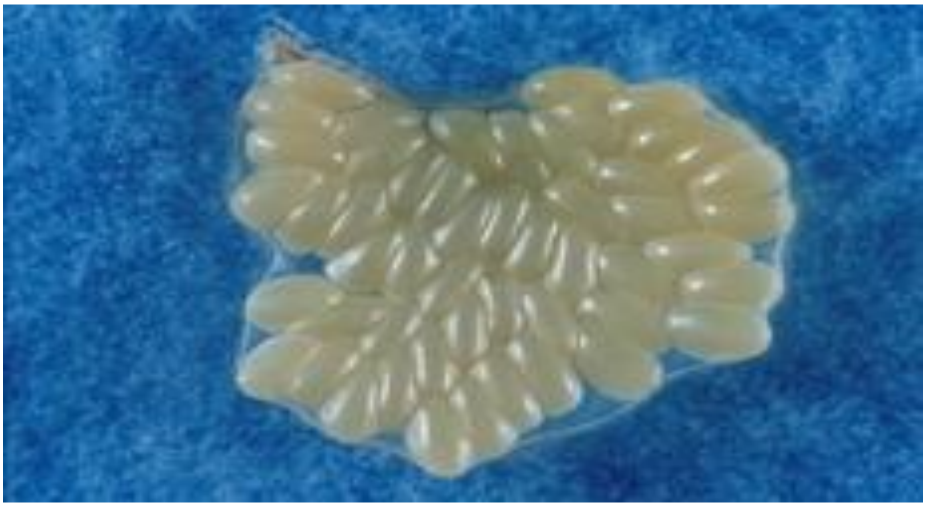

Figure 5: Fuller's rose weevil eggs on wax paper.

Figure 6: Container with mesh at both ends for dipping Fuller's rose weevil eggs on wax paper.

3.1.6 Statistical analysis

Statistical analyses of the high pressure washing removal and viability data were performed with the aims of investigating differences in egg removal and hatch rate among several treatments.

Data were fitted using logistic regression (proc logistic) procedure of the statistical analysis system, SAS version 9.4. The rate of weevil egg removal (removal/total) was analysed based on a binomial model adjusted for over-dispersion (e.g. different total counts among groups). Firth bias correction was added to binomial model to adjust for rare events when analysing hatch rate data (e.g. 0% hatch). *Post hoc* pair-wise differences between fitted means across treatment groups were determined using Fisher's LSD method ($\alpha = 0.05$).

3.2 Comparison of ambient and heated food acid and Prospect dips as treatments for Fuller's rose weevil eggs – trials in Australia

3.2.1 Fuller's rose weevil eggs on citrus fruit

Fuller's rose weevil were collected from citrus orchards in Riverland, South Australia. Adults were held in Insect tents (Bugdorm 2120, 60 x 60 x 60 cm; Megaview Science, Taiwan) in an insect rearing room (22^{0}C, 60%RH & natural light) containing fresh citrus leaves and 10% honey solution.

Navel oranges selected for infestation had intact calyces with a small space between the sepal tip and rind into which weevils could oviposit. Fruit were immersed for 5 minutes in dilute chlorine dioxide (5 ppm free chlorine) to inhibit fungal growth, then air-dried. Infestation was achieved by inverting small plastic cups (35 mL capacity; Hygienic Lily Ltd (Delisted)) containing one adult weevil over the calyx, and secured with a rubber band. Fruit were inspected after 3 days. Fruit and weevils were replaced as required over a 2-week period. Infested fruit were held at 5^{o}C until required and then evenly distributed among treatments by age.

3.2.2 Fuller's rose weevil eggs on wax paper

Strips of non-stick baking paper (wax paper) were placed in the insect tents with adult weevils. The paper was folded and secured with paper clips to provide crevices for egg laying. Folded papers were removed every 3 days over a 9-day period. Infested sections of paper were placed in Petri dishes and sealed with Parafilm to maintain a high relative humidity. The sealed Petri dishes were held at 5^{o}C until required and then evenly distributed among treatments by age.

3.2.3 Dip bioassays

FRW eggs on wax paper or infested fruit were dipped in ambient (20^{o}C) or heated solutions (40^{o}C) for 30 seconds. The treatments consisted of Prospect (Caltex Australia, Sydney NSW) mixed with calcium hypochlorite (200 ppm free chlorine) and either glacial acetic acid, lactic acid or malic acid (Ace Chemicals, Adelaide SA). The food acids and Prospect concentrations were 1.0% and 0.5% or 4.0% and 1.0% (v/v), respectively. The controls were reverse osmosis (RO) water at ambient or heated to 40^{o}C.

All solutions where mixed vigorously prior to dipping. Egg infested wax paper and fruit were dipped in separate trials:

- Fruit were allowed to air-dry on racks at 20°C for 2-3 h, then placed in a cool room (~3°C) until transport to the packing line for high pressure washing.
- Wax papers were allowed to dry before being placed in Petri dishes and sealed with Parafilm M to maintain a high relative humidity. The sealed Petri dishes were placed in an incubator at 25°C and 90% RH.

For both fruit and wax paper bioassays, each egg mass was assessed weekly until all egg hatching had been completed (approximately 30 days). Assessment involved recording the number of eggs that hatched. At least three replicates were conducted for each chemical concentration.

3.2.4 High pressure washer trials

Fruit infested with FRW eggs dipped as described in the wax paper dip bioassay methods. Infested fruit were washed in a single pass (~15 s) on a commercial high pressure wash system in Waikerie, South Australia. The washed fruit were assessed under a binocular microscope. Egg masses were counted after removing calyces and compared with pre-counts. Subsequently, excised egg masses were stored and assessed as described in the dip bioassay methods. The packing line trials were not replicated.

3.3 Evaluating decay control and sanitiser compatibility with food acids and Prospect (Australia)

3.3.1 Products

The food acids, glacial acetic acid, D,L-malic acid and lactic acid were supplied by Ace Chemical Company, South Australia, Australia. The sanitisers used were sodium hypochlorite (12.5% sodium hypochlorite w/v solution, Ajax finechem Pty, NSW, Australia), R70 (680 g/kg chlorine as calcium hypochlorite, Pool Resources Pty Ltd, NSW, Australia) and Tsunami®-On-Farm Biocide (110 g/L hydrogen peroxide and 160 g/L peroxyacetic acid; Ecolab Pty Ltd, South Australia, Australia). Prospect, a food-grade postharvest oil, was supplied by Caltex Australia Pty Ltd.

3.3.2 Evaluating sanitiser compatibility with food acids and Prospect

The compatibility of sanitisers was evaluated by measuring concentration over a period of 24 hours. Various mixtures of sanitiser and food acids, with and without Prospect, were compared with sanitiser alone. The sanitiser rates were adjusted to 200 ppm chlorine or 80 ppm peracetic acid (PAA) for the chlorine products and Tsunami, respectively. Chlorine was measured using chlorine test papers (code 4250-BJ-100, La Motte, Maryland, USA) and PAA using iodide test strips (Insta-Test, La Motte, Maryland, USA). The Prospect rate for most of the sanitiser trials was 3% (v/v) but was reduced to 0.5% (v/v) for a single compatibility experiment with 1% food acid. The food acids were evaluated at 1%, 4% and 10% for acetic (v/v), malic (wt/v) and lactic acid (v/v).

Separate solutions of sanitiser, food acid and Prospect were prepared in 500 mL of reverse osmosis (RO) water (pH 6.0-6.8). The solutions were combined in a 2-L glass beaker and mixed vigorously with a glass rod to achieve the desired concentration of each active ingredient. The concentration of sanitiser was measured immediately on mixing and at 60 s, 5 min, 1 h, 4 h and 24 h.

3.3.3 Evaluating decay control with sanitisers, food acids and Prospect

Green mould (*Penicillium digitatum)* was isolated from oranges sourced from Riverland, South Australia. Isolates were cultured on potato dextrose agar (PDA) in Petri dishes at 20˚C, for 3 to 5 days before use in trials. A sterile paintbrush and RO water mixed with 1-2 drops of Triton X™ were used to remove conidia from the medium surface of the Petri dish. Inoculum suspensions were then passed through nylon cloth to remove large fragments of hyphae. The spore suspension was adjusted to the required concentration using a Neubauer haemocytometer. Fruit were inoculated with a 1×10^6 conidia/ml *P. digitatum* suspension.

Untreated Navel oranges were obtained from a commercial citrus packing shed in the Riverland region of South Australia and stored under coolstore conditions (5°C, 75%RH). Fruit were washed with 5% (v/v) Fruit and Vegetable Kleen® 451 (Decco, Monrovia, California) and then sanitised in sodium hypochlorite (500 ppm free chlorine) for 3 min. Oranges were allowed to air dry prior to being randomised into 5 orange treatment groups. Each orange was submerged in the spore suspension and inoculated 10 times around the equator of the fruit using a nail to pierce 3 mm into the albedo of the fruit (nail diameter 2 mm); a method adapted from Eckert & Brown (1986). Inoculation fruit were left for 2 h before dipping. Fruit were dipped for 30 s in their assigned treatment and allowed to air dry on racks, including experimental controls, which were dipped in RO (reverse osmosis) water. After treating, fruit were placed in plastic bags to ensure high humidity and held in an incubator at 20°C. Fruit inoculation sites were assessed for disease incidence 3 days and 7 days after dipping.

Mixtures of sanitiser and food acids, with and without Prospect, were compared with sanitiser alone. The Prospect rate was 0.5% and 1% (v/v), when mixed with 1% and 4% food acid, respectively. The food acids were evaluated at 1% and 4% for acetic (v/v), malic (wt/v) and lactic acid (v/v). Calcium hypochlorite was adjusted to 200 ppm free chlorine.

In addition, a fungicide was added to one treatment per trial. Imazalil was added to acetic acid (4%), Prospect (1%) and calcium hypochlorite (200 ppm free chlorine). Thiabendazole was added to malic acid (4%) Prospect (1%) and calcium hypochlorite (200 ppm free chlorine). The fungicides (a.i. rate used) (Product; Supplier) were formulated products of imazalil (500 ppm) (Fungaflor® 500EC; Janssen-Cilag Pty Ltd, NSW, Australia) and thiabendazole (1000 ppm) (Tecto SC; Scholar, Syngenta Crop Protection Pty Ltd, NSW, Australia).

3.3.4 Statistical analysis

Statistix 7 (2000) software was used for analysis of variance (ANOVA) with replication. Percentage data were angular transformed before analysis. The formula used was: T value = 180/Pi x (arcsin(sqrt(value/1000))). Mean separation was determined using Tukey's (HSD) procedure ($\alpha = 0.05$).

4 RESULTS

4.1 Comparison of different postharvest dips to enhance removal or reduce viability of Fuller's rose weevil eggs – trials in NZ

4.1.1 Dips + HPW removal and viability of remaining eggs

Overall egg removal was higher after using the rotating HPW system than the standard row HPW system (Figure 7). Using a postharvest dip with 10% lactic acid and 3% Prospect (Treatment 2) and leaving for 24 h followed by HPW with the rotating system resulted in the highest egg removal rates, of 91% (Figure 7). Mixing Prospect oil with lactic acid or malic acid (Treatments 1 and 2) tended to enhance egg removal with HPW compared with using lactic or malic acid alone (Treatments 4 and 5) or Prospect oil alone (Treatment 3), although this was not always a statistically significant improvement. The egg removal rate was reduced when the rates of lactic acid and Prospect oil were reduced to 1% and 0.05%, respectively (Treatment 7). The removal rate of eggs was also lower when fruit were dipped and rinsed and immediately passed over the rotating HPW system (Treatments 1, 2, 7 rinse) rather than dipped and left for 24 h before HPW (Treatments 1, 2, 7).

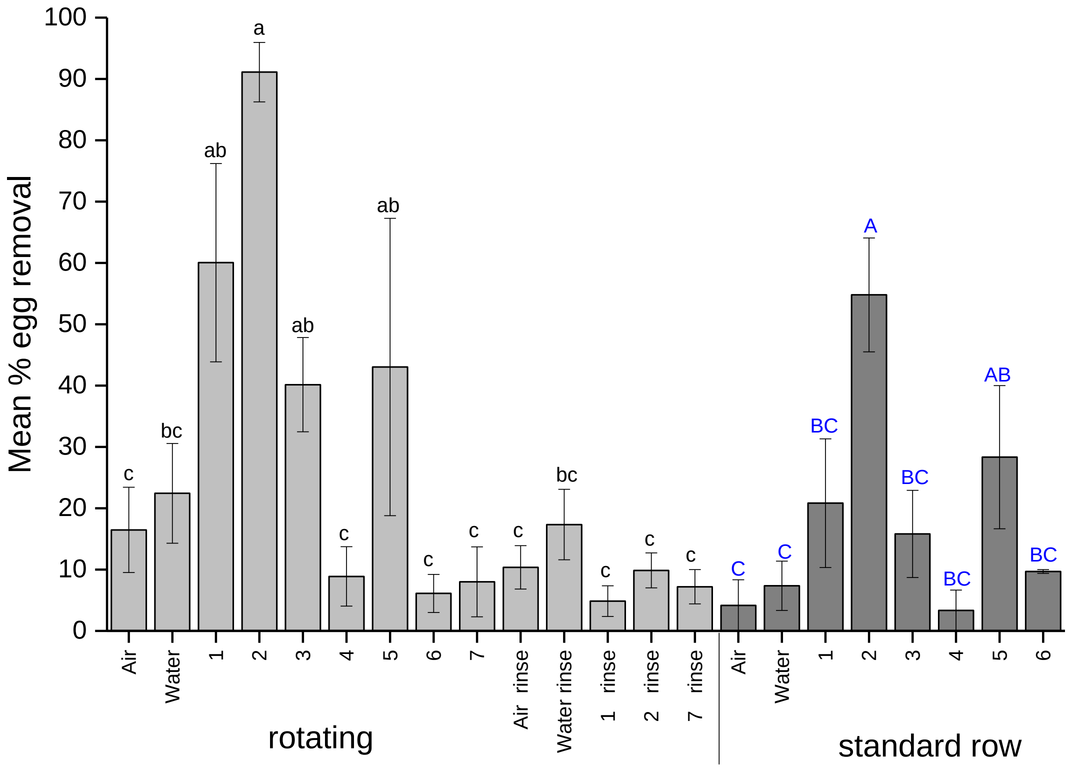

Figure 7: Mean percentage of Fuller's rose weevil egg raft removal from oranges using either the rotating or standard row high pressure washers. Similar letters indicate no significant difference between treatments (P≥0.05). Treatments were compared within washer group only. Treatment key: (1) 10% malic acid + 3% Prospect® oil + 0.02% NaClO, (2) 10% lactic acid + 3% Prospect oil + 0.02% NaClO, (3) 3% Prospect ºil + 0.02% NaClO, (4) 10% malic acid + 0.02% NaClO, (5) 10% lactic acid + 0.02% NaClO, (6) 0.02% NaClO, (7) 1% lactic acid, 0.5% Prospect oil, 0.02% NaClO. Rinse = treatments that were rinsed immediately after postharvest dip.

Of the egg rafts that remained on the fruit after washing, eggs treated with dips containing 10% malic acid + 3% Prospect oil (Treatment 1), 10% lactic acid + Prospect oil (Treatment 2) or 3% Prospect oil with no acid (Treatment 3), resulted in reduced hatched rates. However, only rates in Treatments 1 and 2 (rotating HPW) were significantly different from those in the air and water controls, and the rate in Treatment 2 (standard HPW) was significantly different from that in the water control (Figure 8; Table 2). Dipping with 10% lactic acid or malic + 3% Prospect oil and leaving for 24 h before HPW using rotating HPW reduced egg viability (Treatments 1 and 2) compared with dipping with these treatments, rinsing and immediately HPW (Treatments 1 and 2 rinse).

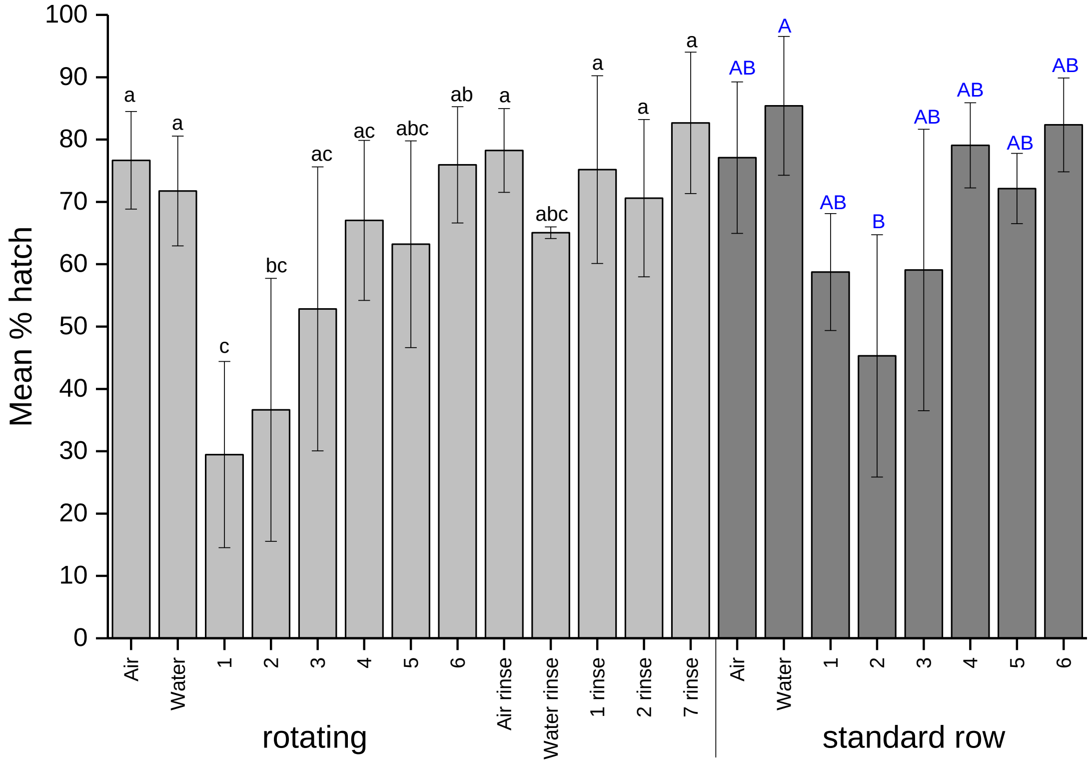

Figure 8: The mean percentage hatch of Fuller's rose weevil eggs on citrus fruit that were dipped in a range of postharvest treatments and passed through a high pressure washer. Similar letters indicate no significant difference between treatments (P≥0.05). Treatments were compared within washer group only. Treatment key: (1) 10% malic acid + 3% Prospect® oil + 0.02% NaClO, (2) 10% lactic acid + 3% Prospect oil + 0.02% NaClO, (3) 3% Prospect oil + 0.02% NaClO, (4) 10% malic acid + 0.02% NaClO, (5) 10% lactic acid + 0.02% NaClO, (6) 0.02% NaClO, (7) 1% lactic acid, 0.5% Prospect oil, 0.02% NaClO. Rinse = treatments that were rinsed immediately after postharvest dip.

In terms of the overall risk reduction of FRW eggs on fruit treated with a postharvest dip followed by HPW, only 15% or 5% of the original numbers of FRW eggs remained and survived after the 10% lactic acid 3% Prospect oil dip followed by the standard or rotating HPW system, respectively (Table 2).

Table 2: The estimated number of Fuller's rose weevil eggs prior to treatment and the resulting percentage hatch after high pressure washing (HPW) treatment. Treatment key: (1) 10% malic acid + 3% Prospect® oil + 0.02% NaClO, (2) 10% lactic acid + 3% Prospect oil + 0.02% NaClO, (3) 3% Prospect oil + 0.02% NaClO, (4) 10% malic acid + 0.02% NaClO, (5) 10% lactic acid + 0.02% NaClO, (6) 0.02% NaClO, (7) 1% lactic acid, 0.5% Prospect oil, 0.02% NaClO.

Washer	Treatment	Estimated number of eggs prior to treatment*	Total number of eggs remaining after HPW treatment	Total larvae hatched	% survival after HPW and dip[1]
Standard row	Air	1575	1313	1156	73.40
	Water	1713	1497	1249	72.91
	1	884	547	334	37.78
	2	912	346	142	15.57
	3	912	788	502	55.06
	4	857	625	518	60.48
	5	884	470	356	40.26
	6	857	488	422	49.27
Rotating	Air	3233	958	796	24.62
	Water	3343	713	601	17.98
	1	967	322	123	12.72
	2	912	116	48	5.26
	3	912	395	255	27.97
	4	884	501	383	43.32
	5	857	322	264	30.82
	6	857	567	461	53.82
	Air 0 hrs	2128	1214	1000	47.00
	Water 0hrs	1188	463	290	24.41
	1 + rinse	1133	981	749	66.12
	2 + rinse	1160	834	587	50.58
	7 + rinse	2708	730	640	23.64

*Based on the average number of eggs in counts of 100 egg batches
[1] As a percentage of the estimated number of eggs prior to treatment

4.1.2 Viability of eggs on fruit treated with a postharvest dip (no HPW)

Of the egg rafts that had been dipped with no rinse and no HPW, those dipped in 10% malic acid + 3% Prospect oil (Treatment 1) had a significantly lower rate of hatch than those dipped in all other treatments apart from Treatment 2 containing 10% lactic + 3% Prospect oil (Figure 9). Eggs exposed to malic acid + Prospect oil or lactic acid + Prospect oil dips (without rinse) had significantly lower hatch rate than eggs exposed to either air or water (Figure 9). Those eggs on fruit treated with the malic or lactic acid + Prospect oil dips and rinsed immediately afterwards had similar hatch rates to untreated or water-dipped eggs.

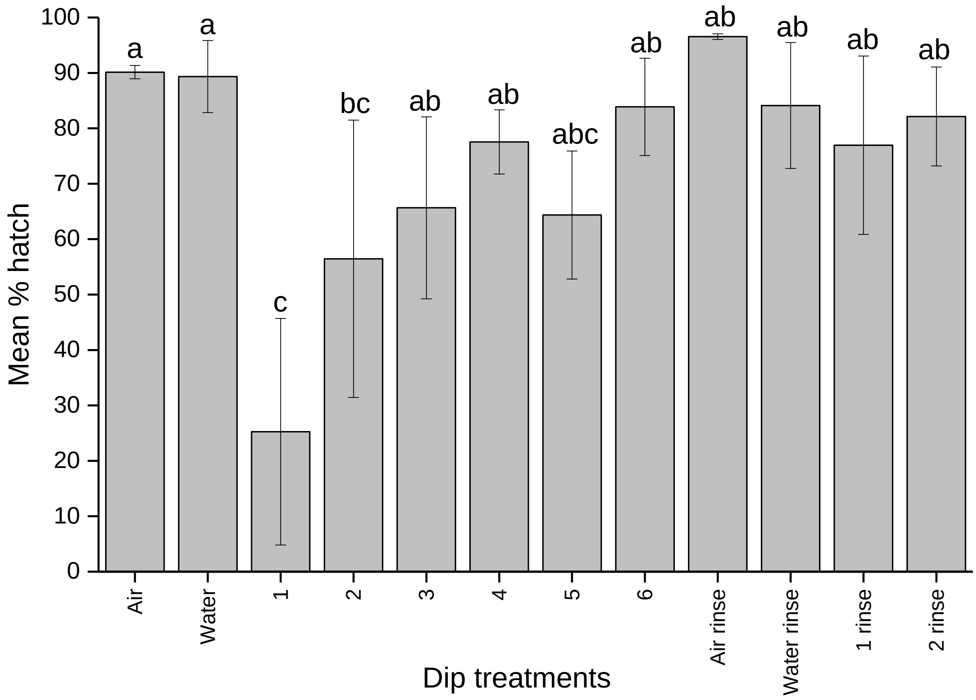

Figure 9: The mean percentage hatch of Fuller's rose weevil eggs on citrus fruit that were dipped in a range of postharvest treatments. Similar letters indicate no significant difference between treatments (P≥0.05). Treatment key: (1) 10% malic acid + 3% Prospect® oil + 0.02% NaClO, (2) 10% lactic acid + 3% Prospect oil + 0.02% NaClO, (3) 3% Prospect oil + 0.02% NaClO, (4) 10% malic acid + 0.02% NaClO, (5) 10% lactic acid + 0.02% NaClO, (6) 0.02% NaClO, (7) 1% lactic acid, 0.5% Prospect oil, 0.02% NaClO Rinse = treatments that were rinsed immediately after dipping treatment.

4.1.3 Viability of FRW eggs on wax paper treated with postharvest dips

Egg rafts laid on wax paper had overall lower hatch rates than those on fruit (Figures 9 and 10). This is probably because the trials on wax paper were carried out after the trials on oranges, and thus the FRW adults were older. Eggs dipped in 10% malic acid + 3% Prospect oil or 10% lactic acid + 3% Prospect oil or 3% Prospect oil alone (Treatments 1, 2 and 3) had lower hatch rates than controls. Eggs dipped in treatments 10% malic acid + 3% Prospect oil or 10% lactic acid + 3% Prospect oil or 1% lactic acid + 3% Prospect oil and then immediately rinsed in water for 1 min (Treatment 1 + rinse, Treatment 2 + rinse, Treatment 7 + rinse), had significantly lower hatch rates than air and water controls (Figure 10).

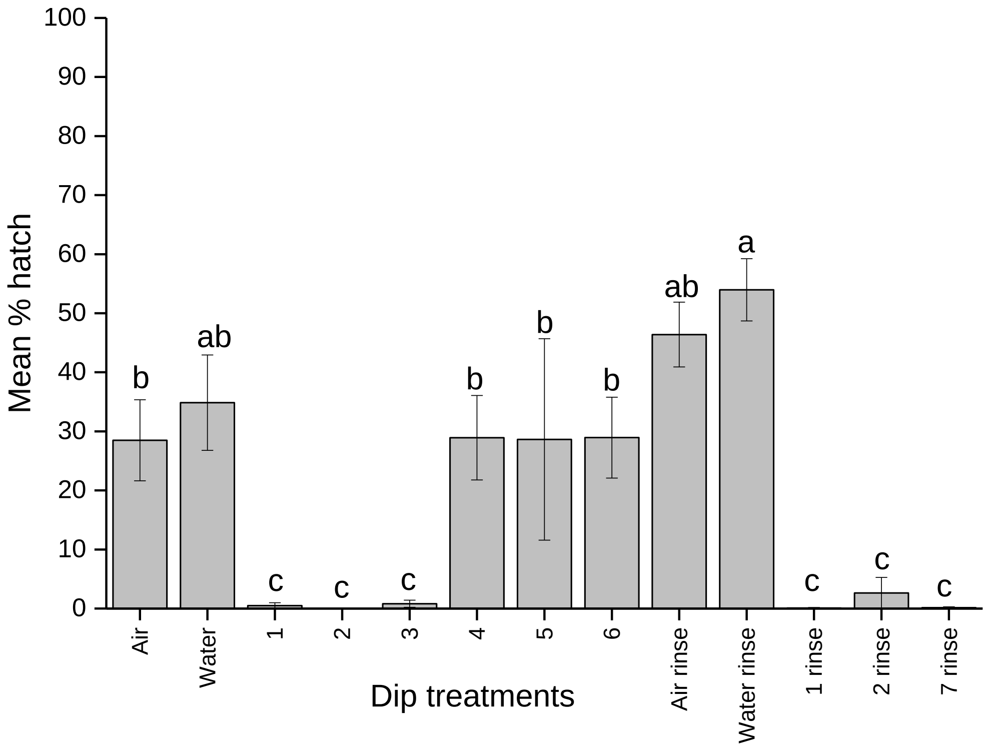

Figure 10: The mean percentage hatch of Fuller's rose weevil eggs on wax paper that were dipped in a range of postharvest treatments. Similar letters indicate no significant difference between treatments (P≥0.05). Treatment key: (1) 10% malic acid + 3% Prospect® oil + 0.02% NaClO, (2) 10% lactic acid + 3% Prospect oil + 0.02% NaClO, (3) 3% Prospect oil + 0.02% NaClO, (4) 10% malic acid + 0.02% NaClO, (5) 10% lactic acid + 0.02% NaClO, (6) 0.02% NaClO, (7) 1% lactic acid, 0.5% Prospect oil, 0.02% NaClO.

4.1.4 Viability of FRW eggs treated with a range of acids at 1 or 4% for 1 minute

All FRW eggs treated with acids at 1% or 4% resulted in significantly lower egg hatch compared with that in the controls (Figure 11).

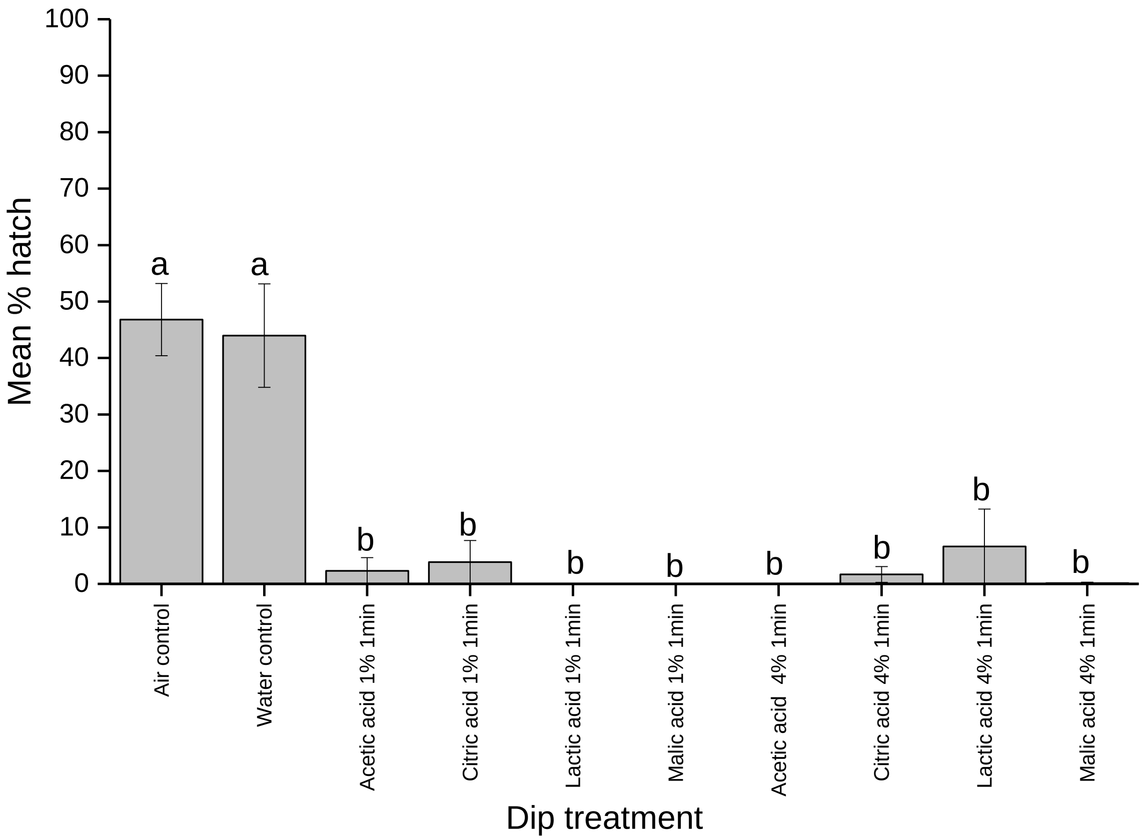

Figure 11: The mean percentage hatch of Fuller's rose weevil eggs on wax paper that were dipped in a range of acids. Similar letters indicate no significant difference between treatments (P≥0.05).

4.1.5 Fruit Quality

Fruit quality data collected on a small number of fruit (13-15 per treatment) indicated that 10% malic acid and 10% lactic acid dips caused an undesirable skin blemish in the form of pitting.

Generally, unacceptability decreased as the duration between dipping and HPW reduced from 1 h to 0 h (Table 3). The addition of a rinse for the 0 h dip before washing only reduced unacceptability in 10% malic acid + 3% Prospect oil + 0.02% NaClO from 28.6 to 7.7% but slightly increased unacceptability in 10% lactic acid & 3 % Prospect oil + 0.02% NaClO from 33.3 to 38.5%. The inclusion of Prospect oil in the no-rinse dips appeared to increase the proportion of unacceptability except for 1 h 10% lactic acid+ 0.02% NaClO, with 73.3%, compared with 10% lactic acid & 3% Prospect oil + 0.02% NaClO, with 35.7%.

Table 3. Percentage of unacceptably blemished Navel oranges after being treated with a range of dip solutions for 1 min, then either being left for 0 (± rinse) or 1 h to dry before being high pressure washed (HPW) with two passes over the rotating washer set at 300 psi. Fruit were then stored for 20 days at 5°C before being assessed.

Postharvest dip treatment	Rinse	Time between dip & HPW (h)	Average skin blemish score	% Incidence	% Unacceptable
Control	N	1	0.2	13.3	6.7
10% lactic acid+ 0.02% NaClO	N	1	1.9	100	73.3
10% lactic acid & 3% Prospect oil + 0.02% NaClO	N	1	1.4	78.6	35.7
10% malic acid + 0.02% NaClO	N	1	0.8	40	26.7
10% malic acid & 3% Prospect oil + 0.02% NaClO	N	1	1.2	60	40
Control	N	0	0.1	14.3	0
10% lactic acid + 0.02% NaClO	N	0	0.7	40	20
10% lactic acid & 3 % Prospect oil + 0.02% NaClO	N	0	1	53.3	33.3
10% malic acid + 0.02% NaClO	N	0	0.5	40	6.7
10% malic acid & 3% Prospect oil + 0.02% NaClO	N	0	1.1	64.3	28.6
Control	Y	0	0.1	7.7	2.6
10% lactic acid + 3% Prospect oil + 0.02% NaClO	Y	0	1.2	61.5	38.5
10% malic acid + 3% Prospect oil + 0.02% NaClO	Y	0	0.5	38.5	7.7

4.2 Comparison of ambient and heated food acid and Prospect dips as treatments for Fuller's rose weevil eggs (Australia)

4.2.1 Wax paper dip bioassays

Exposed FRW eggs were excised from wax paper and dipped in solutions at ambient (20°C) and elevated temperatures (40°C). The mean hatch rate of FRW eggs dipped in ambient water was relatively low (see Tables 4 and 5). Two concentrations of malic acid and Prospect mixtures were assessed; both solutions were sanitised using calcium hypochlorite. The higher acid and Prospect concentrations resulted in low egg survival ($F=105.4$, $P<0.001$) but there were no differences due to temperature ($F=0.35$, $P>0.5$). The lower concentration also significantly reduced the hatch rate ($F=17.3$, $P<0.01$) but there were still no differences due to temperature ($F=0.16$, $P>0.5$).

Table 4: Percentage hatch of Fuller's rose weevil eggs dipped in ambient (20°C) or heated (40°C) solutions of water or a combination of malic acid (4%) + Prospect® (1%) + calcium hypochlorite (200 ppm free chlorine), 30 days after treatment.

Treatment	Mean eggs[x] (±SEM)	Mean hatch (±SEM)	% Hatch[y]
water; 20°C	454 (±36.4)	157 (±26.0)	33.9 a
water; 40°C	468 (±58.4)	156 (±17.1)	34.4 a
4% malic acid + 1% Prospect + calcium hypochlorite; 20°C	377 (±6.3)	8.3 (±5.3)	2.2 b
4% malic acid + 1% Prospect + calcium hypochlorite; 40°C	417 (±25.8)	2.0 (±1.2)	0.4 b

x Mean of 3 replicates (min. 1,000 eggs per treatment)
y Means labelled with similar letters in columns are not significantly different from each other using the least significant difference test, ANOVA on arcsine square root transformed percentage data. $F=35.4$, $p<0.001$.

Table 5: Percentage hatch of Fuller's rose weevil eggs dipped in ambient (20°C) or heated (40°C) solutions of water or a combination of malic acid (1%) + Prospect (0.05%) + calcium hypochlorite (200 ppm free chlorine), 30 days after treatment.

Treatment	Mean eggs[x] (±SEM)	Mean hatch (±SEM)	% Hatch[y]
water;20°C	381 (±38.4)	178 (±24.5)	46.5 a
water; 40°C	406 (±26.6)	187 (±35.2)	45.3 a
1% malic acid + 0.5% Prospect + calcium hypochlorite; 20°C	386 (±38.2)	112 (±20.0)	29.5 b
1% malic acid + 0.5% Prospect + calcium hypochlorite; 40°C	374 (±61.7)	101 (±20.4)	27.7 b

x Mean of 3 replicates (min. 1,000 eggs per treatment)
y Means labelled with similar letters in columns are not significantly different from each other using Tukey's HSD test, ANOVA on angular transformed percentage data. $F=5.83$, $p<0.05$.

4.2.2 Infested fruit dip and wash trials

The high pressure wash system did not remove many egg masses (see Tables 6 and 7). Heated pre-wash dips with 1% food acids with Prospect and calcium hypochlorite did not improve egg mass removal or decrease the egg hatch (Table 6). Subsequent trials were conducted with malic acid, Prospect and calcium hypochlorite mixtures at two different concentrations: 1% malic acid and 0.5% Prospect (Table 7), and 4% malic acid and 1% Prospect (Table 8). Calcium hypochlorite (200 ppm free chlorine) was added to sanitize each mixture.

Egg masses remained largely intact after pressure washing control fruit (water dips). It was observed that some egg masses on fruit dipped in malic acid and Prospect mixtures were dislodged after washing but not removed. The high malic acid and Prospect concentration removed more egg masses than the lower concentration, but overall removal was low (<20% removed). More egg masses were removed from fruit treated with dips at 40°C.

After 30 days, the remaining eggs were assessed for percentage egg hatch. The hatch rate in control fruit was noticeably higher in the second trial, making comparisons between different mixture concentrations more difficult. In both trials, malic acid and Prospect dips reduced the percentage egg hatch compared with that on control fruit (water dips). However, temperature did not appear to influence hatch rate in either trial.

Table 6: Fuller's rose weevil egg mass removal of infested citrus fruit after heated (40°C) dips of water only or Prospect® and calcium hypochlorite (200 ppm free chlorine) with or without 1% food acids, after a single pass on an Australian citrus high pressure washer.

Chemical^x	Dip temperature	# egg masses	# egg mass removed	% egg hatch^y
Water	40°C	32	0	66.6
Malic acid	40°C	32	1	75.3
Lactic acid	40°C	32	0	75.3
Prospect	40°C	30	0	82.5

X - treatment dips include; water only, a mixture of 1% malic acid, 0.5% Prospect and calcium hypochlorite (200 ppm free chorine), a mixture of 1% lactic acid, 0.5% Prospect and calcium hypochlorite (200 ppm free chorine), & 0.5% Prospect and calcium hypochlorite (200 ppm free chorine) only.
Y - min. 300 eggs assessed for hatch per treatment.

Table 7: Fuller's rose weevil egg mass removal of infested citrus fruit after dipping in either water or a 1% malic acid, 0.5% Prospect® and calcium hypochlorite (200 ppm free chlorine) mixture at 20°C or 40°C, after a single pass on an Australian citrus high pressure washer.

Chemical^x	Dip temperature	# egg masses	# egg mass removed	% egg hatch^y
Water	20°C	17	0	80.8
	40°C	20	1	70.4
Malic acid	20°C	20	0	55.0
	40°C	21	3	48.8

X water only & a mixture of 1% malic acid, 0.5% Prospect and calcium hypochlorite (200 ppm free chorine)
Y - min. 200 eggs assessed for hatch per treatment.

Table 8: Fuller's rose weevil egg mass removal of infested citrus fruit after dipping in either water or a 4% malic acid,1% Prospect® and calcium hypochlorite (200 ppm free chlorine) mixture at 20°C or 40°C, after a single pass on an Australian citrus high pressure washer.

Chemical[x]	Dip temperature	# egg masses	# egg mass removed	% egg hatch
Water	20°C	21	0	54.4
	40°C	22	1	46.0
Malic acid	20°C	21	4	33.8
	40°C	17	3	27.7

X water only & a mixture of 4% malic acid, 1% Prospect and calcium hypochlorite (200 ppm free chorine)
Y - min. 200 eggs assessed for hatch per treatment.

4.3 Evaluating decay control and sanitiser compatibility with food acids and Prospect (Australia)

4.3.1 Evaluating sanitiser compatibility with food acids and Prospect

High rates of food acid (10%) and Prospect (3%) resulted in very rapid loss of sanitiser activity. The free chlorine concentration of 10% lactic or malic acid solutions was reduced by 50% after 5 min (Figure 12). The addition of Prospect reduced the chlorine concentration more rapidly.

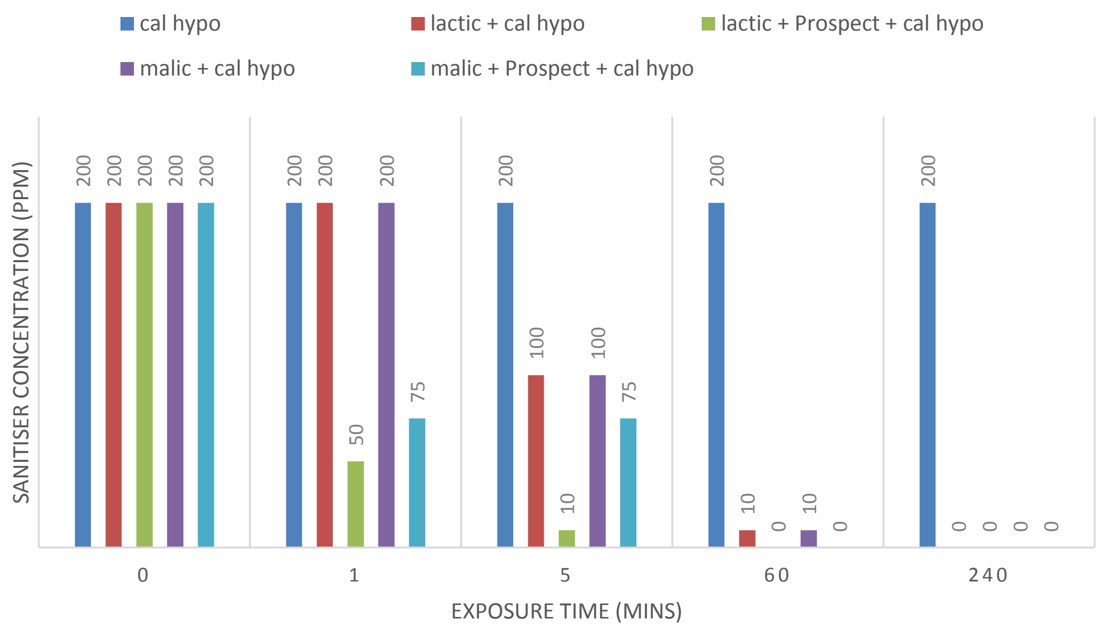

Figure 12: Sanitiser (calcium hypochlorite) concentration of mixed solutions containing 10% lactic acid or 10% malic acid with and without Prospect® (3%), over a 4-hour period.

Lower rates of food acid (4%) improved the stability of free chlorine (200 ppm maintained for 5 min), but the addition of 3% Prospect resulted in much lower chlorine concentrations (Figure 13). Reducing the Prospect concentration (0.5%) improved the chlorine stability, with negligible loss after 5 min and a 50% reduction by 60 min (Figure 14). PAA was more stable with food acids (4%) with or without Prospect (3%) (Figure 15). PAA was very stable in acetic acid mixtures over 4 h.

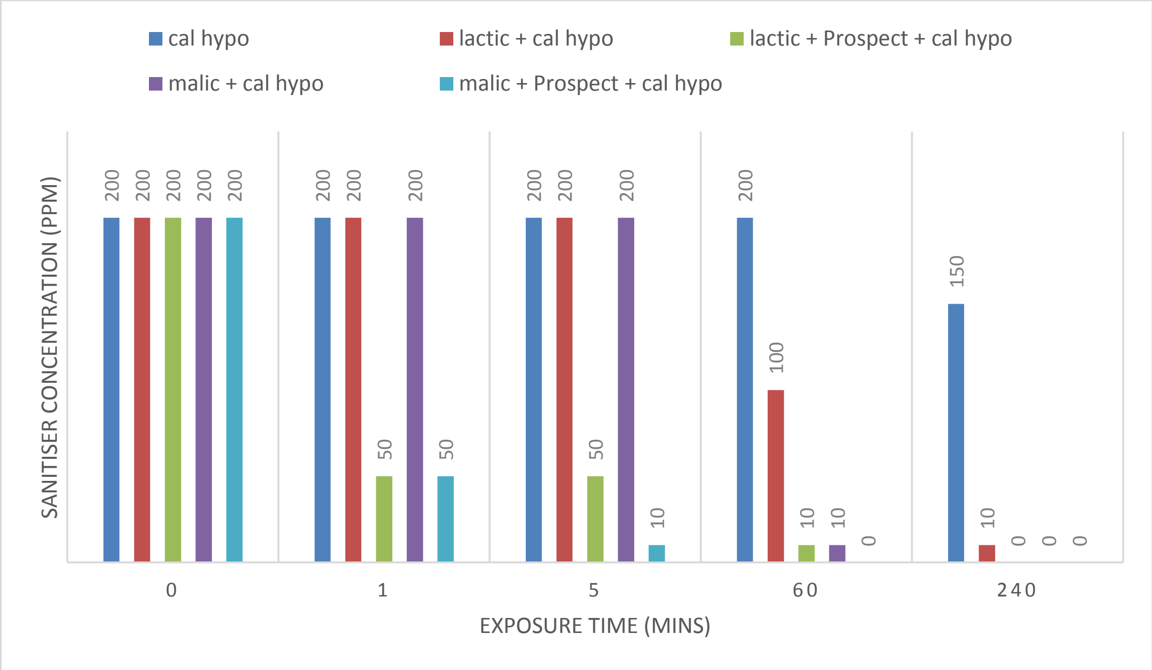

Figure 13: Sanitiser (calcium hypochlorite) concentration of mixed solutions containing 4% lactic acid or 4% malic acid with and without Prospect® (3%), over a 4-h period.

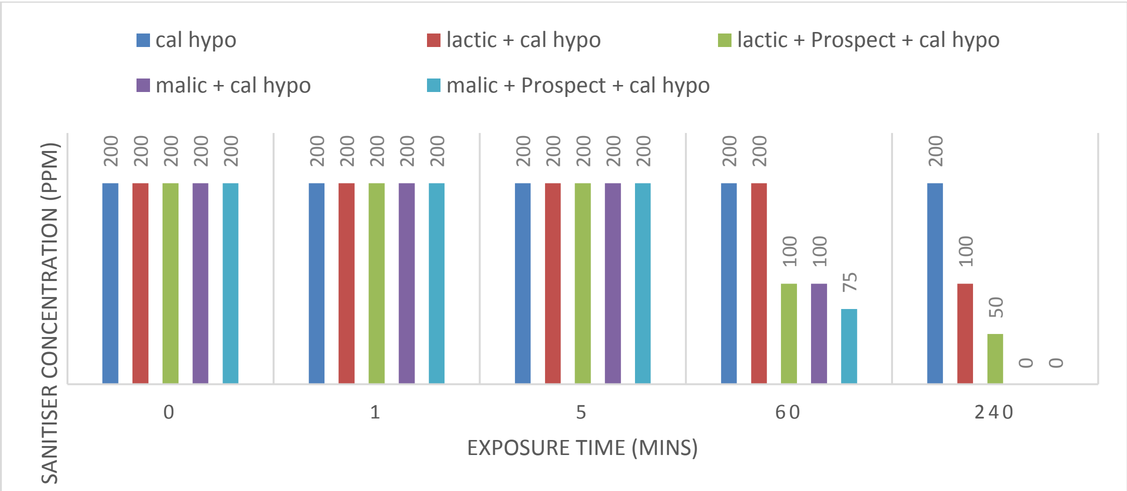

Figure 14: Sanitiser (calcium hypochlorite) concentration of mixed solutions containing 1% lactic acid or 1% malic acid with and without Prospect® (0.5%), over a 4-h period.

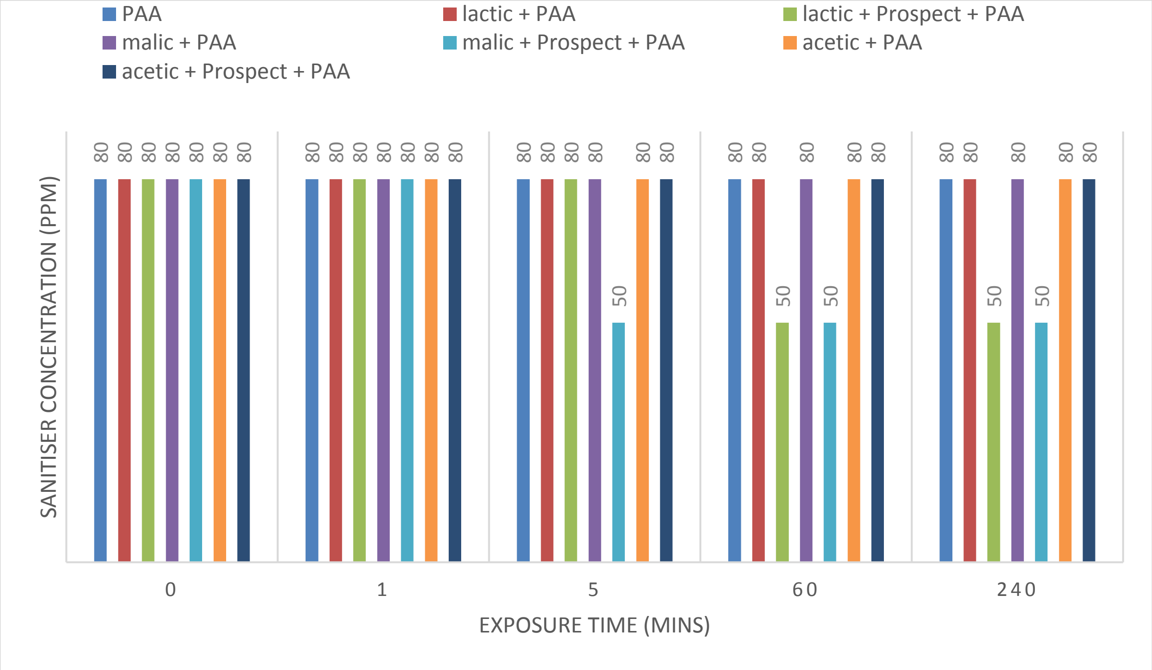

Figure 15: Sanitiser (peracetic acid; PAA) concentration of mixed solutions containing various food acids (4%) with and without Prospect® (3%), over a 4-h period.

4.3.2 Evaluating decay control with sanitisers, food acids and Prospect

Decay was rapid, with high rates of decay in control-treated fruit and 1% food acid-dipped fruit after 3 days at 20°C (Table 9). There were no significant differences in decay between the food acid treatments at 1% with or without Prospect (Table 9). After dipping in 4% food acid (Table 10), decay on oranges was significantly lower in acetic acid-dipped fruit than in malic and lactic acid-dipped fruit (Factorial ANOVA; food acid F=92.5, p<0.001). Presence or absence of Prospect did not influence decay (Factorial ANOVA; Prospect F=1.74, p=0.22). However, fruit in all treatments decayed (100%) after 7 days at 20°C, suggesting that acetic acid dips inhibited fungal growth 3 days after treatment but were not fungicidal 10 days after treatment. Fungicides were also added to a food acid mixture to improve decay control. A mixture of thiabendazole, malic acid, Prospect and calcium hypochlorite resulted in 100% mould control after 7 days. However, a mixture of imazalil, acetic acid, Prospect and calcium hypochlorite resulted in poor mould control (17.5%).

Table 9: Mean mould decay (incidence out of 10 inoculation points) on oranges dipped in various food acids (1%) with and without Prospect® (0.5%), and held 3 days after treatment at 20°C. Solutions sanitised with calcium hypochlorite (200 ppm free chlorine).

Treatment	Prospect	Mean decay (±SEM)[x]
water	-	8.6 (±0.87)
calcium hypochlorite	-	8.2 (±0.66)
lactic acid + calcium hypochlorite	-	5.4 (±1.86)
	+	6.8 (±1.77)
malic acid + calcium hypochlorite	-	9.4 (±0.24)
	+	8.2 (±0.37)
acetic acid + calcium hypochlorite	-	9.6 (±0.24)
	+	7.6 (±0.40)

x Mean incidence of decay out of 10 inoculation points (5 fruit x 10 inoculation points = 50 inoculation points per treatment). Means with same letter are not significantly difference using Tukey's HSD method; one-way ANOVA, F=1.62, p=0.17.

Table 10: Mean mould decay (incidence out of 10 inoculation points) on oranges dipped in various food acids (4%) with and without Prospect® (1%), and held 3 days after treatment at 20°C. Solutions sanitised with calcium hypochlorite (200 ppm free chlorine).

Treatment	Prospect	Mean decay (±SEM)[x]
water	-	8.4 (±0.60) a
calcium hypochlorite	-	7.9 (±0.50) a
lactic acid + calcium hypochlorite	-	8.6 (±0.40) a
	+	6.3 (±1.10) a
malic acid + calcium hypochlorite	-	8.6 (±0.60) a
	+	8.8 (±1.20) a
acetic acid + calcium hypochlorite	-	0.5 (±0.50) b
	+	0.5 (±0.30) b

x Mean incidence of decay of 2 replicates (10 fruit x 10 inoculation points per fruit = 100 inoculation points per treatment). Means with same letter are not significantly difference using Tukey's HSD method; ANOVA, F=30.38, p=0.17.

5 DISCUSSION

Fuller's rose weevil eggs are particularly difficult pests to remove and/or kill, with HPW egg removal results here being the lowest of any pest we have examined to date. The nature of the adults laying eggs under the calyx makes removal a challenge (i.e. the HPW water jets reaching the egg), and this location also protects some of the eggs from dip treatments. However, the aim of this project was to enhance removal of eggs from fruit and/or reduce egg viability, not to provide complete control and we have achieved that firstly by using a new generation rotating washer that enhances from ~5% removal using standard row HPW up to 20% removal of egg batches using the rotating HPW. This increase in egg removal using the rotating washer was consistent with findings last year (Jamieson et al. 2014). Other research has found that rotating HPW systems can enhance removal of key pests such as mites and leafrollers (Rogers et al. 2014).

Secondly, egg batch removal after HPW increased with the use of 1-minute postharvest dips using high rates (10%) of food acids applied 24 h before HPW. The addition of 3% Prospect oil to lactic acid enhanced egg batch removal from 45% to 91% removal; however, dipping using 10% lactic acid or 10% malic acid and leaving for 24 h before HPW resulted in unacceptable rates of damage to the oranges. Fruit quality trials investigated reducing the time between dipping with lactic acid or malic acid and HPW, and included a rinse after dipping, which reduced damage but did not eliminate damage. The use of a lower rate dip of 1% lactic acid + 0.05% Prospect oil dip did not increase egg batch removal compared with that of eggs dipped in water or not dipped. The rate of lactic acid was reduced because of the fruit quality issues encountered. The rate of Prospect oil was lowered to reduce the amount of oil in a commercial packhouse for health and safety reasons e.g. potential slip hazards.

Thirdly, we reduced the viability of FRW eggs on fruit from ~90% viability to 25-57% viability with the use of 1-minute postharvest dips containing 10% malic or lactic acid and 3% Prospect oil. This reduction in egg viability was observed in the same treatment for eggs on wax paper; however, additional treatments containing 3% Prospect oil alone and the high and low rate acid + oil treatments that were rinsed before HPW were also shown to be more effective at reducing egg viability than that of controls when eggs on wax paper were tested. It seems that eggs were more susceptible on wax paper than on fruit, which is logical, as some eggs on fruit were tightly packed under the calyx and probably protected from dips. Further research is required to determine if low rate (~4%) acid + low rate Prospect oil (0.05%) dips can enhance FRW egg removal and reduce egg viability.

The effects of food acids (lactic, malic, citric and acetic acids) applied at 1 or 4% on FRW egg viability were compared. All treatments reduced egg viability compared with those of untreated and water-dipped eggs on wax paper. In Australia, the testing of malic acid and Prospect dips of exposed eggs significantly reduced egg hatch, especially at 4% food acid. The same concentrations of malic acid and Prospect dips on infested fruit were not as efficacious, suggesting liquid was not penetrating entirely under the calyx. Some egg masses were removed by high pressure washing, but removal rates were low regardless of treatment.

Previous work has indicated that higher water temperatures and longer exposure times are required to kill FRW eggs on infested fruit (Jessup et al. 1993). Prospect was expected to improve heat transfer by aiding flow of the solution under the orange calyx. Likewise, heat was expected to aid the chemical flow under the calyx. However, there was no decrease in egg hatch, suggesting that the solution did not penetrate fully under the calyx. In addition, 30 s 40°C water dips did not achieve significant egg mortality on wax paper (exposed) or infested fruit (sheltered). Higher temperatures are required to provide efficacy. Limited trials indicated very high mortality of exposed FRW eggs with 30 s 50°C water dips, and 100% control with 60°C or higher water dips (data not presented). Similar water temperatures and longer contact times would increase efficacy on infested fruit but may be more difficult to achieve in commercial citrus packing lines. Redpath et al. (2015) found that a 52.5°C hot water treatment for 2-3 minutes consistently achieved >90% mortality of mixed life stages of latania scale, onion thrips and diapausing larvae of apple leafcurling midge. Sixty to seventy percent of the most tolerant pest tested, obscure mealybug, were controlled by a 2-3 minute hot water treatment at 51-52.5°C (Redpath et al. 2015). A hot water treatment of 51°C for 2 minutes did not affect the quality of 'Royal Gala', 'Fuji' or 'Braeburn' apples (Redpath et al. 2015). Therefore, there is potential to control a range of pests on oranges with a heated (50-55°C) postharvest dip for 1-3 minutes.

There are disadvantages in using hot water dips on citrus. Hot water (>48°C) can result in increased decay, unless a fungicide is included in the mixture (Smilanick & Margosan 1999). Other factors such as cultivar, fruit size, maturity and other postharvest handling processes are also important (Paull & McDonald 1994). Perhaps the emphasis should be on improving penetration of chemical under the calyx rather than on heat per se.

Lower food acid rates (4%), improved stability of free chlorine except when Prospect (3%) was added. The free chlorine concentrations were more stable when both food acid and Prospect rates were reduced. Another sanitiser, peracetic acid (PAA), was more stable when added to food acids and Prospect. The reason for the difference was not investigated. Presumably, the PAA was more stable in the acid environment created by the food acid (Mehmet 2004), whereas chlorine would be lost as chlorine gas under similar acidic conditions (Suslow 2001). However, the reason for chlorine instability with Prospect is unclear. PAA may be a better choice for water sanitation than chlorine-releasing compounds. Lower rates of food acid and Prospect would be required to maintain chlorine stability. Regardless, the effects on FRW egg hatch and removal need to be considered for these options.

The fruit bioassays confirm that chlorine does not control decay on inoculated fruit. Unfortunately, the food acids did not provide any decay suppression at 1%, which is the rate that maintains some chlorine stability. At higher rates (4%), acetic acid suppressed fungal growth; reducing decay to 5% for up to 3 days after dipping. Acetic acid has been shown to be an effective fumigant on a range of fruits (Tripathi & Dubey 2004). Fruit were sealed in plastic bags after dipping and some acetic acid may remain to volatilise. It is unclear if acetic acid suppressed fungal growth by aqueous contact or fumigant action. If fumigant, dipped fruit may need to be held in airtight storage rooms. In any case, acetic acid only delays growth and a fungicide should be applied within 24-48 h of harvest (Wild & Spohr 1989). Alternatively, a fungicide could be added to the dip, which creates the potential for further interactions. This study suggests that thiabendazole is compatible with malic acid and Prospect. But imazalil was incompatible with acetic acid and Prospect. The effects of these fungicide mixtures on FRW eggs hatch and removal were not investigated.

Overall, it will be a challenge to optimise a compatible dip mixture to maximise the control of FRW eggs and still maintain decay control and overall fruit quality. Further work on heated solutions as part of a systems approach for the control of FRW may still be warranted. Australian citrus packers are moving towards short heated fungicide treatments, which provide the heating capacity for other uses. For FRW control, selecting higher temperatures and maintaining short dip times should increase FRW egg efficacy. However, the range of temperatures evaluated needs to consider the limitations of commercial practice and fruit safety. Prospect and/or other chemicals must aid penetration under the calyx and thus reduce the required dip times. Fungicides may need to be directly added to the dips unless acetic acid mixtures can provide short-term protection from decay. In all instances, the mixtures considered for further evaluation need to fulfil the primary requirement of FRW egg control. The effect on fruit quality needs to be considered concurrently with any FRW egg efficacy work.

6 RECOMMENDATIONS

We recommend that citrus packhouses move to a rotating high pressure washing system to enhance removal of FRW eggs, and potentially other postharvest pests.

Further research is warranted to:

- Determine if low rate (~4%) acids + Prospect oil (0.05%) dips can enhance FRW egg removal and reduce egg viability and the impact of these on fruit quality, sanitizer performance and postharvest decay.
- Investigate the efficacy of applying heated dips (50-55°C) with and without low rates of acids + Prospect oil.
- Determine if a fungicide is required for an effective postharvest dip treatment that reduces the risk of viable FRW eggs infesting fruit and maintains fruit quality.

7 ACKNOWLEDGEMENTS

Thanks to Peter Shaw, Peggy Kashuba, Theresa Tipene, Roger Wallis, and Cathy McKenna for collection of Fuller's rose weevil in New Zealand.

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Appendix 5

Jamieson L, Woolf, A, Redpath S, Page-Weir N, Chhagan A, Griffin M, Olsson S, Rogers D, Taverner P 2015. In-line approaches to control surface pests of concern for export citrus. Proceedings of the Citrus Technical Forum and field Day 16-17 March 2015, Midura Arts Centre, Victoria, Australia.

In-line approaches to control surface pests of concern from export citrus

Lisa Jamieson[1], Allan Woolf[1], Simon Redpath[1], Natalie Page-Weir[1], Asha Chhagan[1], Melissa Griffin[1], Shane Olsson[1], Dave Rogers[1], Peter Taverner[2]

[1] Plant & Food Research (PFR)

[2] South Australian Research & Development Institute (SARDI)

lisa.jamieson@plantandfood.co.nz

Fuller's rose weevil (FRW, *Asynonychus cervinus*) is a quarantine pest in China, Korea and Taiwan and the presence of FRW eggs on Australian citrus is impeding market access growth in these key Asian markets. Strategic research and negotiations are required to overcome increasing global competition and more stringent quarantine requirements.

The Australian citrus industry has supported the development of field-based pest control systems and improved monitoring for FRW eggs; this has reduced the number of shipments rejected during pre or post shipment inspections. However, FRW egg detections continue to limit access for citrus exports to a number of Asian markets.

High pressure washing (HPW) has the potential to decrease infestation further. Research is focusing on enhancing egg removal using optimised and new HPW systems and determining the impact of pre-HPW dips to enhance egg removal and/or reduce egg viability.

The operational performances of five commercial citrus HPWs in Australia were assessed and although they were of similar standard 'Honiball' design, there was a great deal of variability among the HPW set up conditions and performances, with no standardised operating conditions. A report summarising findings with recommendations has been prepared (Redpath et al. 2014), and recommendations given to the packhouse operators during these visits have lifted the operational performance of some HPWs visited.

Trials in New Zealand indicated that small increases in FRW egg removal from oranges could be achieved using a new generation rotating head Compac® HPW (20% removal) compared with a standard Honiball system (5% removal). Further trials investigating the impact of Prospect® oil, sodium hypochlorite and acetic acid dips on FRW egg viability and enhancing subsequent egg removal using HPW indicate that Prospect® oil tended to increase removal rates to ca. 46% and reduce the viability of FRW eggs (Jamieson et al. 2014). However, dips containing Prospect® oil applied in New Zealand at lower temperatures (20-25°C) tended to result in a thick white sticky gelatinous state after fruit are dipped and agitated. Trials in Australia indicated that the viability of FRW eggs could be reduced using a 40°C dip containing Prospect® oil and either acetic or citric acid. Heating the Prospect® oil dip to a temperature that does not result in the gelatinous stage may be required for a commercially acceptable treatment.

Research to reduce FRW egg viability using postharvest dips is being undertaken in the USA using lactic and malic acid and the impact of these dips on FRW egg removal and viability and on the quality of oranges is currently being investigated.

These inline pest reduction techniques along with pre-harvest control measures have the potential to achieve an acceptable level of protection for FRW eggs on Navel oranges.

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Appendix 6

Jamieson L, Woolf A, Redpath S, Page-Weir N, Chhagan A, Griffin M, Olsson S, Rogers D, Taverner P 2015. CT13010 In-line approaches to control surface pests of concern from export citrus. Presentation to the Post Harvest Session at the Citrus Technical Forum and Field Day 16-17 March 2015, Mildura Arts Centre, Mildura, Victoria, Australia.

Available at:

http://www.citrusaustralia.com.au/latest-news/citrus-technical-2015-forum-field-day-16-17-march-2015

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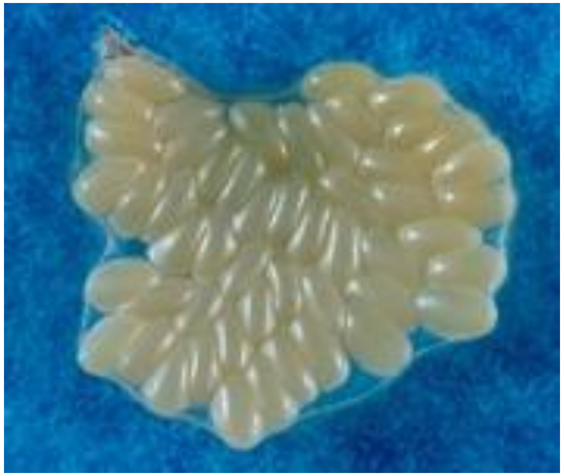
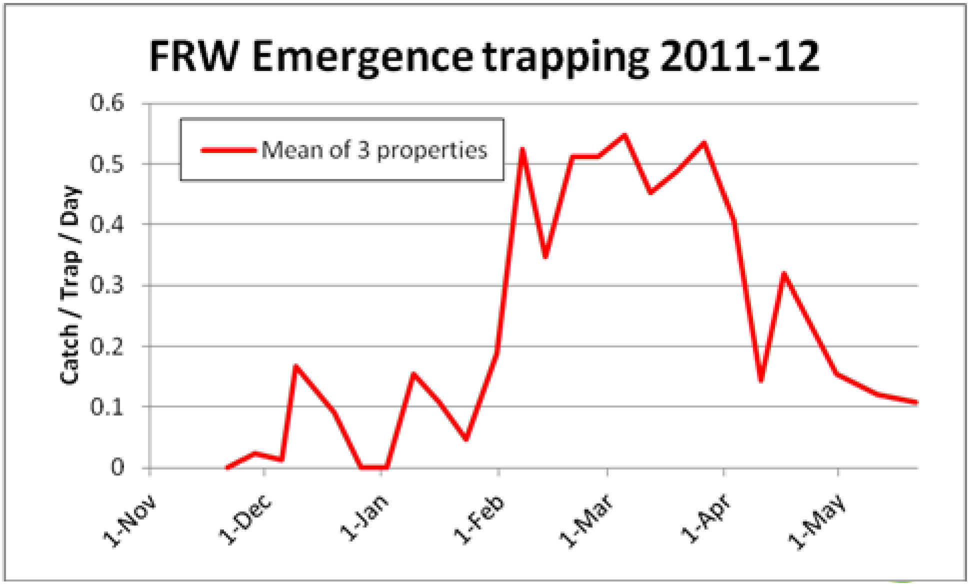
In-line approaches to control FRW eggs – dips + high pressure washing

Lisa Jamieson, Simon Redpath, Allan Woolf, Natalie Page-Weir, Melissa Griffin, Asha Chhagan, Dave Rogers, Peter Taverner

Fuller's Rose Weevil





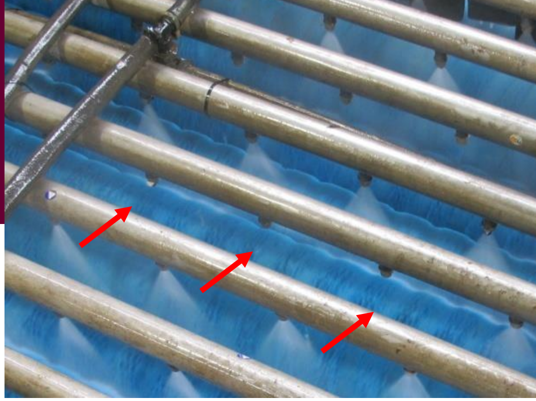
Aims

» Assess different ‘types’ of high pressure washing (HPW) systems and identify the best system for FRW egg removal

» Determine whether selected pre-HPW dips can enhance FRW egg removal and/or reduce egg viability

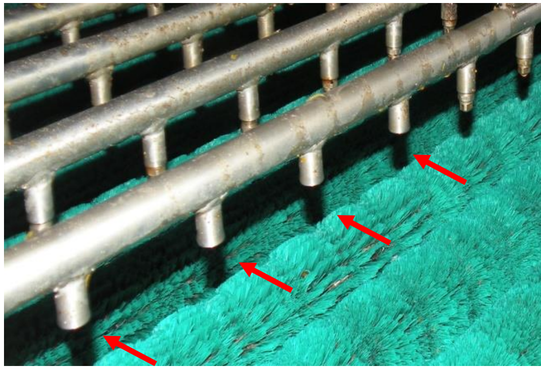
But first – what is the current situation?

Visit to five HPW systems in SA

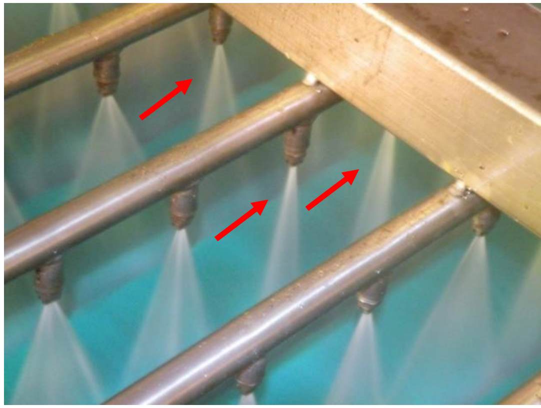


Variability among the HPW set ups in terms of

- pressures (130–170 psi)
- heights (105–270 mm)
- no. nozzles (33–225) set at 95–300 mm apart
- flow rates (7–17 L/min)
- 15–25% nozzles blocked
- paint removal 35–95%



Taverner (2007) – a well set up std HPW with 10 x 23 nozzles operating at 160 psi for 24 seconds generally removed ~6% FRW eggs

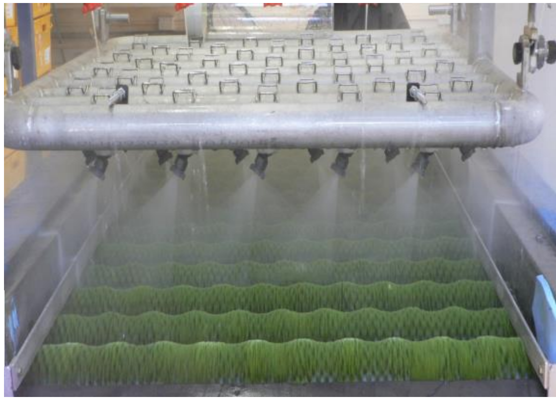


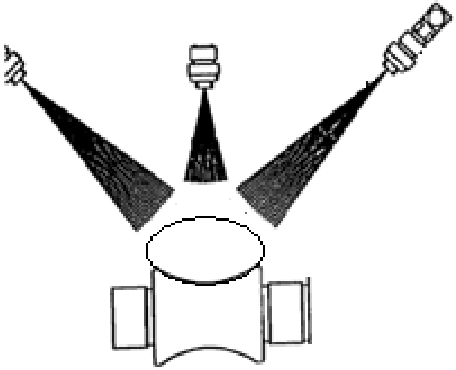
Assess different HPW systems

- Three types HPW systems used in NZ
  - Standard rows of nozzles
  - Rotating nozzles
  - 3 nozzle

Std rows

8 rows 6 nozzles,100-180 psi, 20 sec





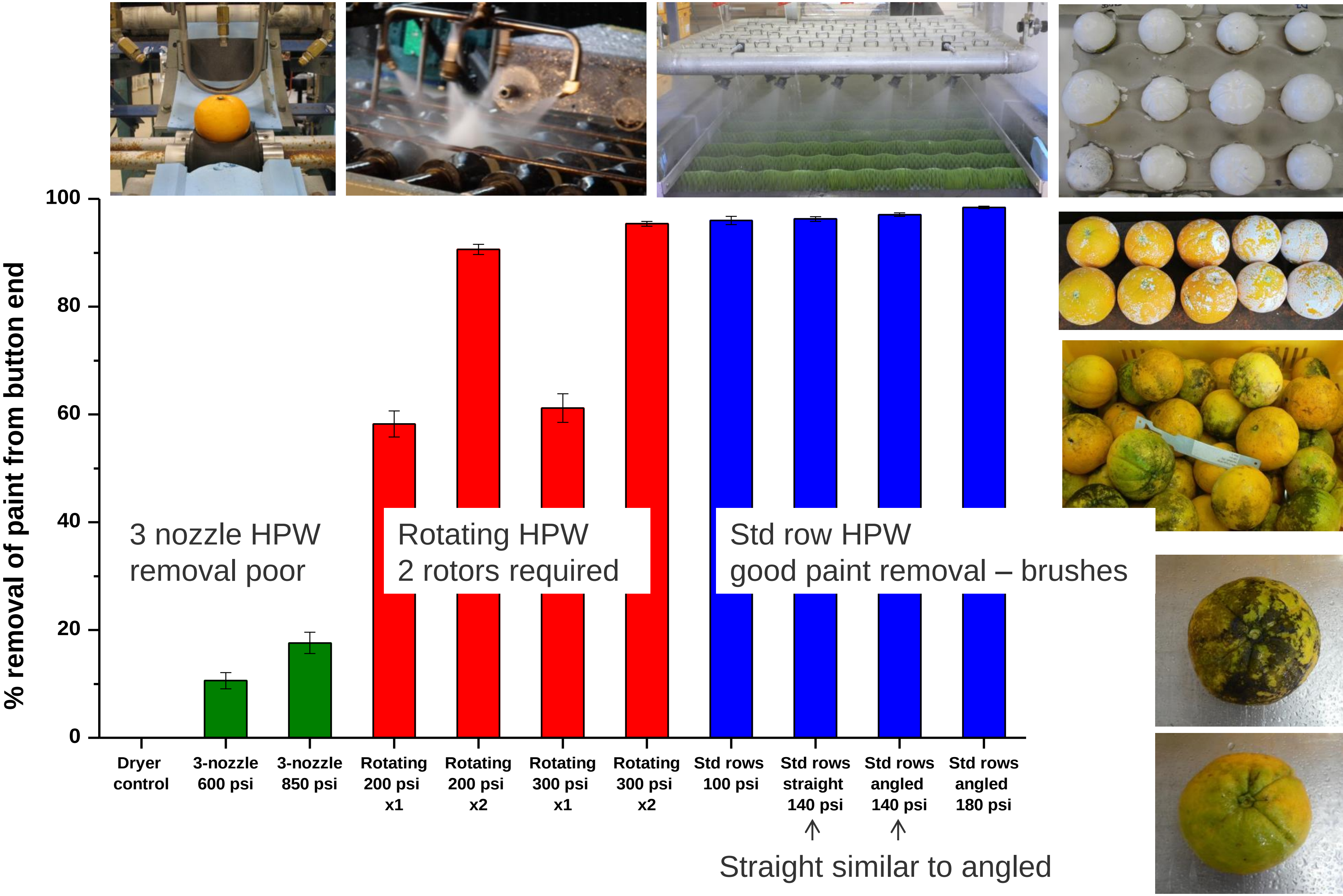
1-2 sec, 600-800 psi

3 nozzle

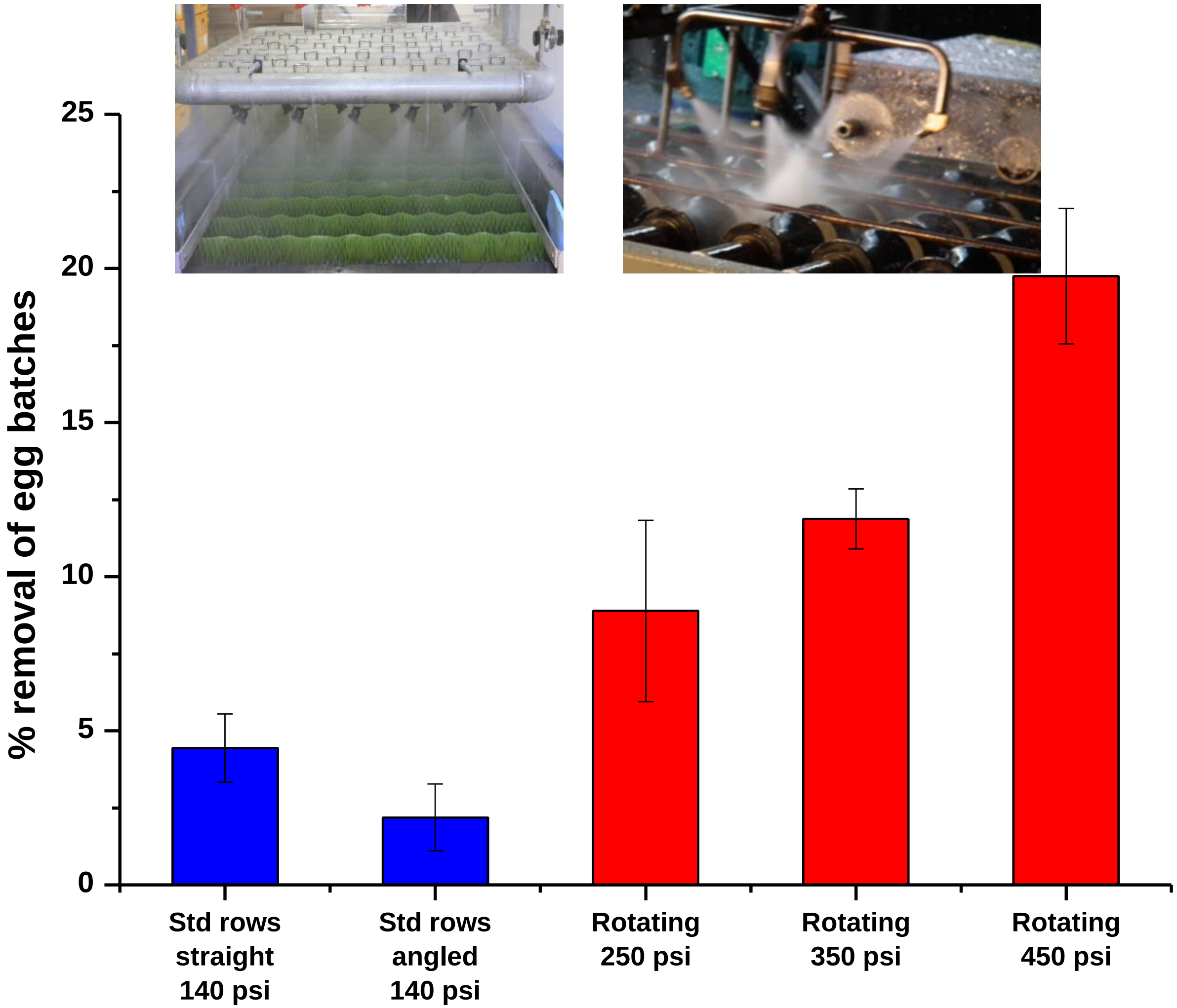
Rotor/wand, 4-6 nozzles, 1000 rpm, 1-2 sec, 200-450 psi

Rotating

Removal of paint from button end – expt HPWs



Removal of FRW eggs – expt HPWs



- FRW egg removal lower than paint removal
- Rotating washer improved removal

Commercial HPWs

16 rows, 12 nozzles, 100 psi

Std rows

Rotating

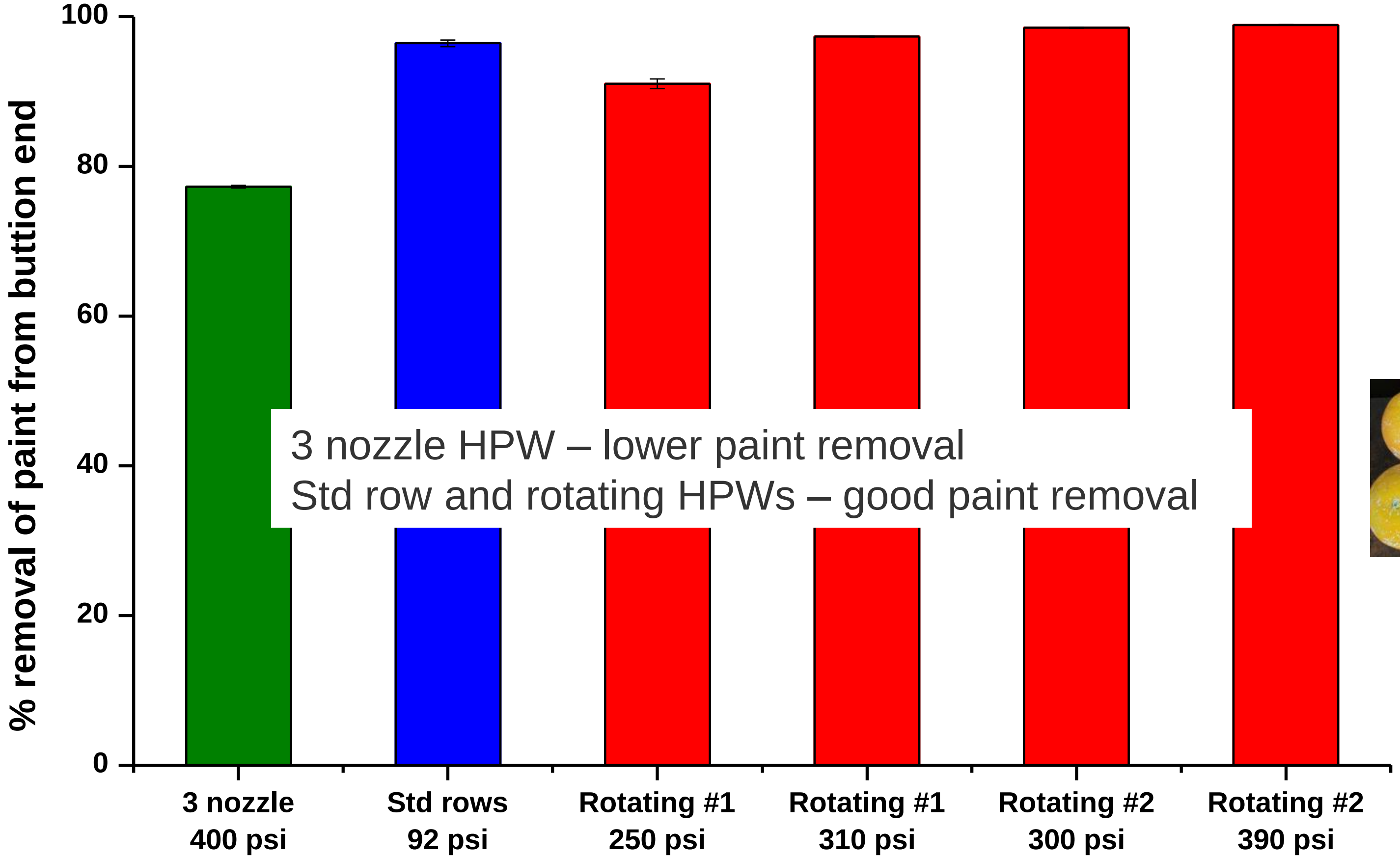
2 wands, 6 nozzles, 250-390 psi, 8 or 9 lanes

400 psi

3 nozzle

Removal of paint from button - commercial HPWs

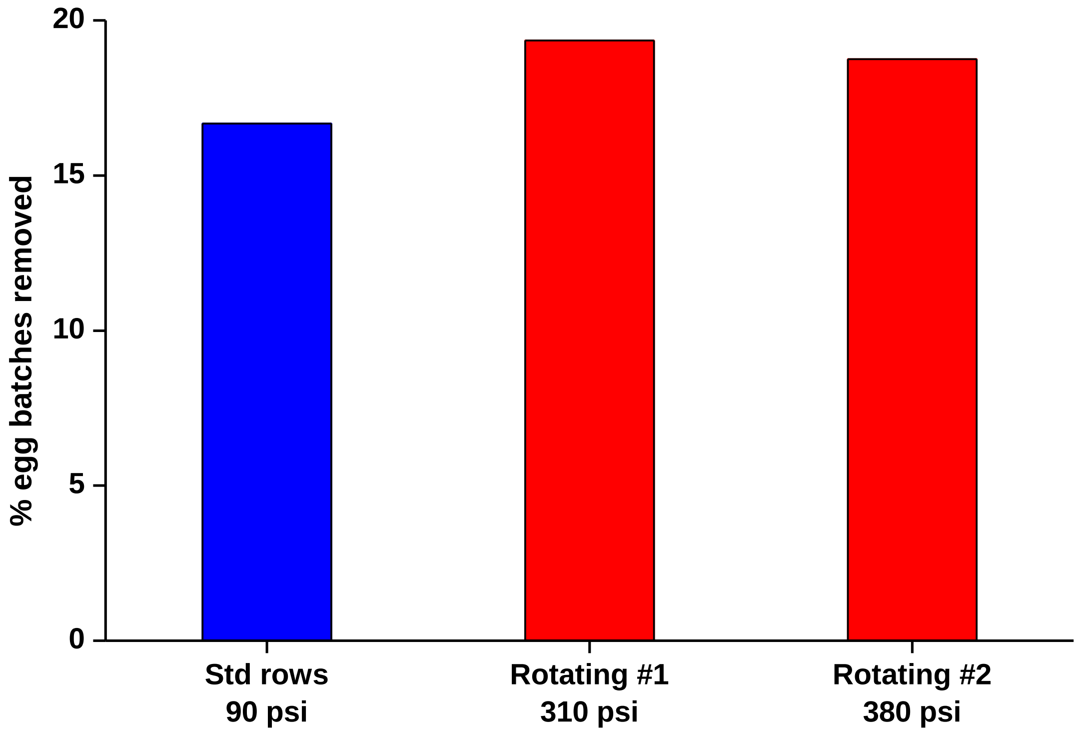


3 nozzle HPW – lower paint removal
Std row and rotating HPWs – good paint removal

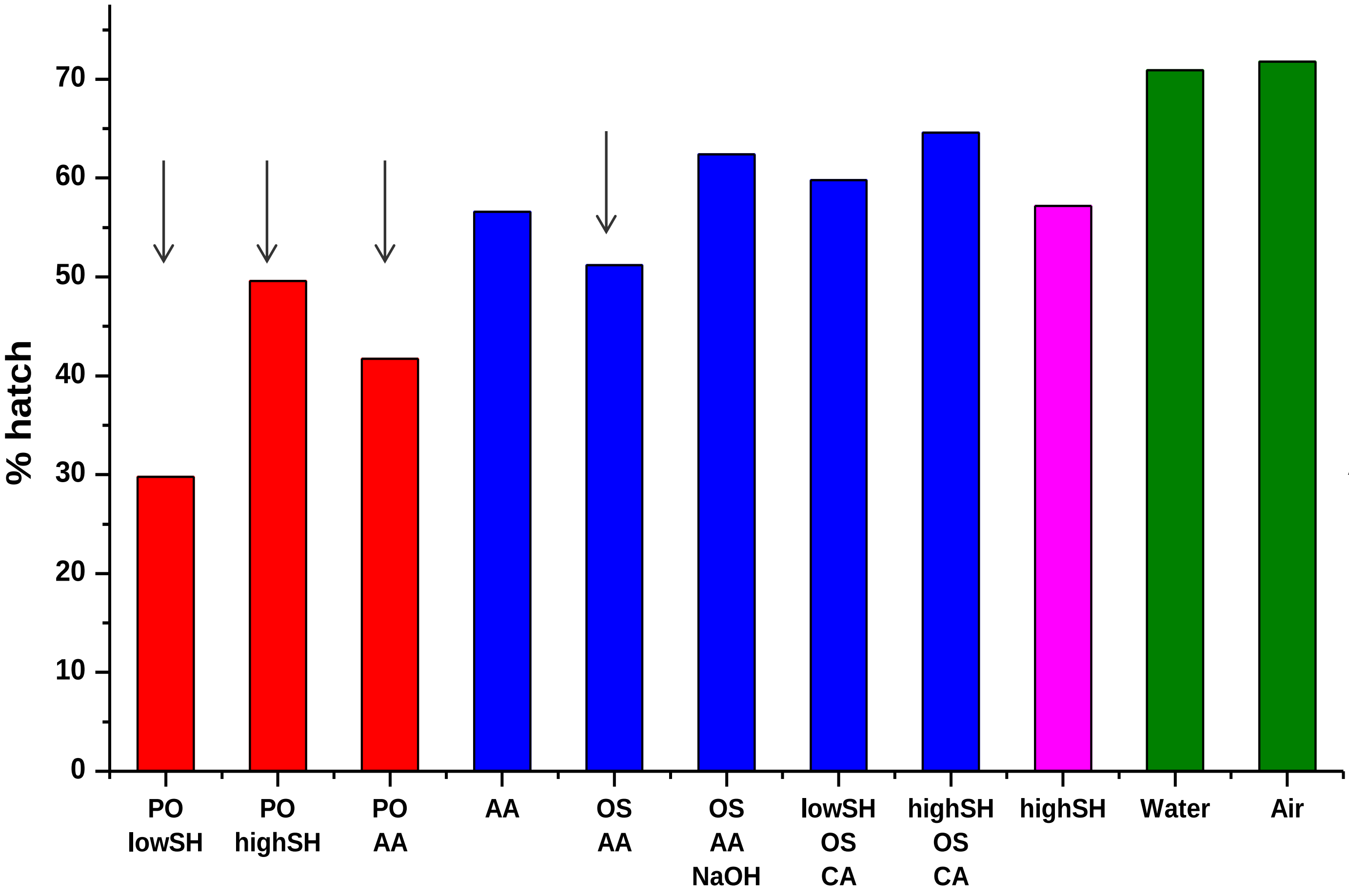
Removal of FRW eggs by commercial HPWs




- » Well set up std rows HPW 17% removal of FRW egg batches
- » Rotating HPW removed ~20% FRW egg batches
- » Compares with ~ 6% removal FRW egg batches at a packer in SA

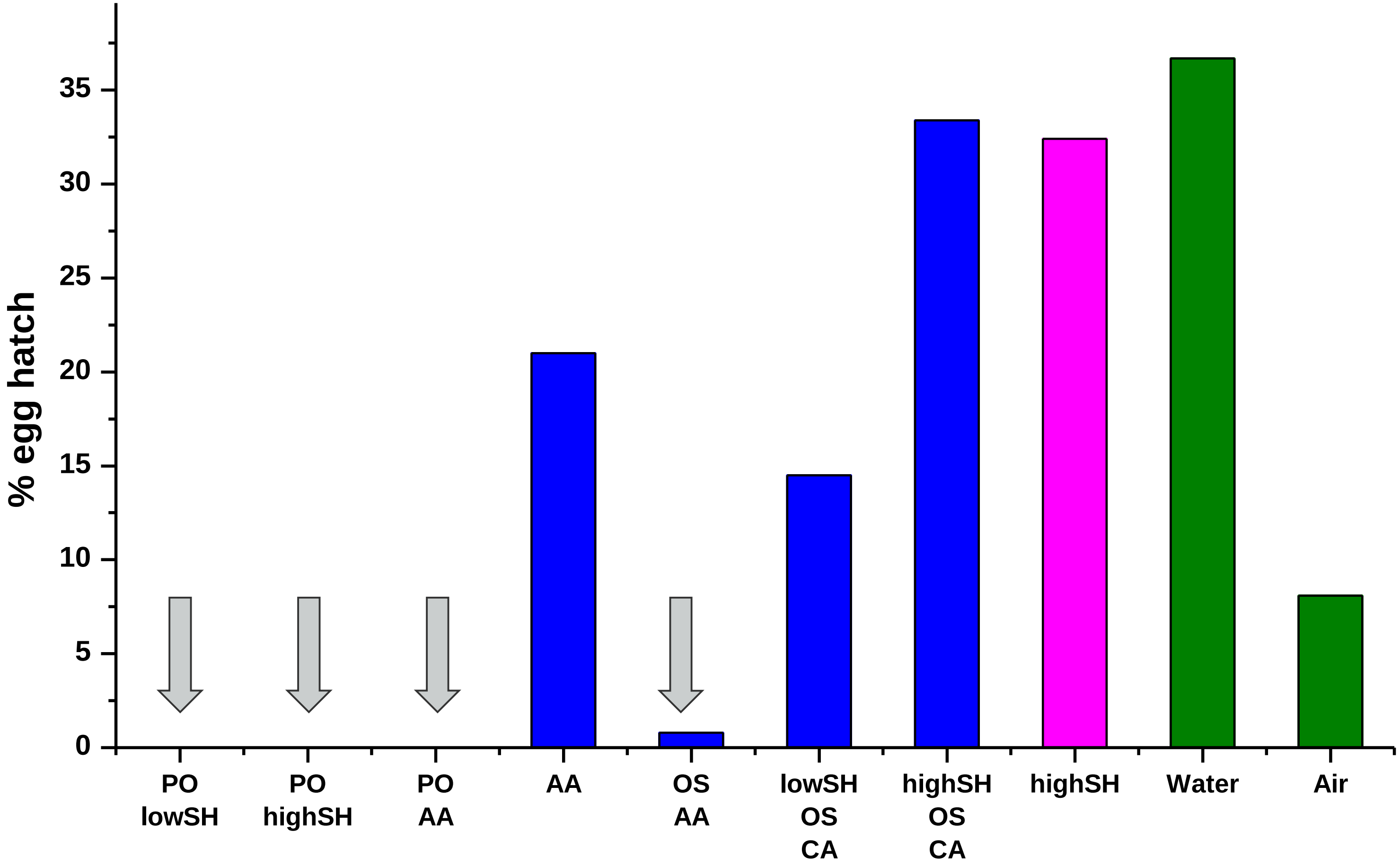
Impact of 1 min dips on egg viability
May 2014



PO = 3% Prospect oil
low SH = 0.02% sodium hypochlorite
high SH = 1% sodium hypochlorite
AA = 5% acetic acid
OS = 0.05% organosilicone
CA = Citric acid
NaOH = sodium hydroxide PH up

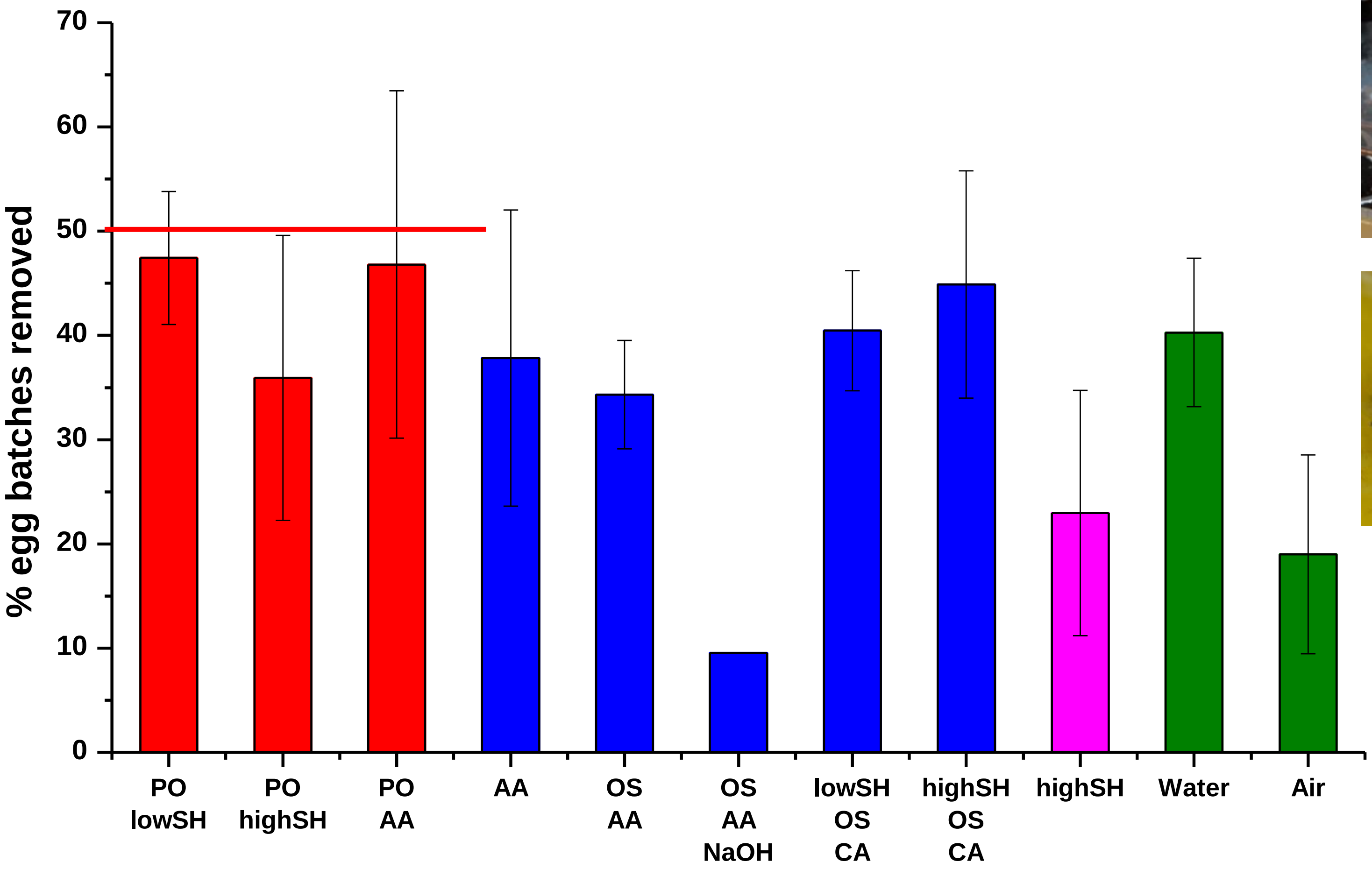
- » Prospect oil tended to reduce egg hatch
- » Maybe organosilicone and acetic acid reduced egg hatch

Impact of 1 min dips on egg viability
July 2014



- Older adults = lower egg hatch
- Prospect oil tended to reduce egg hatch

Impact of dips on egg removal using rotating HPW



- Prospect oil tended to enhance FRW egg batch removal approaching ~50%
- Beware button removal increases as orange ages

End of first season of research – where were we at?

- » Improved current standard row HPW potential to increase egg removal from 6% -17%
  - » 'Best practice user manual for citrus high pressure washing'
- » Rotating HPW increases removal of FRW egg batches ~20% removal
- » Close to 50% removal of egg batches with some Prospect oil dip + rotating HPW treatments
- » Prospect oil tends to reduce egg viability from 70% egg hatch to 30% hatch
- » What level of 'in line' control is required?

Infestation rate	Scenario	HPW removal required <MPL
100%	All fruit infested	99.5%
23%	Minimal field control	90%
5%	Some field control	75%
1%	Good field control	50%
0.6%	Awesome field control	16.7%

0 egg batches in 600 fruit sampled at random

- Maximum pest limit (MPL) = 0.5% fruit infested, 95% confidence
- P_m = mortality or removal rate required (fruit disinfested given that fruit infested)
- P_0 = initial batch infestation
- P_L = infestation level after treatment
- Assuming maximum of 1 pest/fruit

$$p_m = 1 - \frac{p_L}{p_0}$$

USA approaches to control FRW on citrus

- USA researchers – FRW issue to Korea
  aiming for probit 9 control (99.9968% mortality)
  - Approach 1
    - Phosphine 1000 ppm, 48 h, 5C = 93% mortality
    - Phosphine + cold
    - Acetic soak + phosphine + cold
    - Power spray + phosphine + cold
    - Acetic acid + Power spray + phosphine + cold
    - Dryer + above
    - Production controls + above
  - Approach 2
    - Ethyl formate 2%, 8 h = 98%
    - Ethyl formate + cold
    - Citric acid, acetic acid or quinic acid followed by EF = 99.68% with citric acid + 2% EF 6 h
  - Beginning to investigate dips using malic and lactic acid

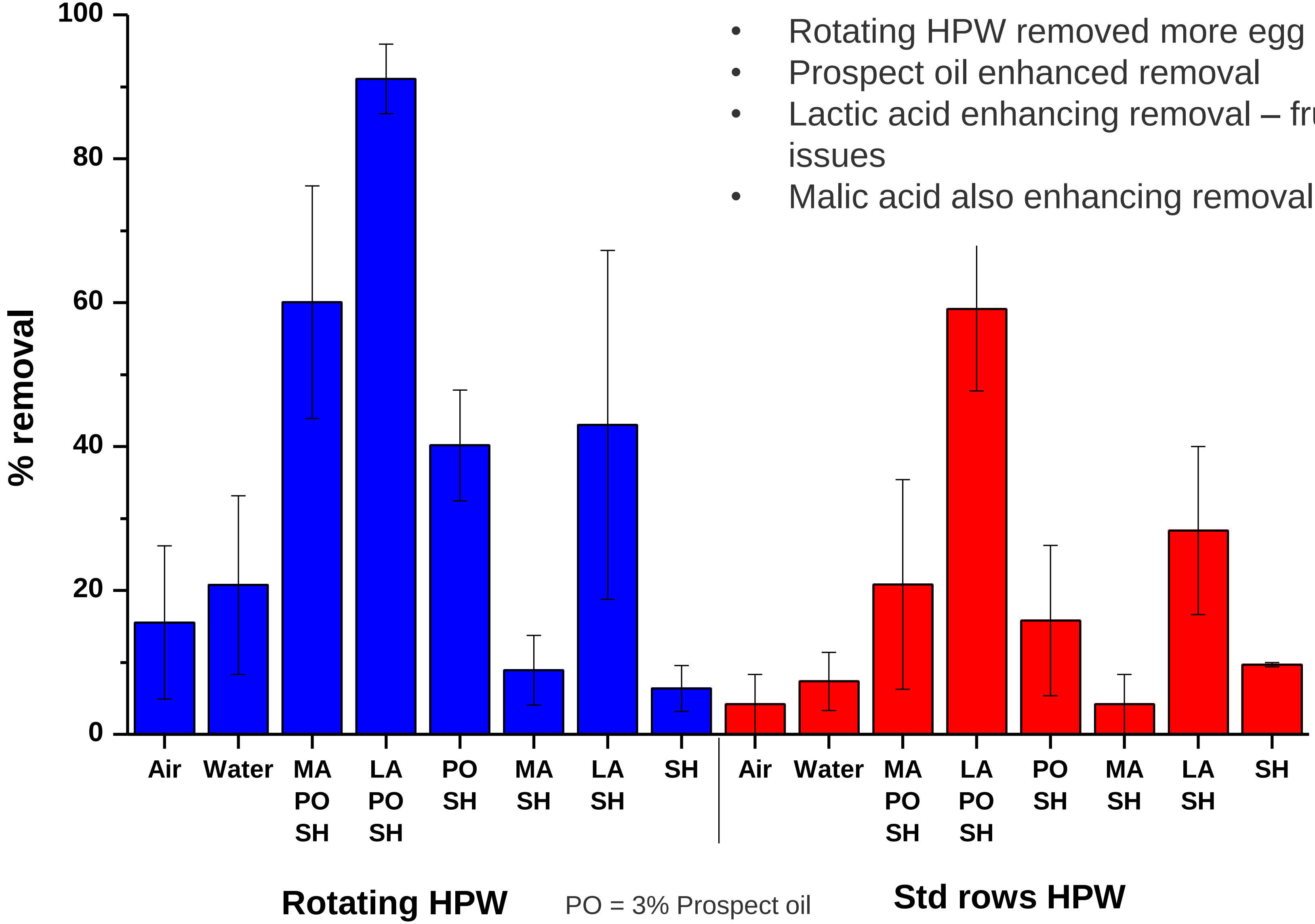
Second season trials in progress

- Impact of malic or lactic acid dips on
  - FRW egg viability
  - FRW egg batch removal using HPW
- Dipping treatments – beginning with 1 minute dips and leave for 24 h until HPW
  1. 10% malic acid + 3% Prospect oil + 0.02% sodium hypochlorite
  2. 10% lactic acid + 3% Prospect oil + 0.02% sodium hypochlorite
  3. 3% Prospect oil + 0.02% sodium hypochlorite
  4. 10% malic acid + 0.02% sodium hypochlorite
  5. 10% lactic acid + 0.02% sodium hypochlorite
  6. 0.02% sodium hypochlorite
  - Water
  - Untreated

- HPW systems
  - Std rows 140 psi
  - Rotating 350 psi
- Confirmatory trials using best combinations – dependant on extension

Impact of 1 min malic and lactic acid on FRW egg removal 24 h later

- Rotating HPW removed more egg batches
- Prospect oil enhanced removal
- Lactic acid enhancing removal – fruit quality issues
- Malic acid also enhancing removal



PO = 3% Prospect oil
MA = 10% Malic acid
LA – 10% Lactic acid
SH = 0.02% sodium hypochlorite

Acknowledgements

- FRW adult collectors
  - Peggy Kashuba, Roger Wallis, Peter Shaw, Cathy McKenna
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Appendix 7

Woolf A, Redpath S, Olsson S, Taverner P, Jamieson L 2015. High pressure washers. Proceedings of the Citrus Technical Forum and Field Day 16-17 March 2015, Mildura Arts Centre, Mildura, Victoria, Australia.

High pressure washers

Allan Woolf[1], Simon Redpath[1], Shane Olsson[1], Peter Taverner[2], Lisa Jamieson[1]

[1] Plant & Food Research (PFR)
[2] South Australian Research & Development Institute (SARDI)

allan.woolf@plantandfood.co.nz

High pressure washing (HPW) before packing removes horticultural surface pests and other contaminants, and can improve access to international markets. The most widely used HPW system uses multiple rows of manifolds each equipped with nozzles directed downwards onto rotating brushes. In our survey of some citrus packhouses, we found pressures ranging from 130 to 170 psi, and a treatment time of 15 to 20 seconds. Our observations showed a number of issues including blocked nozzles, incorrectly oriented nozzles, nozzles not replaced on a regular basis and lack of pressure gauges. Many of these issues are relatively easy to remedy and will increase performance. We also found significant variation between washer designs, including different nozzles, nozzle height, and treatment time. All of these factors will result in very large differences in the how the washer operates and the water impacts on the citrus fruit. On the basis of our experience with a wide range of washers designs, and our observations of the various citrus washers, we have developed a user manual “Best-practice user manual for Citrus high pressure washers”. A draft of this manual will be provided at the workshop for discussion and input.

Appendix 8

Woolf A, Redpath S, Olsson S, Taverner P, Jamieson L 2015. High pressure washers. Presentation to the Field Day at the Citrus Technical Forum and Field Day 16-17 March 2015, Mildura Arts Centre, Mildura, Victoria, Australia.

The New Zealand Institute for Plant & Food Research Limited

Optimising citrus washers – best practice recommendations

Allan Woolf and Simon Redpath

Peter Taverner and Lisa Jamieson

1) Introduction and Background

Removal of external contaminants

Range of washer options

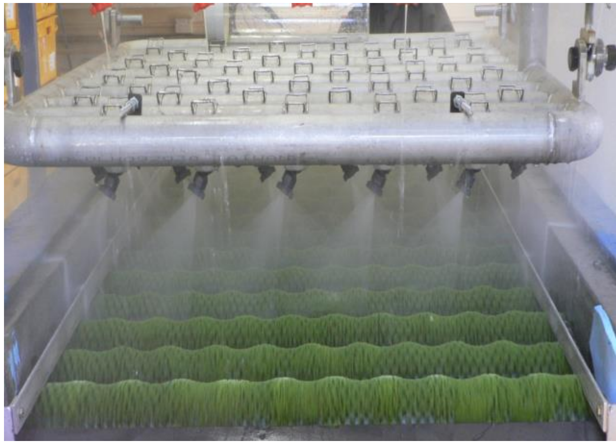
Three types used commercially in NZ

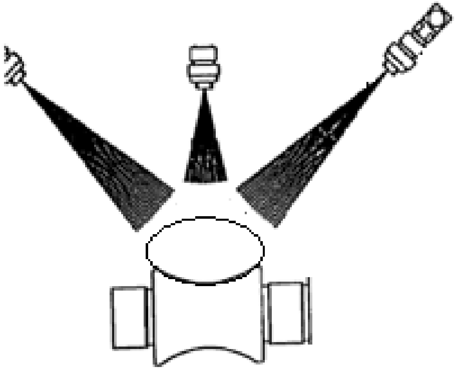
» Standard rows of nozzles

» Rotating nozzles

» 3 nozzle

Honiball / Std rows

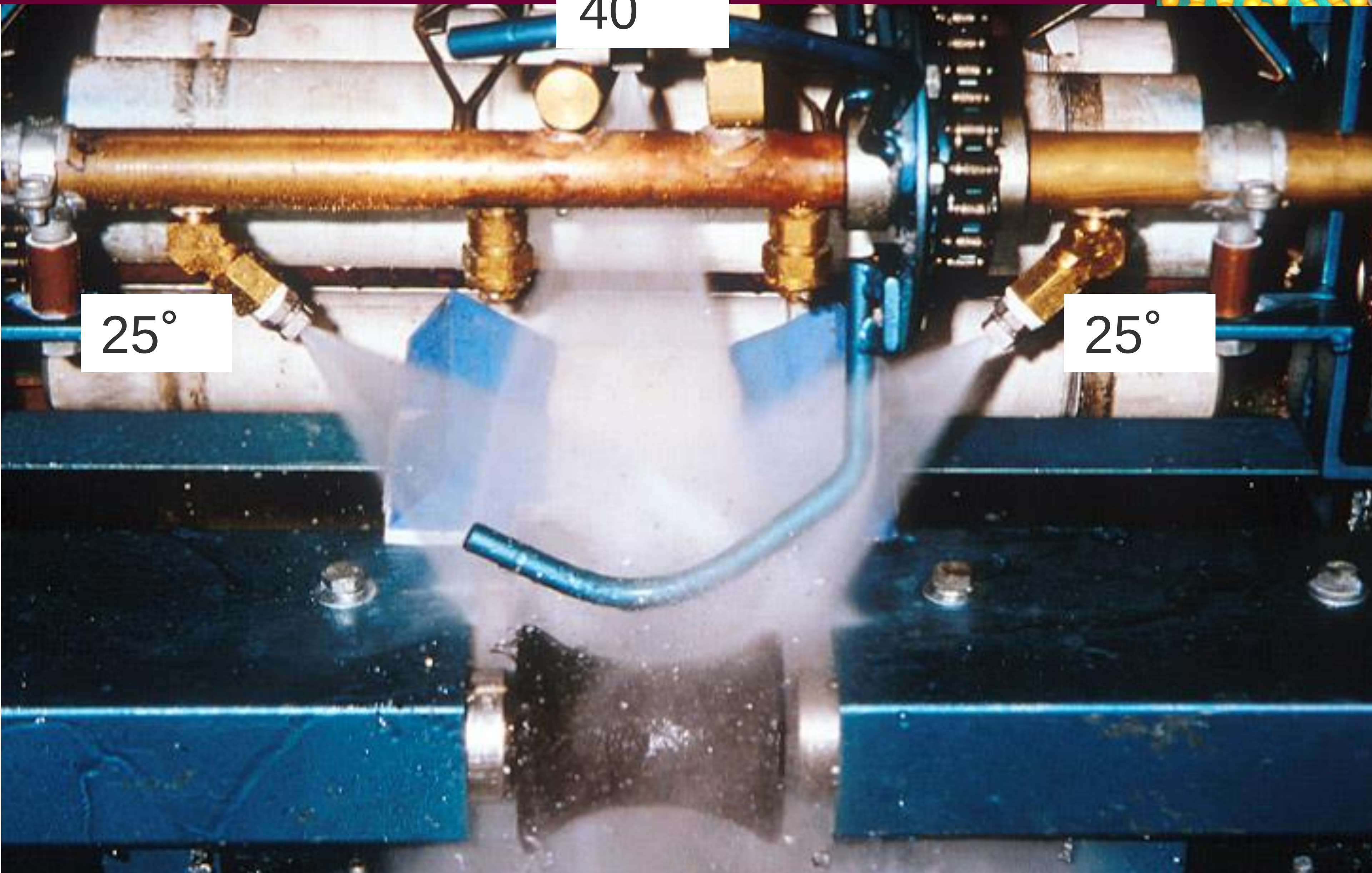




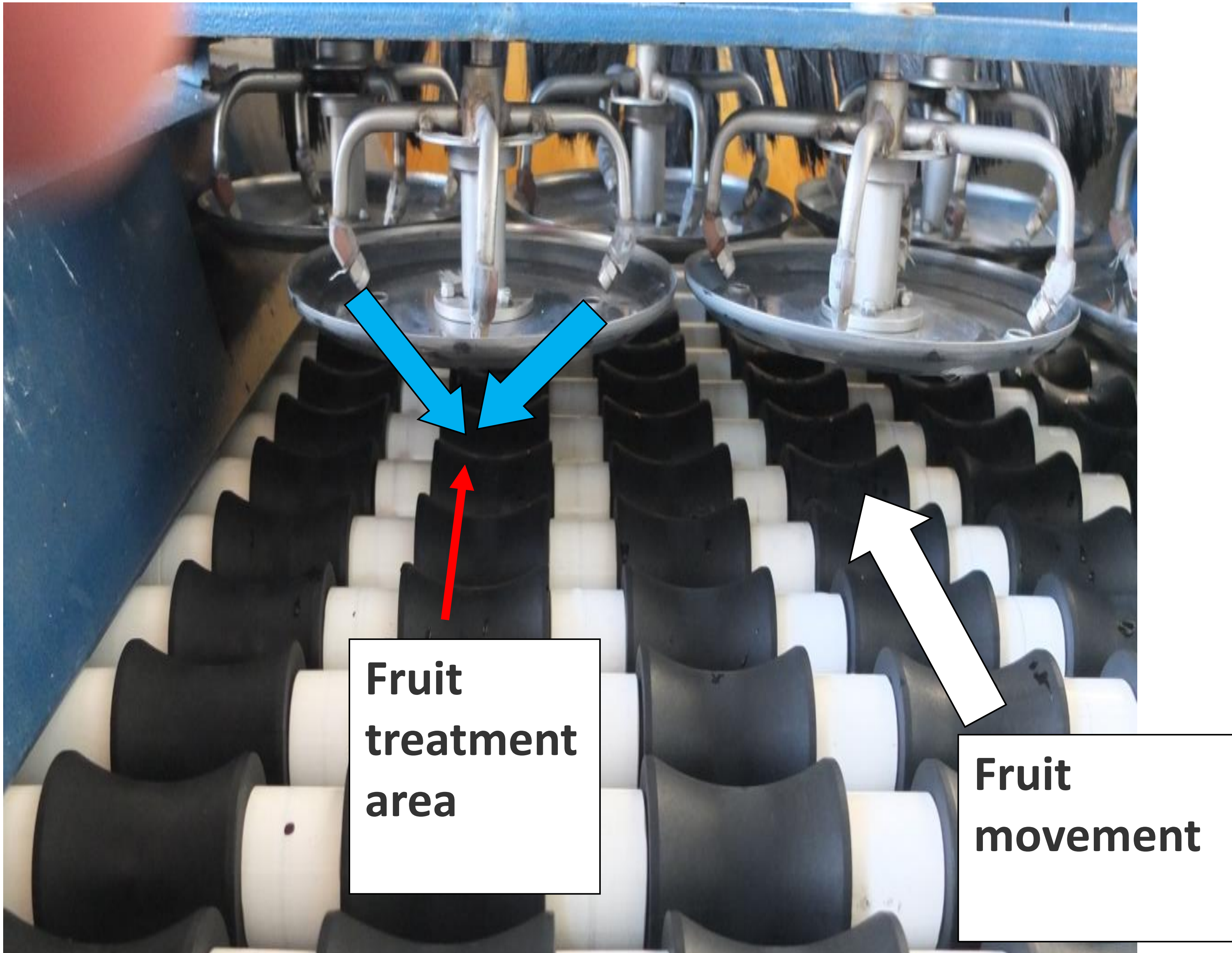
3 nozzle

Rotary

3 nozzles - FSS



Rotary system - Compac



Honiball – Standard rows

Honiball – lower flow

Honiball – high flow

2) Project overview

1. Survey Australia systems
2. View NZ new washing systems
3. Carry out trials looking at removal of FRW
   A. Washing
   B. Washing and dips

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   B. Washing and dips

3) Australia, 5 packhouses

Aims

Visit 5 citrus packhouses of varying sizes with in-line HPW systems to:

1. View and discuss current HPW systems used in Australian citrus industry

2. Assess the operational performance of the HPWs by making a series of measurements

Aims…. continued

3. Assess efficacy of the HPWs by putting Navel oranges covered with a kaolin clay/glue mix through each HPW

4. Discuss current FRW in-orchard control methods, at-harvest infestation rates, target infestation rates, and the standard of compliance data required

5. Discuss the potential of new washing systems

Measurements made at each site

Measurements/information:

1. Flow rate of each nozzle
2. Distance from each nozzle to a standard-sized object
3. Nozzle type
4. Nozzle orientation
5. Nozzle blockage
6. Filtration systems
7. Sanitiser
8. Efficacy of contaminant removal and uniformity using white “painted” fruit.

Discussions:

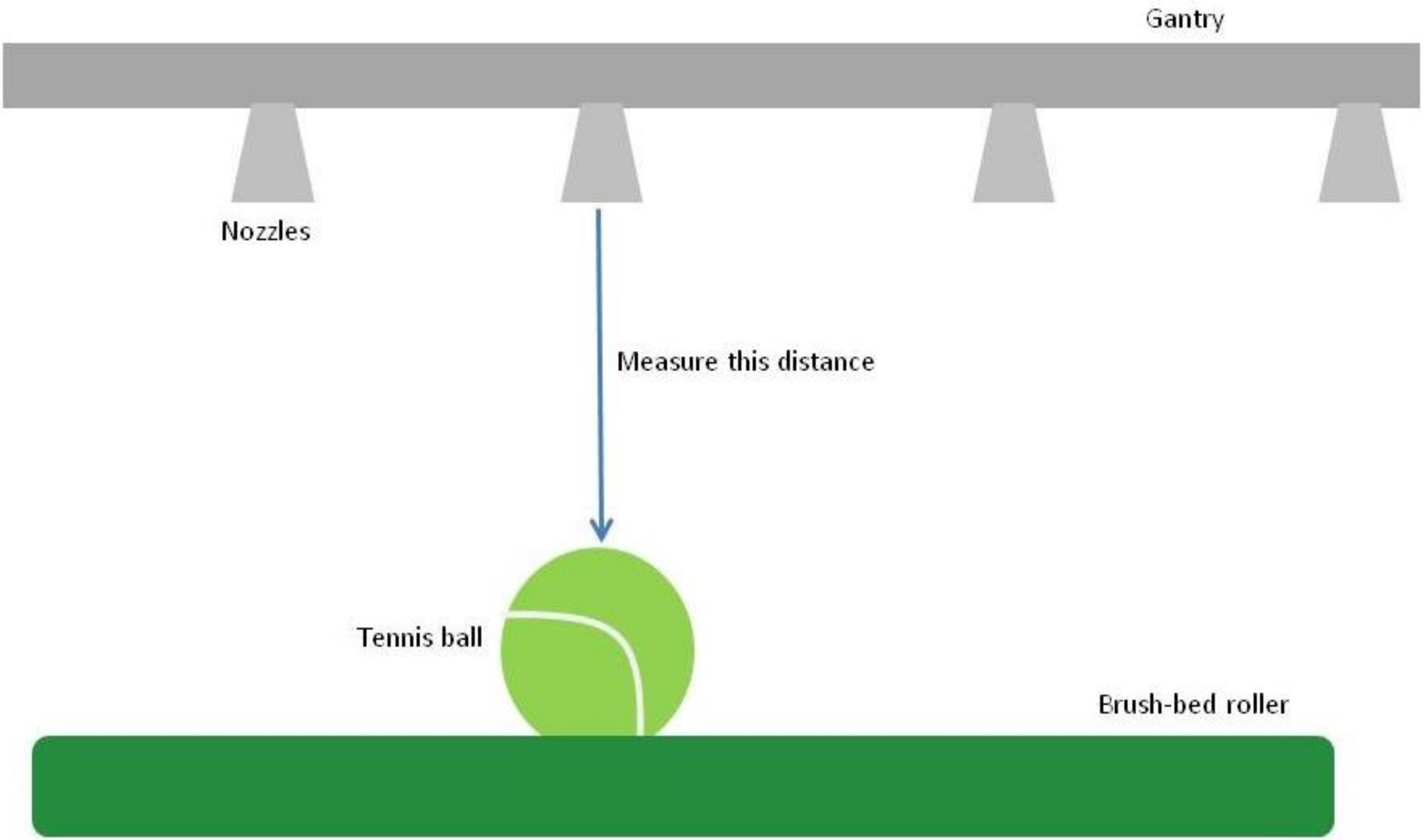
1. Interview packhouse manager, QC, washer operator, engineer (if possible)
2. What systems are in place?

Flow rate

Painted fruit

Painted fruit

Nozzle distance

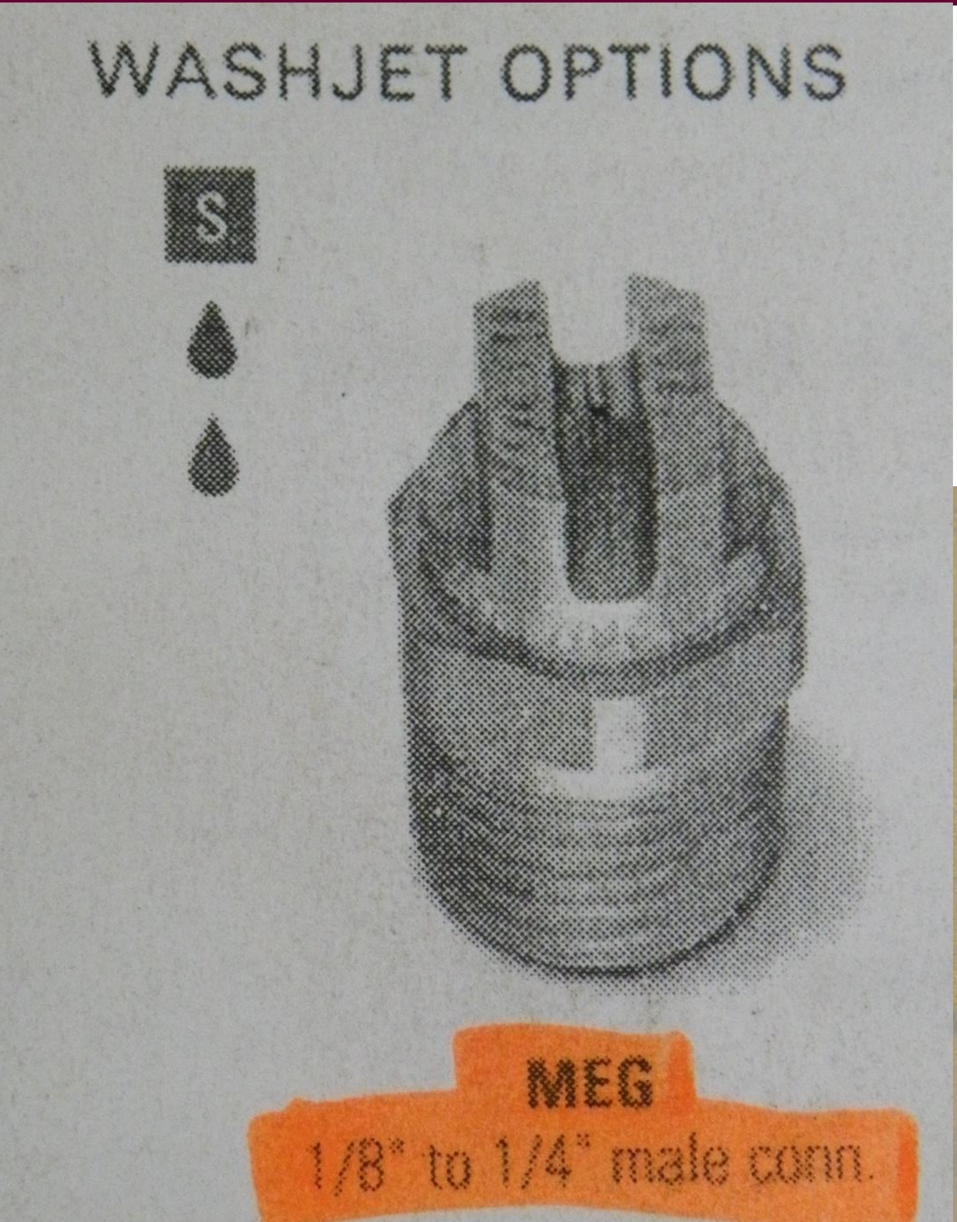


3) Key observations and findings

General observations

1. Similar layout: 10-12 rows, nozzles over roller-bed
2. Nozzle types different
3. Range of pressures: 130 to 170 psi
4. Flow rate: 7 to 17 litres / minute
5. Heights: 105 to 155 mm
6. Treatment duration: 15 to 20 seconds
7. Blockages: 15 to 25%

Some nozzle types



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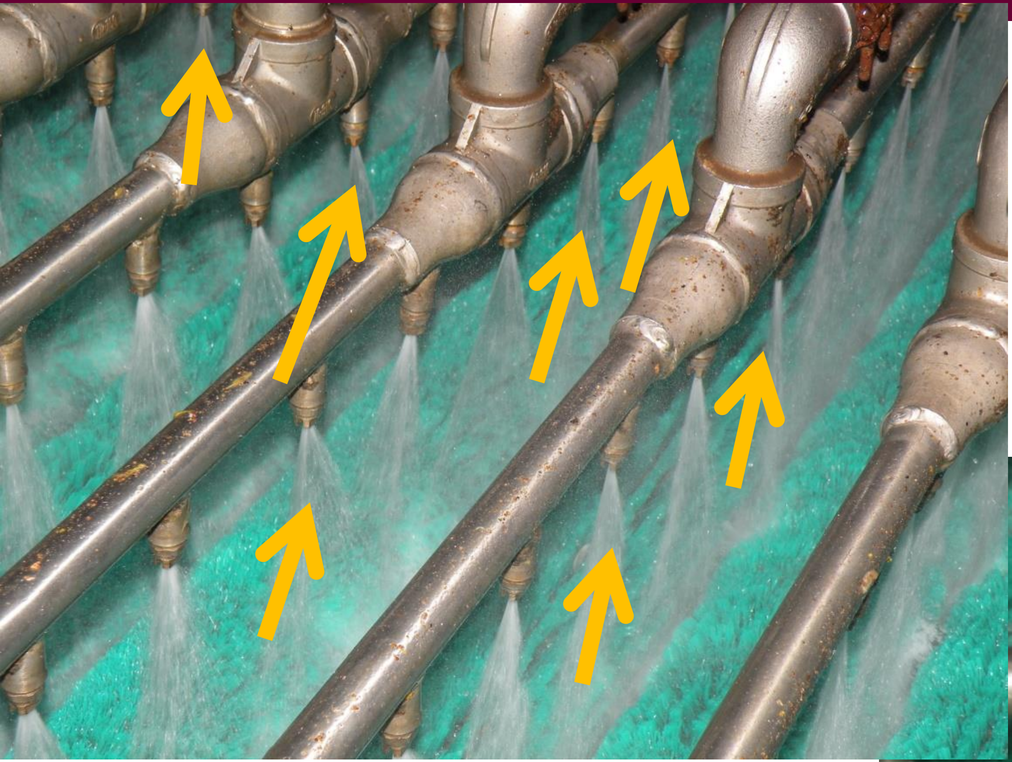
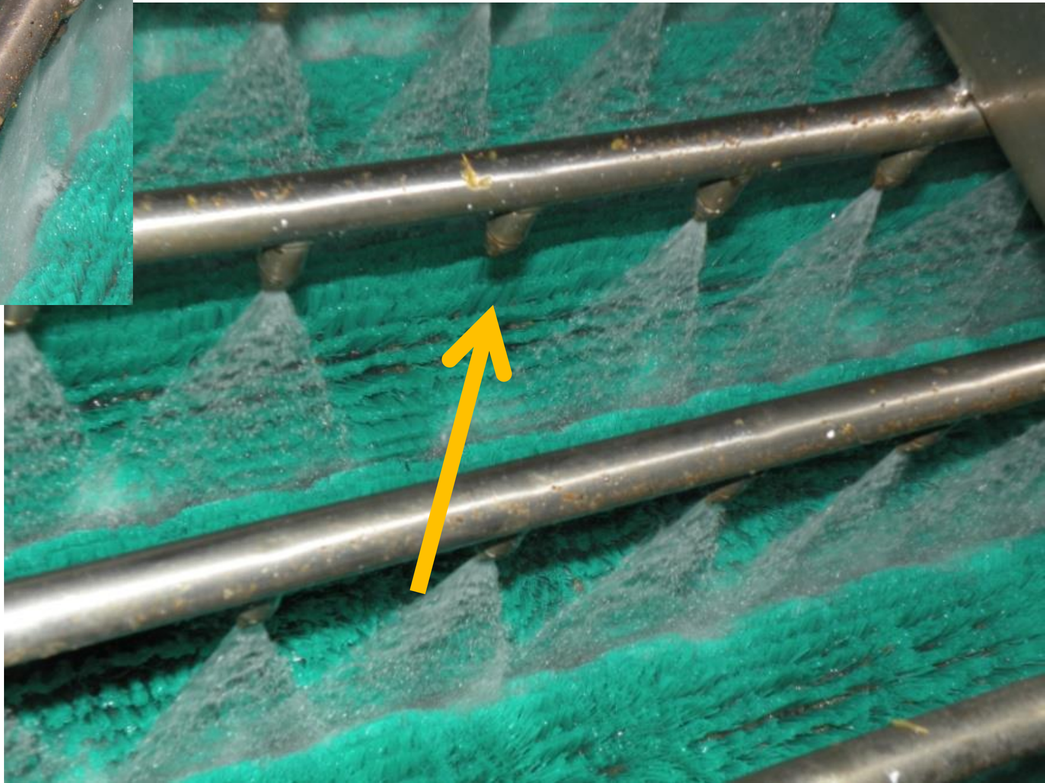
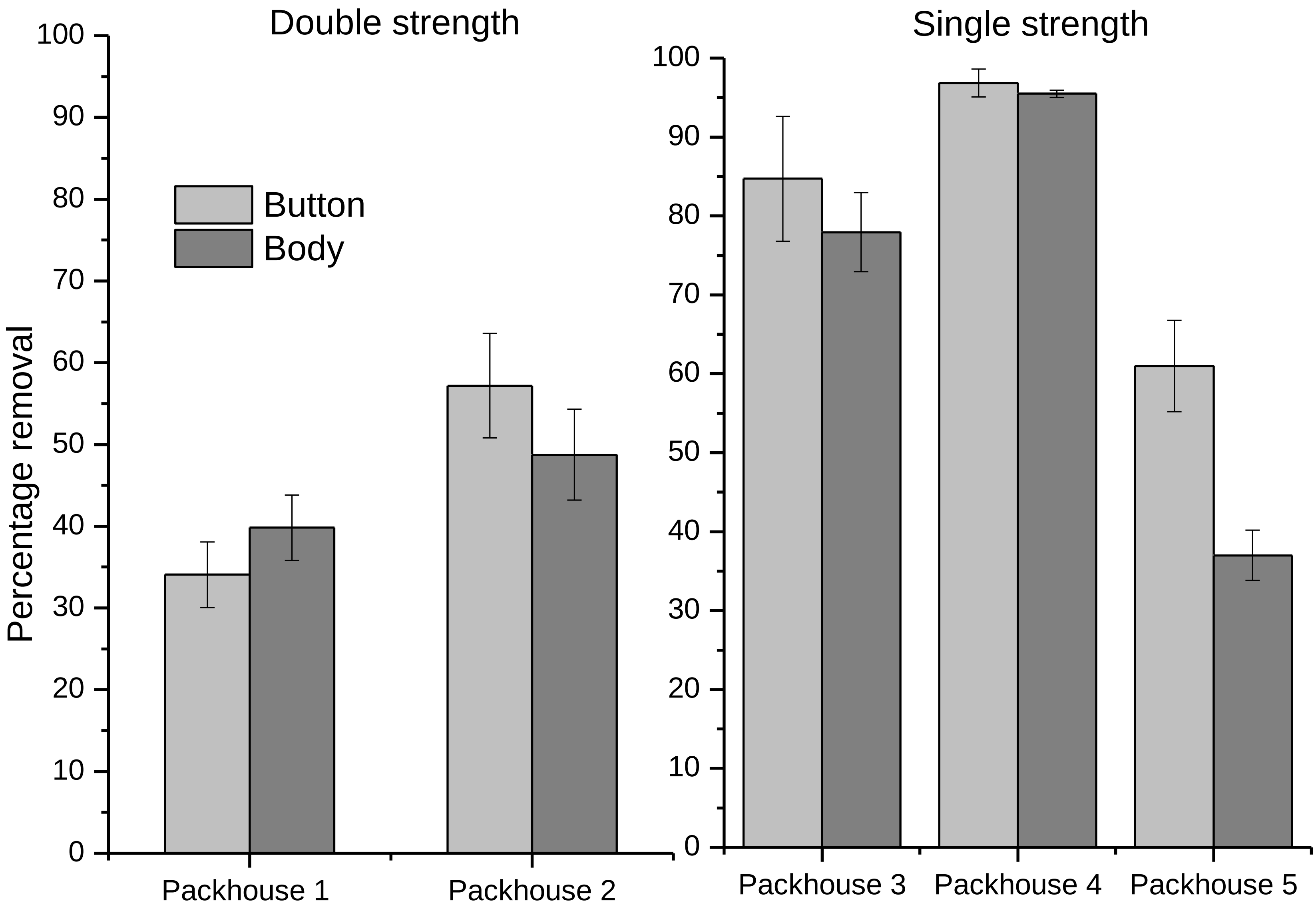
Blockages





Removal – some numbers



Filtration and sanitation

Food safety becoming more important

Challenging!

Fruit residue

Charlie and the chocolate factory


Filtration – multiple steps better

FIltration

Flat stacked filters

Trash / course filters

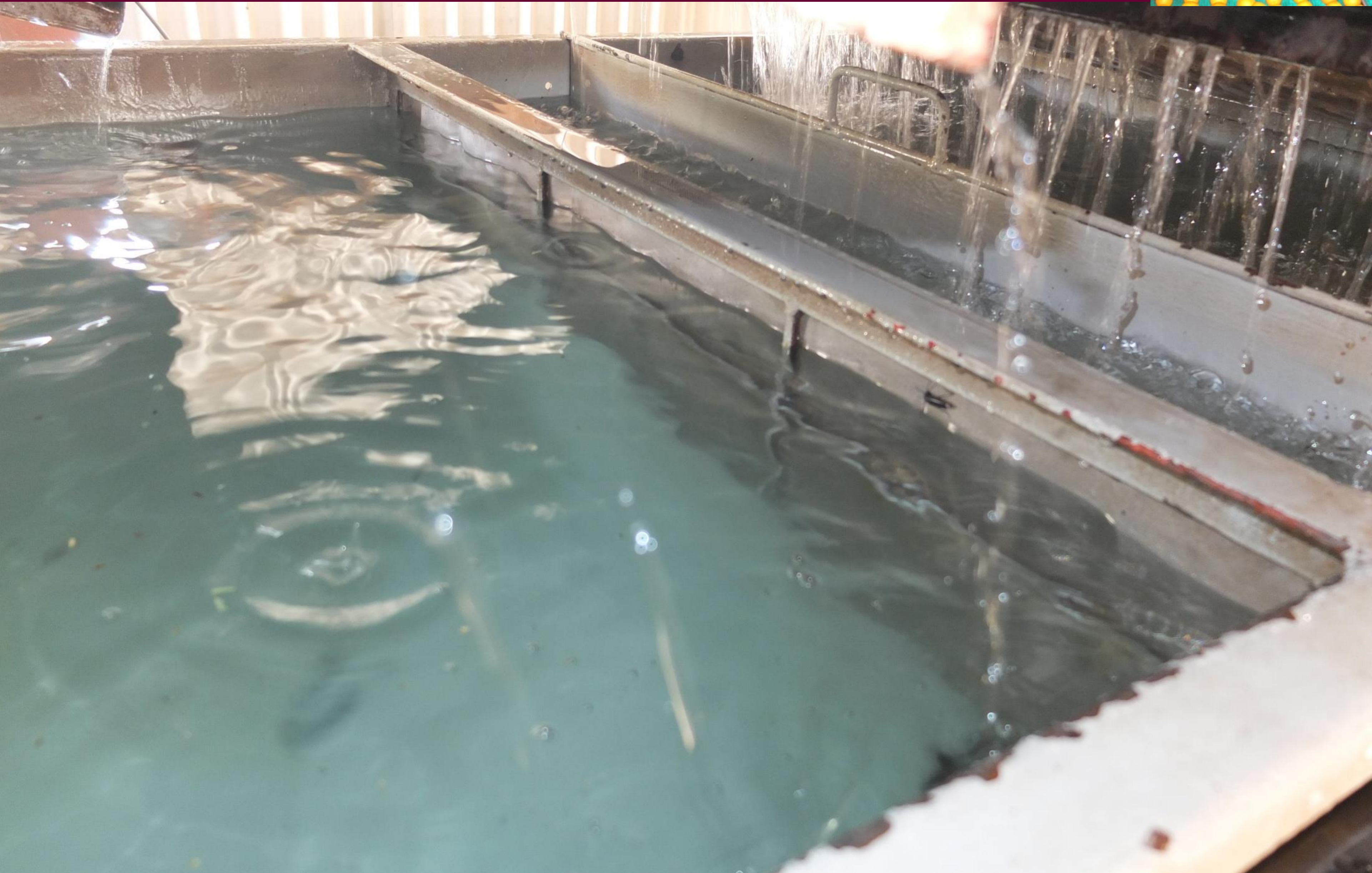
Sloped filter systems

Catridge filters

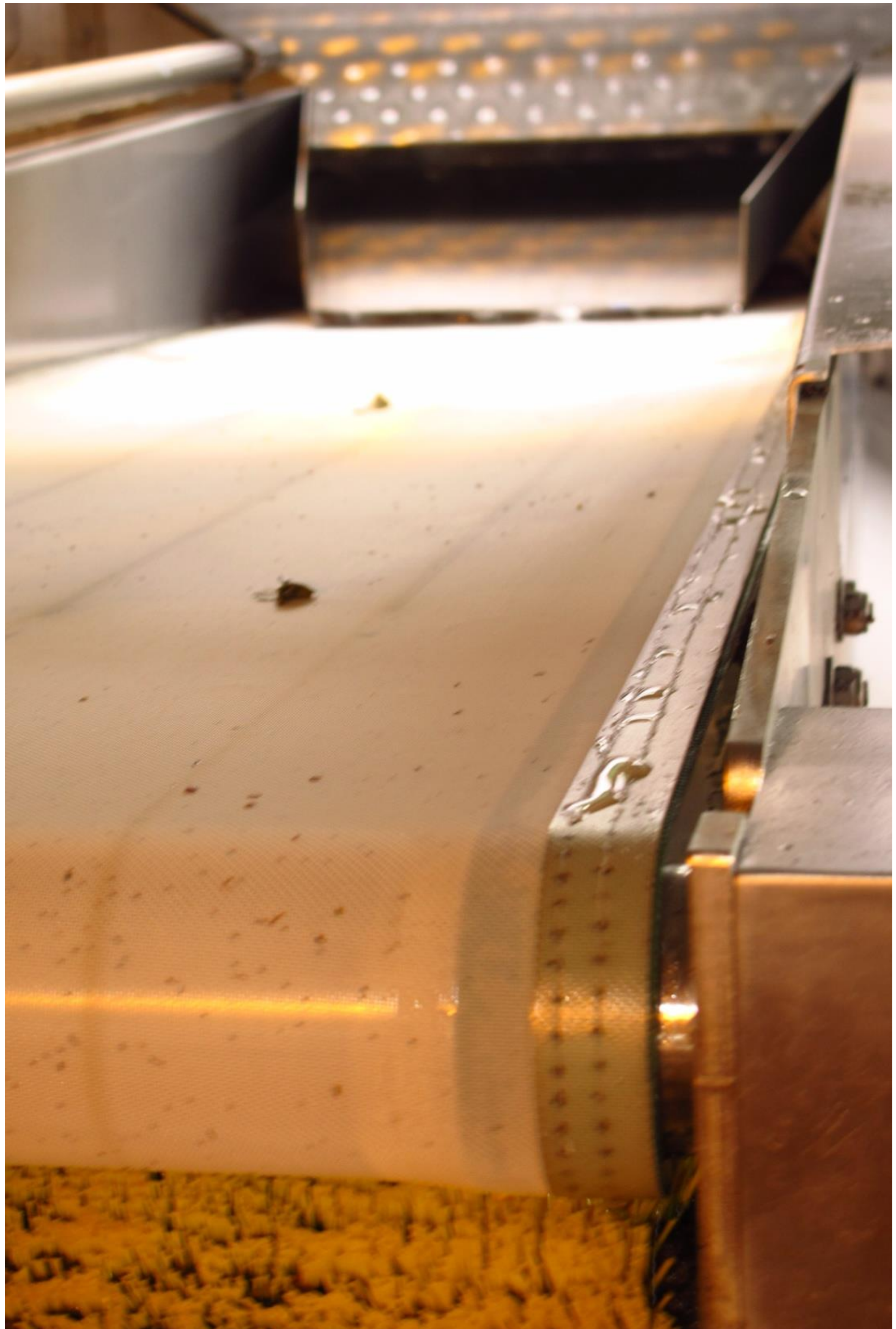
Multiple cartridge filters

Use auto-cleaning type if possible

“Settling” systems



“Settling” systems



Compac apple filter

Water dumping/refilling

General cleaning

Water hygiene / Food safety

Affected by:

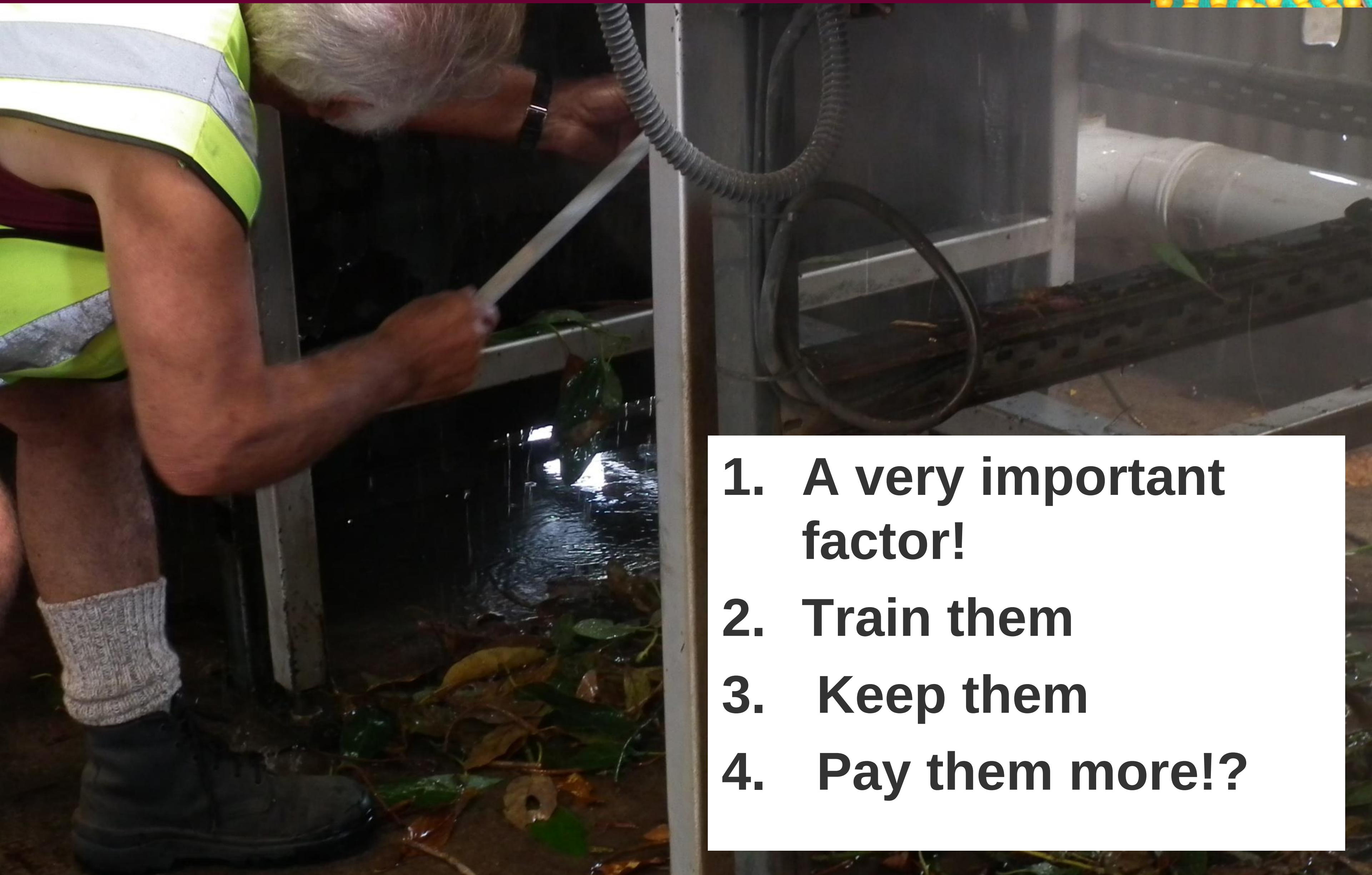
- Fruit volume processed
- Fruit cleanliness (dust, pollen, bird guano, agrichemicals)
- Water volume of unit
- Water availability in and out
- Dilution with fresh water
- Cleaning regime
- Filtration
- Sanitisers
- Post-wash rinse

Sanitisers

- HarvestCide® (Nylate®); Chl-Br
- Chlorine (Na hypochlorite – bleach)
- Tsunami®
- Sporekill™
- Chlorine dioxide (e.g. Oxine™).

Clean water rinse at end

Personnel / operator



1. A very important factor!
2. Train them
3. Keep them
4. Pay them more!?

Access !

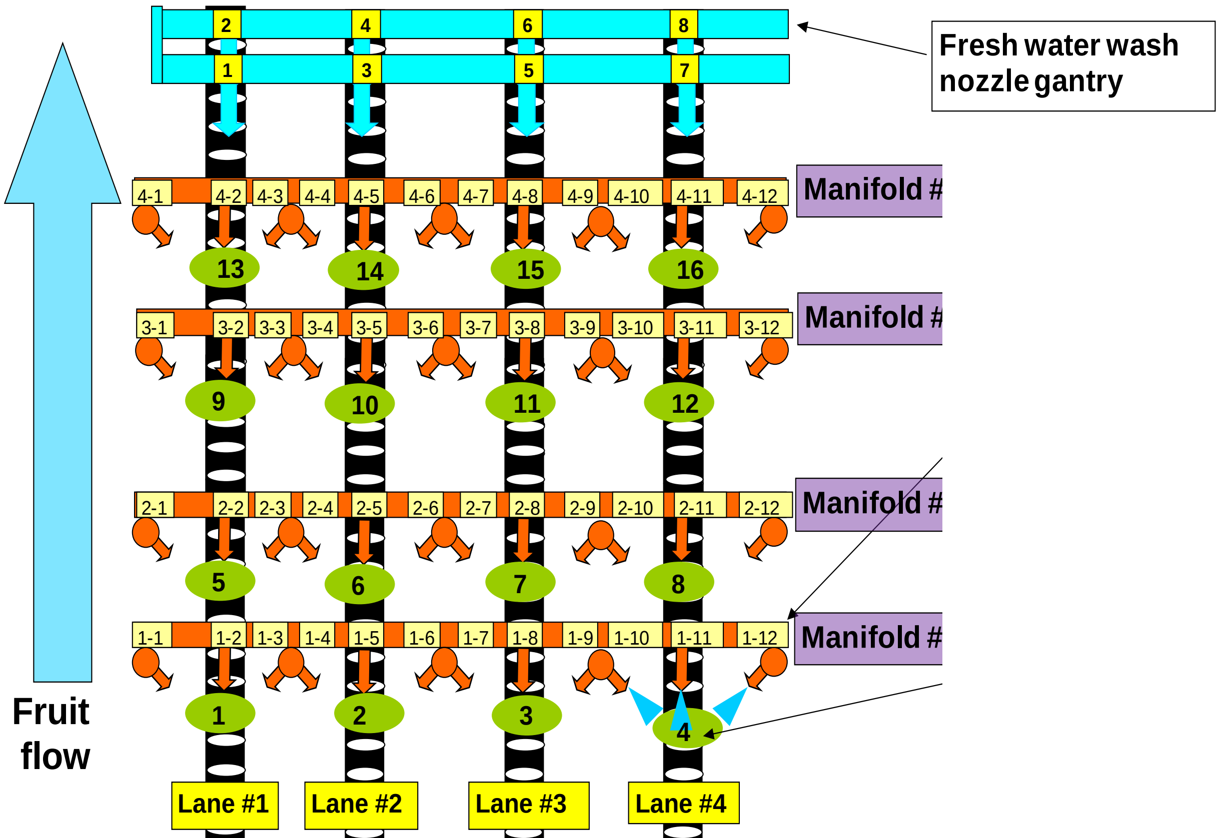
Access

Light

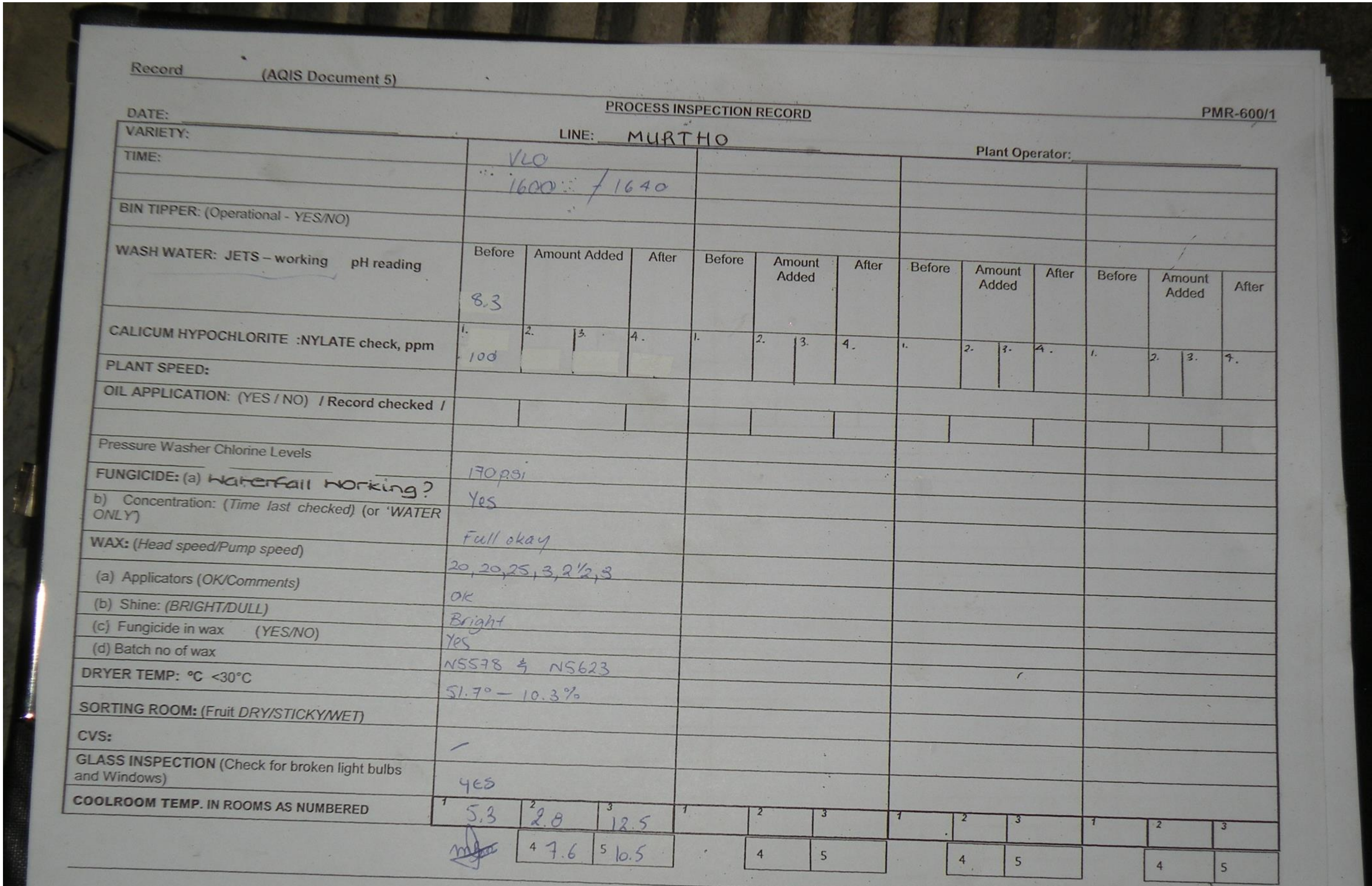
Safety

Systems

1. Labelling / plan of machine
2. Log of checking / maintenance



Systems – Log sheet



Record (AQIS Document 5)

PROCESS INSPECTION RECORD

PMR-600/1

DATE:

LINE: MURTHO

Plant Operator:

VARIETY:	VLO			
TIME:	1600 / 1640			
BIN TIPPER: (Operational - YES/NO)				
WASH WATER: JETS – working pH reading	Before: 8.3 / Amount Added / After	Before / Amount Added / After	Before / Amount Added / After	Before / Amount Added / After
CALICUM HYPOCHLORITE :NYLATE check, ppm	1. 100 / 2. / 3. / 4.	1. / 2. / 3. / 4.	1. / 2. / 3. / 4.	1. / 2. / 3. / 4.
PLANT SPEED:				
OIL APPLICATION: (YES / NO) / Record checked /				
Pressure Washer Chlorine Levels	170psi			
FUNGICIDE: (a) Waterfall working?	Yes			
b) Concentration: (*Time last checked*) (or '*WATER ONLY*')	Full okay			
WAX: (*Head speed/Pump speed*)	20, 20, 25, 3, 2½, 3			
(a) Applicators (*OK/Comments*)	OK			
(b) Shine: (*BRIGHT/DULL*)	Bright			
(c) Fungicide in wax (*YES/NO*)	Yes			
(d) Batch no of wax	NS578 & NS623			
DRYER TEMP: °C <30°C	51.7° — 10.3%			
SORTING ROOM: (Fruit *DRY/STICKY/WET*)				
CVS:	—			
GLASS INSPECTION (Check for broken light bulbs and Windows)	yes			
COOLROOM TEMP. IN ROOMS AS NUMBERED	1: 5.3, 2: 2.8, 3: 12.5, 4: 7.6, 5: 10.5	1 / 2 / 3 / 4 / 5	1 / 2 / 3 / 4 / 5	1 / 2 / 3 / 4 / 5

General

- Similar washing systems
- Generally operate acceptably
- Lots of blocked nozzles
- Need for greater monitoring / checking
- Some significant differences (pressure, nozzles)

Recommendations

<u>1. Packhouse procedures</u>

- Better filtration
- Carry out optimisation of the existing systems
- Instigate regular monitoring and maintenance systems
- Invest in ancillary systems (access gantries, prewash, post-wash rinse)
- Train operators

Recommendations

2. Best practice manual

- Draft available to look at
- Input wanted
- Suggest a standard design?


Citrus Australia
SARDI
RESEARCH AND DEVELOPMENT
Horticulture Innovation Australia
Plant & Food RESEARCH
RANGAHAU AHUMĀRA KAI

PFR SPTS No. 11171

Best-practice user manual for Citrus high pressure washers

Woolf A, Jamieson L, Taverner P, Olsson S, Page N, Griffin M, Chhagan A, Redpath S

February 2015

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- Citrus Australia – Dr Andrew Harty
- Horticulture Innovation Australia
- Packhouse staff

Plant & Food RESEARCH
RANGAHAU AHUMĀRA KAI

The New Zealand Institute for Plant & Food Research Limited

Allan.Woolf@plantandfood.co.nz