Apple washers: removal of insect pests and contaminants from export apples

D.J. Rogers¹, A.B. Woolf², R.M. McDonald³, L.M. Cole¹,
S. McLeod⁴, P. Brookfield¹, J. Robertson¹ and J.T.S. Walker¹

¹*The New Zealand Institute for Plant & Food Research Limited (PFR), Hawke's Bay Research Centre, Private Bag 1401, Havelock North 4157, New Zealand*

²*PFR, Private Bag 92169, Auckland, New Zealand*

³*PFR, Private Bag 3123, Hamilton, New Zealand*

⁴*Mr Apple, PO Box 42, Whakatu, Hawkes Bay 4161, New Zealand*

Corresponding author: dave.rogers@plantandfood.co.nz

Abstract Export markets require high-quality fruit, free from insects and mites of quarantine significance, and with minimal or no agrichemical residues. This presents a challenge for New Zealand's pipfruit sector when developing novel pest management systems to meet these market requirements. Brush-bed apple washers are an important component of a systems approach to remove insects and mites in packhouses before fruit are exported. A new apple washer using multi-nozzle rotors significantly reduced the incidence of insects and mites on apples. Weathered residues of kaolin and hydrated lime were similarly reduced by this apple washer. Assessment of fruit quality after apple washing and cool storage did not identify any commercially significant quality issues on the three apple cultivars examined. Apple washer design to optimise pest removal from all locations on the fruit is discussed.

Keywords apple washers, apple pests, insect removal, quarantine pest.

INTRODUCTION

New Zealand's apple sector faces many sanitary and phytosanitary challenges to maintain access to more than 65 overseas markets for export fruit (Walker et al. 2015). Integrated Fruit Production (IFP) was developed in the 1990s to address market concerns over pesticide use and sustainability (Batchelor et al. 1997; Walker et al. 1998). IFP uses a systems approach for pest management that integrates chemical and biological approaches to reduce the likelihood of quarantine pests, while producing apples in the most sustainable way.

A new approach was required when European supermarkets developed environmental and food compliance programmes, which led to the implementation of the apple sector's very successful low residue programme "Apple Futures" (Kaye-Blake & Zuccollo 2012; Walker et al. 2015). Using apple washers for the postharvest removal of insects and mites, as well as beneficial parasitoids and predators, is an important component within a systems approach that seeks to remove organisms on export fruit and thereby facilitate market access (IPPC 2014). An additional benefit identified by

the Apple Futures programme was that washers also assist with the removal of water-soluble pesticide residues on fruit (J.T.S Walker, Plant & Food Research Ltd, unpublished data). The apple sector introduced “Honiball™” type washers (originally manufactured in New Zealand by Fruit Handling Systems Ltd (now Compac™), but copied by many manufacturers) into packhouses primarily to remove mealybugs in the late 1990s (Woolf et al. 2015). This washer uses multiple overhead manifolds to spray water directly on to the fruit on a rotating brush bed at pressures between 80 and 120 psi for 10–20 seconds (Jamieson et al. 2010; Woolf et al. 2015).

Recently, Compac™ produced new washer equipment (Rotary high pressure apple washer, Compac Sorting Equipment, Hastings, New Zealand) that uses rotating nozzles without a brush bed (Figure 1). This washing method was first used commercially in late 2000s by the avocado sector for the removal of leafroller eggs on fruit (Woolf et al. 2015). Research in 2011 showed that a significant improvement in the removal of quarantine insects could be achieved using a rotary washer designed for apples (D.J. Rogers, Plant & Food Research Ltd, unpublished data). This rotary washing equipment effectively exposes most parts of each fruit to flat fan jets in a very short time because the rotor is

Figure 1 An experimental Compac washer rotor (four-nozzles) as used in preliminary trials on a single lane test-bed conveyer. The rotor incorporated a sealed bearing and was rotated by the force of the water being sprayed from the angled nozzles

spinning at about 1000 rpm (Woolf et al. 2015). It achieves a high throughput of fruit (up to 160 fruit/lane/minute) with better pest removal than the Honiball system (Woolf et al. 2015). A prototype commercial unit (eight lanes) was installed at the Mr Apple pack house in Havelock North, which was used for this study conducted in the 2012 and 2013 apple seasons. In this paper we report on the effectiveness of this new rotary washer at removing common pests and residue contaminants that can be found on export apples.

MATERIALS AND METHODS

Apple washer

The Compac™ rotary apple washer utilises rapidly rotating nozzles to deliver water jets to apples rotating on conveyer roller cups (Figure 1). The washer specifications were provided previously by Woolf et al. (2015). For all washer trials reported here, the washer was operated with an elevator speed of 160 rods/min, a nozzle manifold pressure of 300 psi, fruit rotations set at 50 Hz with two rotors per lane. Trials in the 2012 apple season using insect pests (mealybugs, San José scale, European red mite) and fruit treatments kaolin (Surround® 95% kaolin, Engelhard Corporation, Iselin USA) and hydrated lime (calcium hydroxide, Websters hydrated lime Co., Havelock North NZ) combined a six-nozzle and a four-nozzle rotor on each lane. Trials during the 2013 apple season using insect pests light brown apple moth and woolly apple aphid used two six-nozzle rotors/lane. The species name for each pest is given below.

Citrophilus mealybug, Pseudococcus calceolariae (Maskell)

‘Braeburn’ apples were artificially-infested with *P. calceolariae* mealybug by exposing the fruit to wandering *P. calceolariae* crawlers for about 1 month. Prior to washing, all apples were inspected by eye for the presence of mealybugs. Three replicates, each of 40 mealybug infested apples, were randomly assigned to be washed using the rotary apple washer or to remain unwashed (untreated

dry control). After the apples were washed and then left to dry overnight, they were inspected using a 6-times microscope for the presence of mealybugs and mealybug trash (wax and mealybug insect parts). Mealybugs were counted and recorded in the stem, calyx region and cheek of the apple.

San José scale, *Quadraspidiotus perniciosus* (Comstock) (SJS)

‘Red Delicious’ apples naturally-infested with SJS were harvested and cool-stored for about 6 weeks until required. Prior to washing, all the apples were individually inspected for the presence of SJS.

Three replicates each of 30 scale-infested apples were randomly assigned to be washed using the apple washer or to remain unwashed (untreated dry control). After the apples were washed and left to dry overnight, they were inspected using a 6-times microscope. Any SJS present on the fruit were counted and recorded according to their location in the stem, calyx regions or on the cheek.

Woolly apple aphid, *Eriosoma lanigerum* Hausmann (WAA)

‘Fuji’ apples naturally infested with WAA were washed using the apple washer or remained unwashed (untreated dry control). Three replicates of approximately 60 aphid infested apples each were treated. Aphids, mummies (aphids parasitized by *Aphelinus mali*), wax material, miscellaneous insect parts and sooty mould were all present on the apples before washing. After washing, the apples were left to dry overnight in ambient temperatures. The presence of WAA and associated trash was recorded for different regions of each apple.

European red mite, *Panonychus ulmi* (Koch) (ERM)

‘Granny Smith’ apples naturally infested with ERM overwintering eggs, were randomly assigned to be washed using the apple washer or remained unwashed (untreated dry control), with $n = 78$ and 81 apples respectively. Each apple was considered a replicate. After the

mite-infested apples were treated and dried, they were inspected by 6 to 12-times microscope for ERM eggs, which were counted and recorded.

Lightbrown apple moth eggs, *Epiphyas postvittana* (Walker) (LBAM)

‘Red Delicious’ apples were artificially infested with LBAM eggs, using adult moths provided by the insect rearing group (Plant & Food Research, Auckland). Prior to washing, all apples were numbered, the outlines of egg rafts (batches of eggs) were marked with a permanent marker pen and counted, then randomly allocated to treatments. Treated apples ($n = 30$ per treatment) were washed on either lane 1, 2 or 3 of the washer and a control group of infested apples remained unwashed but was subjected to the same handling as the treated apples. After washing they were left to dry overnight and the remaining egg rafts and individual eggs were counted by 6 to 12-times microscope.

Kaolin-treated apples

‘Granny Smith’ apples were provided by Mr Apple. The apples had been sprayed with kaolin (2.5 kg /100 litres) when on the trees to prevent sunburn and then weathered, leaving a white hard-to-remove kaolin clay residue over all of the fruit, with greater amounts within the stem and calyx regions. Three replicates of ca 100 fruit were washed using the rotary apple washer and compared with an unwashed control. The fruit were left to dry overnight and then assessed for the visual presence of kaolin residue in the stem and calyx regions. The percentage of the cheek of each apple that had kaolin remaining was estimated to the nearest 10%, based upon visual presence or absence of the product.

Hydrated lime

‘Scilate’/Envy™ apples that had season-long applications of hydrated lime (3.2 kg /100 litres, 8 times from bud burst until late February) applied as part of disease control trial were washed and assessed, as described for the kaolin trial above.

Three replicates of 40 fruit were washed and the removal of hydrated lime was compared with the equivalent number of untreated (control) fruit.

Fruit quality

Fruit quality was assessed using three commercial apple cultivars each sourced from five different orchards. Fruit were stored in a commercial cool store for one month at 0.5°C, then washed with the rotary washer. After treatment, fruit were returned to the same cool store in packed cartons. After two ('Royal Gala' and 'Braeburn') or three months ('Sciros'/Pacific Rose™), the fruit were removed from the cool store and placed at 20°C for one week before the quality was assessed. Fruit were assessed for weight loss by weighing subsamples of 50 fruit per carton. Skin greasiness was assessed by tactile feel on a scale of 0–3 where 0 = none, 1 = slight, 2 = moderate, 3 = severe. Flesh firmness (kgf) was assessed using a fruit texture analyser (GÜSS, model GS14, South Africa) fitted with an 11.1-mm diameter probe. All fruit (~ 60 cartons x 100 fruit) were first inspected visually for external disorders followed by at least three equatorial cuts per fruit for internal assessment. The percentage of fruit that was sound (i.e. no disorders), and the incidence of all other disorders, were recorded for each carton of fruit. Shrink in 'Braeburn' and 'Sciros' was categorised according to whether it was noticeable by touch only (skin

could be wrinkled by applying light pressure from opposite sides on the curve of the stem bowl toward the stem) or visible, and whether there was any associated skin discolouration.

Statistical analyses

Minitab (Minitab® 16.1.1 © 2010 Minitab Inc.) was used to calculate means, standard errors and ANOVA. Model adequacy checks were carried out by examining various plots (scatter, histograms and normal probability) of the residuals. The number fruit treated in each replicate varied between insect species and products because most of the fruit were collected directly from the field.

RESULTS

The rotary apple washer effectively removed mealybug and associated trash, compared with the untreated. The washer was particularly effective in removing this pest from the calyx (Table 1). Almost 76% of the apples were completely free of live mealybug and any associated trash (wax and mealybug insect parts) after washing. Insects and contaminants in the stem region were harder to remove than when these were located in the calyx.

The washer removed more SJS on all areas of the fruit compared with the control (Table 1). Almost all SJS was removed from the cheek, but fewer SJS were removed from the stem and calyx areas. Despite the new apple washer removing a large

Table 1 Mean number of citrophilus mealybug and San José scale remaining per apple, and percentage of apples with woolly apple aphid or insect trash, at each location after washing with a Compac® rotary apple washer, compared to an unwashed control.

Pest	Treatment	Stem	Calyx	Cheek	Trash Stem (%)	Trash Calyx (%)	Trash Cheek (%)	% Clean
Mealybug ¹	Control	1.12	1.08	-	65.8	55.8	-	0
	Washed	0.092*	0.017*	-	15.0*	1.67*	-	75.8*
San José Scale ¹	Control	2.81	7.53	3.57	-	-	-	1.1
	Washed	0.82*	1.09	0.078*	-	-	-	33.3*
WAA ²	Control	94.0%	11.7%	-	82.7	27.4	97.3	0
	Washed	10.0%*	0%*	-	41.9*	1.26*	54.8*	24.2*

¹ Treated in 2012, ² Treated in 2013; “-” denotes not measured; and an * indicates that the washed value is significantly different (P<0.05) to the untreated control for each insect species.

Table 2 The percentage of apples with Surround® or hydrated lime residues present in the stem or calyx region of the fruit, and the mean estimated percentage area of the cheek with residue present.

Product	Treatment	Stem	Calyx	% Cheek	% Clean
Kaolin	Control	97.5	96.8	79.0	0
	Washed	46.3*	4.6*	3.68*	25.7*
Hydrated lime	Control	96.7	98.3	79.4	0
	Washed	21.9*	24.4*	33.5*	0.83

An * indicates that ‘washed’ is significantly different ($P<0.05$) to the untreated control for that product.

Table 3 The percentage of clean apple fruit and lightbrown apple moth egg rafts presence before and after washing on the Compac® rotary apple washer.

		Lane 1	Lane 2	Lane 3	Control
Clean fruit (%)		80	80	87	0
Eggs remaining / raft (mean ± SEM)		0.28 ± 0.12	0.75 ± 0.39	0.04 ± 0.02	15.6 ± 1.3
Calyx rafts	Before	41	41	49	55
	After	1	1	4	52
	% remaining	2.43	2.43	6.12	94.5
Cheek rafts	Before	198	171	147	151
	After	1	3	1	105
	% remaining	0.51	1.75	0.68	69.5
Stem rafts	Before	34	43	28	36
	After	5	5	1	32
	% remaining	14.7	11.6	3.57	88.9

number of SJS, this only resulted in about 33% of the apples being completely free of SJS (clean).

Removal of woolly apple aphid (aphids and mummies) using the apple washer was very effective from all parts of the apple, especially from the calyx where no insects were left (Table 1). WAA trash (white wax and or sooty mould) was reduced to nearly 1% in the calyx region of apples, but it was only decreased by about half for the stem and cheek locations (42 and 55% of apples with trash remaining).

The rotary washer reduced the percentage of apples with residual kaolin at all locations compared with the untreated apples (Table 2). Only 4.6% of fruit had kaolin remaining in the calyx compared to 96.8% for untreated apples, suggesting that the apple washer cleaned this region particularly well.

Weathered hydrated lime residues resulting from season-long applications (not a typical commercial practice) were more difficult to

remove than kaolin (Table 2). Almost all the washed fruit still had visible traces of hydrated lime present, although visually the washed fruit appeared much cleaner. In contrast to other insects and contaminants, the cheek region was difficult to wash and still had on average nearly a third of the region covered with traces of hydrated lime.

Significantly fewer ERM eggs remained on the apples after washing (7.8 ± 1.3 , Mean $\pm$ SEM) compared with the untreated control (18.4 ± 3.1). However, the percentage of clean apples (i.e. those with no ERM eggs) only increased from 2.5 to 16.7%, indicating it was difficult to remove all ERM eggs from the fruit.

The rotary washer removed the majority of LBAM eggs from all regions of the fruit (Table 3). The stem appeared to be the most difficult area of the apple to remove egg rafts from, followed by the calyx, with the cheek surface the easiest. There were few differences among the three

washer lanes and so they can be considered replicates rather than different treatments. There was a reduction in the number of egg rafts present after the control fruit were handled, particularly when the rafts were on the apple cheek.

Fruit quality

Generally fruit quality parameters (flesh firmness, colour, skin greasiness, weight loss and shrivel) were not adversely affected by the new high-pressure washer, but some cultivar-specific issues were observed at low levels. For example, the incidence of calyx browning in 'Royal Gala' was higher in fruit treated with the rotary washer, but not at a commercially-significant severity. Core rot incidence in the open calyx cultivar 'Sciros' was slightly higher in fruit treated by the new high-pressure washer.

DISCUSSION

The Compac rotary apple washer significantly reduced pests and contaminants from all regions of the apple compared to untreated apples, with the exception of SJS in the calyx region. For SJS in the calyx there was a large reduction in the number of SJS present in the calyx region compared to untreated apples, but this was not statistically different because of the variability in scale numbers between fruit. It was difficult to remove all ERM eggs and hydrated lime residues from the fruit and so the percentage of clean fruit was not significantly different to the untreated apples. ERM eggs adhered well on apples. Because apples with hydrated lime and kaolin were examined under magnification, small traces were detected. However, many apples where hydrated lime or kaolin was observed still would have been acceptable for export and visually appeared much cleaner than the control fruit. Furthermore, heavy infestation of pests on apples for the purpose of these experiments biased our results so they were not representative of commercial lines of fruit that typically have very low infestation rates. Thus, our fruit represented a

greater challenge for the washer because of the high number /coverage of pests /contaminants, and also because of the high percentage of infested fruit.

This study was focused on removal of the pest rather than killing the organism to eliminate the quarantine threat. Page-Weir et al. (2015) discussed how removal can be preferable because it removes all trace of the organism, thereby facilitating acceptance of the product by official inspection agencies. For some species such as scale insects and mite eggs, determining if they are dead or live can be difficult and so removal is more desirable.

To be effective, apple washers must direct enough force via the water jet to those parts of the fruit where the pest or contaminant is likely to be present. However, the water jets must not damage the apples. Furthermore, the processing speed needs to be fast to be commercially practical. Apples are challenging to wash compared with avocados because they have a calyx and stem cavity where pests are more likely to be present and their shape greatly varies between cultivars (round versus long apples). The Honiball washer relies on a random fruit movement to orientate the calyx and stem regions towards the overhead nozzles and therefore these regions are more likely to be missed on a 'long' fruit that rotates on the stem-calyx axis (Woolf et al. 2015). The Compac rotary washer overcomes this problem by separating the fruit on rotating roller-cups, thereby allowing the angled rotating jets to have greater access to the fruit (Figure 1). Fast rotating multiple jets on this washer also increase the probability of removal by increasing the number of "hits", while enabling fast conveyer speeds for efficient throughput.

The effect of washing on fruit quality was assessed using the following cultivars; 'Braeburn' because it is considered to be at higher risk of shrivel; 'Sciros' because it is at higher risk of core rots; 'Royal Gala' because it makes up >30% of export production. Fruit were selected from five different commercial orchards to allow for orchard variability and 'Sciros' were stored for an additional month to allow greater expression of rots. Ideally, fruit quality trials would have been conducted in successive seasons. However, because this trial

did not highlight any quality issues of commercial significance, the apple industry representatives decided that monitoring using packhouse quality control procedures was sufficient.

The Compac rotary apple washer significantly reduced the incidence of pests and trash present on the trial fruit that had been deliberately infested with large numbers of pests. When used on commercial export fruit that already has a very low pest incidence, this washer would further reduce pest incidence, potentially leading to improved market access for New Zealand apples. Currently, there are two Compac washers being used commercially in apple pack houses. No further development is planned for this washer at this time. Future research could focus on pre-treatment dips to facilitate the removal of hard-to-dislodge pests such as European red mite eggs.

ACKNOWLEDGEMENTS

The authors thank Pernell Hartley, Warren Temperton, Dennis Whiting, Brad Duff and Barbara Alexander from Mr Apple for their contributions. Tara Taylor, Rachael Horner and Natasha Agnew (Plant & Food Research Ltd) provided valuable technical support with assistance from Jan Cox and Dawn Hope (Fruition Horticulture). Monika Walter (Plant & Food Research Ltd, Nelson) provided apples with hydrated lime, and Hans Dovendans (Crasborn Group Ltd) provided fruit infested with European red mite eggs. Lisa Jamieson and Natalie Page-Weir (Plant & Food Research Ltd, Auckland) made valuable editorial comments on this paper. This work was funded by PNZI and MBIE funding from the Market Access programme (C06X0709).

REFERENCES

Batchelor TA, Walker JTS, Manktelow DWL, Park NM, Johnson SR 1997. New Zealand integrated fruit production for pipfruit - charting a new course. Proceedings of the 50th New Zealand Plant Protection Conference: 14-19.

IPPC 2014. The use of integrated measures in a systems approach for pest risk management. In. FAO, Rome, Italy, IPPC. Pp. 40.

Jamieson LE, Page-Weir NEM, Chhagan A, Olsson S, Connolly PG 2010. High pressure water-washing to remove pests from capsicums. New Zealand Plant Protection 63: 118-122.

Kaye-Blake W, Zuccollo J 2012. The economic impact of the Apple Futures programme. In The New Zealand Association of Economists. Palmerston North, New Zealand. Pp. 15.

Page-Weir NEM, Jamieson LE, Redpath SP, Griffin MJ, Olsson SR, Chhagan A, Biswas P, Woolf AB 2015. High-pressure-washing to manage insect infestations on capsicums. New Zealand Plant Protection 68: 348-352.

Walker JTS, Park NM, Butcher MR 2015. Apple Futures: New Zealand's low pesticide residue apple production programme. New Zealand Plant Protection 68: 282-290.

Walker JTS, Wearing CH, Bradley SJ, Shaw PW, Burnip GM, Tomkins AR, Richardson C, Hodson AJ 1998. Integrated fruit production (IFP) for New Zealand pipfruit: evaluation of pest management recommendations. Proceedings of the 51st New Zealand Plant Protection Conference: 166-172.

Woolf A, McDonald R, Rogers D, Olsson S, Redpath S, O'Donoghue E, Cate L, Griffin M, Page-Weir N, Chhagan A, White A, Walker JTS, Jamieson L, Kagy V, Mille C 2015. Advances in application of high pressure washing to enhance market access. Acta Horticulturae: 385-390.