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Effect of high-pressure hot-water washing treatment on fruit quality, insects, and disease in apples and pears
Part III. Use of silicone-based materials and mechanical methods to eliminate surface pests

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Abstract

Surface arthropods on pome fruits can cause export problems and disrupt commercial markets. Eliminating insects and mites on the packing line would be the last opportunity to provide for pest-free produce. In this study, an experimental packing line was used to evaluate techniques using different surfactant baths, pressurized water sprays, and styles of rotating brushes to remove field-collected and laboratory-reared grape mealybug, *Pseudococcus maritimus* (Ehrhorn) (Homoptera: Pseudococcidae), the diapausing two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) and the woolly apple aphid, *Eriosoma lanigerum* (Hausman) (Homoptera: Aphididae). The organosilicone Silwet L-77 was no more effective than a silicone-based food grade defoamer in aiding removal. Mechanical methods, such as the style of rotating brushes and pressurized sprays, were significantly effective in removing surface arthropods. No improvement in removal occurred when pressure was increased beyond 420 kPa. These techniques can be easily adapted to commercial facilities and will reduce the incidence of surface arthropods on marketed fresh fruits.
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1. Introduction

The presence of surface arthropods (spider mites, mealybugs, scale, lepidopteran larvae, and mite eggs) on packed tree fruits has been a concern for many export markets. Inclusion of foliage in the fruit cartons also increases suspicion of possible arthropod hitchhikers. Quarantine pests are not tolerated and non-quarantine pests cannot exceed 2% infestation unless stated otherwise by the importing country (APHIS, 2005). However, state grades of “Fancy” and “Extra Fancy” can exceed federal standards and these must be free of insects (e.g., Washington apples (Anon., 2003)).

The organosilicone surfactant, Silwet L-77 has shown great promise in killing spider mites (Cowles et al., 2000; Purcell and Schroeder, 1996; Tipping et al., 2003), which have become an increasing quarantine concern. Such a surfactant can be added to the spray water or serve as a dip along the packing line. However, Silwet is not currently approved as a postharvest treatment and regulatory compliance for its use will need to be negotiated. Other silicone-based materials, including food grade defoamers and emulsifiers, may be as efficient in removing surface arthropods. Screening these materials is necessary for identifying potential cleaning agents.

The removal of mites and other surface arthropods may be enhanced by the use of a mechanical surface cleaning system, such as high-pressure water sprays and/or rotating brushes (Walker et al., 1996; Whiting et al., 1998; Whiting and

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Jamieson, 1999). Many warehouses are using high-pressure washing to clean apples and pears, and these systems are becoming more popular as the use of Surround® (Kayolin clay) increases. Estimation of the effects of high-pressure washing on pear fruit quality and decay removal on winter pears indicates that a heated contact loop is essential for controlling the spread of decay microorganisms within the recycled water sprays. The temperature and pressure of the spray can greatly impact market quality of the pears.

The objectives of this study were to determine the removal and lethal effects, on various surface arthropods, of food grade silicone-based materials that are suitable for commercial packing lines and to evaluate efficacy in combination with high-pressure water sprays and brushes with different stiffness. The global project consists of five sections. This section describes the removal of surface pests. Part I (Bai et al., 2006) describes the system and the effect of the system on fruit quality; Part II (Spotts et al., 2006) discusses the effect of the system on fruit decay and spore buildup within the system; and Part IV (Neven et al., 2006) discusses the effect of the system on removing surface arthropods.

2. Materials and methods

2.1. Experimental design

Tests were conducted between December 2001 and April 2004 to determine removal of various targeted surface arthropods on a simulated packing line at the Oregon State University Experiment Station in Hood River, Oregon. The surface arthropods tested were the grape mealybug, *Pseudococcus maritimus* (Ehrhorn) (Homoptera: Pseudococcidae), the diapausing two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) and the woolly apple aphid, *Eriosoma lanigerum* (Hausman) (Homoptera: Aphididae). Each season two bins of 'd'Anjou' pears were obtained from a commercial packinghouse in Hood River, Oregon. The pears were examined with a dissecting microscope at the Wapato laboratory and those pears found to be field infested with diapausing two-spotted spider mites were set aside. In the 2002 season, a bin of 'Pink Lady' apples, obtained from a Wapato commercial grower, was infested with both grape mealybugs and woolly apple aphids. In some tests 'Fuji' or 'Red Delicious' apples were infested with grape mealybugs, obtained from a colony reared on acorn squash at the Wapato laboratory.

All infested fruits were tested on the experimental packing line. The packing line contains a high-pressure hot-water system which consists of a boiler, hot-water mixing tank, contact loop, heat exchanger, high-pressure pump, spray tank, high-pressure spray manifold and low-pressure fresh-water spray manifold (Bai et al., 2006). Treatments performed used different combinations of water spray temperatures (none, 40 and 50 °C), spray pressures (0, 210, 420, 560, 700, and 840 kPa) and Silwet (0, 0.2 and 0.3%) (Helena Chemical Company, Memphis, TN), a silicone defoamer (0, 0.01 and 0.1%) (Ivanhoe Industries Inc., Mundelein, IL), and two styles of washing brushes (Table 1). The brushes were 124 mm in diameter with either 0.38 mm (firm) or the newer 0.30 mm (soft) PEC bristles (American Brush Company, Portland, OR). Chemical dips were applied by immersing fruits for 60 s in a plastic tub holding 20 L of dip solution. The fruits were hand-placed onto the packing line, just after the dump tank, and processed through the high-pressure hot-water (HPHW) wash manifold, and removed just before the dryer section. A treatment replicate was considered as a separate run through line. Infested fruits were treated at the same time as fruits used in the quality tests (Bai et al., 2006). Controls were untreated fruits held at room temperature. After treatment, the fruits were examined at the Wapato laboratory to determine the number of remaining arthropods.

Table 1
Treatment combinations for five tests evaluating procedures to remove surface arthropods from an experimental packing line

Treatment	Test no./year				
	1/2001	2/2002	3/2003	4/2004	5/2004
Spray temperature (°C)	None	None	None	None	None
	40	30	10	10	10
	50	40	27	27	27
Spray pressure (kPa)	None	None	None	None	
	210	210	420	420	420
	560	560	–	–	560
	–	–	–	–	700
	–	–	–	–	840
Chemical	Water	Water	Water	Water	Water
	Silwet 0.2%	Silwet 0.3%	Silwet 0.3%	Defoamer 0.01%	Defoamer 0.01%
	Silwet 0.3%		Defoamer 0.1%	Defoamer 0.1%	Defoamer 0.1%
Brush	Firm(A)	Firm(A)	Firm(A)	Firm(A)	Soft(B)
			Soft(B)	Soft(B)	

2.2. Test 1

The targeted pest was the diapausing two-spotted spider mite located in the calyx end on field-infested 'd'Anjou' pears. The pears were examined by using a dissecting microscope to determine total number of mites. Fruits were randomly set into treatment replicates, each replicate having a minimum of 15 mites. The total number of mites along with a treatment code for identification was recorded on each fruit. Test combinations consisted of using water spray temperatures (none, 40 and 50 °C), pressures at (none, 210 and 560 kPa) with Silwet concentrations (0.0, 0.2 and 0.3%). All treatments were made using the firm (A) brushes. Each treatment had three replicates.

2.3. Test 2

The targeted pests were the diapausing two-spotted spider mite on field-infested 'd'Anjou' pears, and the woolly apple aphid and grape mealybug on field-infested 'Pink Lady' apples, and grape mealybug on laboratory-infested 'Red Delicious' apples. 'Red Delicious' apples were infested in the laboratory with grape mealybugs by transferring 20 insects from acorn squash onto the calyx end of each apple using a dissecting microscope; each treatment replicate had two apples, for a total of 40 insects per replicate. Field-infested 'd'Anjou' pears were examined by using a dissecting microscope to determine total number of arthropods present, and were randomly set into treatment replicates with each replicate having a minimum of 30 mites. The numbers of grape mealybugs and woolly apple aphids on field-infested 'Pink Lady' apples were determined by using a dissecting microscope and placed into size categories where 0 = none, 1 = 1–10 insects, 2 = 11–20 insects, 3 = 21–30 insects, 4 = 31–40 insects and 5 = 41 or more insects. Test combinations consisted of using water spray temperatures (none, 40 and 50 °C), pressures at (none, 210 and 560 kPa), solutions (water, 0.3% Silwet), and only the style A washing brush.

2.4. Test 3

This test compared the efficacy of two silicone materials to increase removal. The targeted pests were the diapausing two-spotted spider mite on field-infested 'd'Anjou' pears and the laboratory-infested grape mealybug on 'Fuji' apples. Artificial infestation of apples was done as described in Test 2. The field-infested 'd'Anjou' pears had a minimum of 30 mites per treatment replicate. Test combinations consisted of using water spray temperatures (10 or 27 °C), pressures (none or 420 kPa), solutions (water, 0.3% Silwet, or 0.1% silicone defoamer), and either firm (A) or soft (B) brushes.

2.5. Test 4

This test compared the efficacy of different concentrations of the same silicone material for removal. The targeted pests were the diapausing two-spotted spider mite on field-infested 'd'Anjou' pears and the grape mealybug on laboratory-infested 'Fuji' apples. Each apple was infested with 15 individuals as describe in Test 2, for a minimum of 30 insects per treatment replicate. The field-infested pears had a minimum of 50 mites per treatment replicate. Test combinations consisted of using water spray temperatures (10 or 27 °C), pressures (none or 420 kPa), solutions (water, 0.01 or 0.1% defoamer). The same two washing brush styles were used as in Test 3. Each treatment had three replicates.

2.6. Test 5

The targeted pest was the grape mealybug on laboratory-infested 'Red Delicious' apples. Each apple was infested with 15 insects as before for a minimum of 30 insects per replicate. Test combinations consisted of using water spray temperatures (10 or 27 °C), pressures (none, 420, 560, 700 or 840 kPa), solutions (water, 0.01 or 0.1% defoamer) and only the soft (B) brushes. There were three replicates for each treatment.

2.7. Statistical analysis

Data were organized by using Excel 2002® worksheets (Office 10, Microsoft Corp., Redmond, WA). Linear correlation tests were done using the CORREL function in Excel. Other data were analyzed using SAS® (SAS Institute, Cary, NC). PROC MEANS was used for calculating univariate statistics, such as means and standard error. Because of the lack of homogeneity among the variances, non-parametric tests were used to determine significant differences by first arranging data according to rank by using PROC RANK, then performing an analysis of variance by using PROC GLM. This approach is equivalent to a Wilcoxon rank sum test for two samples and the Kruskal–Wallis *k*-sample test for more than two samples (Zolman, 1993).

3. Results

3.1. Test 1

The rate of removal of diapausing two-spotted spider mites increased with the addition of a surfactant and with the pressure sprays (Table 2). The higher pressure generally removed more than the lower one, but the retention rates were not significantly different among the temperatures and surfactant concentrations. The lowest retention rates were achieved with the higher concentration of surfactant; however, there was no significant difference between the lower concentration of surfactant or water at the same temperature and pressure.

3.2. Test 2

The use of a surfactant, spray water pressure and spray water temperature, in combination or singly, all contributed

Table 2
Percent retention of diapausing two-spotted spider mites after different concentrations of surfactant (Silwet) baths at different temperatures and pressures of water sprays

Bath concentraton[a] (%)	Spray		% Retained (mean ± S.E.M.[b])	Significance[c]
	Temperature (°C)	kPa		
0.0	None	None	55.6 ± 8.9	–[d]
0.0	40	210	22.2 ± 12.1	*
0.0	40	560	19.4 ± 11.1	*
0.0	50	210	25.0 ± 25.0	ns
0.0	50	560	9.4 ± 5.8	*
0.2	40	210	21.2 ± 16.9	ns
0.2	40	560	18.2 ± 18.2	ns
0.2	50	210	9.1 ± 5.3	*
0.2	50	560	9.1 ± 9.1	*
0.3	40	210	6.1 ± 3.0	*
0.3	40	560	0.0 ± 0.0	**
0.3	50	210	3.0 ± 3.0	*
0.3	50	560	6.1 ± 6.1	**

[a] Concentraton of Silwet.
[b] S.E.M. = standard error of mean.
[c] Significant difference from control using equivalent to a Wilcoxon rank sum test (df = 4); *: <0.05, **: <0.01, ns: not significant.
[d] Control.

to the reduction of surface arthropods (Table 3). The 0.3% Silwet dip was significantly more effective in removing woolly apple aphid under 560 kPa sprays at 30 and 40 °C (both $F_{df=4} = 36$, $P < 0.01$). Casual observations following treatment suggested that this material dissolved the waxy coating surrounding the insects. The Silwet dip was more effective against the diapausing spider mites than the water dip at each of the spray pressures. The retention rates between treated field and laboratory-reared grape mealybugs differed only for water dips followed by 40 °C sprays at 560 kPa ($F_{df=4} = 13.5$, $P < 0.05$), and for 0.3% Silwet dips followed by no pressure sprays ($F_{df=4} = 15.4$, $P < 0.05$) or 40 °C sprays at 210 kPa ($F_{df=4} = 15.4$, $P < 0.05$). Laboratory-infested grape mealybugs were more susceptible to removal than field-infested grape mealybugs.

3.3. Test 3

Two-spotted spider mites were slightly more susceptible than mealybugs to removal by the treatment procedures (Table 4). Among the surfactants, the defoamer tended to perform better than Silwet for removing both surface arthropods. Brush B tended to be more effective than Brush A in removing the mites, and Brush A tended to be more effective than Brush B in removing mealybugs. None of these comparisons between surfactants or brush styles were statistically significant for a particular method. However, the pressurized sprays consistently increased removal efficacy, particularly for the two-spotted spider mites. The percent retained was more closely associated with the percent live for the mites ($r = 0.843$), indicating that those remaining on the fruits were alive, than for the mealybugs ($r = 0.235$) where considerable mortality occurred in those samples dipped in Silwet that were not sprayed with pressurized water.

3.4. Test 4

Treatments tended to remove proportionally more grape mealybugs than two-spotted spider mites (Table 5). The defoamers were effective in removing the surface arthropods when used with the brushes. There were no significant differences in percent retained between the defoamer concentrations for any of the brush treatments of both species, except for the mites with Brush A and no pressurized spray ($F_{df=4} = 13.5$, $P < 0.05$). Brush A tended to be more effective against both pests than Brush B, but there were no significant differences in paired treatments between brush types. Except for a few grape mealybug samples, treatment efficacy increased when pressurized sprays were combined with either brush type. Linear correlation between percent retained and percent live was higher for two-spotted spider mites ($r = 0.929$) than for mealybugs ($r = 0.540$), signifying that mites remaining after treatments were generally alive whereas most of the mealybugs were dead. Linear correlation tests of percent retained between the same treatments for Tests 3 and 4 were $r = 0.841$ for the spider mites and $r = 0.746$ for the grape mealybugs, which indicated the repeatability of the tests.

3.5. Test 5

The defoamer, at either concentration, significantly reduced the number of mealybugs on the fruit surface (Table 6). For fruits treated in a defoamer bath, increasing the spray pressure did not increase removal efficacy. There were no significant differences between the defoamer concentrations for any of the pressure treatments. Linear correlation between the percent retained and percent alive ($r = 0.866$) indicated that most of those insects found on the fruits after treatment were alive.

Table 3
Percent retention of field-collected woolly apple aphids, field-collected and laboratory-reared grape mealybugs, and diapausing two-spotted spider mites after different treatments in surfactant (water and 0.3% Silwet) baths and pressurized water sprays

Pest[a]	Bath treatment[b] (%)	Spray		% Retained (mean ± S.E.M.[c])	Signficance[d]
		Temperature (°C)	kPa		
WAA	None	None	None	100 ± 0	–[e]
	Water	None	None	73.3 ± 13	ns
	Water	30	210	11.1 ± 11	**
	Water	30	560	66.7 ± 0	**
	Water	40	210	33.3 ± 0	**
	Water	40	560	77.8 ± 11	ns
	0.3	None	None	100 ± 0	ns
	0.3	30	210	38.9 ± 20	**
	0.3	30	560	22.2 ± 11	**
	0.3	40	210	44.4 ± 11	**
	0.3	40	560	33.3 ± 0	**
GMB field	None	None	None	100 ± 0	–[e]
	Water	None	None	95.8 ± 4.2	ns
	Water	30	210	41.7 ± 10	**
	Water	30	560	30.5 ± 2.8	**
	Water	40	210	46.7 ± 24	**
	Water	40	560	40.3 ± 5	**
	0.3	None	None	93.3 ± 6.7	ns
	0.3	30	210	16.7 ± 17	**
	0.3	30	560	45 ± 16	**
	0.3	40	210	56.7 ± 18	**
	0.3	40	560	21.7 ± 12	**
GMB lab	None	None	None	71.7 ± 16	–[e]
	Water	None	None	80 ± 12	ns
	Water	30	210	21.7 ± 4.4	*
	Water	30	560	20 ± 12	ns
	Water	40	210	11.7 ± 6	*
	Water	40	560	11.7 ± 7.3	*
	0.3	None	None	61.7 ± 6	ns
	0.3	30	210	18.3 ± 4.4	*
	0.3	30	560	20 ± 2.9	*
	0.3	40	210	8.3 ± 4.4	*
	0.3	40	560	1.7 ± 1.7	*
TSSM diapause	None	None	None	87.6 ± 2.6	–[e]
	Water	None	None	98.7 ± 1.3	*
	Water	30	210	10 ± 5	*
	Water	30	560	6.7 ± 1.7	*
	Water	40	210	20.3 ± 7.3	*
	Water	40	560	8.3 ± 6	*
	0.3	None	None	91.2 ± 2.8	ns
	0.3	30	210	0 ± 0	**
	0.3	30	560	0 ± 0	**
	0.3	40	210	0 ± 0	**
	0.3	40	560	3.3 ± 3.3	*

[a] Pests examined: WAA = woolly apple aphid, GMB = grape mealybug, TSSM = two-spotted spider mite.
[b] Treatments were no bath, water or 0.3% Silwet.
[c] S.E.M. = standard error of mean.
[d] Significant difference from control using equivalent to a Wilcoxon rank sum test (df = 4); *: <0.05, **: <0.01, ns: not significant.
[e] Control.

4. Discussion

The surface arthropods reacted differently to the various treatments. Using the most severe removal method (from Test 2: water or 0.3% Silwet with 40 °C sprays at 560 kPa), the woolly apple aphid was the most resistant among the four pest populations examined while the laboratory-reared grape mealybug and the diapausing two-spotted spider mite were close to being the most susceptible. Because most of the tests used these last two arthropods, removal evaluations may be slightly optimistic when applied to the other pests. For example, in most cases the treatment results between the field-infested and laboratory-reared grape mealybugs were similar with a

Table 4
Percent retention and percent live laboratory-reared grape mealybugs and diapausing two-spotted spider mites after different treatments in surfactant baths, rotating brush style, and pressurized water sprays

Pest[a]	Bath treatment (%)	Brush	Spray (kPa)	% Retained		% Live	
				Mean ± S.E.M.[b]	Significance[c]	Mean ± S.E.M.	Significance
TSSM	None	None	None	80.0 ± 8.9	–[d]	68.2 ± 7.9	–[d]
	Water	None	None	81.1 ± 7.8	ns	54.4 ± 21.1	ns
	Water	A	None	41.1 ± 8.0	*	35.6 ± 11.0	ns
	Water	A	420	0.0 ± 0.0	**	0.0 ± 0.0	**
	Water	B	None	18.4 ± 12.4	*	10.8 ± 7.7	*
	Water	B	420	2.1 ± 1.1	*	2.1 ± 1.1	*
	0.3% Silwet	None	None	48.3 ± 6.1	*	0.0 ± 0.0	**
	0.3% Silwet	A	None	45.1 ± 16.5	ns	3.2 ± 1.9	*
	0.3% Silwet	A	420	8.8 ± 8.8	*	0.0 ± 0.0	**
	0.3% Silwet	B	None	28.7 ± 4.2	*	8.3 ± 2.8	*
	0.3% Silwet	B	420	0.0 ± 0.0	**	0.0 ± 0.0	**
	0.1% Defoamer	None	None	52.2 ± 16.4	ns	38.9 ± 21.6	ns
	0.1% Defoamer	A	None	40.1 ± 10.5	*	24.1 ± 13.2	*
	0.1% Defoamer	A	420	0.0 ± 0.0	**	0.0 ± 0.0	**
	0.1% Defoamer	B	None	30.2 ± 10.1	*	10.7 ± 2.5	*
	0.1% Defoamer	B	420	1.1 ± 1.1	*	0.0 ± 0.0	**
GMB	None	None	None	76.7 ± 4.4	–[d]	61.7 ± 4.4	–[d]
	Water	None	None	48.3 ± 6.0	*	40.0 ± 5.0	*
	Water	A	None	80.0 ± 11.5	ns	58.3 ± 10.1	ns
	Water	A	420	35.0 ± 5.8	*	26.7 ± 1.7	*
	Water	B	None	63.3 ± 11.7	ns	43.3 ± 7.3	ns
	Water	B	420	55.0 ± 5.8	*	36.7 ± 1.7	*
	0.3% Silwet	None	None	85.0 ± 10.4	ns	0.0 ± 0.0	**
	0.3% Silwet	A	None	81.7 ± 3.3	ns	3.3 ± 1.7	*
	0.3% Silwet	A	420	18.3 ± 3.3	*	8.3 ± 4.4	*
	0.3% Silwet	B	None	73.0 ± 8.8	ns	18.3 ± 8.8	*
	0.3% Silwet	B	420	31.7 ± 3.3	*	20.0 ± 2.9	**
	0.1% Defoamer	None	None	88.3 ± 3.3	ns	58.3 ± 3.3	ns
	0.1% Defoamer	A	None	41.7 ± 6.0	*	40.0 ± 5.0	*
	0.1% Defoamer	A	420	40.0 ± 12.6	*	31.7 ± 4.4	*
	0.1% Defoamer	B	None	60.0 ± 8.7	ns	41.7 ± 4.4	*
	0.1% Defoamer	B	420	38.3 ± 11.7	**	30.0 ± 5.8	*

[a] Pests examined: GMB = grape mealybug, TSSM = two-spotted spider mite.
[b] S.E.M. = standard error of mean.
[c] Significant difference from control using equivalent to a Wilcoxon rank sum test (df = 4); *: <0.05, **: <0.01, ns: not significant.
[d] Control.

third of the treatments signifying any statistical difference.

In some cases, a water dip by itself contributed to the removal of surface arthropods. Adding a surfactant increased treatment efficacy. This material breaks the surface tension of water, allowing the liquid to reach previously protected areas, such as the stem and calyx ends. Microscopic examinations revealed that the waxy coatings of grape mealybugs and woolly apple aphids were reduced when in contact with surfactants. As shown in earlier studies (Cowles et al., 2000; Purcell and Schroeder, 1996; Tipping et al., 2003), Silwet also killed two-spotted spider mites directly. Our data demonstrated that the organosilicone dips alone enhanced removal and mortality. Furthermore, efficacy was increased when the dips were done in combination with mechanical removal methods, such as pressurized sprays and roller brushes.

Although Silwet is registered as a surfactant for preharvest control, it is not approved for postharvest use. Registration is a long, costly process. Our early tests showed that the silicone defoamer performed as well as Silwet in removing surface arthropods. The defoamer is already widely used in commercial operations and is classified as food grade. For these reasons, we decided to concentrate our examinations on the defoamer. Depending on state regulations, the defoamer may still require special handling for disposal, but defoamers are already used on fruit packing lines.

Initial tests showed no advantage in using the higher temperature sprays for removing the surface arthropods. To the contrary, thermal fruit injury was seen at the high temperature range (50 °C) (Bai et al., 2006). Thus, the high temperature range was deleted for the later removal tests.

Earlier studies on brushes involved removal of decay organisms (Fallik et al., 2001; Porat et al., 2000; Prusky et al., 1999). Brushes of both styles increased removal of surface arthropods and neither was statistically better than the other. Thus, the selection of the style of brush was dependent on the

Table 5
Percent retention and percent live laboratory-reared grape mealybugs and diapausing two-spotted spider mites after different treatments in defoamer baths, rotating brush style, and pressurized water sprays

Pest[a]	Bath treatment (%)[b]	Brush	Spray (kPa)	% Retained		% Live	
				Mean ± S.E.M.[c]	Signficance[d]	Average ± S.E.M.	Significance
TSSM	None	None	None	98.0 ± 2.0	–[e]	98.0 ± 2.0	–[e]
	Water	None	None	75.9 ± 2.9	*	62.6 ± 2.1	*
	Water	A	None	54.6 ± 11.0	*	38.1 ± 9.3	*
	Water	A	420	0.0 ± 0.0	**	0.0 ± 0.0	**
	Water	B	None	72.3 ± 9.4	*	58.7 ± 14.9	*
	Water	B	420	4.7 ± 2.9	*	2.0 ± 1.2	*
	0.01%	None	None	83.3 ± 9.3	ns	62.0 ± 19.7	ns
	0.01%	A	None	39.3 ± 8.5	*	30.0 ± 11.0	*
	0.01%	A	420	8.0 ± 8.0	*	0.0 ± 0.0	**
	0.01%	B	None	50.0 ± 14.4	*	13.3 ± 5.5	*
	0.01%	B	420	20.7 ± 19.7	*	18.7 ± 18.7	*
	0.1%	None	None	80.8 ± 12.5	ns	74.4 ± 13.7	ns
	0.1%	A	None	75.2 ± 3.8	*	37.9 ± 19.0	*
	0.1%	A	420	11.3 ± 11.3	*	9.3 ± 9.3	*
	0.1%	B	None	54.0 ± 14.7	*	26.7 ± 17.7	*
	0.1%	B	420	0.0 ± 0.0	*	0.0 ± 0.0	**
GMB	None	None	None	81.1 ± 4.0	–[e]	24.5 ± 2.2	–[e]
	Water	None	None	71.1 ± 2.2	*	48.9 ± 4.0	ns
	Water	A	None	68.9 ± 4.0	ns	3.3 ± 3.3	*
	Water	A	420	18.9 ± 4.0	*	1.1 ± 1.1	*
	Water	B	None	61.1 ± 19.5	ns	2.2 ± 1.1	*
	Water	B	420	14.4 ± 5.9	*	0.0 ± 0.0	**
	0.01%	None	None	76.7 ± 1.9	ns	8.9 ± 1.1	ns
	0.01%	A	None	4.5 ± 2.2	*	0.0 ± 0.0	**
	0.01%	A	420	11.1 ± 2.2	*	0.0 ± 0.0	**
	0.01%	B	None	44.4 ± 19.7	ns	2.2 ± 1.1	*
	0.01%	B	420	8.9 ± 1.1	*	0.0 ± 0.0	**
	0.1%	None	None	85.5 ± 2.2	ns	2.2 ± 1.1	*
	0.1%	A	None	30.0 ± 12.0	*	0.0 ± 0.0	**
	0.1%	A	420	16.7 ± 9.6	*	1.1 ± 1.1	*
	0.1%	B	None	8.9 ± 2.2	*	0.0 ± 0.0	**
	0.1%	B	420	18.9 ± 8.0	*	0.0 ± 0.0	**

[a] Pests examined: GMB = grape mealybug, TSSM = two-spotted spider mite.
[b] Treatments were no bath, water, 0.01 or 0.1% defoamer.
[c] S.E.M. = standard error of mean.
[d] Significant difference from control using equivalent to a Wilcoxon rank sum test (df = 4); *: 0.05, **: 0.01, ns: not significant.
[e] Control.

effect of fruit quality (Bai et al., 2006). Brush B had softer bristles and tended not to damage the fruit surface, yet could impact many of the surface pests.

Previous studies on removing surface arthropods used pressurized sprays ranging from 2240 to 5516 kPa (Walker et al., 1996; Whiting et al., 1998). Our early tests demonstrated that the pressurized sprays at 560 kPa were more effective than those at 210 kPa in pest removal, but also damaged the fruit surface (Bai et al., 2006). Sprays at 420 kPa were as effective and did not cause injury. Furthermore, increasing the pressure to 840 kPa did not statistically increase efficiency. Presumably, the sprays contact the pests in depressed areas of the fruits, particularly at the stem and calyx ends.

Organosilicones have insecticidal properties against aphids (Wood and Tedders, 1997), spider mites (Cowles et al., 2000) and mealybugs (Tipping et al., 2003). Although these silicone materials are not registered as insecticides, they do affect pest survival, particularly when used alone. However, when combined with other removal methods, the rate of retention decreased significantly. Those pests remaining somehow avoided the impact of the pressurized sprays followed by brushing. Those arthropods were also more likely to be alive. Thus, the insecticidal properties of the organosilicones do not play a significant role in pest removal and these materials should not be considered as insecticides.

In summary, a pest removal system has been developed that is compatible with commercial packing line operations. In our tests, we evaluated severely infested fruits with pests in well-protected locations. Under commercial conditions, such fruit lots would be identified before processing and particular attention devoted to their removal. The use of a bath containing an organosilicone surfactant along with mechanical methods, such as pressurized sprays and rotating brushes, can effectively remove a considerable proportion of surface arthropods likely to attack fresh pome fruits. Even pests situated in difficult areas, like the indented surfaces of the calyx

Table 6
Percent retention and percent live laboratory-reared grape mealybugs after different treatments in defoamer baths and pressurized water sprays

Bath treatment (%)[a]	Spray (kPa)	% Retained		% Live	
		Mean ± S.E.M.[b]	Significance[c]	Mean ± S.E.M.	Significance
None	None	71.1 ± 2.9	–[d]	65.6 ± 9.9	–[d]
Water	None	96.7 ± 3.3	*	66.7 ± 13.3	ns
Water	420	67.2 ± 11.1	ns	42.8 ± 6.4	ns
Water	560	53.3 ± 12.0	ns	31.7 ± 10.9	*
Water	700	26.7 ± 6.7	*	15.0 ± 7.6	*
Water	840	28.3 ± 13.0	*	15.0 ± 10.4	*
0.01%	None	45.0 ± 11.5	*	25.0 ± 5.0	*
0.01%	420	41.7 ± 18.3	*	31.7 ± 13.6	ns
0.01%	560	55.0 ± 5.8	*	35.0 ± 2.9	*
0.01%	700	40.0 ± 2.9	*	16.7 ± 3.3	*
0.01%	840	48.3 ± 4.4	*	40.0 ± 2.9	*
0.10%	None	58.3 ± 4.4	*	30.0 ± 5.8	*
0.10%	420	58.3 ± 1.7	*	38.3 ± 1.7	*
0.10%	560	33.3 ± 8.8	*	25.0 ± 5.0	*
0.10%	700	45.0 ± 12.6	*	11.7 ± 3.3	*
0.10%	840	58.3 ± 7.3	ns	28.3 ± 1.7	*

[a] Treatments were no bath, water, 0.01% or 0.1% defoamer.
[b] S.E.M. = standard error of mean.
[c] Significant difference from control using equivalent to a Wilcoxon rank sum test (df = 4); *: 0.05, **: 0.01, ns: not significant.
[d] Control.

and stem ends, are susceptible to removal. Providing pest-free fruits will aid in the international commerce of these fruits because of standards established for grading and exporting fresh commodities. As fruit quality increases, so will the value of the commodity.

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