



Evaluation of two non-destructive sampling methods for bean thrips (Thysanoptera: Thripidae) detection in navel oranges

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Abstract

Adult bean thrips, *Caliothrips fasciatus* (Pergande), over-wintering inside the navel of navel oranges in California are an export problem when detected in fruit sent to Australia. At present, a systems approach is used to reduce fruit infestation levels and one component of this approach is to search for thrips inside the navel by cutting 50 fruit per orchard prior to harvest and 75 fruit per grower lot before packing in the packinghouse with any detection of live bean thrips leading to that grower lot not being eligible for shipment to Australia. Given that bean thrips infestation levels are often 0.5% of the fruit or less, this amount of fruit cutting can lead to shipment of infested lots of citrus to Australia. As an alternative to cutting more fruit, two non-destructive methods of sampling for bean thrips inside the navel of navel oranges were investigated which might be used on larger numbers of fruit and result in fewer infested lots being shipped to Australia. A light trap at the apex of a pyramid-shaped black cloth tent caught 41.1% of adult bean thrips released at the bottom of the tent. When this experiment was repeated with the tent placed over a citrus bin two-thirds full of fruit, however, only 9.3% of thrips released at the bottom of the bin were captured. A second method of sampling, washing bean thrips out of the navel onto a screen, resulted in close to 90% recovery of thrips with each of the five spray rinses evaluated, including distilled water. Regression analysis indicated there was no statistical difference between results with the five rinses. Thus, it might be worthwhile trying to scale-up our laboratory method of rinsing with distilled water to a method that might be used in a commercial packinghouse for detection of bean thrips in large numbers of fruit. Even if one assumes that cutting fruit is 100% efficient in finding bean thrips inside the navel of navel oranges, sampling a much larger number of fruit using a method with 90% efficiency is shown to result in higher odds of finding any bean thrips that are present.

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1. Introduction

The bean thrips, *Caliothrips fasciatus* (Pergande), has been reported on more than sixty genera of plants in the state of California, including more than forty cultivated crops (Bailey, 1937). Although early reports suggested that it could cause yield losses in alfalfa, beans, cantaloupes, cotton, lettuce, pears, and peas, it has not been reported as a pest of economic significance in California since 1940 (Bailey, 1940), suggesting that perhaps early reports

overemphasized its importance. The region of origin of bean thrips is unknown but has been speculated to be California, Florida, or Brazil (Moulton, 1907; Watson, 1923; Bondar, 1924). This species is reported as present in fourteen US states, including Arizona and California (Bailey, 1933, 1938). It is also reported from Argentina and the west coast of Mexico (Bailey, 1933, 1938), and a single specimen was collected by Steinweden and Moulton (1930) in Foochow, China.

The bean thrips over-winters as an adult and a favored over-wintering site in California is inside the navel of navel oranges, *Citrus sinensis* L. Osbeck cv. 'Navel' (Bailey, 1937; Harman et al., 2007). This insect is not considered an

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1 economic pest on citrus in California (Flint et al., 1991) but
 2 it became a problem for California growers shipping navel
 3 oranges to Australia during the 1996–1997 season when 28
 4 of 982 shipments (estimated value of all 982 shipments was
 5 \$6.9 million) from California were found infested. Infested
 6 loads were fumigated with methyl bromide, which is
 7 damaging to the fruit and costly to the importer, but a
 8 larger concern was potential loss of the Australian citrus
 9 market if interception levels were not reduced. Mound and
 10 Houston (1987) reported two species of *Caliothrips* as
 11 present in Australia but to date, established populations of
 12 *C. fasciatus* have not been detected there. They indicated
 13 that there were 19 known species in this genus, seven from
 14 North America, and the majority of species are found in
 15 the tropics. Due to a long history of California citrus being
 16 sent to Australia, Hoddle et al. (2006) surveyed areas
 17 around airports, seaports, public recreational parks, and
 18 major agricultural areas in the states of Queensland, New
 19 South Wales, Victoria, South Australia, and Western
 20 Australia. Although a total of 4675 thrips encompassing
 21 at least 76 species from 47 genera were detected, *C.*
 22 *fasciatus* was not found.

23 Starting in November 2002, USDA-APHIS imposed an
 24 “Australian Export Bean Thrips Mitigation Plan” on all
 25 California growers shipping navel oranges to Australia.
 26 Each year the Plan is revised and as part of the 2005–2006
 27 Plan, 50 fruit per grove, spread throughout the grove, must
 28 be cut in the field prior to harvest and any live bean thrips
 29 that are found disqualify fruit from that grove from
 30 possible shipment to Australia. As an added precaution,
 31 the packinghouse must cut an additional 75 fruit per
 32 grower lot and detection of live bean thrips results in that
 33 lot not being eligible for shipment to Australia. Unfortu-
 34 nately, the probability of successfully detecting thrips using
 35 this technique at the low (generally less than 0.5%, J.G.M.,
 36 unpublished data) infestation rates occurring in California
 37 orchards is relatively small (see Table 1). Cutting sufficient

39 Table 1
 40 Probability (p) of finding an infested fruit when cutting a sample of n fruit
 41 from a navel orange grove with the bean thrips infestation rate (i) is as
 42 follows: $p = 1 - (1 - i)^n$

Actual percent of fruit infested with bean thrips (%)	Odds of finding a bean thrips in various size (n) fruit samples			
	$n = 50$ (%)	$n = 75$ (%)	$n = 125$ (%)	$n = 2000$ (%)
0.01	0.5	0.7	1.2	18.1
0.025	1.2	1.9	3.1	39.4
0.05	2.5	3.7	6.1	63.2
0.1	4.9	7.2	11.8	86.5
0.25	11.8	17.1	26.9	99.3
0.5	22.2	31.3	46.6	100.0
1.0	39.5	52.9	71.5	100.0
2.5	71.8	85.0	95.8	100.0
5.0	92.3	97.9	99.8	100.0

53 Note that $n = 2000$ represents the total minimum number of oranges in a
 54 bin, rather than a realistic number for sampling.

fruit to make detection more likely would negatively
 impact grower profits by using additional fruit and labor. 59

60 Because use of methyl bromide is now banned apart
 61 from quarantine and pre-shipment usage and effective
 62 post-harvest treatments have yet to be identified for bean
 63 thrips control, the focus of the work described herein was
 64 on possible methods of improving detection of infested lots
 65 of fruit. Examination of thrips extraction literature from a
 66 variety of crop types suggested several possibilities worth
 67 investigating including the use of heat, attraction towards
 68 light, and use of various liquid rinses. Only a small number
 69 of recent possible citations are listed below. A Berlese-type
 70 trap using heat and light was used to extract thrips from
 71 cowpea, onions, and orchids (Hoerner, 1947; Doederlein
 72 and Sites, 1993; Tamo et al., 1993; Hollingsworth et al.,
 73 2002). Various rinses have been used on a variety of thrips
 74 species to extract them from apple blossoms, coleus shoots,
 75 cotton, grapes, roses, and weeds (Shibao et al., 1992; Terry
 76 and DeGrandi-Hoffman, 1998; Warnock and Loughner,
 77 2002; Cook et al., 2003; Atakan and Uygur, 2004;
 78 Duraimurugan and Jagadish, 2004).

79 Two possible non-destructive methods of detecting bean
 80 thrips were investigated as alternatives to cutting addi-
 81 tional fruit. Fruit are normally transported to the packing-
 82 house in a standard sized plastic bin and the first study
 83 evaluated covering the bin with a darkened chamber with a
 84 pyramidal ceiling and a sticky trap with a light at the apex
 85 (based on observations that bean thrips are positively
 86 phototropic and negatively gravitropic). The second
 87 method of detection investigated was washing fruit with a
 88 variety of aqueous solutions to flush bean thrips from the
 89 navels onto a wire mesh where they could be spotted by a
 90 trained observer. 91

92 2. Materials and methods 93

94 2.1. Rearing and handling of bean thrips 95

96 A colony of bean thrips was maintained in the
 97 laboratory on baby lima bean plants (*Phaseolous lunatus*
 98 L., FM Inc., Portland, OR). Thrips used in the experiments
 99 were aspirated by mouth into 10 mm vials with mesh lids. 100
 101 An attempt was made to aspirate ten thrips into each vial,
 102 but their small size and tendency to cluster on leaves made
 103 controlling the exact number difficult; also, they would
 104 occasionally be injured and die in the aspiration process. 105
 106 Healthy and dead or injured thrips in each vial were
 107 therefore counted under a dissecting microscope approxi-
 108 mately 30 min after aspiration, allowing time for those
 109 injured in the aspiration process to die or become sluggish
 110 enough to distinguish from their healthy conspecifics. 111
 112 Before using them in experiments and prior to opening
 113 vials, thrips were anaesthetized by blowing CO₂ at
 moderate pressure through the mesh lids of their vials for
 approximately 30 s, ensuring they would not escape.

2.2. Infesting oranges

The cut-off upper third (2 cm length) of a 7 dram plastic vial (2.5 cm inner diameter) was sealed over the navel of each orange using a ring of adhesive putty (Loctite® non-toxic mounting putty distributed by Menco, Inc., Avon, OH) molded around the navel. Thrips were then anaesthetized with CO₂, dumped into the vial tops, and the lids immediately sealed over them. Based on the results of preliminary trials studying temperature and exposure period that resulted in bean thrips entering the navel, the oranges were then placed in a 4 °C cold room for 48 h.

2.3. Tent apparatus

Preliminary tests used a cardboard box (23 × 29 × 41.5 cm³ high) with the top flaps cut into triangles and sealed at the edges to form a pyramid leading up to an inverted funnel of translucent plastic with a 4.7 cm diameter vial sealed over it. Seventy thrips were released from vials from the bottom of the box and a light shone down through the funnel. After 1 h, twenty of the thrips were visible inside the vial, appearing to support our hypothesis that bean thrips in a dark, enclosed environment with a light source at the top would tend to move toward that light source.

An analogous apparatus was then constructed that would fit over a MacroBin Model 26-A-FV (a plastic picking bin commonly used in CA for transporting commercial citrus from field sites to the packinghouse; internal dimensions 113.0 × 112.7 × 70.0 [height] cm, 0.813 m³ capacity, Macro Plastics, Inc., Fairfield, CA). This device consisted of a square frame around the bin with a pyramidal upper section and a black, light-proof tent that fit snugly over the frame. The frame was constructed of 2.5 cm diameter, high-pressure PVC pipe (J. M. Manufacturing, Inc., Livingston, NJ) and four types of joints: “T” joints, “+” joints, and 45° and 90° elbows (Nibco, Inc., Elkhart, IN). The base was 150 cm square and 76 cm high, with a T joint connected to two 45° elbows at each lower corner and a + joint connected to three 45° elbows at each upper corner (connected joints were held together with 5 cm sections of pipe that fit entirely inside the joints). The pyramid arms rising from the upper corners of the base were 127 cm long, giving the frame an overall height of 160 cm (i.e. it fit over the sides of the bin, extending 90 cm above the top of the bin). At the top was a 25 cm square “crown” consisting of four “T” joints connected to the arms and four 90° elbow joints, with strips of Velcro (1.19 cm wide, Velcro USA, Manchester, NH) hot-glued all the way around the outer rim to attach the tent.

The tent consisted of an outer layer of water-resistant black fabric and an inner liner of light-proof, black twill, with approximately 15 cm of slack at the bottom that was tucked under the base of the frame when in use. The tent had Velcro strips sewn into the upper rim to attach it to the frame, and along both sides of the single open edge to seal

it shut. At the top of the apparatus was a square section of foam-core board glued to the crown, with the rim of a 16.7 × 16.7 × 4.8 (height) cm disposable food storage container (Ralph’s Sure Seal disposable/reusable container, 739 ml volume; Presto Products Co., Cincinnati, OH) glued into it. The rest of the lid was cut out, leaving the top of the apparatus open and allowing the inverted container to be sealed over it. The inside of the container was entirely coated with Tangle-Trap Insect Trap Coating (The Tanglefoot Co., Grand Rapids, MI), ensuring that any thrips that crawled or flew onto it would remain there. Two portable work lights with 23 W spiral fluorescent bulbs (illumination equivalent to 100-W incandescents, but generating less heat) were clamped to brackets screwed onto the crown so that they shone down through the trap container. To ensure there were no or few holes through which the thrips could escape, the senior author climbed inside the empty bin while the tent cover was lowered over the bin, making sure that it was uniformly dark within the bin when the light at the top of the tent was turned off.

2.4. Empty tent experiments

All experiments took place on a loading dock in Field 16 at Agricultural Operations on the University of California, Riverside campus. The apparatus was placed on a sheet of white butcher paper taped to the floor. The first round of experiments used the tent alone, with no oranges or bin inside. For each replication of the experiment, fifteen vials, each with ca. 10 live adult thrips, were placed upright on the floor in the center of the tent. Ten of the vials were opened, while the remaining five were kept closed (with mesh lids) to provide an estimate of thrips mortality within the tent. As an additional control, the box apparatus from the preliminary experiment (Section 2.3) was modified, replacing the funnel with a Rubbermaid container identical to the one used at the top of the tent, and set on the loading dock beside the tent. Five vials of thrips were placed in it (three open, two closed) at the same time the fifteen were placed in the tent.

After 4 h, the tent was tapped along each side to knock loose any thrips clinging to the fabric and was then lifted off the butcher paper. The tent was then opened by removing the trap container from the top of the frame. All open vials were closed, and all thrips that could be seen on the paper or inside the cardboard box were aspirated into additional vials. Thrips in the vials and in the trap container were then counted under a dissecting microscope, and the number missing from each apparatus was calculated by subtracting those trapped, aspirated from the butcher paper or the interior of the box, or still found in the open vials from the total number released into each apparatus. The experiment was repeated three times over three consecutive days from 1400 to 1800 h.

1 2.5. Loaded bin experiments

3 For the second round of experiments, the apparatus was
 5 placed over a citrus bin filled approximately two thirds of
 7 the way to the top with Valencia oranges (*C. sinensis* L.
 9 Osbeck cv. “Valencia”). Valencia oranges were used
 11 because navel oranges were unavailable at the time of the
 13 experiments. Thrips were again placed in fifteen vials in the
 15 bottom center of the bin, with five closed with mesh serving
 17 as mortality controls. A 91.4 cm length of PVC pipe was
 19 used to place vials near the bottom of the bin. The PVC
 21 pipe was manipulated through the oranges until it
 23 contacted the bottom of the bin and the vials were then
 25 slid down the inside of the pipe. The small box was again
 27 used beside the bin as a control. After 4 h, data were
 29 collected as above (2.4), except that the opportunities for
 31 concealment afforded to the thrips by the bin of oranges
 33 made it impractical to aspirate live or dead thrips
 35 remaining in the tent or in the bin among the oranges.
 37 This experiment was also repeated three times over three
 39 consecutive days from 1400 to 1800 h.

23 2.6. Wash detection of bean thrips

25 Thrips were driven into the navel of navel oranges as
 27 described above (Section 2.2) and various rinses were
 29 compared as a means of washing thrips out of the navel.
 31 Before washing but right after removal from cold storage,
 33 the vial on top of each orange was opened and any thrips
 35 visible on the surface or in the vial were counted and
 37 removed. The number of thrips concealed in the navel was
 39 determined by subtracting this count from the number of
 41 thrips originally placed on each orange. Five 946 ml Plant
 43 and Garden Sprayer Non-aerosol spray bottles (Sprayco,
 45 Detroit, MI) of the type commonly sold for watering plants
 47 and household cleaning were used for the washing
 49 experiment. The solutions tested included 25% ethanol,
 51 distilled vinegar (5% acetic acid), 1% Kem Tech bleach
 53 (Kem Tech Industries, Inc., Ixonia, WI), 0.05% Triton X-
 55 100 (Sigma Aldrich, St. Louis, MO), and distilled water.
 57 The oranges were washed over plastic funnels lined with
 paper towels to catch the thrips as they were washed out
 (being black, bean thrips are easily spotted on a white
 surface). Each orange was held over the funnel with the
 navel angled down approximately 45° and sprayed thirty
 times; the oranges were rotated 60° around the navel axis
 after every five sprays to ensure that the spray reached
 every part of the navel. The oranges were cut immediately
 after washing and all thrips remaining in the navels were
 counted. In addition, the depth and width of the navel of
 each fruit was measured to the nearest millimeter using lab
 calipers. Width was measured across the surface of the
 navel and depth was measured from the surface to the
 deepest point after the orange was cut. This study was
 performed in four blocks over time, with 10 randomly
 chosen fruit washed per treatment in each of the first three
 and 20 per treatment washed in the final block.

3. Results

3.1. Empty tent and loaded bin experiments

~~The results of the~~ initial trials with the empty tent
 indicated that a dark enclosure covered with a lighted trap
 had potential as a means of post-harvest detection of bean
 thrips. Capture rates ranged from 29.2% to 57.1% (mean
 of 41.1%), suggesting a higher probability of detecting a
 sparse infestation of bean thrips than the conventional
 technique of cutting 125 oranges (50 in the field, 75 in the
 packinghouse) per grower lot (Tables 1 and 2). A typical
 citrus bin holds 2000–3000 navel orange fruit, depending
 on fruit size, which can vary from year to year. For
 example, with a 0.5% infestation rate, one would have a
 46.6% chance of detecting bean thrips by cutting 125 fruit
 (Table 1) but would catch 4.1–6.2 bean thrips with
 2000–3000 fruit in a bin if the recapture rate was 41.1%

Unfortunately, the trials with oranges present in the bin
 yielded a far lower capture rate, even though the thrips
 were released from vials and did not have to crawl out of
 the navel as they would in the case of a natural infestation
 within navel oranges (Table 3). Also, because the bin was
 filled two-thirds full of Valencia oranges, the bean thrips
 did not have access to navels to crawl into as they made
 their way upward towards the lighted trap. Only
 2.0–15.2% (mean of 9.3%) of released thrips were
 recaptured in the trap at the top of the tent over the bin
 after 4 h. The similar results from the control box for both
 experiments (77.0 ± 1.1% of free thrips were trapped in the
 three trials when the empty tent study was run vs.
 84.6 ± 6.6% during the time when the loaded bin study
 was run) supported the comparison of trap recapture
 between the tent over the empty tent and the loaded bin.
 Had the results been biased by external factors such as
 temperature variation, a reduction in thrips captured in the
 box apparatus would be expected similar to that seen in the
 tent apparatus. We therefore conclude that this method of
 detection is not sufficiently promising to warrant further
 experimentation.

3.2. Wash detection of bean thrips

The probability of detecting thrips in a batch of oranges
 with a particular level of infestation can be estimated by a
 simple iterative probability equation (see Table 1). The
 probability of *failing* to detect thrips in a batch of oranges
 with a sampling method that is assumed to be 100%
 effective (i.e. cutting) is equal to the reciprocal of the
 infestation rate raised to the power of the number of
 oranges cut; the probability of success is the reciprocal of
 that, thus $p = 1 - (1 - i)^n$. For a sampling method that is
 known to be less than 100% effective (i.e. washing), the
 equation was modified by multiplying the infestation rate
 by a sampling efficiency factor: $p = 1 - (1 - iw)^n$, where w is
 the probability of detecting thrips in an individual orange
 with the sampling method in question.

Table 2

Trials on three successive days evaluating the capture of adult bean thrips with a funnel trap placed above the empty tent

Replicate date	6/25/2005	6/26/2005	6/27/2005	Mean ± SD
<i>Thrips inside the control chamber placed outside and next to the tent</i>				
Thrips in control vials	20	22	22	21.2 ± 1.2
Dead thrips in control vials (percent mortality)	11 (55.0%)	3 (13.6%)	1 (4.5%)	5.0 ± 5.3 (24.4 ± 26.9%)
Free thrips ^a	29	32	35	32.0 ± 3.0
Free thrips trapped	22 (75.9%)	25 (78.1%)	27 (77.1%)	24.7 ± 2.5 (77.0 ± 1.1%)
Thrips unaccounted for	0	0	0	0.0
<i>Thrips placed in vials at the bottom of the tent</i>				
Thrips in control vials	52	57	47	52.0 ± 5.0
Dead thrips in control vials (percent mortality)	5 (9.6%)	2 (3.5%)	4 (8.5%)	3.7 ± 1.5 (7.2 ± 3.3%)
Free thrips ^a	108	106	112	108.7 ± 3.1
Free thrips trapped	40 (37.0%)	31 (29.2%)	64 (57.1%)	45.0 ± 17.1 (41.1 ± 14.4%)
Thrips unaccounted for	28 (25.9%)	20 (18.9%)	14 (12.5%)	20.7 ± 7.0 (19.1 ± 6.7%)

^aFree thrips is a count of the total number of thrips in the 10 open vials (3 in the control box) at the beginning of the trial exclusive of the dead thrips found in the vials at the end of the trial.

Table 3

Trials on three successive days evaluating the capture of adult bean thrips with a funnel trap placed above a citrus bin filled two-thirds full with Valencia oranges

Replicate date	6/29/2005	6/30/2005	7/1/2005	Mean ± SD
<i>Thrips inside the control chamber placed outside and next to the bin</i>				
Thrips in control vials	25	21	21	22.3 ± 2.3
Dead thrips in control vials (percent mortality)	6 (24.0%)	14 (66.7%)	4 (19.0%)	8.0 ± 5.3 (36.6 ± 26.2%)
Free thrips ^a	34	25	29	29.3 ± 4.5
Free thrips trapped	28 (82.4%)	23 (92.0%)	23 (79.3%)	24.7 ± 2.9 (84.6 ± 6.6%)
Thrips unaccounted for	0	0	0	0.0
<i>Thrips placed in vials at the bottom of the bin</i>				
Thrips in control vials	64	62	54	60.0 ± 5.3
Dead thrips in control vials (percent mortality)	4 (6.3%)	2 (3.2%)	2 (3.7%)	2.7 ± 1.2 (4.4 ± 1.6%)
Free thrips ^a	100	83	79	87.3 ± 11.2
Free thrips trapped	2 (2.0%)	9 (10.8%)	12 (15.2%)	7.7 ± 5.1 (9.3 ± 6.7%)

Note that “thrips unaccounted for” is not listed inside the bin because aspiration of loose thrips was not practical with the bin two-thirds full of fruit.

^aFree thrips is a count of the total number of thrips in the 10 open vials (3 in the control box) in at the beginning of the trial exclusive of the dead thrips found in the vials at the end of the trial.

The ~~results of the~~ washing experiments indicated that rinsing the navel of an infested navel orange with water or an aqueous solution over a filter is an effective means of detecting bean thrips hiding within the navel. All solutions tested, including distilled water, had sampling efficiencies close to 90% (Table 4). A more sophisticated statistical analysis was needed to determine whether the differences in sampling efficiency between the various liquids were statistically significant.

3.3. Development of a statistical model for analysis of fruit washing data

Because the design of the washing experiment allowed us to treat each orange as a separate data point, this experiment was amenable to regression analysis under the following model: the number of thrips, Y , washed out from a navel is a binomial random variable with probability p and size n , where n is the total number of thrips originally

in each navel. The probability p is related to several factors: the liquid used to wash the orange (liquid), the replication of the experiments (rep), the navel width (width), and the navel depth (depth). The rate at which thrips were washed out of the navel (rate) is Y/n . A generalized linear model is proposed for the data, in which $\log(p/(1-p))$ is a linear function in terms of the effects of these factors (Table 5).

The experiment used a randomized complete block design with four blocks, with each treatment appearing once in each of the first three blocks and twice in the final block. With Y_{ijk} and n_{ijk} denoting the number of thrips washed out of the navel and the total number of thrips, respectively, the statistical model is

$$Y_{ijk} \sim \binom{n_{ijk}}{y} p_{ij}^y (1 - p_{ij})^{n_{ijk} - y},$$

$$\log \frac{p_{ij}}{1 - p_{ij}} = m + a_i + b_j,$$

1 Table 4
 Evaluation of various spray rinses used to drive adult bean thrips out of the navel of navel oranges 59

3	Replicate date	6/14/2005	6/16/2005	6/22/2005	2/25/2006 A	2/25/2006 B	Mean ± SD	61
5	<i>Distilled water</i>							
	Total thrips in navels	44	38	28	37	46	38.6 ± 7.1	63
7	Thrips washed out	35	36	25	35	45	35.2 ± 7.1	
	Thrips found in navels	9	2	3	2	1	3.4 ± 3.2	65
9	Percent washed out	79.5	94.7	89.3	94.6	97.8	91.2 ± 7.2	
	<i>25% ethyl alcohol</i>							
11	Total thrips in navels	35	43	30	56	46	42.0 ± 10.1	67
	Thrips washed out	30	38	29	50	43	38.0 ± 8.9	
	Thrips found in navels	5	5	1	6	3	4.0 ± 2.0	69
13	Percent washed out	85.7	88.4	96.7	89.3	93.5	90.7 ± 4.3	
	<i>5% acetic acid (vinegar)</i>							
15	Total thrips in navels	47	28	17	40	36	33.6 ± 11.5	
	Thrips washed out	35	27	17	40	34	30.6 ± 8.9	73
17	Thrips found in navels	12	1	0	0	2	3.0 ± 5.1	
	Percent washed out	74.5	96.4	100.0	100.0	94.4	93.1 ± 10.7	75
19	<i>1% Kem Tech bleach</i>							
	Total thrips in navels	35	43	17	47	32	34.8 ± 11.6	77
21	Thrips washed out	27	38	15	45	32	31.4 ± 11.4	
	Thrips found in navels	8	5	2	2	0	3.4 ± 3.1	79
23	Percent washed out	77.1	88.4	88.2	95.7	100.0	89.9 ± 8.7	
	<i>0.05% Triton X-100</i>							
25	Total thrips in navels	47	31	14	43	32	33.4 ± 12.9	81
	Thrips washed out	42	28	12	41	30	30.6 ± 12.2	83
	Thrips found in navels	5	3	2	2	2	2.8 ± 1.3	
27	Percent washed out	89.4	90.3	85.7	95.3	93.8	90.9 ± 3.8	85

29
 31 Table 5
 Statistical analysis of various spray rinses used to drive adult bean thrips 87

33 out of the navel of navel oranges
 35

	Estimate	Standard error	z-Value	p-Value	
35	Intercept	2.90	0.36	8.06	0.00
37	Bleach-water	-0.07	0.38	-0.18	0.85
	Ethanol-water	-0.11	0.36	-0.30	0.77
	Triton-water	0.21	0.39	0.54	0.59
39	Vinegar-water	0.13	0.39	0.35	0.73
	rep1-rep4	-1.48	0.30	-4.94	0.00
41	rep2-rep4	-0.56	0.35	-1.59	0.11
	rep3-rep4	-0.39	0.44	-0.90	0.37

43 The total effect of liquids is not significant (p -value = 0.989).

45 where $i = 1$ (water), 2 (bleach), 3 (ethanol), 4 (triton), 5
 47 (vinegar); $j = 1, 2, 3, 4$; and $k = 1$ for $j = 1, 2, 3$ but $k = 2$
 49 for $j = 4$. In order to identify the parameters, a baseline
 51 must be selected. The selected baseline was (water, date 4).
 This means that $a_1 = 0$ and $b_4 = 0$, where a_i denotes the
 53 difference between treatment i and water for $i > 1$ and b_j
 denotes the difference between date j and date 4 for $j < 4$.
 Parameter estimates are shown in Table 5. A large p -value
 (0.96) was observed for the χ^2 test for

55 $H_0 : a_i = 0 \quad \forall i = 1, 2, 3, 4, 5$ against $H_1 : \text{otherwise}$.

57

4. Discussion

Promising bean thrips recapture rates with the empty tent covered with the funnel trap were not surprising given our laboratory observations that bean thrips will fly upward when disturbed and often fly towards artificial lights or natural light provided by a window. As noted by Bailey (1937), bean thrips often hop around, showing an apparent reluctance to fly unless they are disturbed. A lack of food inside the empty tent, increasing temperature provided by the light at the top of the tent, and the contrast between the dark interior of the tent/funnel trap and the light at the top of the trap likely induced them to fly upward.

Unfortunately, these promising results were not repeated when the bin was filled two-thirds full with Valencia oranges and the bean thrips were released as before at the bottom of the tent (in this case, inside the bin). Several factors might have contributed to lower bean thrips recovery over the 4-h trial period. First, the thrips may have been delayed while feeding on the oranges (they are often seen feeding on fruit in the field). Second, the fruit matrix may have slowed their movement to the upper layers of fruit where the light at the top of the trap would have been more apparent.

The washing experiment yielded more positive results: all washes had sampling efficiencies of approximately 90%,

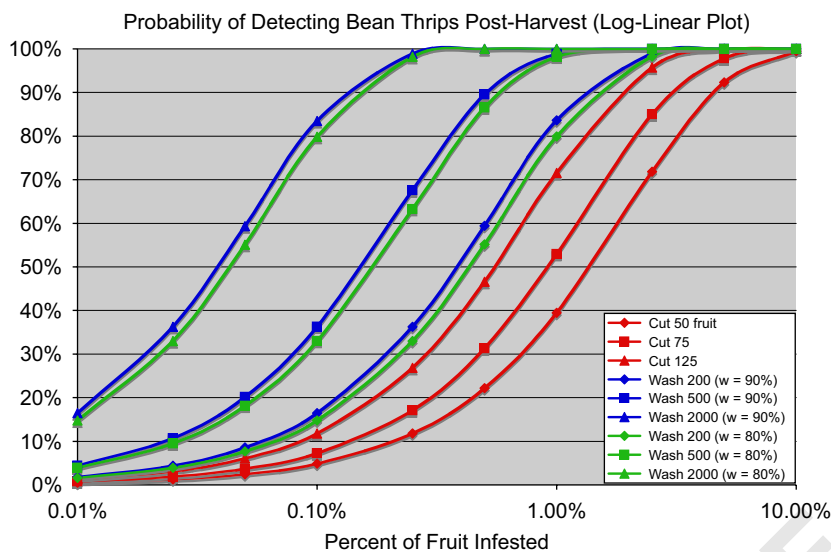


Fig. 1. The probability of detecting bean thrips inside the navel of navel oranges given various actual levels of fruit infestation with thrips (the x-axis is presented on a log scale), and using either fruit cutting of 50, 75, or 125 fruit (assuming 100% detection efficiency) or washing 200, 500, or 2000 fruit with a wash efficiency of $w = 80\%$ vs. $w = 90\%$.

including distilled water, and regression analysis revealed no statistically significant differences between the washes. Due to its relative speed and non-destructive nature, this technique could be used to sample larger numbers of fruit than under the current cutting protocol, allowing for a greatly increased probability of detection. Even at a sampling efficiency of 80%, far less than the average for any of the washes tested herein, washing as few as 200 fruit improves detection rates over cutting 125 (see Fig. 1).

Based on the results of the fruit washing experiment, it appears that washing navel oranges post-harvest may be an effective means of non-destructive monitoring of fruit for bean thrips infestation. In the absence of significant differences between results with the five rinses, water might be used for this purpose with the advantage of adding little cost or danger of negative impacts on the fruit (fruit are routinely washed during packinghouse processing). Future experimentation in this area should focus on ways to scale up the process to allow many oranges to be washed simultaneously. The use of a large tub in which an entire bin of oranges could be submerged and agitated, following by careful filtration of the wash water, and examination of the filters for bean thrips might prove more efficient than current protocols for detection of bean thrips which use cutting of fruit in the field and the packinghouse. Ideally, such a method would be relatively rapid and minimally labor intensive. Packinghouses would likely need to utilize a dissecting microscope to examine suspected bean thrips and differentiate them from debris of a similar size or dark phases of the western flower thrips, *Frankliniella occidentalis* (Pergande), the most common thrips that is similar in color to the dark black bean thrips and is likely to be found in or on navel oranges (Bryan and Smith, 1956; Harman et al., 2007).

At present, a systems approach is being used in the “Australian Export Bean Thrips Mitigation Plan” to reduce the likelihood that a viable number of bean thrips might enter Australia via shipment of California navel oranges. This includes (1) field trapping with sticky cards placed around all four sides of blocks possibly sending fruit to Australia and elimination of groves with bean thrips levels above a threshold level, (2) in-field cutting of 50 fruit, (3) packinghouse inspection of 100 fruit and cutting of 75 fruit, (4) fruit must be held in a sweat room at 18.3 °C for 8 h prior to fruit immersion or washing, (5) each carton of fruit must contain a grower lot number allowing trace back should bean thrips be intercepted in Australia, (6) a County Agricultural Inspector must conduct a phytosanitary inspection of 600 fruit on a representative sample of grower lots in each shipment destined for Australia, cutting a minimum of 15 fruit to look for bean thrips, and (7) fruit are inspected by Australian inspectors either in the US (under a cooperative Pre-Clearance Program first instituted in 2004–2005) or in Australia. If fruit cutting finds bean thrips during Steps 2, 3, or 6, that lot of citrus cannot be sent to Australia. With the improved ability of detecting bean thrips by washing larger numbers of fruit, we suggest that fruit washing should be further investigated as a possible alternative to one or several of the components of the current systems approach.

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