Postharvest management of New Zealand flower thrips (*Thrips obscuratus*) on apricots using ethyl formate or pyrethrum-based treatments

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Abstract New Zealand flower thrips (NZFT, *Thrips obscuratus* (Crawford)) were exposed to a range of ethyl formate (EF) and pyrethrum-based postharvest treatments on apricots. Research showed that EF+CO₂ or EF+N₂ were effective treatments against NZFT and caused negligible damage to apricot fruit quality. However, pyrethrum dipping did not effectively control NZFT and caused significant internal damage to apricot fruit. Lethal concentration (LC₉₉) estimates were developed for adult and larval NZFT using a range of EF concentrations (0–1.27% EF+CO₂) and temperatures (5, 15 and 25°C). It is estimated that treatments of 1% (30.7 g/m³) EF at 5 or 25°C or a higher concentration of 1.5% (46.3 g/m³) at 15°C will achieve 99% mortality of NZFT adults and larvae on apricot fruit with 95% confidence.

Keywords New Zealand flower thrips, *Thrips obscuratus*, apricots, disinfestation, pyrethrum, ethyl formate.

INTRODUCTION

New Zealand apricots are currently exported to Australia, the USA, the UK and Europe. Increasing export volume and value relies on the ability to ensure fruit are free of quarantine pests and that quarantine measures used do not reduce fruit quality or exceed residue limits. New Zealand flower thrips (NZFT, *Thrips obscuratus* Crawford) (Thysanoptera: Thripidae) is the most abundant pest on NZ apricots at harvest and is an actionable quarantine pest for all of the apricot export markets. Current control methods rely on the use of carbaryl as a close-to-harvest treatment, which is increasingly becoming unacceptable in several key markets including Australia due to residue levels and its toxicity to

humans. Consequently, there is a need to develop reliable, non-toxic alternatives to control NZFT for the export apricot industry.

A review of postharvest disinfestation technologies for fruit and vegetables (Jamieson et al. 2009) identified ethyl formate (EF) and pesticidal dips and drenches as short-term options for future summerfruit disinfestation research. Ethyl formate is a volatile compound that occurs naturally in a variety of products including beef, cheese, rice, fruit and wine (Hiroyasu et al. 1972; Desmarchelier 1999), and is a “Generally Recognized As Safe” (GRAS) compound. A GRAS compound is determined by the US Food and Drug Administration (US

FDA) and such compounds are considered safe for use with human food (Anonymous 1993). The advantage of treatments utilising GRAS compounds is that they are already accepted by the United States Congress as a series of strict criteria have been satisfied. GRAS substances may therefore be excluded from mandatory premarket approval by the US FDA (Hallagan & Hall 1995) when used on produce to control pests. Ethyl formate has been used as a GRAS fumigant of dried fruit (Desmarchelier 1999) and is under investigation as a fumigant for a range of other commodities and pest species (Simpson et al. 2004; DeLima 2006; Mitcham et al. 2007; Simpson et al. 2007; Griffin et al. 2013). Residues of ethyl formate break down to formic acid and ethanol in the presence of water (Vincent & Lindgren 1972; Desmarchelier 1999). Ethyl formate is flammable and explosive when mixed with air at concentrations required to kill pests, but formulations in CO₂ reduce this risk significantly (Lawrence 2005). Ethyl formate is available in New Zealand under the trade name Vapormate™ (16.7% (by weight) EF dissolved in liquid CO₂; Ryan & Bishop 2003) and is currently registered in New Zealand against pests of cereals, grains, oilseeds, lettuce, onions, sweet peppers, cut flowers, callas, kumara, rhubarb, bananas, pineapples, grapes, strawberries and kiwifruit.

Pyrethrum is effective against a broad range of insect pests, has low toxicity to mammals and a short soil half-life of 8-12 days. Pyrethrum-based products can be applied as postharvest dips or drenches.

A study conducted by Plant & Food Research in 2011 investigated the efficacy of EF- and pyrethrum-based treatments to control thrips on apricots (Jamieson et al 2011). In that study, EF treatments were applied as a fumigant in a custom built 250-litre chamber. Pyrethrum was applied as a fog, drench or dip. Of the treatments trialled, EF (27 g EF/m³ or 0.88%) in CO₂ or N₂, and pyrethrum dip treatments resulted in good control of thrips with minimal damage to the apricot fruit. This paper describes subsequent trials further investigating the efficacy of different concentrations of EF- and pyrethrum-based treatments against NZFT at various temperatures

and any impacts of these treatments on fruit quality. The long-term objective of this research is to develop a reliable, non-toxic postharvest disinfestation treatment to control NZFT for the NZ export apricot industry.

MATERIALS AND METHODS

Insect and fruit supply

Flax flowers (*Phormium* sp.) with adult and larval NZFT were collected into large ziplock bags from the Auckland region on the day before treatment. This was done to minimise the time between collection and treatment to ensure the viability of the insects. The collected insects were held at 20°C before treatment.

Apricots for the NZFT disinfestation component of the trials were sourced from the Plant & Food Research orchard in Clyde. The fruit were washed and dried before use to remove any NZFT from the field. Apricots for the fruit quality component of the trials were commercially harvested class 1 'Clutha Gold' apricots from Central Otago orchards. The fruit were transported to Plant & Food Research in Auckland and stored at 0°C until required for treatment.

Year 1—ethyl formate fumigation and pyrethrum dip

In February 2012, a trial was conducted to investigate the efficacy of EF fumigation and a pyrethrum dip to control NZFT and to assess the impact of these treatments on apricot fruit quality. NZFT were exposed to the following three treatments: EF+CO₂ (mimicking Vapormate™), EF+N₂ and a pyrethrum dip. The EF treatments were applied at calculated target doses of 0.16, 0.32, 0.48, 0.65, 0.96 and 1.28% EF for 1 h. The pyrethrum dip treatment was applied at 0.01, 0.05, 0.1 and 0.5% for 1 min. These were compared with an untreated control that remained at 20°C throughout the treatments. Another set of apricots was exposed to the following treatments to assess fruit quality post treatment: EF+CO₂ (mimicking Vapormate™), EF+N₂ and a pyrethrum dip. The EF treatments were applied at calculated target doses of 0, 0.96 and 1.92% EF for 1 h and 2 h, while the pyrethrum dip treatment was applied at 0, 0.1 and 0.5% for 1 and 2 min.

The day before treatment, 100 adult NZFT were transferred from the flax flowers and placed onto three apricots inside a plastic insect proof container. This was carried out using a fine-tipped paintbrush. Each container was 10 cm in height, tapering from 10.5 cm diameter at the top to 8.5 cm at the base. The containers were also vented with fine wire gauze at either end (base and lid) to allow for the flow of either the gas or dipping solution but prevent insects from escaping. Each container represented one replicate, with three replicates (a total of 300 adults) per treatment. Similarly, NZFT larvae were removed from flax flowers and caged on to apricots (20 larvae per fruit; 5 fruit per replicate). Both 1st and 2nd instar larvae were used, randomly brushed into the cages to ensure a range of sizes in each cage. Cages were oval in shape and approximately 2.8 × 3.5 cm in diameter and 1 cm in height, with the top surface covered with fine mesh gauze. Each cage was securely attached to the cheek of an apricot using Blu-Tak®. There were three replicates (300 larvae) per treatment. Insects were held at 20°C until treatment the next day. The day before treatment, the fruit quality apricots were removed from cool storage to allow fruit to be equilibrated to ambient temperature. Each fruit quality treatment comprised eight trays of fruit (four trays for each of two orchards, with 32 fruit/tray).

The EF treatments were carried out using a 250-litre chamber fitted with a liquid ring vacuum pump (Model TRMB 32-75, Travaini Pumps,

USA), a compound gauge (WIKA EN-8371, 316L) and a water bath-chemical heating system to allow conversion of liquid EF to vapour before entering the treatment chamber. The treatment chamber was connected to either a CO₂ or N₂ gas cylinder depending on the treatment being applied. Inside the chamber was a 110 mm diameter spark-proof fan to ensure uniformity of treatment conditions. Average temperature (± SEM) measured during the EF treatments was 21.7 ± 0.39°C (temperature range=18.8–24.9°C). EF was monitored in the chamber by extracting 1 ml samples from the chamber and injecting into a gas chromatograph (GC) unit (Philips® PYE UNICAM PU4500 Chromatograph). The extracted sample was decreased to 0.2 ml and balanced with air to dilute the high concentrations of EF for the GC. The calculated target and actual concentrations of EF applied during the treatments are presented in Table 1. Carbon dioxide was also monitored by extracting a 1 ml sample and injecting into a carbon dioxide analyser with Hewlett Packard® integrator.

Solutions of Key Pyrethrum™ were formulated in 100-litre plastic drums. Containers with NZFT-infested fruit were rotated and bags with fruit quality apricots were gently shaken while submerged within the solution to remove any air bubbles. After dipping for the specified time, NZFT-infested apricots and fruit quality apricots were allowed to dry before storage.

Treated and untreated NZFT-infested fruit were stored at 20°C for 24 h, before assessing

Table 1 Calculated and actual concentrations of ethyl formate (EF) during fumigation targeting *Thrips obscuratus*, with 0–0.52% EF+CO₂ or EF+N₂ for 1 h at 21.7°C on apricot fruit in Year 1.

Calculated EF (g/m ³)	Calculated EF (%)	EF injected into 250-litre chamber (g)	EF+CO ₂		EF+N ₂	
			Actual EF (%)	Calculated CO ₂ (%)	Actual EF (%)	Calculated N ₂ (%)
Untreated	0.00	0.00	0.00	n/a	0.00	n/a
4.90	0.16	1.32	0.05	1.29	0.06	2.00
9.84	0.32	2.65	0.12	2.57	0.10	4.00
14.77	0.48	3.99	0.19	3.86	0.18	6.00
19.67	0.64	5.31	0.24	5.14	0.27	8.00
29.44	0.96	7.95	0.38	7.72	0.39	12.00
39.31	1.28	10.61	0.52	10.29	0.51	15.99

and recording the number of live and dead thrips. Assessments were conducted under a 10–50× microscope. Treated fruit quality apricots were cool stored at 0°C for 2 or 4 weeks plus 4 days of simulated shelf life at 20°C before assessment at 18 and 32 days after treatment (DAT). Fruit quality attributes assessed included flesh firmness and the number of fruit in each tray showing disorders such as rots, blemishes, internal browning and internal mould. Flesh firmness (kilogram force or kgf) was measured on two sides of each fruit along the equatorial zone using a 7.9 mm diameter probe attached to a FUSS FTA (GUSS Manufacturing Ltd, South Africa). Penetration speed, trigger force and penetration distance were set at 10 mm/s, 50 g and 8 mm, respectively. Higher flesh firmness values indicate firmer fruit.

Year 2–ethyl formate fumigation

In January 2013, a trial was conducted to investigate the efficacy of EF fumigation to control NZFT at various concentrations and temperatures. Based on the results of the trial in Year 1, NZFT were exposed to EF+CO₂ (mimicking Vapormate™) at calculated target doses of 0.00, 0.06, 0.16, 0.48, 0.96, 1.28 and 1.60% EF for 1 h at 5, 15 and 25°C. Calculated target doses varied slightly according to temperature. These treatments were compared with an untreated control that remained at 20°C throughout the treatments. Another set of apricots was exposed to the following treatments to assess fruit quality post-treatment: 0, 2.4 and 4.9% EF for 1 h at 15°C. In addition, the sorption of EF was measured in the treatment chambers for 1 h with the following: empty chamber, fruit only, boxes only and fruit and boxes. Sorption of fumigants by packaging materials can affect the efficacy of treatments and therefore it was important to determine the level of sorption of EF by commercial apricot packaging materials. EF samples were taken approximately every 15 min for each chamber using a 50 µl syringe and injected into a gas chromatograph unit. The EF concentration profile over time in chambers with fruit and/or boxes was compared with that

in the empty chambers. This was based on a loading of three commercial 5 kg modular bulk (MB) boxes in a 76.8-litre chamber.

Adult and larval NZFT were setup as in Year 1 with 300 NZFT adults and 300 NZFT larvae exposed per treatment. The day before treatment, the fruit quality apricots were removed from cool storage to allow fruit to be equilibrated to ambient temperature. Each fruit quality treatment comprised three replicates of three boxes (30 fruit/box) of fruit (270 fruit per treatment).

The EF treatments were carried out in the Volatile Treatment Facility (VTF) at Plant & Food Research in Auckland. Fourteen identical 76.8-litre steel gas-tight chambers were used for this trial in a controlled temperature room. The amount of EF and CO₂ delivered to each chamber was controlled by the user input into the computer program. A CO₂ gas stream (10 litres/min) was passed through a heated bead bath (75°C) and liquid EF was delivered using a micro-dispenser into the heated gas stream. The gas was again passed through the heated bead bath to volatilise the EF before delivery to the chamber. The chambers filled automatically one after the other and were purged of EF once the treatment time was completed. EF was monitored in each chamber with 50 µl samples taken from the chamber and injected into a gas chromatograph unit. The calculated and actual concentrations of EF applied during the treatments are presented in Table 2.

Treated and untreated NZFT-infested fruit as well as treated fruit quality apricots were stored and assessed as in Year 1.

Statistical analysis

The NZFT mortality data were analysed and presented in figures based on actual EF concentrations rather than target concentrations. The effect of EF on the mortality of NZFT was analysed using a robust version of the Generalized Linear Model (GLM) capabilities (Chambers & Hastie 1992) in R version 2.15.2 (R Core Development Team 2012). Variance was assumed proportional to that for a binomial

Table 2 Calculated and actual concentrations of ethyl formate (EF) during fumigation targeting *Thrips obscuratus*, with doses of 0–1.27% EF+CO₂ for 1 h at 5, 15 and 25°C on apricot fruit in Year 2.

Calculated EF (g/m ³)	Calculated EF (%) at 15°C	EF injected into 76.8-litre chamber (g)	5°C		15°C		25°C	
			Actual EF (%)	Actual CO ₂ (%)	Actual EF (%)	Actual CO ₂ (%)	Actual EF (%)	Actual CO ₂ (%)
Untreated	0.00	0.00	0.00	n/a	0.00	n/a	0.00	n/a
0	0.00	0.00	0.00	8.52	0.00	9.15	0.00	8.78
2.42	0.08	0.20	0.08	2.49	0.06	2.56	0.07	2.63
4.72	0.15	0.38	0.14	5.27	0.15	5.43	0.15	5.37
14.56	0.46	1.18	0.44	5.93	0.48	6.47	0.51	6.37
30.43	0.97	2.47	0.83	8.66	0.93	9.21	0.94	8.86
40.57	1.29	3.29	1.00	7.84	1.10	8.50	1.15	7.98
50.71	1.62	4.11	1.18	8.32	1.21	8.74	1.27	8.61

distribution. The analysis assumed that the form of dependence of mortality on concentration was that given by a logit model, with concentration as the explanatory variable. A complementary-log-log model was also attempted but the deviance was larger than that for the logit model for most trial runs. The assumed form of response was $\log(p/(1 - p)) = a + bc$, where p = expected mortality and c = concentration of EF. From the derived coefficients, the LC₉₉ (calculated lethal concentration) or the concentration required to produce a mortality of 99%, was calculated with adjustment for sources of mortality other than EF. Two possible sources of extraneous mortality were considered: handling and treatment with CO₂ or N₂. The mortality attributed to these sources was compared using a simpler binomial GLM and found not to be significantly different. Therefore, the handling control and treatment control mortality data were combined and used as the control mortality, cm , in the calculation of the LC₉₉ values: $cm + (1 - cm) \times 0.99$. The geometric means of the four replicates for each lifestage and temperature were calculated along with a 95% confidence interval.

For mortality response figures (Figures 1-5), non-parametric loess fits (Chambers & Hastie 1992) were calculated and plotted on an arcsine scale in R version 2.15.2 (R Core Development Team 2012). Smooth lines were drawn through

the mean percentage mortality points for each NZFT lifestage-temperature combination after exposure to EF+CO₂, EF+N₂ or pyrethrum treatments at each concentration. The arcsine scale was used to ensure the SEM of the fit produced would be applicable over the entire mortality range.

The fruit quality data were analysed using a GLM in SAS version 9.2 (SAS Institute Inc. USA). The fruit firmness data were analysed using an ANOVA to determine if fruit firmness was significantly different between treatments. The incidence of disorders was calculated for each tray and analysed based on an arcsine transformation: $\arcsine(\sqrt{\text{incidence}})$.

RESULTS AND DISCUSSION

Year 1—ethyl formate fumigation and pyrethrum dip

Figures 1 and 2 show the mortality responses of NZFT to EF+CO₂ and EF+N₂. NZFT larvae tended to be more tolerant than adults to EF+CO₂ fumigation, while the tolerance of NZFT larvae and adults to EF+N₂ fumigation was found to be similar. Calculated mean lethal EF (+CO₂) concentrations of 0.16 or 0.24% EF (5.0 or 7.4 g/m³) were required to achieve 99% mortality (LC₉₉) of NZFT adults or larvae in a 1 h treatment, respectively. This is comparable to results investigating fumigation to control

other thrips species. DeLima (2010) estimated that EF concentrations of 14.1 and 12.6 g/m³+10% CO₂ were required to achieve 99% mortality of western flower thrips (WFT;

Figure 1 Percentage mortality of adult and larval *Thrips obscuratus* at 24 h after fumigation with actual doses of 0–0.52% EF+CO₂ for 1 h on apricot fruit in Year 1 (calculated target doses=0–1.28% EF). n=134–506 per data point. Error bars= SEM.

Figure 2 Percentage mortality of adult and larval *Thrips obscuratus* at 24 h after fumigation with actual doses of 0–0.51% EF+N₂ for 1 h on apricot fruit in Year 1 (calculated target doses=0–1.28% EF). n=90–536 per data point. Error bars= SEM.

Frankliniella occidentalis) larvae or adults, respectively in a 1 h treatment in the absence of fruit. For plague thrips (*Thrips imaginis*), concentrations of 12.4 and 13.3 g/m³+10% CO₂, were required to achieve 99% mortality of larvae or adults in a 1 h treatment, respectively. The author recommended treatments of 24 g/m³+10% CO₂ for 1 h or 20 g/m³+10% CO₂ for 2 h for susceptible species, such as western flower thrips and plague thrips. Simpson (2007) reported a 1 h exposure of 10.2 g/m³ at 24°C resulted in 100% mortality of WFT in table grapes. Although dipping in 0.5% pyrethrum achieved 100% mortality of adult NZFT, only 66% of larval NZFT were killed by this treatment (Figure 3).

Treatments with mean EF concentrations of 0.30–1.14% and 0.28–1.03% for 1 or 2 h, respectively, did not have a negative impact on apricot fruit quality. An exception was that fruit treated with 0.30% EF+N₂ for 1 h had a significantly higher incidence of disorders compared with the control fruit at 18 DAT. However, this difference was not seen in the equivalent longer exposure treatment (2 h) or at 32 DAT (Table 3). In general, there was no statistical difference in apricot fruit firmness

Figure 3 Percentage mortality of adult and larval *Thrips obscuratus* at 24 h after dipping in pyrethrum solution with doses of 0.00–0.50% for 1 min on apricot fruit in Year 1. n=117–330 per data point. Error bars= SEM.

Table 3 Mean apricot flesh firmness (kgf $\pm$ SE) and mean incidence of disorders (rots, blemishes, internal browning, internal mould) (% $\pm$ SE) in Year 1 on apricot fruit 18 days after treatment (DAT) (14 days of cool storage at 0°C and 4 days of simulated shelf life at 20°C) and 32 DAT (28 days of cool storage at 0°C and 4 days of simulated shelf life at 20°C) after fumigation with doses of 0–1.14% ethyl formate (EF)+CO₂ or EF+N₂ for 1 and 2 h, or pyrethrum dip treatments for 1 and 2 min. Means within a treatment that are significantly different to the treatment control at P<0.05 are indicated by *.

Treatment	Time	Calculated values		Actual EF values (%)			Flesh firmness (kgf $\pm$ SE)		Incidence of disorders (% $\pm$ SE)	
		EF (g/m ³)	EF (%)	Mean ¹	Initial ²	Final ³	18 DAT	32 DAT	18 DAT	32 DAT
EF+CO ₂	0 h	0	0.00	0.00	0.00	0.00	0.66 $\pm$ 0.09	0.68 $\pm$ 0.07	1.67 $\pm$ 0.96	0.00 $\pm$ 0.00
		29.44	0.96	0.38	0.52	0.33	0.73 $\pm$ 0.09	0.69 $\pm$ 0.07	0.83 $\pm$ 0.83	0.83 $\pm$ 0.83
		58.95	1.92	1.14	1.41	1.05	0.74 $\pm$ 0.09	0.94 $\pm$ 0.10*	0.83 $\pm$ 0.83	1.67 $\pm$ 0.96
	2 h	29.44	0.96	0.28	0.30	0.25	0.66 $\pm$ 0.08	0.81 $\pm$ 0.07	1.50 $\pm$ 1.60	3.33 $\pm$ 2.36
		58.95	1.92	0.86	1.05	0.75	0.87 $\pm$ 0.10	0.90 $\pm$ 0.10	0.83 $\pm$ 0.83	0.83 $\pm$ 0.83
	0 h	0	0.00	0.00	0.00	0.00	0.95 $\pm$ 0.12	0.83 $\pm$ 0.09	0.83 $\pm$ 0.83	1.67 $\pm$ 1.67
EF+N ₂	1 h	29.44	0.96	0.30	0.29	0.29	0.91 $\pm$ 0.08	0.85 $\pm$ 0.07	5.00 $\pm$ 1.67*	0.83 $\pm$ 0.83
		58.95	1.92	1.09	1.30	1.02	0.76 $\pm$ 0.07	0.80 $\pm$ 0.07	0.00 $\pm$ 0.00	0.00 $\pm$ 0.00
		29.44	0.96	0.39	0.49	0.27	0.82 $\pm$ 0.08	0.83 $\pm$ 0.07	0.00 $\pm$ 0.00	0.83 $\pm$ 0.83
	2 h	58.95	1.92	1.03	1.14	0.73	0.74 $\pm$ 0.10	0.83 $\pm$ 0.07	1.67 $\pm$ 0.96	0.00 $\pm$ 0.00
		0.00	0.00	0.00	0.00	0.00	0.95 $\pm$ 0.12	0.83 $\pm$ 0.09	0.83 $\pm$ 0.83	1.67 $\pm$ 1.67
	0 h	0	0.00	0.00	0.00	0.00	0.95 $\pm$ 0.12	0.83 $\pm$ 0.09	0.83 $\pm$ 0.83	1.67 $\pm$ 1.67
Pyrethrum dip	1 min	0.10	0.10	0.10	0.10	0.10	0.92 $\pm$ 0.09	0.78 $\pm$ 0.07	0.83 $\pm$ 0.83	35.83 $\pm$ 7.25*
		0.50	0.50	0.50	0.50	0.50	0.69 $\pm$ 0.07*	1.00 $\pm$ 0.08*	3.33 $\pm$ 3.33	40.00 $\pm$ 7.58*
		0.10	0.10	0.10	0.10	0.10	0.77 $\pm$ 0.07*	0.81 $\pm$ 0.07	0.83 $\pm$ 0.83	39.17 $\pm$ 6.14*
	2 min	0.50	0.50	0.50	0.50	0.50	0.71 $\pm$ 0.08*	0.83 $\pm$ 0.09	2.50 $\pm$ 0.83	51.67 $\pm$ 3.15*
		0.10	0.10	0.10	0.10	0.10	0.92 $\pm$ 0.09	0.78 $\pm$ 0.07	0.83 $\pm$ 0.83	35.83 $\pm$ 7.25*
		0.50	0.50	0.50	0.50	0.50	0.69 $\pm$ 0.07*	1.00 $\pm$ 0.08*	3.33 $\pm$ 3.33	40.00 $\pm$ 7.58*

¹The mean concentration of EF measured over the treatment time.

²The initial concentration of EF measured 10–20 minutes after the start of the treatment.

³The final concentration of EF measured at the conclusion of the treatment.

between EF- treated and control fruit at 18 DAT. Pyrethrum dipping of apricot fruit resulted in a significantly higher incidence of fruit with disorders compared with the control fruit at 32 DAT. Over 50% of fruit treated with 0.50% pyrethrum for 2 min were determined to have disorders, in particular internal mould (Table 3). Pyrethrum dipping also resulted in softer fruit compared with the control fruit after short term storage (18 DAT). However, this difference was only seen after the longer storage time (32 DAT).

The actual concentrations of EF applied during the treatments in the 250-litre chamber were consistently found to be lower than the calculated target doses. Therefore, future research focused on developing a new treatment system that could deliver fumigants at the required concentrations.

Although EF treatments with both CO₂ and N₂ were found to be similarly effective against NZFT and resulted in comparable fruit quality results, EF+CO₂ was chosen as a focus for future research as it is already commercially available under the trade name Vapormate™. Research in Year 2 focused on further investigating the efficacy of different concentrations of EF+CO₂ against NZFT at various temperatures and impacts on fruit quality. This research was conducted in the VTF facility at Plant & Food Research in Auckland.

Year 2– ethyl formate fumigation

Figures 4 and 5 show the mortality response of NZFT adults and larvae to EF+CO₂ at 5, 15 and 25°C. The tolerance of NZFT larvae and adults to EF fumigation was found to be similar. Calculated lethal EF (+CO₂) concentrations of 0.19–0.93 (5.74–28.7 g/m³), 0.51–1.22 (15.9–37.5 g/m³) and 0.24–0.77% (7.43–23.6 g/m³) EF were required to achieve 99% mortality (LC₉₉) of NZFT adults in a 1 h treatment at 5, 15 and 25°C, respectively. Calculated lethal EF (+CO₂) concentrations of 0.22–0.84 (6.75–26.0 g/m³), 0.26–1.32 (8.1–40.7 g/m³) and 0.21–0.74% (6.42–22.8 g/m³) EF were required to achieve 99% mortality (LC₉₉) of NZFT larvae in a 1 h treatment at 5, 15 and 25°C, respectively. These concentrations were found to be higher than those required to achieve 99% mortality in Year

1. It was observed that more adults were found in and around the stone of the apricot fruit in Year 2, which may account for the higher estimated lethal doses required to achieve 99% mortality. Also, the high pest pressure (100 NZFT adults/ three apricots) was an unnatural situation to ensure large numbers of NZFT were treated to demonstrate treatment efficacy. This most likely resulted in an overestimation of the lethal concentration of EF required to control NZFT that would otherwise be naturally found on the surface under lower natural fruit infestation densities (less than 10 thrips per 100 fruit). However, overcrowding may also lead to stress, which could lead to increased mortality. Ultimately treatment efficacy will need to be determined against NZFT in both an artificially high density situation to demonstrate a high level of treatment efficacy and in a naturally infested situation.

Apricot fruit treated with mean EF concentrations of 0.54–1.7%+CO₂ at 15°C for 1 h were significantly firmer than control fruit after long-term storage (32 DAT). This is likely to be an effect of the high CO₂ associated with high EF during the treatment, rather than the effect of EF alone. Nevertheless, average fruit firmness across all treatments was in an acceptable ripe firmness range (i.e. 0.5–1.2 kgf). The effect of treatment temperature on the response of fruit to EF fumigation requires further investigation. A high proportion of fruit was found to be blemished across all treatments both at 18 and 32 DAT (Table 5). This may have been a result of extra handling during the trial (e.g. fruit randomisation, treatment, repacking). However, levels of rots, internal browning and internal mould were found to be negligible. This is consistent with the results gathered in Year 1. Other studies have also reported minimal damage to fruit following EF treatments. DeLima (2006) found that treatment of table grapes with EF had no negative effect on fruit quality. Simpson et al. (2004) reported that there was no significant difference in strawberry fruit firmness or berry damage levels between EF-treated and untreated fruit. However, strawberry fruit showed calyx damage in fruit exposed to

Table 4 The calculated mean ethyl formate (EF) concentrations (%) +CO₂ to result in 99% mortality (LC₉₉) of adult and larval *Thrips obscuratus* in a 1 h treatment at 5, 15 or 25°C in Year 2.

Thrips lifestage	Temp. (°C)	Mean (% ± SE)	95% C.I.	Replicates
Adults	5	0.48 ± 0.17	0.25–0.92	4
	15	0.78 ± 0.17	0.40–1.49	4
	25	0.47 ± 0.16	0.22–0.99	3
Larvae	5	0.51 ± 0.16	0.27–0.98	4
	15	0.68 ± 0.24	0.35–1.30	4
	25	0.40 ± 0.13	0.21–0.78	4

Figure 4 Percentage mortality of adult *Thrips obscuratus* at 24 h after fumigation with actual doses of 0–1.18% ethyl formate (EF)+CO₂ for 1 h at 5°C, 0–1.21% EF+CO₂ for 1 h at 15°C and 0–1.27% EF+CO₂ for 1 h at 25°C on apricot fruit in Year 2 (calculated target doses= 0–1.60%). n=239–708 per data point. Error bars= SEM.

Figure 5 Percentage mortality of larval *Thrips obscuratus* 24 h after fumigation with actual doses of 0–1.18% EF+CO₂ for 1 h at 5°C, 0–1.21% ethyl formate (EF)+CO₂ for 1 h at 15°C and 0–1.27% EF+CO₂ for 1 h at 25°C on apricot fruit in Year 2 (calculated target doses= 0–1.60%). n=173–490 per data point. Error bars= SEM.

Table 5 Mean apricot flesh firmness (kgf $\pm$ SE) and mean incidence of blemishes (% $\pm$ SE) in Year 2 on apricot fruit 18 days after treatment (DAT) (14 days of cool storage at 0°C and 4 days of simulated shelf life at 20°C) and 32 DAT (28 days of cool storage at 0°C and 4 days of simulated shelf life at 20°C) after fumigation with doses of 0–3.0% ethyl formate (EF)+CO₂ for 1 h at 15°C. Means within a treatment that are significantly different to the treatment control at P<0.05 are indicated by *.

Chamber contents	Calculated EF		Actual EF (%)			Actual CO ₂ (%)	Flesh firmness (kgf $\pm$ SE)		Incidence of blemishes (% $\pm$ SE)	
	(g/m ³)	(%)	Mean ¹	Initial ²	Final ³		18 DAT	32 DAT	18 DAT	32 DAT
Empty	76.10	2.43	1.70	1.60	1.70					
	152.40	4.86	3.00	2.90	3.30					
Fruit & box	0.00	0.00	0.00	0.00	0.00	1.77	0.72 $\pm$ 0.09	0.56 $\pm$ 0.05	44.07 $\pm$ 3.92	58.70 $\pm$ 6.33
	76.10	2.43	0.54	0.76	0.40	11.87	0.76 $\pm$ 0.08	0.73 $\pm$ 0.07*	46.67 $\pm$ 3.29	60.22 $\pm$ 4.08
	152.40	4.86	1.19	1.77	0.77	13.52	0.74 $\pm$ 0.07	0.88 $\pm$ 0.08*	41.85 $\pm$ 4.31	53.40 $\pm$ 6.78
Fruit only	0.00	0.00	0.00	0.00	0.00	1.04	0.72 $\pm$ 0.07	0.53 $\pm$ 0.02	45.19 $\pm$ 3.77	62.26 $\pm$ 6.16
	76.10	2.43	0.91	1.62	0.47	12.09	0.76 $\pm$ 0.07	0.73 $\pm$ 0.04*	41.11 $\pm$ 6.48	61.41 $\pm$ 5.40
	152.40	4.86	1.70	2.70	0.80	13.73	0.81 $\pm$ 0.09	0.86 $\pm$ 0.09*	41.85 $\pm$ 4.31	62.00 $\pm$ 5.83

¹The mean concentration of EF measured over the treatment time.

²The initial concentration of EF measured 10–20 minutes after the start of the treatment.

³The final concentration of EF measured at the conclusion of the treatment.

concentrations of 1.6% and 2.4%. Also, increased levels of acetaldehyde, ethanol, ethyl acetate and EF were detected in fruit exposed to EF.

During a 1 h EF+CO₂ treatment with initial concentrations of 0.76–2.7% EF, fruit absorbed 72–73% EF, boxes absorbed 40–42% EF, and a combination of fruit and boxes absorbed 74–77% EF compared with empty chambers. The effect of EF sorption of apricot fruit and packaging on the efficacy of EF against NZFT warrants further investigation.

The actual concentrations of EF applied during the treatments in the VTF facility in Year 2 were generally found to be more accurate and consistent than those applied in the 250-litre chamber in Year 1. The actual concentrations of EF applied during treatments in the VTF facility were comparable with the calculated target doses at the lower EF concentrations. However, there were inconsistencies at the higher EF concentrations. Therefore, the VTF delivery system will require further development for future fumigation research.

CONCLUSION

Results from this study show that EF+CO₂ is a promising postharvest treatment to control NZFT on apricots in New Zealand. The data show that a treatment of 1% (30.7 g/m³) EF at 5 or 25°C will achieve 99% mortality of NZFT, whereas a higher concentration (1.5% EF or 46.3 g/m³ EF) at 15°C will achieve 99% mortality of NZFT. Larger volume EF sorption rates of fruit will need to be assessed and incorporated into the final application dose. Future research will investigate the logistics and practicalities associated with applying EF-based postharvest treatments to New Zealand export apricots on a commercial level. Also, other pests that may cause market access issues for export apricots, such as species of mites and mealybugs, will need to be considered when developing EF treatment protocols for New Zealand export apricots.

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