Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Methyl Eugenol and Trap Height Affect Captures of *Bactrocera dorsalis* (Diptera: Tephritidae) and Non-Target Insects on Yellow Sticky Traps in a Water Apple (*Syzygium aqueum*) Orchard

Meiliana Friska

melianafriska90@gmail.com

Universitas Graha Nusantara

Siti Hardianti Wahyuni

Universitas Graha Nusantara

Surya Handayani

Universitas Graha Nusantara

Jumaria Nasution

Universitas Graha Nusantara

Akhiruddin Pulungan

Universitas Graha Nusantara

Research Article

Keywords: Bactrocera dorsalis, Methyl eugenol, Trap height, Male annihilation, Non-target insects, Syzygium aqueum

Posted Date: October 26th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11307838/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

The oriental fruit fly, *Bactrocera dorsalis* (Hendel), is the key pest of water apple (*Syzygium aqueum*) in Indonesia, yet how trap design and placement interact in this crop is unknown. We evaluated three trap types (P0, yellow non-sticky control; P1, yellow sticky trap; P2, yellow sticky trap + methyl eugenol, ME) at three heights (50, 100 and 150 cm) in a water apple orchard in North Sumatra, using a 3 × 3 factorial randomised complete block design with three blocks. Catches were recorded five times at 2-day intervals. In total, 684 *B. dorsalis* (682 males) and 212 non-target insects were captured; control traps retained none. Among sticky traps, trap type and height interacted significantly for cumulative fruit fly catch ($F_{2,10}$ = 5.34, P = 0.026). The ME-baited trap at 100 cm (P2T2) caught 67.67 ± 4.33 flies per trap, 68% more than the next best combination (Tukey HSD, $P < 0.05$); four of nine combinations produced 80.1% of all captures. Nearly half of the catch (43.7%) occurred within 2 days of installation, consistent with rapid volatilisation of ME mixed into the adhesive. Non-target catches were affected by trap type and height but not by their interaction, and were highest on unbaited traps at 50 cm, including predatory lady beetles. P2T2 was also the most selective combination (86.8% *B. dorsalis*). ME-baited yellow sticky traps placed at about 100 cm, within the fruiting canopy, with regular lure renewal, are recommended for monitoring and male suppression of *B. dorsalis* in water apple.

1. Introduction

Water apple (*Syzygium aqueum* (Burm.f.) Alston; Myrtaceae) is a tropical fruit tree native to Southeast Asia and widely grown in Indonesian home gardens and smallholder orchards. Its fruit, together with that of the closely related wax apple (*S. samarangense*) (Hanifah and Haryanti 2016), is sold fresh in local markets, and sweet cultivars such as 'Madu' (honey water apple) are particularly popular. Because the fruit is thin-skinned, juicy and harvested at full colour, its marketable yield and quality are highly vulnerable to insect damage.

Tephritid fruit flies are among the most destructive pests of horticultural crops worldwide (Ekesi et al. 2016). The tribe Dacini alone comprises more than 930 described species (Doorenweerd et al. 2018), of which the oriental fruit fly, *Bactrocera dorsalis* (Hendel), is the most important in Asia (Clarke et al. 2005). The species is highly polyphagous, attacking several hundred cultivated and wild hosts, and has spread from its native Asian range to Africa, Oceania and new areas of China (Lux et al. 2003; Vargas et al. 2007, 2015; Clarke et al. 2019; Liu et al. 2019; Zeng et al. 2019; Mutamiswa et al. 2021). Bioclimatic models indicate that most of the humid tropics are suitable for the species, and its global establishment risk is among the highest of all economically important tephritids (Stephens et al. 2007; Qin et al. 2015; De Villiers et al. 2016). Following an integrative taxonomic revision, *B. papayae*, *B. philippinensis* and *B. invadens* are now treated as junior synonyms of *B. dorsalis* (Schutze et al. 2015; Hee et al. 2015), and the melon fly and *B. tau* have been transferred to the genus *Zeugodacus* (Doorenweerd et al. 2018); the latter, *Z. tau*, is itself a major pest of cucurbits and fruits in Asia (Jaleel et al. 2018). These changes matter for Indonesia, where about 90 indigenous dacine species have been recorded in the western part of the archipelago, of which eight were listed as major pests (Siwi et al. 2006).

Damage is caused by females, which insert eggs beneath the skin of ripening fruit; a single female may lay 1–10 eggs per fruit and up to 40 eggs per day (Herlinda et al. 2007). Larvae feed inside the pulp, so infested fruits often look intact while rotting internally, and many drop prematurely. The owner of the study orchard reported yield losses of 30–60%, rising to 80% in the absence of control (personal communication, 2023). Infestation intensifies under cool, humid conditions with light wind (Herlinda et al. 2007), and population levels closely follow host fruiting phenology and rainfall (Ye and Liu 2005; Mwatawala et al. 2006; Vayssières et al. 2009). Local growers mainly protect fruit by bagging, which is effective but labour-intensive and costly on tall trees (Ali et al. 2021), while calendar insecticide sprays leave residues on a fruit eaten fresh. Low-cost, selective and environmentally safe alternatives are therefore needed (Dias et al. 2018).

Trapping with male lures is one such alternative. Methyl eugenol (ME), a phenylpropanoid occurring in many plants, has been known as a powerful male attractant for *B. dorsalis* for more than 70 years (Steiner 1952). Males that feed on ME convert it into sex-pheromone components stored in the rectal gland and gain a mating advantage, which explains their compulsive attraction to the compound (Nishida et al. 1988; Shelly and Dewire 1994; Hee and Tan 2004; Wee et al. 2007; Tan and Nishida 2012; Tan et al. 2014). ME-baited traps are the standard tool for detecting and monitoring *B. dorsalis* and, when deployed at high density with a toxicant or sticky surface, form the basis of the male annihilation technique (MAT) (Vargas et al. 2012, 2015; Suckling et al. 2016; Manoukis et al. 2019). Visual cues complement chemical cues: fruit flies use colour and contrast to locate host plants and fruit (Prokopy and Owens 1983), yellow traps are particularly attractive to *B. dorsalis* (Wu et al. 2007), and adhesive surfaces retain insects without insecticide (Dias et al. 2018). However, simple yellow sticky traps attract many insect groups (Meilin 2018) and are therefore not selective, so they may also capture natural enemies and other non-target insects (Thomas 2003; Blackmer et al. 2008).

Trap performance also depends on where the trap is placed. Fruit flies forage, mate and oviposit mostly within the host canopy, where males of *B. dorsalis* also form leks (Shelly 2018), so the optimum trap height varies with canopy architecture and crop (Saha and Chandran 2023; Bausin et al. 2024). Hasyim et al. (2006) evaluated trap model and trap height for capturing male *Bactrocera* in Indonesia, but most height studies have been conducted in mango, guava, citrus or vegetables rather than in *Syzygium*. To our knowledge, no study has examined how trap type and trap height interact in water apple, or quantified the trade-off between target catch and non-target bycatch for the resulting combinations. The objectives of this study were therefore to (i) determine the interaction between trap type and trap height on captures of *B. dorsalis* in a water apple orchard; (ii) describe the temporal pattern of captures after trap installation; and (iii) evaluate the selectivity of each combination by quantifying non-target insect catches. We hypothesised that ME-baited sticky traps placed at mid-canopy height would capture the most flies with the least bycatch.

2. Materials and Methods

2.1. Study site and period

The experiment was conducted from February to April in a smallholder 'Madu' water apple orchard of 168 trees in Aek Tuhul Village, Batunadua Sub-district, Padangsidimpuan City, North Sumatra, Indonesia (about 289 m above sea level). Twenty-seven trees at the fruit-maturation stage (1.5–2 months after flowering) were selected for the experiment. The trees were 3 years old and about 200 cm tall, planted at a spacing of 3 m. Before the study, the grower protected the fruit by bagging it with plastic. Insect identification was carried out in the laboratory of the Faculty of Agriculture, Universitas Graha Nusantara, Padangsidimpuan.

2.2. Experimental design and treatments

A two-factor experiment was laid out in a randomised complete block design (RCBD) with three blocks. The first factor was trap type, with three levels: P0, a yellow-painted trap without adhesive (visual-only control); P1, a yellow-painted trap coated with adhesive; and P2, a yellow-painted trap coated with adhesive mixed with methyl eugenol. The second factor was trap height above the ground, with three levels: T1, 50 cm; T2, 100 cm; and T3, 150 cm. Each block comprised nine trees, and the nine treatment combinations were randomly allocated to trees within each block, giving 27 traps in total, with one trap per tree.

2.3. Trap construction and installation

Each trap consisted of a 240 mL clear plastic cup fixed upside-down on top of a bamboo pole (Fig. 1a). Pole length equalled the treatment height plus 10 cm, which was inserted into the soil. The outer surface of every cup was painted yellow. For P1, the cup surface was evenly coated with a transparent adhesive (Lem Tikus Cap Gajah, a commercial rodent glue); for P2, the adhesive was first mixed with 5 mL of a commercial ME formulation (Petrogenol 800 L, 800 g L^{-1} methyl eugenol) and then applied over the whole surface. Traps were installed 30 cm from the trunk of each tree at 09:00 local time (WIB).

2.4. Sampling and identification

Traps were inspected every 2 days at 17:00 WIB, giving five observations at 2, 4, 6, 8 and 10 days after installation (DAI) (Fig. 1b, c). Trapped fruit flies were removed with fine forceps, counted, sexed by the presence of an ovipositor under a hand lens, and preserved in 70% ethanol. Fruit flies were identified to species using the identification literature for Indonesian *Bactrocera* (Siwi et al. 2006), following the current nomenclature of Schutze et al. (2015) and Doorenweerd et al. (2018). Other insects on the traps were counted and sorted to morphospecies based on external morphology (body shape, colour, size, and number and form of appendages) and identified to the lowest possible taxon. Rainfall was noted in the field; rain fell on day 5 after installation.

2.5. Data analysis

The response variables were the numbers of *B. dorsalis* (all, males and females) and of non-target insects per trap at each observation, and their cumulative totals over the five observations. Because the non-sticky P0 traps retained no insects (all values zero, hence zero variance), they were reported

descriptively and excluded from inferential tests. Data from the six sticky-trap combinations were analysed by two-way ANOVA for a 2 × 3 factorial RCBD, with block, trap type (P1, P2), trap height (T1, T2, T3) and their interaction as sources of variation (error df = 10). Normality of residuals and homogeneity of variances were checked with the Shapiro–Wilk and Levene tests; both assumptions were met for the cumulative data (Table 2), and residuals were also normally distributed at every observation date (Shapiro–Wilk $P \geq 0.08$), so untransformed counts were analysed. Means were separated by Tukey's honestly significant difference (HSD) test at $\alpha = 0.05$. To identify the treatment combinations that contributed most to the total catch, a Pareto analysis was performed: the nine combinations were ranked by mean cumulative catch, and the cumulative percentage contribution was plotted against rank; combinations reaching the 80% threshold were considered the 'vital few'. Trap selectivity was expressed as a selectivity index, $SI = F / (F + N) \times 100$, where F and N are the cumulative numbers of *B. dorsalis* and of non-target insects per treatment combination. Analyses were performed in Python 3.13 with SciPy 1.18.1, and figures were produced with matplotlib 3.11.2.

3. Results

3.1. Effect of trap type and trap height on fruit fly captures

Over the five observations, 684 fruit flies were captured, all on sticky traps; the non-sticky P0 traps retained no insects at any height (Table 1). The cumulative catch was significantly affected by block, trap type, trap height and the trap type × height interaction (Table 2). The ME-baited sticky trap at 100 cm (P2T2) caught 67.67 ± 4.33 flies per trap, significantly more than all other combinations (Tukey HSD = 25.15, $P < 0.05$) and 68% more than the next-best combination, P1T1 (40.33 ± 5.61). The remaining five combinations did not differ significantly from one another.

Table 1
Cumulative captures per trap (mean ± SE, n = 3) of *Bactrocera dorsalis* and non-target insects over five observations, and selectivity index (SI) for each trap type × trap height combination.

Treatment	*B. dorsalis* (all)	Males	Females	Non-target insects	SI (%)
P0T1	0.00	0.00	0.00	0.00	–
P0T2	0.00	0.00	0.00	0.00	–
P0T3	0.00	0.00	0.00	0.00	–
P1T1	40.33 ± 5.61 b	40.33 ± 5.61 b	0.00	18.67 ± 1.20 a	68.4
P1T2	39.00 ± 6.66 b	39.00 ± 6.66 b	0.00	11.33 ± 0.88 b	77.5
P1T3	15.33 ± 5.46 b	15.33 ± 5.46 b	0.00	11.67 ± 1.33 b	56.8
P2T1	35.67 ± 2.73 b	35.67 ± 2.73 b	0.00	12.00 ± 2.52 b	74.8
P2T2	**67.67 ± 4.33 a**	**67.00 ± 4.04 a**	**0.67**	**10.33 ± 2.33 b**	**86.8**
P2T3	30.00 ± 12.01 b	30.00 ± 12.01 b	0.00	6.67 ± 0.67 b	81.8

Within a column, means of sticky-trap combinations followed by the same letter are not significantly different (Tukey HSD, α = 0.05). P0 traps (yellow, no adhesive) retained no insects and were excluded from the ANOVA. P1, yellow sticky trap; P2, yellow sticky trap + methyl eugenol; T1, 50 cm; T2, 100 cm; T3, 150 cm. SI = *B. dorsalis* / (*B. dorsalis* + non-target insects) × 100.

Table 2
Two-way ANOVA (RCBD) of cumulative catches per sticky trap: F values with P values in parentheses.

Source of variation	df	*B. dorsalis* (all)	*B. dorsalis* (males)	Non-target insects
Block	2	5.53 (0.024)	5.13 (0.029)	6.26 (0.017)
Trap type (P)	1	9.51 (0.012)	8.91 (0.014)	18.56 (0.002)
Trap height (T)	2	17.94 (< 0.001)	17.03 (< 0.001)	14.13 (0.001)
P × T	2	5.34 (0.026)	4.99 (0.031)	2.94 (0.099)
Error	10			
CV (%)		23.3	23.8	17.7
Shapiro–Wilk P (residuals)		0.86	0.81	0.43
Levene P		0.90	0.90	0.82

Analysis of the six sticky-trap combinations (P1, P2 × T1, T2, T3) with three blocks.

The Pareto analysis (Fig. 2) showed that catches were concentrated in a few combinations: P2T2 alone contributed 29.7% of all fruit flies captured, and P2T2, P1T1, P1T2 and P2T1 together contributed 80.1%. The 150 cm traps of both sticky types (P2T3 and P1T3) contributed only 19.9%, and the P0 traps contributed nothing.

The interaction arose because the two sticky trap types responded differently to height (Figs. 3a and 4a). For the unbaited sticky trap (P1), catches were similar at 50 cm and 100 cm (40.33 and 39.00 flies per trap) but fell by 62% at 150 cm (15.33). For the ME-baited trap (P2), catches peaked sharply at 100 cm (67.67), 90% more than at 50 cm (35.67) and 126% more than at 150 cm (30.00). Averaged across heights, P2 traps caught 41% more flies than P1 traps (44.44 vs 31.56 flies per trap; $F_{1,10} = 9.51$, $P = 0.012$). Averaged across trap types, catches at 100 cm (53.33) were significantly higher than at 50 cm (38.00), which in turn were higher than at 150 cm (22.67) ($F_{2,10} = 17.94$, $P < 0.001$; Tukey HSD = 14.03). Block effects were also significant (Table 2), indicating spatial heterogeneity in fly pressure across the orchard and confirming the value of blocking.

3.2. Temporal pattern of captures

Captures were highest at the first observation, declined to a minimum at 6 DAI and then partially recovered (Fig. 5; Table S1 in Online Resource 1). Summed across the six sticky-trap combinations, mean catches were 99.67 flies at 2 DAI, representing 43.7% of the entire catch, 33.00 at 4 DAI and a minimum of 19.00 at 6 DAI, after rain on day 5; catches then recovered to 28.00 at 8 DAI and 48.33 at 10 DAI. The effects of the treatments changed over time (Table 3). At 2 DAI, catches were affected by trap type and height, and P2T2 (35.00 ± 2.00 flies per trap) was significantly higher than all other combinations; the ME advantage was not significant at 4–8 DAI and reappeared at 10 DAI. The trap type × height interaction was significant only at 4 DAI, when the unbaited trap at 50 cm (P1T1) caught the most flies (11.00 ± 1.15).

Table 3
F values from two-way ANOVA (RCBD) of *Bactrocera dorsalis* and non-target insect catches per sticky trap at each observation date.

DAI	*B. dorsalis*			Non-target insects		
	P (df 1)	T (df 2)	P × T (df 2)	P (df 1)	T (df 2)	P × T (df 2)
2	10.18∗∗	14.31∗∗	3.33 ns	4.77 ns	1.04 ns	1.97 ns
4	0.09 ns	8.17∗∗	6.86∗	1.69 ns	5.42∗	1.32 ns
6	0.25 ns	4.03 ns	0.31 ns	6.67∗	3.80 ns	2.07 ns
8	0.02 ns	1.17 ns	3.37 ns	1.59 ns	0.31 ns	2.79 ns
10	7.46∗	4.14∗	1.69 ns	0.11 ns	0.57 ns	1.17 ns

∗ P < 0.05; ∗∗ P < 0.01; ∗∗∗ P < 0.001; ns, not significant. Error df = 10. P, trap type; T, trap height. Means ± SE for each date are given in Table S1 in Online Resource 1.

3.3. Sex ratio and species composition

Of the 684 fruit flies captured, 682 (99.7%) were males. Only two females were recorded, both on the same P2T2 trap (block II), one at 6 DAI and one at 10 DAI (mean 0.67 females per P2T2 trap over the study; Table 1). Female catches were too rare for statistical analysis, and the male data therefore mirror the total catch, with the same significant interaction (Table 2) and the same best combination (P2T2, 67.00 ± 4.04 males per trap). All specimens were identified as *B. dorsalis* (Fig. 6): adults have a black scutum with lateral yellow vittae, a narrow costal band and a T-shaped black pattern on the abdomen, and females have a pointed ovipositor.

3.4. Non-target insects and trap selectivity

In total, 212 non-target insects were captured, all on sticky traps. Cumulative non-target catches were significantly affected by trap type ($F_{1,10}$ = 18.56, P = 0.002) and trap height ($F_{2,10}$ = 14.13, P = 0.001), but not by their interaction ($F_{2,10}$ = 2.94, P = 0.099) (Table 2). P2 traps captured 30% fewer non-target insects than P1 traps (9.67 vs 13.89 per trap), and traps at 50 cm captured more non-target insects (15.33) than those at 100 cm (10.83) or 150 cm (9.17) (Tukey HSD = 3.29). Consequently, the unbaited trap at 50 cm (P1T1) caught significantly more non-target insects (18.67 ± 1.20 per trap) than every other combination, whereas the ME-baited trap at 150 cm (P2T3) caught the fewest (6.67 ± 0.67) (Table 1; Figs. 3b and 4b). At individual dates, trap type affected non-target catches only at 6 DAI and height only at 4 DAI (Table 3).

Combining target and non-target catches showed that P2T2 was not only the most effective but also the most selective combination: 86.8% of the insects it captured were *B. dorsalis* (Fig. 7). Selectivity was lowest for P1T3 (56.8%) and P1T1 (68.4%). Four groups of non-target insects were recognised (Table 4; Fig. 8): lady beetles (Coleoptera: Coccinellidae), the rice bug *Leptocorisa oratorius* (Fabricius) (Hemiptera: Alydidae), treehoppers (Hemiptera: Membracidae) and orange-red sap-feeding bugs (Hemiptera: Pyrrhocoridae).

Table 4
Non-target insects captured on the traps and their main diagnostic features.

Taxon	Order: Family	Main diagnostic features	Ecological role
Lady beetle	Coleoptera: Coccinellidae	Body rounded and convex; orange elytra with black spots; hind wings membranous, folded beneath elytra; short legs; head deflexed	Predator (beneficial)
Rice bug, *Leptocorisa oratorius*	Hemiptera: Alydidae	Slender, brown-green, 14–17 mm long and 3–4 mm wide; long legs and antennae; piercing–sucking rostrum	Herbivore (pest of rice)
Treehopper	Hemiptera: Membracidae	7–10 mm long, dark brown; short legs; horn-like pronotal projection	Phloem feeder
Orange-red bug	Hemiptera: Pyrrhocoridae	About 10 mm long; orange head, thorax and wings with black spots on head and thorax; piercing–sucking mouthparts	Sap feeder

4. Discussion

This study shows that, in water apple, the number of *B. dorsalis* caught by a trap depends jointly on what the trap offers and where it is placed. The ME-baited sticky trap at 100 cm (P2T2) clearly outperformed all other combinations, and four of nine combinations produced 80% of the catch. For practical purposes, the Pareto analysis narrows the decision to ME-baited sticky traps at about 100 cm, with the 50 cm placement as a less effective fallback.

The superiority of ME-baited traps agrees with the well-documented potency of ME as a male lure for species in the *B. dorsalis* complex (Steiner 1952; Tan and Nishida 2012; Tan et al. 2014; Royer 2015). ME is volatile and releases a fragrant odour that guides males towards the trap (Kardinan et al. 2009), and the near-absence of females (2 of 684 flies) confirms that ME acts as a male-specific parapheromone rather than a food or host-odour cue (Shelly and Dewire 1994; Wee et al. 2007). Similar male-biased catches have been reported for ME and other male lures in Indonesia (Lengkong et al. 2011) and elsewhere (Vargas et al. 2015). Because male removal at high trap densities can reduce mating and subsequent fruit infestation, and has contributed to the eradication of tephritid populations in several regions (Suckling et al. 2016), these results support the use of ME-baited sticky traps as a low-cost MAT component for water apple smallholders (Vargas et al. 2012; Manoukis et al. 2019).

Unexpectedly, unbaited sticky traps (P1) also caught substantial numbers of flies, all of them males. Two non-exclusive explanations are plausible. First, yellow is an attractive visual cue for tephritids, which use colour to locate ripening fruit and foliage (Prokopy and Owens 1983; Wu et al. 2007; Dias et al. 2018). Second, and probably more important, P1 traps were interspersed with ME-baited P2 traps within the same blocks, so males drawn into the orchard by the ME plumes may have been intercepted by nearby yellow sticky surfaces. Such trap interference is a recognised source of bias in lure trials, because the

effective sampling range of an attractant trap can exceed the distance between neighbouring traps (Wall and Perry 1987; Shelly et al. 2014; Manoukis et al. 2014), and an entirely male catch is difficult to explain by visual attraction alone. The temporal data support this interpretation: the advantage of P2 over P1 was significant only at 2 and 10 DAI, and at 4 DAI the unbaited P1T1 trap caught the most flies. Future studies should separate lure treatments by larger distances or use separate plots to quantify the contribution of visual cues independently of ME. The P0 control caught nothing because, lacking an adhesive or a killing agent, it could not retain insects; it therefore demonstrates that a retention mechanism is essential, but it is not an informative control for attraction. Trap design is known to influence strongly which sexes and species are retained (Epsky et al. 1999; Manrakhan et al. 2017).

Trap height had a strong, trap-type-dependent effect. Captures were lowest at 150 cm for both sticky trap types; with ME they peaked at 100 cm, whereas without ME they were similar at 50 and 100 cm. These results add crop-specific evidence to earlier Indonesian work on trap height for male *Bactrocera* (Hasyim et al. 2006) and agree with studies showing that the optimum height differs between crops: cue-lure traps caught the most melon flies at the lowest height tested in cucumber (Saha and Chandran 2023), whereas ME traps performed best at about 5 ft in mango trees (Bausin et al. 2024). In the study orchard, 100 cm corresponded to the lower fruiting canopy of the 'Madu' trees (about 200 cm tall), where ripening fruit, shade and humidity attract foraging and lekking flies (Shelly 2018). Traps at 150 cm were in the upper, more exposed part of the canopy, where higher wind speed may disperse the odour plume and reduce trap visibility (Cardé and Willis 2008; Manoukis et al. 2015), whereas traps at 50 cm were below most fruit. The sharper peak for P2 than for P1 suggests that the ME plume is most effective when released within the zone where males are active, so lure placement deserves as much attention as lure choice. Because the optimum height is tied to canopy architecture, the 100 cm recommendation should be adjusted for taller trees or pruned, high-density orchards. The significant block effect further indicates that fly pressure varied across the orchard, so trap networks should cover the whole orchard rather than a single row.

The marked decline in captures after the first 2 days probably reflects the rapid loss of ME mixed directly into the adhesive. ME is highly volatile (Tan and Nishida 2012), and even formulated ME dispensers lose attractiveness as they weather in the field (Jang et al. 2013); an open, thin film releases it far faster than the controlled-release wicks, plugs or wafers used in operational programmes (Vargas et al. 2012). In line with this, the difference between ME-baited and unbaited traps was largest at 2 DAI and disappeared at 4–8 DAI. The further dip at 6 DAI coincided with rainfall on day 5, which suppresses fly activity and may wash lure from the trap surface, while the recovery at 8–10 DAI may reflect renewed fly activity under drier conditions and the emergence of new adults; rainfall and temperature are major drivers of *B. dorsalis* trap catches in other tropical systems (Ye and Liu 2005; Vayssières et al. 2009). The progressive harvest of ripe fruit during the study may also have reduced the number of flies attracted to the orchard. In practice, ME should be dispensed from a separate controlled-release dispenser rather than mixed into the glue, and should be replenished at regular intervals.

Yellow sticky surfaces are inherently non-selective, and our traps captured herbivorous Hemiptera as well as predatory lady beetles, in line with the diverse bycatch reported for fruit fly surveillance traps (Thomas 2003). Bycatch depended additively on trap type and height: it was greatest on low, unbaited traps (P1T1) and lowest on high, ME-baited traps (P2T3), consistent with the effects of trap colour and placement height on non-target captures in other systems (Blackmer et al. 2008). Adding ME improved selectivity because it increased the target catch while reducing the non-target catch, so that P2T2 combined the highest efficacy with the highest selectivity (86.8%). The capture of coccinellid predators, which are important biological control agents (Obrycki and Kring 1998), is a cost that should be weighed in integrated pest management, and further gains in selectivity could be achieved by using enclosed ME traps (e.g. Steiner-type traps with a toxicant or retention device), which exclude most non-target insects, or by limiting the yellow surface area (Manrakhan et al. 2017; Dias et al. 2018).

This study has limitations. It was conducted in one orchard over a single 10-day period during the fruiting season, with three blocks and one trap per treatment per block, and it measured trap catches rather than fruit infestation. Catch data indicate relative attraction but do not by themselves demonstrate crop protection, and the interspersion of baited and unbaited traps within blocks may have allowed interference between lure treatments. Multi-season trials across several orchards, with wider trap spacing, assessments of fruit infestation and comparisons of ME dispensers and trap densities, are needed before area-wide recommendations can be made. Nevertheless, the results provide the first practical guidance on trap placement for *B. dorsalis* in water apple and highlight the value of simultaneously reporting target and non-target catches.

5. Conclusions

Trap type and trap height interacted significantly to determine cumulative captures of *B. dorsalis* in water apple, whereas their effects on non-target insects were additive. Yellow sticky traps baited with methyl eugenol and placed at 100 cm (P2T2) caught the most fruit flies, almost exclusively males, and were also the most selective, whereas unbaited sticky traps at 50 cm captured the most non-target insects. Captures were concentrated in the first 2 days after installation, indicating that the lure must be renewed regularly or dispensed in a controlled-release form. For monitoring and male suppression of *B. dorsalis* in water apple, we recommend ME-baited traps placed at about 100 cm, within the fruiting canopy, combined with existing practices such as fruit bagging and orchard sanitation.

Declarations

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Ethics approval

Not applicable. This study involved field trapping of insects only and did not involve human participants or vertebrate animals.

Funding

No funding was received for conducting this study.

Author Contribution

Author 1 conceptualisation, investigation, methodology, data curation, formal analysis, writing original draft; Author 2: conceptualisation, supervision, methodology, validation; Author 3: supervision, validation, formal analysis, writing – review and editing; Author 4: data curation, visualisation, writing – review and editing; Author 5: software, formal analysis, visualisation.

All authors read and approved the final manuscript.

Acknowledgements

The authors thank the owner of the water apple orchard in Aek Tuhul Village for permission to conduct this study.

Data Availability

All data generated or analysed during this study are included in this published article.

References

1. Ali MM, Anwar R, Yousef AF, Li B, Luvisi A, De Bellis L, Aprile A, Chen F (2021) Influence of bagging on the development and quality of fruits. Plants 10:358. https://doi.org/10.3390/plants10020358
2. Bausin CA, Sampiano KFS, Bayang SS, Aceres LV, Sibongga LMA (2024) Effects of trap height on the capture of *Bactrocera* spp. (Diptera: Tephritidae) in mango orchard of Tagum City, Davao del Norte, Philippines. Curr Appl Sci Technol 24:e0257143. https://doi.org/10.55003/cast.2024.257143
3. Blackmer JL, Byers JA, Rodriguez-Saona C (2008) Evaluation of color traps for monitoring *Lygus* spp.: design, placement, height, time of day, and non-target effects. Crop Prot 27:171–181. https://doi.org/10.1016/j.cropro.2007.05.002
4. Cardé RT, Willis MA (2008) Navigational strategies used by insects to find distant, wind-borne sources of odor. J Chem Ecol 34:854–866. https://doi.org/10.1007/s10886-008-9484-5
5. Clarke AR, Armstrong KF, Carmichael AE, Milne JR, Raghu S, Roderick GK, Yeates DK (2005) Invasive phytophagous pests arising through a recent tropical evolutionary radiation: the *Bactrocera dorsalis*

complex of fruit flies. Annu Rev Entomol 50:293–319. https://doi.org/10.1146/annurev.ento.50.071803.130428

6. Clarke AR, Li Z-H, Qin Y-J, Zhao Z-H, Liu L-J, Schutze MK (2019) *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) is not invasive through Asia: it's been there all along. J Appl Entomol 143:797–801. https://doi.org/10.1111/jen.12649
7. De Villiers M, Hattingh V, Kriticos DJ, Brunel S, Vayssières J-F, Sinzogan A et al (2016) The potential distribution of *Bactrocera dorsalis*: considering phenology and irrigation patterns. Bull Entomol Res 106:19–33. https://doi.org/10.1017/S0007485315000693
8. Dias NP, Zotti MJ, Montoya P, Carvalho IR, Nava DE (2018) Fruit fly management research: a systematic review of monitoring and control tactics in the world. Crop Prot 112:187–200. https://doi.org/10.1016/j.cropro.2018.05.019
9. Doorenweerd C, Leblanc L, Norrbom AL, San Jose M, Rubinoff D (2018) A global checklist of the 932 fruit fly species in the tribe Dacini (Diptera, Tephritidae). ZooKeys 730:19–56. https://doi.org/10.3897/zookeys.730.21786
10. Ekesi S, De Meyer M, Mohamed SA, Virgilio M, Borgemeister C (2016) Taxonomy, ecology, and management of native and exotic fruit fly species in Africa. Annu Rev Entomol 61:219–238. https://doi.org/10.1146/annurev-ento-010715-023603
11. Epsky ND, Hendrichs J, Katsoyannos BI, Vásquez LA, Ros JP, Zümreoglu A et al (1999) Field evaluation of female-targeted trapping systems for *Ceratitis capitata* (Diptera: Tephritidae) in seven countries. J Econ Entomol 92:156–164. https://doi.org/10.1093/jee/92.1.156
12. Hanifah HM, Haryanti S (2016) Morfoanatomi daun jambu air (*Syzygium samarangense*) var. Demak normal dan terserang hama ulat. Buletin Anatomi dan Fisiologi 1:1–8
13. Hasyim A, de Muryati WJ (2006) Efektivitas model dan ketinggian perangkap dalam menangkap hama lalat buah jantan, *Bactrocera* spp. J Hortik 16:314–320
14. Hee AKW, Tan KH (2004) Male sex pheromonal components derived from methyl eugenol in the hemolymph of the fruit fly *Bactrocera papayae*. J Chem Ecol 30:2127–2138. https://doi.org/10.1023/B:JOEC.0000048778.02561.75
15. Hee AK-W, Wee S-L, Nishida R, Ono H, Hendrichs J, Haymer DS, Tan K-H (2015) Historical perspective on the synonymization of the four major pest species belonging to the *Bactrocera dorsalis* species complex (Diptera, Tephritidae). ZooKeys 540:323–338. https://doi.org/10.3897/zookeys.540.6028
16. Herlinda S, Mayasari R, Adam T, Pujiastuti Y (2007) Populasi dan serangan lalat buah *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) serta potensi parasitoidnya pada pertanaman cabai (*Capsicum annuum* L.). In: Prosiding Seminar Nasional dan Kongres Ilmu Pengetahuan Wilayah Barat, Palembang, 3–5 June 2007
17. Jaleel W, Lu L, He Y (2018) Biology, taxonomy, and IPM strategies of *Bactrocera tau* Walker and complex species (Diptera; Tephritidae) in Asia: a comprehensive review. Environ Sci Pollut Res 25:19346–19361. https://doi.org/10.1007/s11356-018-2306-6

18. Jang EB, Ramsey A, Carvalho LA (2013) Performance of methyl eugenol + matrix + toxicant combinations under field conditions in Hawaii and California for trapping *Bactrocera dorsalis* (Diptera: Tephritidae). J Econ Entomol 106:727–734. https://doi.org/10.1603/EC12371
19. Kardinan A, Bintoro MH, Syakir M, Amin AA (2009) Penggunaan selasih dalam pengendalian hama lalat buah pada mangga. Jurnal Penelitian Tanaman Industri 15:101–109
20. Lengkong M, Rante CS, Meray M (2011) Aplikasi MAT dalam pengendalian lalat buah *Bactrocera* sp. (Diptera: Tephritidae) pada tanaman cabe. Eugenia 17:121–127
21. Liu H, Zhang D, Xu Y, Wang L, Cheng D, Qi Y, Zeng L, Lu Y (2019) Invasion, expansion, and control of *Bactrocera dorsalis* (Hendel) in China. J Integr Agric 18:771–787. https://doi.org/10.1016/S2095-3119(18)62015-5
22. Lux SA, Copeland RS, White IM, Manrakhan A, Billah MK (2003) A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) group detected in East Africa. Insect Sci Appl 23:355–361. https://doi.org/10.1017/S174275840001242X
23. Manoukis NC, Hall B, Geib SM (2014) A computer model of insect traps in a landscape. Sci Rep 4:7015. https://doi.org/10.1038/srep07015
24. Manoukis NC, Siderhurst M, Jang EB (2015) Field estimates of attraction of *Ceratitis capitata* to trimedlure and *Bactrocera dorsalis* (Diptera: Tephritidae) to methyl eugenol in varying environments. Environ Entomol 44:695–703. https://doi.org/10.1093/ee/nvv020
25. Manoukis NC, Vargas RI, Carvalho L, Fezza T, Wilson S, Collier T, Shelly TE (2019) A field test on the effectiveness of male annihilation technique against *Bactrocera dorsalis* (Diptera: Tephritidae) at varying application densities. PLoS ONE 14:e0213337. https://doi.org/10.1371/journal.pone.0213337
26. Manrakhan A, Daneel J-H, Beck R, Virgilio M, Meganck K, De Meyer M (2017) Efficacy of trapping systems for monitoring of Afrotropical fruit flies. J Appl Entomol 141:825–840. https://doi.org/10.1111/jen.12373
27. Meilin A (2018) Teknologi penggunaan perangkap kuning sederhana untuk monitoring dan pengendalian serangga hama ramah lingkungan. Balai Pengkajian Teknologi Pertanian (BPTP) Jambi, Jambi
28. Mutamiswa R, Nyamukondiwa C, Chikowore G, Chidawanyika F (2021) Overview of oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in Africa: from invasion, bio-ecology to sustainable management. Crop Prot 141:105492. https://doi.org/10.1016/j.cropro.2020.105492
29. Mwatawala MW, De Meyer M, Makundi RH, Maerere AP (2006) Seasonality and host utilization of the invasive fruit fly, *Bactrocera invadens* (Dipt., Tephritidae) in central Tanzania. J Appl Entomol 130:530–537. https://doi.org/10.1111/j.1439-0418.2006.01099.x
30. Nishida R, Tan KH, Serit M, Lajis NH, Sukari AM, Takahashi S, Fukami H (1988) Accumulation of phenylpropanoids in the rectal glands of males of the Oriental fruit fly, *Dacus dorsalis*. Experientia 44:534–536. https://doi.org/10.1007/BF01958941

31. Obrycki JJ, Kring TJ (1998) Predaceous Coccinellidae in biological control. Annu Rev Entomol 43:295–321. https://doi.org/10.1146/annurev.ento.43.1.295
32. Prokopy RJ, Owens ED (1983) Visual detection of plants by herbivorous insects. Annu Rev Entomol 28:337–364. https://doi.org/10.1146/annurev.en.28.010183.002005
33. Qin Y, Paini DR, Wang C, Fang Y, Li Z (2015) Global establishment risk of economically important fruit fly species (Tephritidae). PLoS ONE 10:e0116424. https://doi.org/10.1371/journal.pone.0116424
34. Royer JE (2015) Responses of fruit flies (Tephritidae: Dacinae) to novel male attractants in north Queensland, Australia, and improved lures for some pest species. Austral Entomol 54:411–426. https://doi.org/10.1111/aen.12141
35. Saha T, Chandran N (2023) Evaluation of optimum heights of pheromone trap on attraction of fruit flies (Diptera: Tephritidae) in cucumber in North Eastern India. Int J Trop Insect Sci 43:289–295. https://doi.org/10.1007/s42690-023-00942-7
36. Schutze MK, Aketarawong N, Amornsak W, Armstrong KF, Augustinos AA, Barr N et al (2015) Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. Syst Entomol 40:456–471. https://doi.org/10.1111/syen.12113
37. Shelly TE (2018) Sexual selection on leks: a fruit fly primer. J Insect Sci 18:9. https://doi.org/10.1093/jisesa/iey048
38. Shelly TE, Dewire AM (1994) Chemically mediated mating success in male oriental fruit flies (Diptera: Tephritidae). Ann Entomol Soc Am 87:375–382. https://doi.org/10.1093/aesa/87.3.375
39. Shelly T, Epsky N, Jang EB, Reyes-Flores J, Vargas R (eds) (2014) Trapping and the detection, control, and regulation of tephritid fruit flies: lures, area-wide programs, and trade implications. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-9193-9
40. Siwi SS, Hidayat P, Suputa (2006) Taksonomi dan bioekologi lalat buah penting, *Bactrocera* spp. (Diptera: Tephritidae) di Indonesia. Balai Besar Penelitian dan Pengembangan Bioteknologi dan Sumberdaya Genetik Pertanian, Bogor
41. Steiner LF (1952) Methyl eugenol as an attractant for oriental fruit fly. J Econ Entomol 45:241–248. https://doi.org/10.1093/jee/45.2.241
42. Stephens AEA, Kriticos DJ, Leriche A (2007) The current and future potential geographical distribution of the oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae). Bull Entomol Res 97:369–378. https://doi.org/10.1017/S0007485307005044
43. Suckling DM, Kean JM, Stringer LD, Cáceres-Barrios C, Hendrichs J, Reyes-Flores J, Dominiak BC (2016) Eradication of tephritid fruit fly pest populations: outcomes and prospects. Pest Manag Sci 72:456–465. https://doi.org/10.1002/ps.3905
44. Tan KH, Nishida R (2012) Methyl eugenol: its occurrence, distribution, and role in nature, especially in relation to insect behavior and pollination. J Insect Sci 12:56.

https://doi.org/10.1673/031.012.5601

45. Tan KH, Nishida R, Jang EB, Shelly TE (2014) Pheromones, male lures, and trapping of tephritid fruit flies. In: Shelly T, Epsky N, Jang EB, Reyes-Flores J, Vargas R (eds) Trapping and the detection, control, and regulation of tephritid fruit flies. Springer, Dordrecht, pp 15–74. https://doi.org/10.1007/978-94-017-9193-9_2
46. Thomas DB (2003) Nontarget insects captured in fruit fly (Diptera: Tephritidae) surveillance traps. J Econ Entomol 96:1732–1737. https://doi.org/10.1603/0022-0493-96.6.1732
47. Vargas RI, Leblanc L, Putoa R, Eitam A (2007) Impact of introduction of *Bactrocera dorsalis* (Diptera: Tephritidae) and classical biological control releases of *Fopius arisanus* (Hymenoptera: Braconidae) on economically important fruit flies in French Polynesia. J Econ Entomol 100:670–679. https://doi.org/10.1603/0022-0493(2007)100[670:IOIOBD]2.0.CO;2
48. Vargas RI, Souder SK, Mackey B, Cook P, Morse JG, Stark JD (2012) Field trials of solid triple lure (trimedlure, methyl eugenol, raspberry ketone, and DDVP) dispensers for detection and male annihilation of *Ceratitis capitata*, *Bactrocera dorsalis*, and *Bactrocera cucurbitae* (Diptera: Tephritidae) in Hawaii. J Econ Entomol 105:1557–1565. https://doi.org/10.1603/EC12122
49. Vargas RI, Piñero JC, Leblanc L (2015) An overview of pest species of *Bactrocera* fruit flies (Diptera: Tephritidae) and the integration of biopesticides with other biological approaches for their management with a focus on the Pacific region. Insects 6:297–318. https://doi.org/10.3390/insects6020297
50. Vayssières J-F, Korie S, Ayegnon D (2009) Correlation of fruit fly (Diptera Tephritidae) infestation of major mango cultivars in Borgou (Benin) with abiotic and biotic factors and assessment of damage. Crop Prot 28:477–488. https://doi.org/10.1016/j.cropro.2009.01.010
51. Wall C, Perry JN (1987) Range of action of moth sex-attractant sources. Entomol Exp Appl 44:5–14. https://doi.org/10.1111/j.1570-7458.1987.tb02232.x
52. Wee SL, Tan KH, Nishida R (2007) Pharmacophagy of methyl eugenol by males enhances sexual selection of *Bactrocera carambolae*. J Chem Ecol 33:1272–1282. https://doi.org/10.1007/s10886-007-9295-0
53. Wu W-Y, Chen Y-P, Yang E-C (2007) Chromatic cues to trap the oriental fruit fly, *Bactrocera dorsalis*. J Insect Physiol 53:509–516. https://doi.org/10.1016/j.jinsphys.2007.02.003
54. Ye H, Liu JH (2005) Population dynamics of the oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae) in the Kunming area, southwestern China. Insect Sci 12:387–392
55. Zeng Y, Reddy GVP, Li Z, Qin Y, Wang Y, Pan X, Jiang F, Gao F, Zhao Z-H (2019) Global distribution and invasion pattern of oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae). J Appl Entomol 143:165–176. https://doi.org/10.1111/jen.12582

Figures



Figure 1

Traps and sampling: (a) yellow-painted plastic-cup traps before installation; (b) a sticky trap with captured insects in the orchard, inspected with a hand lens; (c) removal of *Bactrocera dorsalis* from the adhesive with forceps. Photographs: authors (2023)

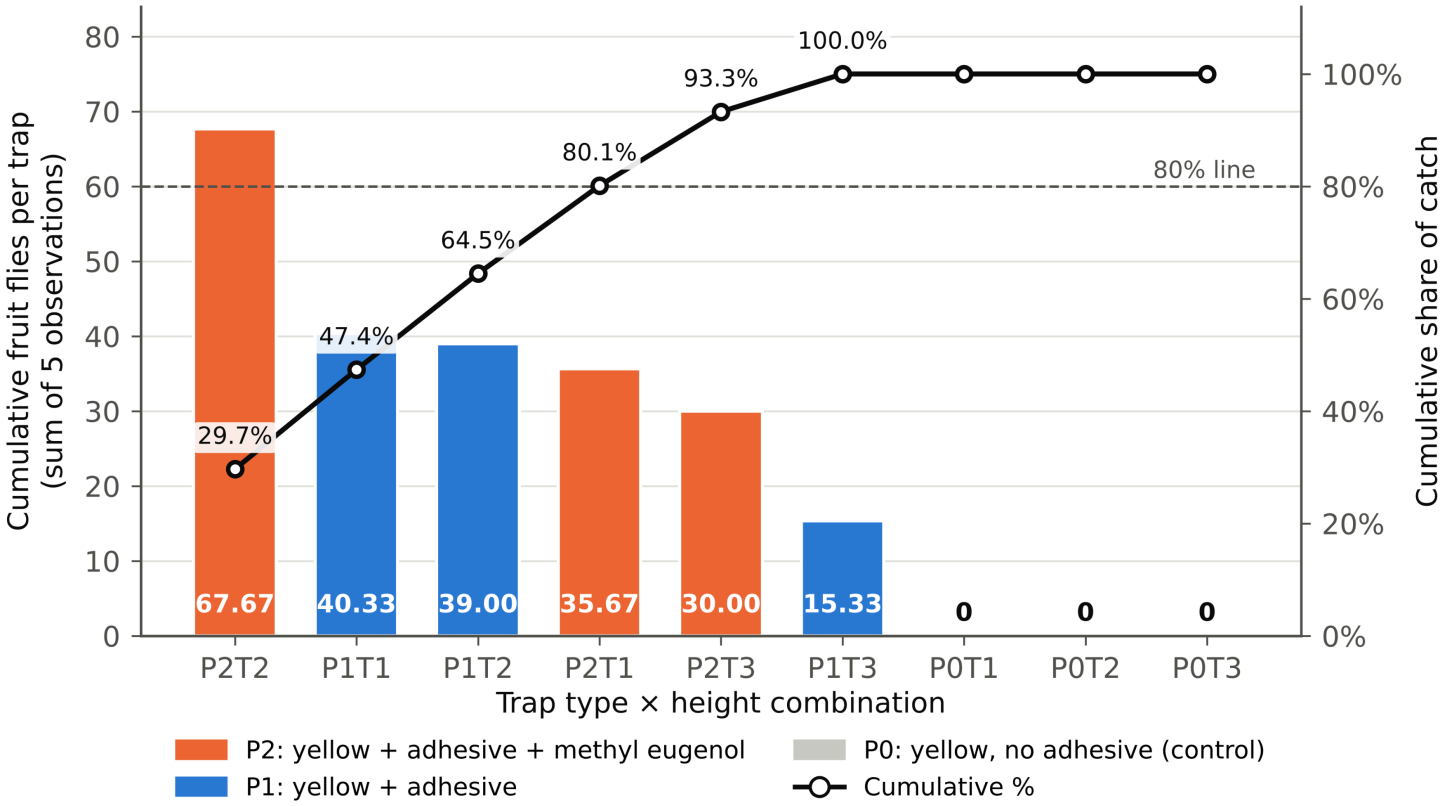


Figure 2

Pareto chart of cumulative *Bactrocera dorsalis* catch per trap (mean of three replicates, summed over five observations) for the nine trap type × trap height combinations. Bars are ranked in descending order; the line shows the cumulative percentage of the total catch, and the dashed line marks the 80%

threshold. P0, yellow trap without adhesive; P1, yellow sticky trap; P2, yellow sticky trap + methyl eugenol; T1, 50 cm; T2, 100 cm; T3, 150 cm

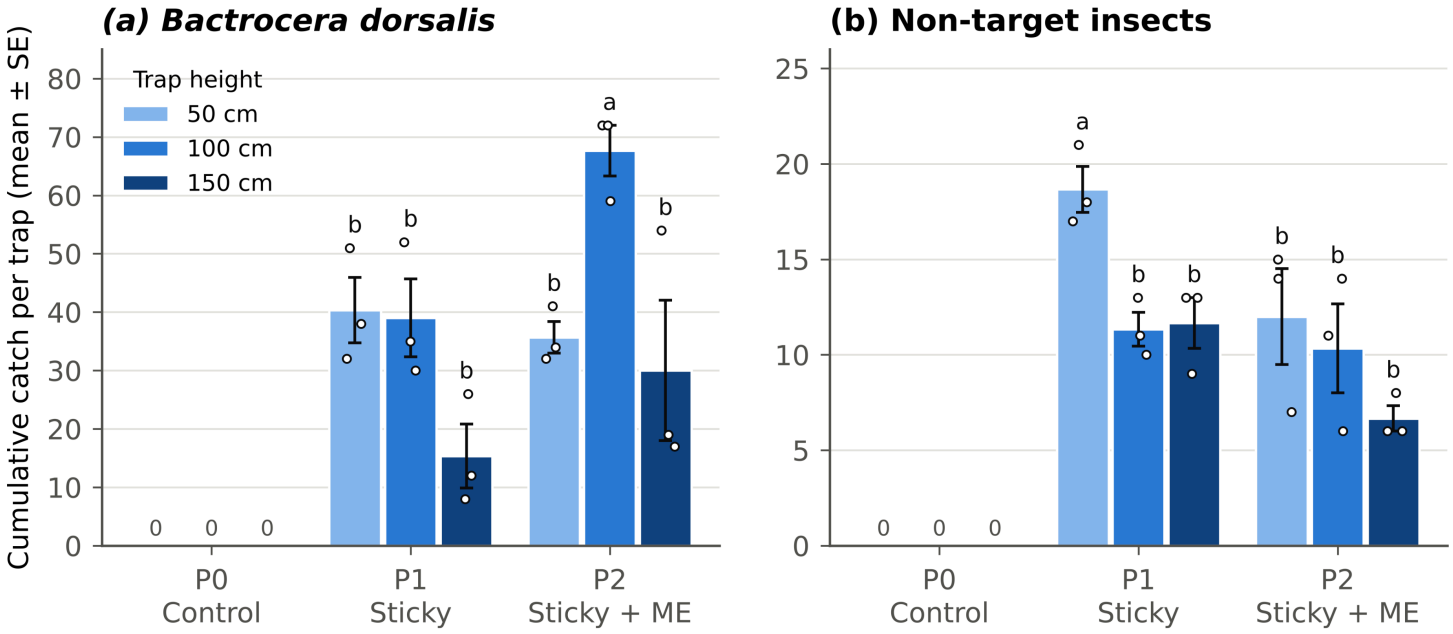


Figure 3

Cumulative catch per trap (mean ± SE, n = 3) of (a) *Bactrocera dorsalis* and (b) non-target insects by trap type and trap height. Open circles show individual replicate traps. Bars of sticky-trap combinations topped by the same letter are not significantly different (Tukey HSD, α = 0.05). Trap type codes as in Fig. 2

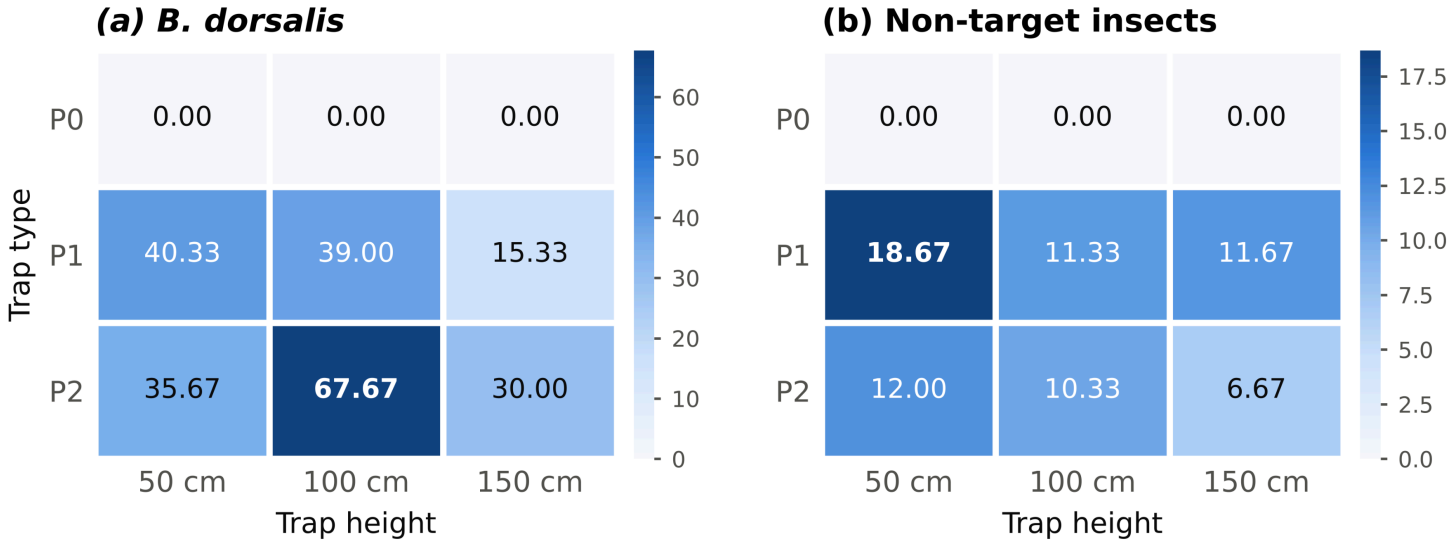


Figure 4

Interaction heat maps of trap type × trap height for mean cumulative catches of (a) *Bactrocera dorsalis* and (b) non-target insects per trap. Darker cells indicate higher catches; the highest value in each panel is shown in bold

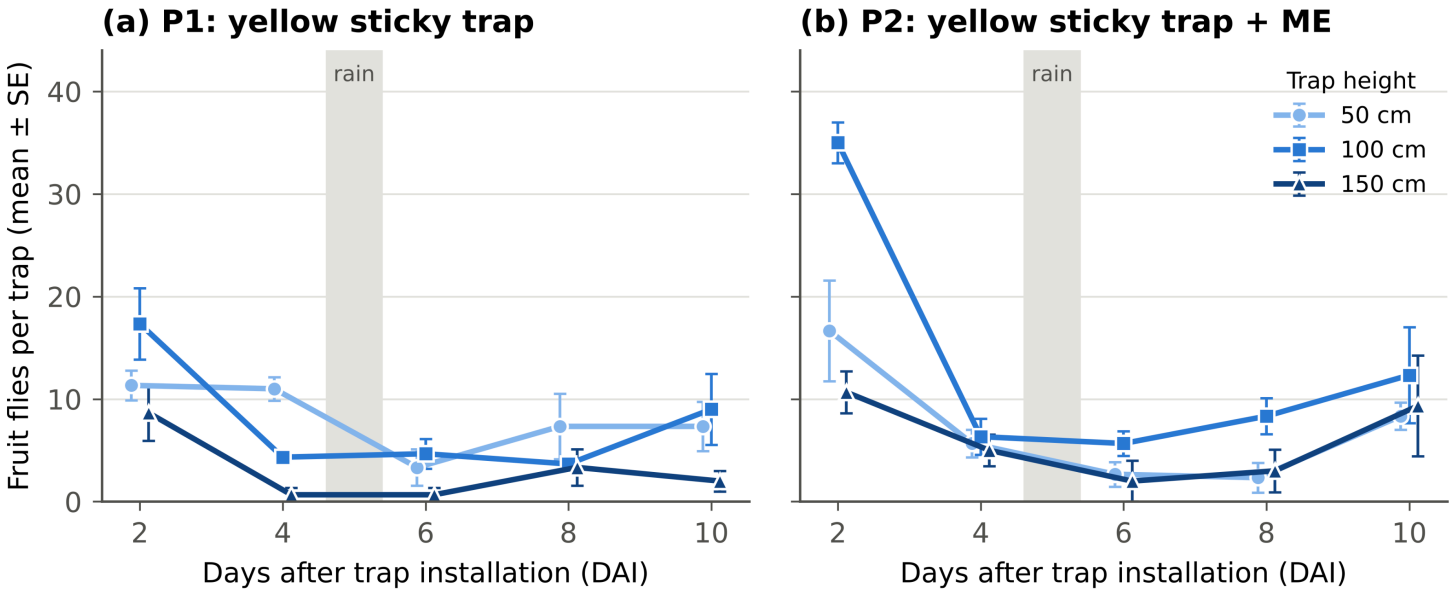


Figure 5

Temporal dynamics of *Bactrocera dorsalis* captures (mean ± SE, n = 3) at three trap heights for (a) yellow sticky traps and (b) yellow sticky traps baited with methyl eugenol. Points are slightly offset horizontally for clarity. The grey band marks the rain event on day 5 after installation

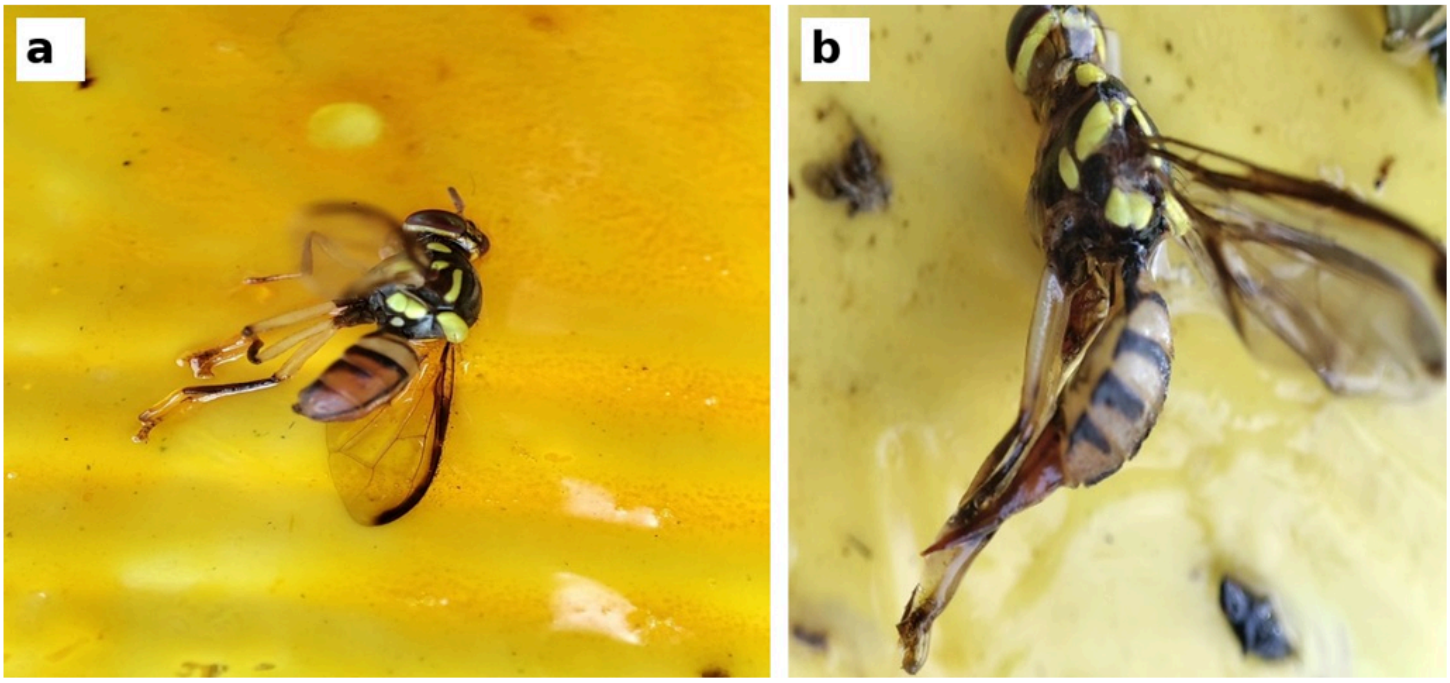


Figure 6

Bactrocera dorsalis captured on yellow sticky traps in a water apple orchard: (a) male; (b) female, showing the ovipositor at the tip of the abdomen. Photographs: authors (2023)

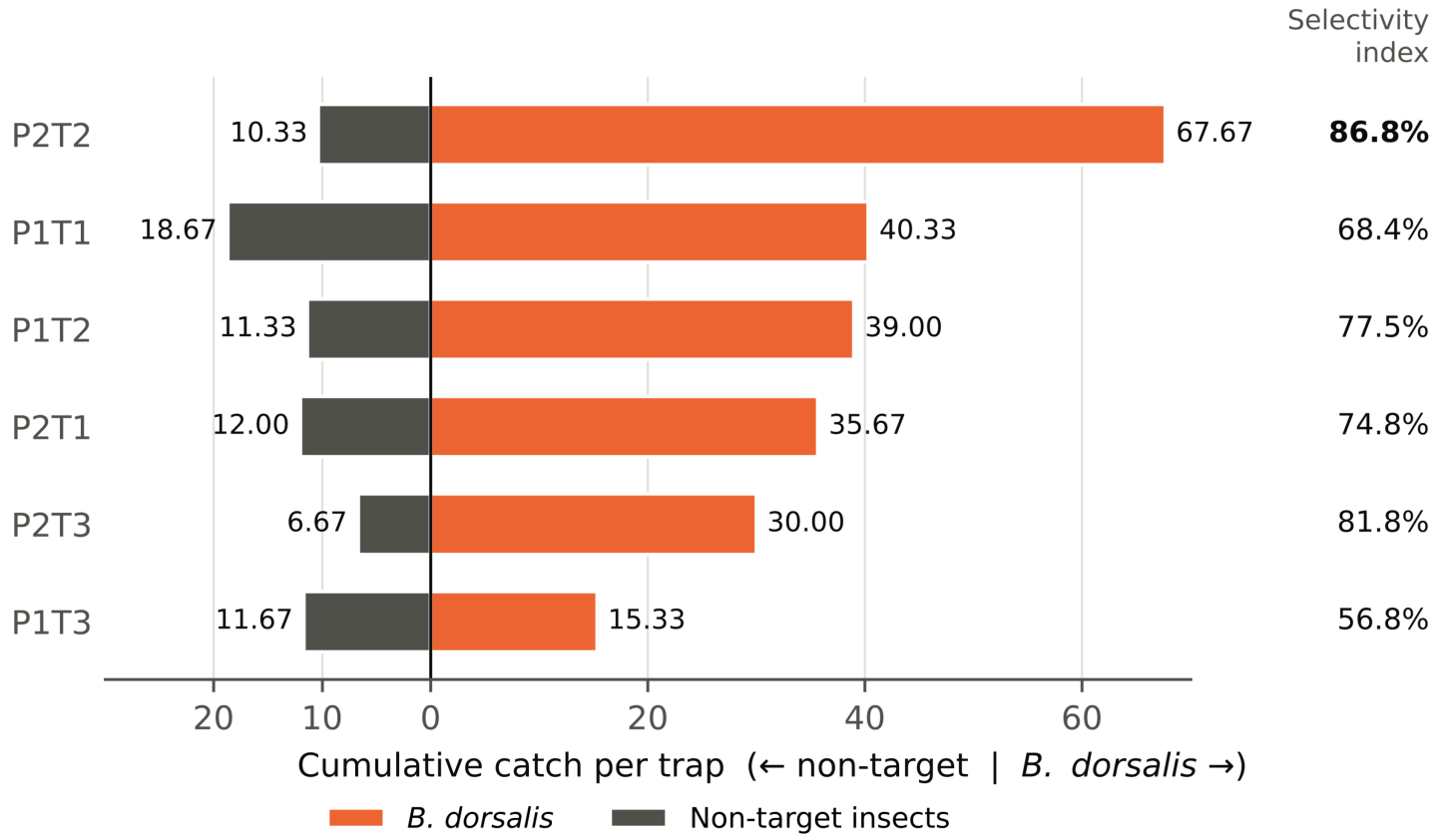


Figure 7

Butterfly chart comparing mean cumulative catches per trap of non-target insects (left) and *Bactrocera dorsalis* (right) for the six sticky-trap combinations, ranked by fruit fly catch. The selectivity index (right column) is the percentage of all trapped insects that were *B. dorsalis*



Figure 8

Non-target insects captured on yellow sticky traps: (a) lady beetle (Coccinellidae); (b) rice bug, *Leptocorisa oratorius* (Alydidae) (1), and orange-red sap-feeding bugs (2); (c) treehopper (Membracidae).