

Field Performance of Fruit-Waste Eco-Enzyme Baits for Trapping *Bactrocera* Spp. in Chili (*Capsicum Frutescens* L.) Fields of Tomohon City, Indonesia.

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Abstract. Eco-enzyme (EE) liquids produced by fermenting fruit waste may provide low-cost, locally available odor sources for fruit-fly monitoring. This study evaluated the effectiveness of EE baits prepared from nutmeg, banana, and pineapple wastes, as well as a mixed formulation, for trapping *Bactrocera* spp. in chili (*Capsicum frutescens* L.) fields in Kakaskasen I Village, Tomohon City, Indonesia. The experiment used a randomized complete block design with four EE treatments and five replicates. Traps were installed in fruiting-stage chili plots at approximately 1.5 m above ground level with ~5 m spacing and were observed over four sampling rounds at 6-day intervals. Captured adult fruit flies were counted and identified morphologically, and treatment effects were analyzed using analysis of variance followed by an LSD (BNT) test at the 5% significance level. Two species were recorded, *Bactrocera dorsalis* and *B. cucurbitae*. Mean trap catches (adults per trap) were highest for pineapple EE (6.3), followed by mixed EE (3.1), nutmeg EE (1.7), and banana EE (1.3). Pineapple EE differed significantly from the other treatments (LSD5% = 3.7), whereas the remaining treatments did not differ significantly. Captures were reported to be predominantly female, and non-target insects were also collected, indicating limited selectivity. Overall, pineapple fruit-waste EE showed the strongest field performance and warrants further development as a practical bait for *Bactrocera* spp. monitoring in chili agroecosystems.

Keywords: *Bactrocera dorsalis*, *Capsicum frutescens*, eco-enzyme, fermented fruit waste, food-baited trapping

INTRODUCTION

Cayenne pepper (*Capsicum frutescens* L.) is an important horticultural crop that contributes to household nutrition and food culture through its characteristic pungency and diverse culinary uses. Peppers also contain bioactive compounds and vitamins that support their value as functional foods (Vella et al., 2025). In Indonesia, chili commodities are economically significant and strongly linked to production–distribution dynamics and farm productivity, making yield stability a priority for growers and local markets (Al-Aziz & Suryani, 2024).

A major biological constraint to chili production is fruit fly infestation (Diptera: Tephritidae), particularly species within *Bactrocera*. In tropical and subtropical regions, *Bactrocera dorsalis* is widely recognized as a destructive and invasive pest with a broad host range and strong impacts on horticultural production and

marketability (Wijekoon et al., 2025). Infested chili fruits may appear externally intact while undergoing internal decay associated with larval feeding, resulting in quality deterioration and yield loss. Field and laboratory evidence indicates that susceptibility to *B. dorsalis* infestation varies among chili genotypes, highlighting the importance of integrating management strategies are required (Syamsudin et al., 2022).

In many smallholder systems, fruit fly outbreaks are commonly addressed through repeated applications of synthetic insecticides. However, intensive insecticide use can suppress beneficial organisms and contribute to pest resurgence and the development of resistance, weakening long-term control. Reports of resistance mechanisms in *B. dorsalis* populations reinforce the need for more sustainable approaches that reduce dependence on chemical control (Fan et al., 2025). In

addition, insecticide-based management can alter the composition of fruit fly and parasitoid communities, which may reduce the effectiveness of ecological regulation and complicate integrated pest management (IPM) implementation (Tarno *et al.*, 2025).

Attractant-based trapping is a key component of monitoring and suppressing tephritid fruit flies and is compatible with IPM. Two broad categories of attractants are commonly used: male lures and food-based attractants. Male lures can be highly potent but are typically sex-specific and may also be taxon-specific, whereas food-based attractants can capture both sexes and support early detection and population assessment (Enkerlin *et al.*, 2025). Among male lures, methyl eugenol is well known for strongly attracting male *B. dorsalis* and is widely used in surveillance and control (Zhang *et al.*, 2025). Nevertheless, because egg-laying females are directly responsible for crop damage, attractants that improve female capture remain particularly important for crop protection (Henneken *et al.*, 2022).

Fermentation-based odor sources have long been associated with fruit fly attraction because microbial fermentation generates volatile cues that can draw adult flies to potential feeding and oviposition sites (Enkerlin *et al.*, 2025; Henneken *et al.*, 2022). In this context, locally produced fermented liquids derived from fruit waste (often referred to as “eco-enzyme” in community-based waste utilization practices) may provide a low-cost, locally available odor source suitable for trap baits. The present study focuses on eco-enzyme attractants produced from common fruit wastes (nutmeg, banana, and pineapple) as well as a mixed formulation, reflecting materials readily available to households and fruit vendors in the study area.

Despite the broad use of male lures and protein/food baits in tephritid management, evidence remains limited regarding the field performance of fruit-

waste-derived eco-enzyme attractants for trapping *Bactrocera* spp. in chili agroecosystems, particularly in eastern Indonesian production centers. This study addresses that gap by evaluating eco-enzyme baits prepared from different fruit wastes to capture *Bactrocera* spp. in a chili field setting. The novelty of this work lies in its comparative, field-based assessment of multiple locally sourced eco-enzyme formulations (single-source and mixed-waste baits) within a replicated experimental design, providing practical evidence for a waste-to-resource attractant strategy that can support environmentally responsible fruit fly monitoring and suppression.

Accordingly, the objective of this study was to determine the species composition and abundance of *Bactrocera* spp. captured in traps baited with fruit-waste eco-enzyme attractants in chili fields in Kakaskasen I Village, Tomohon City, Indonesia.

MATERIALS AND METHODS

Study area

The study was conducted in a chili (*Capsicum frutescens* L.) production area in Kakaskasen I Village, Tomohon City, Indonesia, which is described as a local chili production center. The selected chili field area was approximately 1 ha, and trapping was performed when the crop had already entered the fruiting stage.

Materials and equipment

Materials and tools included chili plants; fruit wastes of nutmeg (*Myristica fragrans*), banana (*Musa* spp.), and pineapple (*Ananas comosus*); brown sugar; sterile water; alcohol for specimen preservation; traps; collection bottles; a plastic container/box; bamboo poles; plastic rope; labels; a blender; a weighing balance; A4 paper; writing instruments; and a microscope for identification.

Preparation of eco-enzyme attractants

Eco-enzyme (EE) attractants were prepared from fruit waste using a fermentation method described in the original manuscript as following the commonly used ratio of sugar:organic material:water = 1:3:10, with a fermentation duration of 3 months. This approach is consistent with published descriptions of eco-enzyme as a fermented liquid produced from sugar and fruit/vegetable waste,

commonly using a 1:3:10 ratio and multi-month fermentation (Benny *et al.*, 2023).

Treatments and experimental design

The experiment used a randomized complete block design with four EE bait treatments and five replicates (blocks), giving 20 experimental units (traps). The evaluated treatments are summarized in Table 1.

Table 1. The evaluated treatments are summarized

Treatment code	Eco-enzyme (EE) bait formulation	Feedstock source
A	EE Nutmeg (EE Pala)	Nutmeg fruit waste
B	EE Banana (EE Pisang)	Banana fruit waste
C	EE Pineapple (EE Nanas)	Pineapple fruit waste
D	EE Mixed (EE Pala + Pisang + Nanas)	Nutmeg + banana + pineapple fruit wastes

Table 1 indicates that three treatments consisted of single-feedstock eco-enzymes (nutmeg, banana, and pineapple), while one treatment combined all three feedstocks into a mixed eco-enzyme formulation. This design enables a direct comparison of fruit-waste sources under the same field conditions to determine whether *Bactrocera* spp. catches are higher for a specific fruit-waste eco-enzyme or for a mixed bait that may provide a broader fermentation-volatile profile.

Trap installation and observation schedule

Traps were installed in the fruiting-stage chili field and sampling was conducted on four occasions at 6-day intervals. Traps were hung on bamboo poles at approximately 1.5 m above ground level, with about 5 m spacing between traps, and were deployed in the morning at approximately 09:00–10:00 local time.

Collection and identification of fruit flies

At each sampling occasion, adult fruit flies captured in each trap were collected and counted. Specimens were identified to species level using morphological characters observed under a microscope. For *Bactrocera dorsalis* and related taxa, morphological diagnosis is commonly

based on consistent external characters and may be supported by validated identification protocols when needed (Taddei *et al.*, 2023). Captured specimens were preserved in alcohol prior to identification.

Statistical analysis

Trap catch data were analyzed using analysis of variance (ANOVA) consistent with the randomized complete block design (Jones *et al.*, 2023; Kumar, 2024; Madan *et al.*, 2025). When significant differences were detected, treatment means were compared using the BNT test (LSD) at a 5% significance level.

RESULTS AND DISCUSSION

Field trapping in chili plots recovered two tephritid fruit-fly species, identified as *Bactrocera dorsalis* and *B. cucurbitae* based on adult morphological characters (head, thorax, abdomen, wings, and legs). In addition to *Bactrocera* spp., multiple non-target insects were captured, indicating that the eco-enzyme (EE) baits functioned as general odor attractants under field conditions. *Bactrocera dorsalis* is a highly polyphagous and economically important tephritid pest, making reliable monitoring tools and environmentally safer suppression strategies essential for vegetable-based

production systems. *Bactrocera cucurbitae* (melon fly) is also widely distributed and can infest a broad range of hosts, particularly cucurbits, but it may also occur in other crops (including chili) depending on local agroecosystem conditions.

Trap captures were recorded across four observation rounds at 6-day intervals. The mean number of adult *Bactrocera* spp. captured per observation period for each EE bait is summarized in Table 2.



Figure 1. Adult fruit flies captured in chili-field traps: (a) *Bactrocera dorsalis* and (b) *B. cucurbitae*

Table 2. Mean number of adult *Bactrocera* spp. captured in chili fields across four observation rounds using eco-enzyme baits.

Treatment	Observation I	Observation II	Observation III	Observation IV	Mean
A (EE Nutmeg)	0.6	2.6	0.6	3	1.7
B (EE Banana)	0.6	2.2	0.2	2.2	1.3
C (EE Pineapple)	2.6	6.8	11	4.6	6.3
D (EE Mixed: nutmeg + banana + pineapple)	0.4	7.2	2	2.8	3.1

Across sampling rounds, EE Pineapple (Treatment C) consistently produced higher captures than the other EE baits, with the highest mean capture occurring in Observation III (11.0 adults). In contrast, EE Banana (Treatment B) showed the lowest overall mean capture (1.3 adults), while the mixed bait (Treatment D) was intermediate

(3.1 adults). These results indicate that the pineapple-based EE formulation produced the strongest attraction signal under the tested field conditions.

To evaluate treatment effects statistically, the original analysis (ANOVA followed by LSD/BNT at 5%) is summarized in Table 3.

Table 3. LSD (BNT, 5%) mean separation among eco-enzyme attractant treatments for *Bactrocera* spp. capture.

Treatment	Mean	Group
B (EE Banana)	1.3	a
A (EE Nutmeg)	1.7	a
D (EE Mixed)	3.1	a
C (EE Pineapple)	6.3	b

LSD (BNT) 5% = 3.7

Mean separation indicates that EE Pineapple differed significantly from the other treatments, whereas EE Banana, EE Nutmeg, and EE Mixed did not differ

significantly from one another. Therefore, among the tested fruit-waste EE formulations, pineapple-based EE was the

most effective lure for capturing *Bactrocera* spp. adults in chili fields.

The superior performance of EE Pineapple is plausibly linked to fermentation-driven changes in volatile composition. Fermentation can alter the abundance of alcohols, organic acids, and esters, compounds that contribute to strong “fruity” or acidic odor signatures that insects can detect and respond to (Hu *et al.*, 2024). In broader fruit-fly surveillance and management programs, food-based attractants are valued because they can attract both sexes (often with female-biased captures) and can complement reduced-insecticide approaches (Enkerlin *et al.*, 2025). Consistent with this mechanism, the present study observed that captured *Bactrocera* spp. were predominantly females, which is operationally advantageous because removing females can reduce subsequent oviposition pressure in the crop.

However, the traps also captured non-target insects from several orders (Diptera, Coleoptera, Orthoptera, and Lepidoptera), indicating limited selectivity of the EE baits. This observation is consistent with the general behavior of food-based lures, where attraction can extend beyond target tephritids depending on lure chemistry and trap design (Kean *et al.*, 2024; Wang *et al.*, 2024). Therefore, further optimization of bait formulation and/or trap configuration may be required if higher selectivity is needed for routine monitoring.

CONCLUSION

This study provides baseline information on ground dwelling soil insects in vegetable fields of Modinding District, South Minahasa, North Sulawesi. The survey recorded eight orders comprising seventeen families, with ecological roles represented by decomposers, predators, herbivores, vectors, parasitoids, and omnivores. The Shannon Wiener diversity index ranged from 0.255 to 1.333 across

host crops, indicating low to moderate diversity and suggesting that several crop fields were characterized by high dominance of a limited number of taxa. Community structure differed among crops. Several fields showed strong dominance of decomposers, particularly Collembola from Hypogastruridae, whereas some fields had a higher proportion of predators such as ants (Formicidae). These results support the use of soil and ground dwelling insects as practical indicators for biomonitoring in intensive vegetable production landscapes. Given that farmers reported routine applications of insecticides, fungicides, and herbicides, future monitoring should integrate detailed pesticide use records and habitat measurements to better explain variation in diversity and functional composition across crops and villages.

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