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Insecticidal potential of botanical extracts for management of, the oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritidae)

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Abstract

Background *Bactrocera dorsalis* (Hendel) poses a significant threat to global fruit production and quality, including in Pakistan, where it causes substantial losses. Traditional control methods have heavily relied on the indiscriminate and imprudent use of insecticides, leading to challenges such as insecticide resistance, environmental pollution, fruit contamination, and health risks. This study explores the insecticidal potential of seven selected botanicals: *Artemisia vulgaris* L., *Capparis spinosa* L., *Mentha longifolia*, *Mentha piperita*, *Peganum harmala*, *Eucalyptus globulus*, and *Callistemon viminalis*, each at three different concentrations (10mL, 20mL, and 30mL), against *Bactrocera dorsalis* (*B. dorsalis*). Two in vitro experiments involving the application of plant extracts mixed with protein bait and direct spray were conducted.

Results Both experimental results demonstrated a direct correlation between the concentration of plant extract and the mortality of *B. dorsalis*. In the plant extract mixed with protein bait, results recorded after 96 h at 10 mL ranged from 8.667 ± 1.52 – 47.000 ± 3.00 , at 20 mL from 18.667 ± 1.52 – 53.667 ± 6.02 , and 30 mL from 26.000 ± 5.29 – 67.667 ± 2.08 . Meanwhile, for direct spray, mortality ranged from 2.333 ± 1.15 – 32.333 ± 6.80 at 10 mL, 1.000 ± 1.00 – 42.667 ± 7.02 at 20 mL, and 9.667 ± 2.30 – 61.333 ± 8.50 at 30 mL, respectively. The plant species exhibiting the highest toxic potential against the respective pests was *C. viminalis*, followed by *A. vulgaris* L. In contrast, the least toxic effect was observed in *Eucalyptus globulus* at all concentrations. The highest mean mortality and repellence % were recorded in *C. viminalis* and *E. globulus* in both experimental trials. The results revealed the highest efficacy of *C. viminalis* with an LC_{50} value of 9685.15 and 19,909.11 ppm, for the extract mixed with protein bait and sprayed, was obtained, respectively, the most toxic to the pest followed by the extracts *E. globulus* and *C. spinosa* L.

Conclusion Based on our experimental results, it is concluded that *C. viminalis* and *A. vulgaris* L. are an effective alternative for the management of *B. dorsalis*.

Keywords *C. viminalis*, *E. globulus*, *A. vulgaris* L., Mortality, Protein bait, Repellence

Background

Fruit flies are recognized as serious pests, with the annual cost of infestation estimated to be in the range of 1300–1900 million USD (Enkerlin, 2021). In Pakistan, multiple fruit fly species, including *Bactrocera* and *Drosophila*, have been reported attacking various fruits, particularly mangoes and guavas. The global rejection of mango export shipments poses a significant economic threat (Khan et al., 2017). Fruits hold paramount importance

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globally, both nutritionally and economically, serving local consumption and export purposes.

Apricots (*Prunus armeniaca* L.) are a staple fruit in Gilgit-Baltistan (GB), cultivated across all ten districts (Akhtar & Khan, 2014; Akram et al., 2023). However, apricots are susceptible to pest infestations, which lead to reduced productivity and substantial monetary losses. The apricot fruit fly (Akram et al., 2023) stands out as one of the most destructive insects globally, particularly in GB. *B. dorsalis* (Hendel) is an extremely invasive species, posing a significant quarantine risk worldwide (Akram et al., 2023; CABI, 2019). This pest targets over 250 different types of fruits and vegetables (CABI, 2019; David & Ramani, 2011), causing damage levels of up to 100% in unprotected fruits like apples (*Malus domestica*), apricots (*P. Armeniaca* L.), nectarines (*Prunus persica* var. *nucipersica*), pears (*Pyrus communis*), peaches (*Prunus persica*), and quinces (*Cydonia oblonga*) (Akram et al., 2023; David & Ramani, 2011; USDA, 2016).

Chemical insecticides (Malathion, Methomyl, and Pyrethroids) have been the primary means of controlling *B. dorsalis* since the middle of the last century (Skouras et al., 2007; Wang et al., 2023). Recently, "attract and kill" tools for fruit flies, utilizing food lures (protein baits) or semi-chemicals combined with an insecticide, have emerged as a novel control strategy in tephritid Integrated Pest Management (IPM). This approach is particularly applicable to limited apricot tree canopy areas, offering a selective method that primarily affects the target tephritid pest while minimizing impacts on non-target species (Gregg et al., 2018; Papadopoulos et al., 2023).

Traditionally, organophosphates like dimethoate and fenitrothion were incorporated into tephritid baits (Rizzo et al., 2020), known for their documented negative effects on beneficial insects (Inskeep, 2022). The adverse impacts of excessive pesticide use on human health (e.g., stinging eyes, rashes, blisters, blindness, nausea, dizziness, diarrhea, and even death) have been underscored (Shah, 2020), as well as its environmental consequences, including a decrease in overall soil biodiversity (Mahmood et al., 2016). Furthermore, it can lead to the development of cross- and multi-resistance in targeted insect populations (Sparks & Nauen, 2015). In response to these concerns, recent "attract and kill" initiatives have shifted towards replacing synthetic pesticides with environmentally friendly natural active ingredients, such as spinosad (Boulahia-Kheder, 2021).

There is a growing interest in environmentally friendly management measures, encompassing the utilization of mineral products like clay and copper (Thakur & Gupta, 2016), as well as natural products such as biopesticides like abamectin, imidacloprid, and diazinon (El-Gendy et al., 2021; Pavela & Benelli, 2016). Recent studies have

highlighted the antifungal, antimicrobial, cytostatic, and insecticidal properties of plant essential oils (EOs) (Miresmailli & Isman, 2014).

Essential oils are natural mixtures of compounds with low molecular weight, volatility, and lipophilic nature found in various plant families, including Asteraceae, Apiaceae, Lamiaceae, Myrtaceae, Lauraceae, and Rutaceae, exhibiting significant insecticidal action (Pavela et al., 2019). Moreover, many of these natural products are considered safe by the US FDA (Food and Drug Administration) and EPA (Environmental Protection Agency). As a result, some of these essential oils hold promise for the development of real-world insecticides (Isman, 2020; Miresmailli & Isman, 2014).

While the potential of essential oils (EOs) as sources of green pesticides for practical applications against various arthropods of agricultural importance (primarily aphids and moths) and those relevant to public health (primarily mosquitoes and ticks) has been thoroughly explored (Benelli & Pavela, 2018a, 2018b; Stevenson et al., 2017), our understanding of their effectiveness against tephritid species remains incomplete. The insecticidal activity of EOs has been primarily studied against the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) (Diptera: Tephritidae) (Ghabbari et al., 2018), with limited information available for the olive fruit fly (*Bactrocera oleae*) (Canale et al., 2013), and other *Bactrocera* flies (El-Minshawy et al., 2018).

Recent research has emphasized the potential utility of EOs as sources of chemicals for attracting and killing control efforts (Barud et al., 2014; Canale et al., 2013; Malheiro et al., 2015). Based on this premise, in the present study, we selected plant extracts obtained from seven plant species. The herbs included Mugwort (*Artemisia vulgaris* L.), Caper (*Capparis spinosa* L.), Horsemint (*Mentha longifolia*), Peppermint (*Mentha piperita*), and Wild rue/Harmel (*Peganum harmala*). Meanwhile, the shrubs Southern blue gum (*E. globulus*) and Bottlebrush (*C. viminalis*) yielded intriguing outcomes for potential usage as natural pesticides in the future. These have been recently reported on various insect pests and vectors (Abbas and Nisar, 2020; Ahmad et al., 2023; Akter et al., 2021; Alkhaibari & Alanazi, 2022; El Amin et al., 2022; Gao et al., 2020; Mazumder et al., 2022; Nassar, 2019; Rekioua et al., 2022).

Furthermore, obtaining plant extracts from commercially grown crops could offer a cost-effective means of production. Given the aforementioned considerations, the objective of this study was to assess the effectiveness of extracts from *A. vulgaris* L., *C. spinosa* L., *M. longifolia*, *M. piperita*, *P. harmala*, *E. globulus*, and *C. viminalis* as insecticides against *B. dorsalis*. The leaf extracts from these seven plants were incorporated into protein bait

and applied through spraying. Laboratory ingestion bioassays were then conducted to evaluate their insecticidal activity against *B. dorsalis* adults.

Methods

Plant material

Leaves from the plants *A. vulgaris* L., *C. spinosa* L., *M. longifolia*, *M. piperita*, and *P. harmala* were collected from Barkulti Yasin (36°28'56"N; 37°23'39" E, 2442 M) village in Ghizer District. Meanwhile, leaves from *E. globulus* and *C. viminalis* were sourced from Karakoram International University (35°55'33"N; 74°21'52" E, 1483 M), GB, in June 2022. These plants are widely available in GB, Pakistan.

Plant extract extraction and filtration

Plant leaves were air-dried in the shade for three months. The dried plant leaf material was then ground to a powder using an electric grinder. Subsequently, 500 g of the dried plant leaves was soaked overnight with 2L of distilled water in a 5-L round flask and boiled for approximately 2 h. Metabolites were extracted at room temperature using a soaking process with the organic solvent methanol (Khan et al., 2016; Padin et al., 2013). The solvent layer was filtered with Whatman No.1 filter paper after 2 days, and this process was repeated three times. The filtrate was concentrated at 35 °C using a rotary evaporator, and the resulting extracts were stored at 4 °C.

Fruit fly rearing

The fruit flies were obtained from the Integrated Pest Management (IPM) laboratory of the Department of Agriculture, Government of GB. Adults of both sexes were placed inside plastic boxes (30×30 x 45 cm) and placed in a climatic room at 21±1 °C with a 16:8 (L/D) photoperiod. Flies were fed and reared with an aqueous solution of artificial protein bait weighing a total of 500 mL (by volume). The bait was formulated with egg yolk (50 g), banana (250 g), leader syrup (0.2–0.4 mL), yeast (1 g), honey (~ 4.2 g), sugar (50 g), and distilled water, which were blended in an electric blender to form a uniform paste (Hasnain et al., 2023; Khan et al., 2016; Rizzo et al., 2020).

Ingestion toxicity bioassays

Bioassays were conducted using groups of 90 adults of both sexes, randomly selected from the main rearing cages and aged between 10–15 days. The flies were placed inside transparent plastic boxes measuring 15×15×20cm, with a thin mesh on top for air exchange, following the protocol outlined by Benelli et al. (2012) and Canale et al. (2013). Fruit flies were provided with

various concentrations (10, 20, and 30 mL/1000 mL) of the tested extracts mixed with protein bait and sprayed.

To prevent insect drowning, a small dish of sterile cotton wool soaked with water was placed inside a plastic petri dish, and both were positioned within each plastic box. Protein baits were mixed with the tested extract concentrations at 10, 20, and 30 mL. Three replicates were maintained for each concentration, and data were recorded at 24-h intervals, following the methodology described by Khan et al. (2016). All tests were conducted in a climatic room with a photoperiod of 16:8 (L/D) and a temperature of 21 ± 1 °C (Rizzo et al., 2020).

Data analysis

The study employed a completely randomized design (CRD), with each treatment divided into three replicates. The formula used to determine percent repellence was as follows:

$$\%R = [1/2 (A - B)/A] \times 100,$$

where R represents repellence, A represents half of the number of flies settled on both treated and untreated diets, and B represents the number of flies settled on the treated diet (Khan et al., 2016; ur Rehman et al., 2009).

Differences in mortality and repellence induced by different plant extracts were analyzed using one-way analysis of variance (ANOVA), and complementary pairwise comparisons of means were made using Tukey's HSD test ($p < 0.05$). All statistical evaluations were performed using Statistix 8.1 software. Statistical analysis after the experimental mortality was corrected using Abbott's formula (1925). Whereas, using probit analysis, the ingestion LC₅₀ and its associated 95% confidence interval (CI) and Chi-squares were calculated (Finney, 1978).

$$\%C = X - Y/X \times 100,$$

where C represents the control, X represents % living in the check, Y represents % living in the treatment, and X–Y represents the % killed by the treatments.

Results

The seven leaf extracts tested in this study demonstrated significant insecticidal activity against *B. dorsalis* when incorporated into protein baits and sprayed (Tables 1, 2, 3, and 4). Figures 1 and 2 reveal a positive linear relationship between the concentrations of extracts and the % mortalities of the fruit flies in both experiments. However, an inverse effect was observed between the increases in concentration and % repellence.

Significant effects of the tested extracts of *A. vulgaris* L., *C. spinosa* L., *M. longifolia*, *M. piperita*, *P. harmala*, *E. globulus*, and *C. viminalis*, their concentrations (10,

Table 1 Toxic potential of botanical extracts mixed with protein baits against adults of *Bactrocera dorsalis*

Plant extract(10 ml) mixed with diet				
Treatments	24H (Mean. M ± SD)	48H (Mean. M ± SD)	72H (Mean. M ± SD)	96H (Mean. M ± SD)
<i>Artemisia vulgaris</i> L	3.333 ± 5.77 ^{BC}	16.667 ± 5.77 ^{A-E}	23.333 ± 5.77 ^{B-F}	26.667 ± 5.77 ^{F-H}
<i>Capparis spinosa</i> L	0.00 ± 0.00 ^A	12.667 ± 2.51 ^{B-E}	17.333 ± 2.51 ^{D-G}	18.667 ± 1.52 ^{HI}
<i>Mentha longifolia</i>	0.000 ± 0.00 ^A	20.667 ± 1.15 ^{A-E}	30.667 ± 2.08 ^{B-E}	36.333 ± 4.72 ^{C-F}
<i>Mentha piperita</i>	0.00 ± 0.00 ^A	12.667 ± 3.78 ^{B-E}	19.333 ± 0.57 ^{C-G}	25.000 ± 5.00 ^{GH}
<i>Peganum harmala</i>	1.333 ± 1.52 ^{BC}	4.333 ± 3.78 ^{DE}	11.333 ± 1.52 ^{FG}	16.667 ± 3.51 ^{HI}
<i>Eucalyptus globulus</i>	1.000 ± 1.73 ^C	2.667 ± 3.05 ^E	4.000 ± 4.58 ^G	8.667 ± 1.52 ^I
<i>Callistemon viminalis</i>	10.667 ± 9.29 ^{A-C}	17.000 ± 15.13 ^{A-E}	27.333 ± 15.30 ^{B-F}	47.000 ± 3.00 ^{B-D}

Mean mortality ± SD within a column followed by the same letter does not differ significantly (ANOVA followed by Tukey's HSD test, $p < 0.05$). Each value is the mean of 3 replications with 90 insects per replicate

Table 2 Toxic potential of botanical extracts mixed with protein baits against adults of *Bactrocera dorsalis*

Plant extract (20 mL) mixed with diet				
Treatments	24H (Mean. M ± SD)	48H (Mean. M ± SD)	72H (Mean. M ± SD)	96H (Mean. M ± SD)
<i>Artemisia vulgaris</i> L	6.667 ± 5.77 ^{A-C}	18.333 ± 2.88 ^{A-E}	31.667 ± 10.40 ^{A-E}	40.000 ± 13.22 ^{C-E}
<i>Capparis spinosa</i> L	3.000 ± 3.00 ^{BC}	10.667 ± 2.08 ^{C-E}	20.333 ± 2.51 ^{C-G}	27.333 ± 2.51 ^{F-H}
<i>Mentha longifolia</i>	12.000 ± 2.64 ^{A-C}	26.000 ± 3.60 ^{A-C}	33.333 ± 3.51 ^{A-D}	47.333 ± 2.51 ^{BC}
<i>Mentha piperita</i>	12.333 ± 2.51 ^{A-C}	20.667 ± 4.04 ^{A-E}	26.667 ± 6.50 ^{B-F}	36.000 ± 3.60 ^{D-G}
<i>Peganum harmala</i>	3.667 ± 6.36 ^{BC}	7.667 ± 8.02 ^{DE}	16.000 ± 6.08 ^{D-G}	22.667 ± 6.65 ^H
<i>Eucalyptus globulus</i>	2.667 ± 2.51 ^{BC}	5.000 ± 4.35 ^{DE}	13.667 ± 3.51 ^{E-G}	18.667 ± 1.52 ^{HI}
<i>Callistemon viminalis</i>	11.333 ± 11.01 ^{A-C}	21.000 ± 9.84 ^{A-D}	34.333 ± 3.78 ^{A-D}	53.667 ± 6.02 ^B

Mean mortality ± SD within a column followed by the same letter does not differ significantly (ANOVA followed by Tukey's HSD test, $p < 0.05$). Each value is the mean of 3 replications with 90 insects per replicate

Table 3 Toxic potential of botanical extracts mixed with protein baits against adults of *Bactrocera dorsalis*

Plant extract (30 mL) mixed with diet				
Treatments	24H (Mean. M ± SD)	48H (Mean. M ± SD)	72H (Mean. M ± SD)	96H (Mean. M ± SD)
<i>Artemisia vulgaris</i> L	18.333 ± 2.88 ^A	30.000 ± 5.00 ^{AB}	41.667 ± 7.63 ^{AB}	53.333 ± 7.63 ^B
<i>Capparis spinosa</i> L	13.667 ± 3.21 ^{AB}	21.667 ± 2.88 ^{A-D}	26.333 ± 3.21 ^{B-F}	27.333 ± 2.51 ^{F-H}
<i>Mentha longifolia</i>	13.333 ± 3.51 ^{A-C}	30.000 ± 8.88 ^{AB}	41.667 ± 7.37 ^{AB}	56.000 ± 3.60 ^B
<i>Mentha piperita</i>	18.333 ± 2.88 ^A	26.333 ± 3.51 ^{A-C}	37.000 ± 3.00 ^{A-C}	47.000 ± 2.64 ^{B-D}
<i>Peganum harmala</i>	4.000 ± 4.58 ^{BC}	14.000 ± 3.46 ^{AE}	28.000 ± 2.64 ^{B-F}	35.667 ± 3.78 ^{E-G}
<i>Eucalyptus globulus</i>	4.000 ± 3.60 ^{BC}	11.333 ± 2.30 ^{C-E}	18.667 ± 3.21 ^{C-G}	26.000 ± 5.29 ^{F-H}
<i>Callistemon viminalis</i>	17.000 ± 6.08 ^A	32.000 ± 10.44 ^A	50.333 ± 9.07 ^A	67.667 ± 2.08 ^A

Mean mortality ± SD within a column followed by the same letter does not differ significantly (ANOVA followed by Tukey's HSD test, $p < 0.05$). Each value is the mean of 3 replications with 90 insects per replicate

20, and 30 mL/1000 mL), and the interaction of the tested extract consent were observed. The % mortality and repellence were recorded at 24, 48, 72, and 96 h post-treatment.

B. dorsalis mortality in plant extract mixed with protein bait

The highest efficacy was achieved by testing the concentration of 10-30 mL (10–30%) extract mixed with protein

bait from *C. viminalis*, ranging from 47.000 ± 3.00^{B-D}-67.667 ± 2.08^A (52.22–75.18%) after 96 h. In contrast, the least efficacy was recorded in *E. globulus* within the range of (8.667 ± 1.52^I-26.000 ± 5.29^{F-H}) with a mean mortality % range of (9.62–28.88%) at the end of the experiment.

The other extracts demonstrated efficacy within ranges, such as *A. vulgaris* L. (29.62–59.25% with a range of 26.667 ± 5.77^{F-H}-53.333 ± 7.63^B),

Table 4 Toxic effect of different concentrations of botanical extracts spray on adults of *Bactrocera dorsalis*

Plant extracts (10 mL) sprayed				
Treatments	24H (Mean. M ± SD)	48H (Mean. M ± SD)	72H (Mean. M ± SD)	96H (Mean. M ± SD)
<i>Artemisia vulgaris</i> L	21.667 ± 2.88 ^{BC}	24.333 ± 5.13 ^B	31.000 ± 4.00 ^C	34.000 ± 5.56 ^B
<i>Capparis spinosa</i> L	0.0000 ± 0.00 ^E	2.333 ± 1.15 ^C	3.667 ± 1.15 ^{DE}	9.333 ± 2.51 ^{CDE}
<i>Mentha longifolia</i>	0.0000 ± 0.00 ^E	2.667 ± 0.57 ^C	3.667 ± 0.57 ^{DE}	6.667 ± 1.15 ^{C-E}
<i>Mentha piperita</i>	0.0000 ± 0.00 ^E	1.333 ± 1.52 ^C	4.000 ± 3.46 ^{DE}	5.000 ± 3.60 ^{DE}
<i>Peganum harmala</i>	0.0000 ± 0.00 ^E	0.333 ± 0.57 ^C	0.667 ± 0.57 ^E	2.333 ± 0.57 ^E
<i>Eucalyptus globulus</i>	0.0000 ± 0.00 ^E	0.333 ± 0.57 ^C	2.000 ± 1.00 ^E	2.333 ± 1.15 ^E
<i>Callistemon viminalis</i>	17.333 ± 4.61 ^{B-D}	23.667 ± 8.32 ^B	29.000 ± 7.22 ^C	32.333 ± 6.80 ^B

Mean mortality ± SD within a column followed by the same letter does not differ significantly (ANOVA followed by Tukey's HSD test, $p < 0.05$). Each value is the mean of 3 replications with 90 insects per replicate

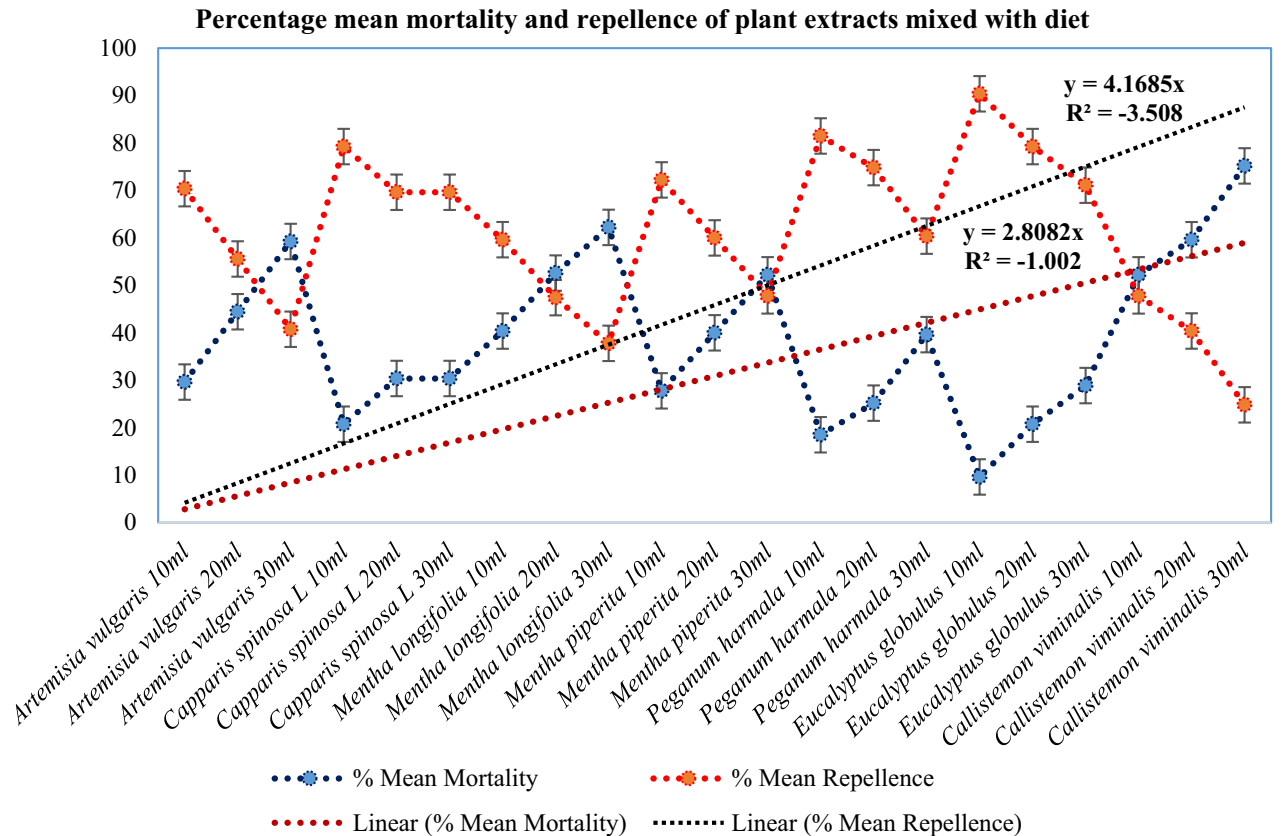


Fig. 1 Percent means mortality and repellence of different concentrations of botanical extracts mixed with protein baits against adults of *Bactrocera dorsalis*

C. spinosa L. (20.74–30.37% with a range of 18.667 ± 1.52^{HI} – $27.333 \pm 2.51^{F-H}$), *M. longifolia* (40.3–62.22% with a range of $36.333 \pm 4.72^{C-F}$ – 56.000 ± 3.60^B), *M. piperita* (27.77–40% with a range of 25.000 ± 5.00^{GH} – $47.000 \pm 2.64^{B-D}$), and *P. harmala* (18.51–39.62% with a range of 16.667 ± 3.51^{HI} – $35.667 \pm 3.78^{E-G}$) of mortality, as shown in Tables 1, 2, and 3 and Fig. 1.

B. dorsalis mortality in plant extract sprayed
The highest and lowest mortality ranges for the direct spray method of the extracts were observed for the 10–30% (10–30 mL) concentration of *C. viminalis*, ranging from (32.333 ± 6.80^B – 61.333 ± 8.50^A) with the mean mortality percentage range of 35.29–68.14% at 10 and 30% concentration of the extract. In contrast, *E. globulus* showed 2.59–10.74% mean % mortality with the

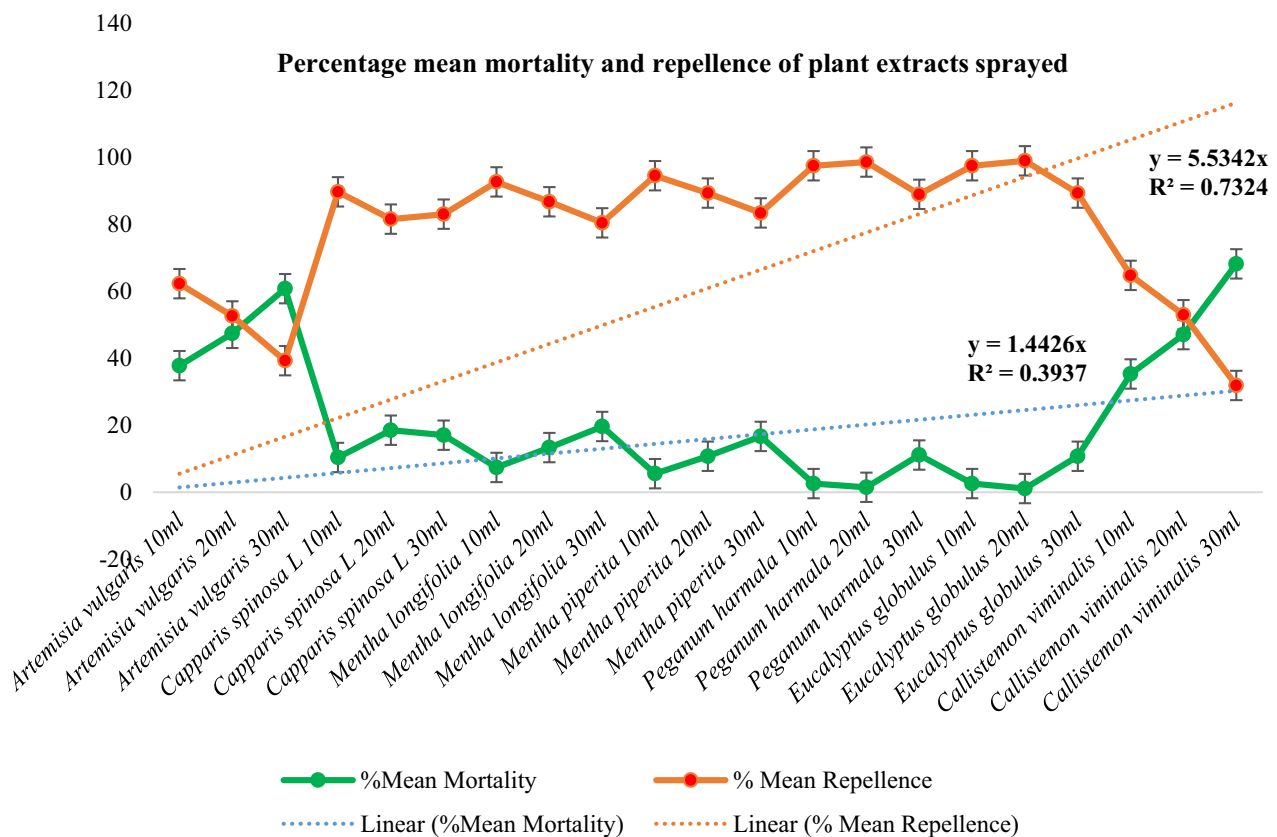


Fig. 2 Percent means mortality and repellence of different concentrations of botanical extracts sprayed against adults of *Bactrocera dorsalis*

range of $(2.333 \pm 1.15^E - 9.667 \pm 2.30^{C-E})$ at the same concentrations at the end of the experiment. However, the other extracts demonstrated efficacy in between the highest mortality and lowest mortality. The range was observed in *A. vulgaris* L. ($37.77 - 60.74\%$ with a range of $34.000 \pm 5.56^B - 54.667 \pm 5.50^A$), *C. spinosa* L ($10.37 - 17.03\%$ with a range of $9.333 \pm 2.51^C - E - 15.333 \pm 5.68^{CD}$), *M. longifolia* ($7.4 - 19.62\%$ with a range of $6.667 \pm 1.15^{C-E} - 17.667 \pm 2.08^C$), *M. piperita* ($5.55 - 16.66\%$ with a range of

$5.000 \pm 3.60^{DE} - 15.000 \pm 5.56^{CD}$), and *P. harmala* ($2.59 - 11.11\%$ with a range of $2.333 \pm 0.57^E - 10.000 \pm 3.00^{C-E}$). The results are shown in Tables 4 and 5 and Fig. 2.

B. dorsalis repellence

The mean lowest and highest repellence percentages recorded in the plant extract mixed with protein bait (diet) were 24.82% for *C. viminalis* at 30 mL and 90.38% for *E. globulus* at 10 mL at the end of the experiment.

Table 5 Toxic effect of different concentrations of botanical extracts spray on adults of *Bactrocera dorsalis*

Plant extracts (20 mL) sprayed				
Treatments	24H (Mean. M $\pm$ SD)	48H (Mean. M $\pm$ SD)	72H (Mean. M $\pm$ SD)	96H (Mean. M $\pm$ SD)
<i>Artemisia vulgaris</i> L	25.667 ± 5.13^{AB}	29.333 ± 4.04^{AB}	36.000 ± 9.00^{BC}	42.667 ± 7.02^B
<i>Capparis spinosa</i> L	5.0000 ± 5.00^{DE}	7.333 ± 3.51^C	11.333 ± 4.61^{DE}	16.667 ± 4.61^C
<i>Mentha longifolia</i>	6.6667 ± 5.77^{DE}	7.667 ± 4.93^C	9.667 ± 4.16^{DE}	$12.000 \pm 4.35^{C-E}$
<i>Mentha piperita</i>	6.6667 ± 5.77^{DE}	7.333 ± 5.50^C	8.000 ± 4.35^{DE}	$9.667 \pm 4.16^{C-E}$
<i>Peganum harmala</i>	0.0000 ± 0.00^E	0.667 ± 0.57^C	0.667 ± 0.57^E	1.333 ± 1.52^E
<i>Eucalyptus globulus</i>	0.0000 ± 0.00^E	0.667 ± 0.57^C	1.000 ± 1.00^E	1.000 ± 1.00^E
<i>Callistemon viminalis</i>	22.000 ± 7.21^{AB}	29.667 ± 3.05^{AB}	35.667 ± 4.61^{BC}	42.333 ± 6.80^B

Mean mortality $\pm$ SD within a column followed by the same letter does not differ significantly (ANOVA followed by Tukey's HSD test, $p < 0.05$). Each value is the mean of 3 replications with 90 insects per replicate

The other extracts exhibited repellence percentages falling between the highest and lowest mean repellence percentages, as depicted in Fig. 1. For the spray treatment, the highest mean repellence percentage was observed as 98.89% in *E. globulus* at 20 mL, while the lowest mean repellence percentage of 31.86% was recorded in *C. viminalis* at 30 mL. The remaining extracts showed mean repellence percentages falling between the lowest and highest mortality percentages, as illustrated in Fig. 2.

LC₅₀ of the extracts in both treatments

LC₅₀ values for each extract in both experiments are presented in Table 6, with significant LC₅₀ and the highest mean mortality observed in the extract of *C. viminalis*. This indicates that the plant extract can cause 50% of deaths in *B. dorsalis* at a concentration of 9.68 mL/1000 mL (9685.15 ppm) when mixed with protein bait. Conversely, the lowest mean mortality and LC₅₀ were observed in the extract of the plant *C. spinosa*

L., indicating that the extract of this plant can cause 50% deaths at a concentration of 55.57 mL/1000 mL (55,576.32 ppm) when mixed with protein bait. The other plants exhibited LC₅₀ and mean mortality values between the highest and lowest for *B. dorsalis* in extract mixed with protein bait, as represented in Fig. 3.

For the direct spray of extracts on *B. dorsalis*, LC₅₀, the highest and lowest mean mortality values are presented in Table 7. The highest mean mortality was recorded in *C. viminalis*, indicating that a concentration of 19.9 mL/1000 mL (19,909.11 ppm) of extract can cause 50% of deaths in *B. dorsalis*, representing the best LC₅₀ value. Conversely, the least LC₅₀ and mean mortality were observed in the treatment of *M. piperita*, showing that this plant extract can cause 50% of deaths in *B. dorsalis* at a concentration of 90.13 mL/1000 mL (90,136.08 ppm). Similarly, extracts of other plants showed values between the highest and lowest mean mortality and LC₅₀ values, as represented in Fig. 3.

Table 6 Toxic effect of different concentrations of botanical extracts spray on adults of *Bactrocera dorsalis*

Plant extract (30 mL) sprayed				
Treatments	24H (Mean. M ± SD)	48H (Mean. M ± SD)	72H (Mean. M ± SD)	96H (Mean. M ± SD)
<i>Artemisia vulgaris</i> L	36.333 ± 7.09 ^A	39.667 ± 7.02 ^A	47.333 ± 8.08 ^{AB}	54.667 ± 5.50 ^A
<i>Capparis spinosa</i> L	6.6667 ± 5.77 ^{DE}	9.000 ± 6.92 ^C	11.333 ± 6.65 ^{DE}	15.333 ± 5.68 ^{CD}
<i>Mentha longifolia</i>	7.0000 ± 6.08 ^{DE}	11.000 ± 3.60 ^C	15.333 ± 4.04 ^D	17.667 ± 2.08 ^C
<i>Mentha piperita</i>	7.3333 ± 6.42 ^{C-E}	9.667 ± 6.11 ^C	11.000 ± 7.00 ^{DE}	15.000 ± 5.56 ^{CD}
<i>Peganum harmala</i>	6.6667 ± 5.77 ^{DE}	7.667 ± 4.93 ^C	8.000 ± 4.35 ^{DE}	10.000 ± 3.00 ^{C-E}
<i>Eucalyptus globulus</i>	6.6667 ± 5.77 ^{DE}	8.000 ± 4.35 ^C	8.333 ± 3.78 ^{DE}	9.667 ± 2.30 ^{C-E}
<i>Callistemon viminalis</i>	26.667 ± 6.02 ^{AB}	39.667 ± 1.15 ^A	52.000 ± 6.08 ^A	61.333 ± 8.50 ^A

Mean mortality ± SD within a column followed by the same letter does not differ significantly (ANOVA followed by Tukey's HSD test, *p* < 0.05). Each value is the mean of 3 replications with 90 insects per replicate

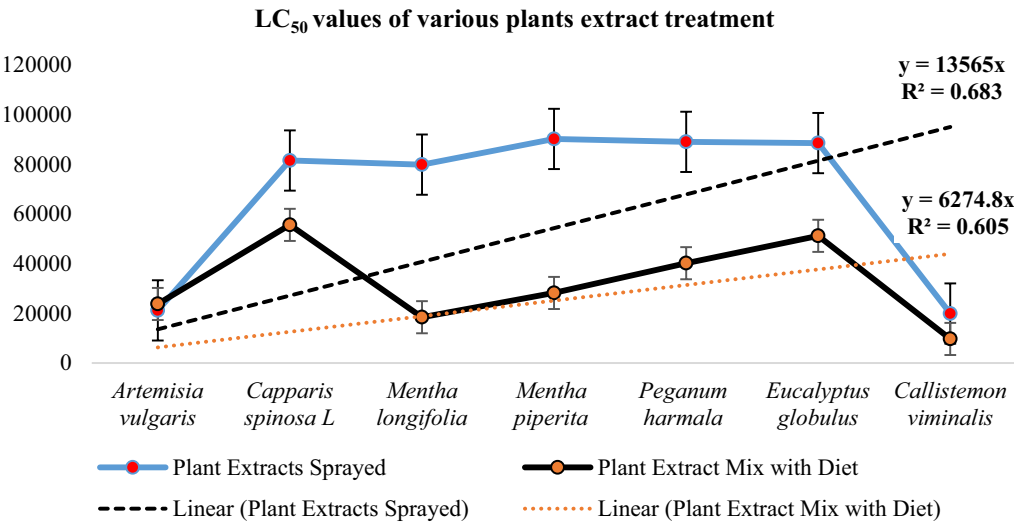


Fig. 3 LC₅₀ of plant extract mixed with protein bait and sprayed with their linear regressions

Table 7 LC₅₀ of botanical extracts sprayed and mixed with diet treatments against adults of *Bactrocera dorsalis*

LC ₅₀ values for various plant extract treatments		
Plant extract	Plant extracts sprayed (ppm)	Plant extract mix with diet (ppm)
<i>Artemisia vulgaris</i> L	21,176.82	23,755.2
<i>Capparis spinosa</i> L	81,454.34	55,576.32
<i>Mentha longifolia</i>	79,802.66	18,426.89
<i>Mentha piperita</i>	90,136.08	28,182.68
<i>Peganum harmala</i>	88,964.36	40,151.1
<i>Eucalyptus globulus</i>	88,473.21	51,167
<i>Callistemon viminalis</i>	19,909.11	9685.15

90 individuals per replicate, three replicates per concentration, 3 concentrations per assay, adults for every test; LC: lethal concentration (10, 20, and 30mL Mixed method and in spray method), CL: confidence limits

Discussion

Management of fruit flies, specifically *B. dorsalis*, poses significant challenges for researchers and pest managers (Mohanpuria et al., 2021). The global demand for horticultural crops, especially fruits free of fruit fly infestation, is on the rise (Khan & Naveed, 2017; Papadopoulos et al., 2024). Despite the existing control measures (Boulahia-Kheder, 2021), there is an ongoing need for environmentally sustainable and effective management (Nisar et al., 2020). The use of insecticides to control the oriental fruit fly, *B. dorsalis* Hendel (Diptera: Tephritidae), is a fundamental aspect of the fruit fly's current management (Wang et al., 2024). However, the prolonged use of synthetic insecticides has led to reports of resistance and cross-resistance to insecticides such as organophosphates, carbamates, and pyrethroids (Chou et al., 2010; Hsu & Feng, 2006; Kamran et al., 2022). In addition, botanical pesticides are an effective alternative way for removing numerous pest insects (Damalas & Koutroubas, 2020).

The results of our bioassay revealed that all seven plant leaf extracts in both treatments (extract mixed with protein bait and extract direct spray) can kill and repel *B. dorsalis* fruit flies to varying degrees due to their different modes of action (Jaffar & Lu, 2022). There is a strong positive association between all characteristics and dosage, particularly concentration and mode of action (Elsayed et al., 2022). A high pesticide dosage has long been recommended for effectively controlling agricultural insects and pests while limiting the emergence of resistance (Jacquet et al., 2022; Tandon & Mittal, 2018).

C. viminalis exhibited higher toxicity in both experiments, causing the most significant mortality impact on *B. dorsalis* compared to the other plant extracts. Notably, *C. viminalis* showed significantly lower repellence.

Our current findings on mortality and repellence induced by *C. viminalis* align with the studies of (Das et al., 2024; Nassar, 2019; Starr et al., 2007), which reported the insecticidal potential of *C. viminalis* against the genus *Bactrocera* (*B. dorsalis*) species. Similar insecticidal efficiency of *C. viminalis* has also been documented by (Silvestre et al., 2021; Somnuek et al., 2021; Yingklang et al., 2022).

Similarly, *E. globulus* treatment revealed the lowest mortality and maximum repellence in *B. dorsalis*. These findings align with the results of (Boulamta et al., 2021; Sadraoui-Ajmi et al., 2022), who reported that *E. globulus* essential oils have the potential to kill the Mediterranean fruit fly *C. capitata* (Tephritidae). However, various studies discussed the insecticidal properties of *E. globulus* against *Bactrocera* species, including *Drosophila melanogaster* (Boulamta et al., 2021), *Drosophila suzukii* (Pineda et al., 2023; Souza et al., 2022), and *B. oleae* (Giunti et al., 2022). Similarly, other studies have discussed the insecticidal properties of *E. globulus* (Bessike et al., 2023; Čmiková et al., 2023).

Our results demonstrated that *A. vulgaris* L. possesses insecticidal properties, showing significant mortality and repellence against *B. dorsalis* in both experiments. These findings are consistent with previous studies conducted by Liu et al. (2010) and Jaffar and Lu (2022). However, *Artemisia* species were used against *B. zonata* (Niroumand et al., 2016), and *Bactrocera correcta* (Echavarría et al., 2020). Similarly, various studies discussed the insecticidal potential of *Artemisia* (Alhuraysi et al., 2021; Gao et al., 2020; Sofi et al., 2022; Xiao et al., 2023). In addition, *C. spinosa* L showed insecticidal activity against *B. dorsalis* although it caused less mortality and repellence in both experiments; however, it has the insecticidal quality against *B. cucurbitae* (Hamid et al., 2013; Mani, 2022), whereas studies found the insecticidal potential of *C. spinosa* L (Alkhaibari & Alanazi, 2022; Ladhari et al., 2013).

Similarly, the extract of *M. longifolia* also caused mortality in both experiments, the protein bait mixture, and direct spray, in *B. dorsalis*. These findings were supported by Ramniwas and Singh (2021), whereas Tajdar et al. (2020) discussed the repellence potential of *M. longifolia* in *B. zonata*, and their results support our findings. However, various studies found the insecticidal efficacy of *M. longifolia* (Hassan et al., 2021; Kadoglidou & Chatzopoulou, 2023), while the findings have also shown that *M. piperita* has insecticidal properties and causes mortality in *B. zonata* (Elsayed et al., 2022; Tajdar et al., 2023), although it has significant efficacy as an insecticidal, as discussed in previous literature (Peeyush et al., 2011; Prasannakumar et al., 2023).

The treatments of *P. harmala* extracts showed less mortality, but it showed strong repellence in both experiments such as extract mixed with protein bait and spray against *B. dorsalis* species, which supports the results of Fazeli-Dinan et al. (2023) who discussed the repellence activity of *P. harmala* in *B. oleae*, whereas their insecticidal properties against *B. zonata* were also discussed in studies of ur Rehman et al. (2009). However, in the current experiments, *C. viminalis* with the combination of protein bait and the spray treatment of the extract showed significant mortality and the best LC₅₀ value in the experiments (Oladipupo, 2022). The current study showed the insecticidal activity of selective plant leaf extracts and their efficacy against *B. dorsalis* and recommended *C. viminalis* as a potential insecticide against the *Bactrocera* species.

Conclusions

This research underscores the potential of plant extracts from *Artemisia vulgaris* L., *Capparis spinosa* L., *Mentha longifolia*, *Mentha piperita*, and *Peganum harmala* in pest management strategies. Among these, *Callistemon viminalis* exhibited the highest efficacy, significantly increasing insect mortality with rising concentrations, highlighting its potential for effective dosage and duration-based applications. Additionally, *Eucalyptus globulus* and *P. harmala* showed considerable repellence against *Bactrocera dorsalis*. In underdeveloped nations, farmers frequently rely on synthetic pesticides to control tephritid fruit flies, often leading to harmful residues in fruits that jeopardize human health and the environment. This study revealed LC values from plant extract testing that are consistent with prior findings on ingestion toxicity against *B. dorsalis* adults. Particularly, *M. longifolia*, *A. vulgaris* L., and *C. viminalis* at concentrations of 10–30 mL/1000 mL demonstrate significant promise for the development of eco-friendly lure-and-kill formulations. Future research should focus on isolating the active compounds in these promising extracts through advanced chromatographic techniques. These isolated chemicals should be further evaluated for their chemosterilant, neurotoxic, and genotoxic properties, as well as their effects on insect hormonal balance and reproductive functions. Such studies will provide critical insights into developing safe, effective, and commercially viable biopesticides to combat insect pests while reducing environmental and health risks.

Abbreviations

IPM	Integrated Pest Management
EO	Essential oil
US	United State
GB	Gilgit-Baltistan
FDA	Food and Drug Administration
EPA	Environmental Protection Agency

CI	Confidence interval
L	Light
D	Dark
LC	Lethal concentration

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Author contributions

AH, team leader, contributed to manuscript designing and review. WA was involved in the manuscript drafting and data analysis, field and lab research activities and descriptive statistics and manuscript designing. Both authors provided responses and comments on the research flow, data analysis, and interpretation as well as the shape of the manuscript. However, QA and AA have significantly contributed to the revision and improvement of the final manuscript, warranting recognition for their valuable input. The authors have read and approved the final manuscript.

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Availability of data and materials

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

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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