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Original Research Article

A POLLINATOR-FRIENDLY, COST-EFFECTIVE MANGO HOPPER MANAGEMENT STRATEGY DEVELOPED BASED ON PEST BEHAVIOR

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Abstract: *The mango hopper is the most destructive pest of the mango crops. If unmanaged, this pest may decrease 80-100 % of crops. Hence, we designed a strategy to manage the hoppers based on the timing of the pest activity and the pest abundance peaks at different times of the year. The experiment was conducted in the experimental orchards of the Mango Research Institute Multan Punjab, Pakistan, from 2023 to 2024 in a density mango orchard. Three insecticides (dinotefuran, clothianidin, and flonicamid) were sprayed in various treatments, viz., summer spray only on the stem, winter spray on the only stem, post-harvest application (whole tree spray), summer prays only on stem + post-harvest spray, post-harvest spray + winter spray, summer + post-harvest + winter spray against the mango hopper. Overall, the mango hopper population was deficient in the treatment where the spray was done (one in summer, 2nd at the post-harvest stage (whole tree spray) and 3rd spray was done in winter on tree trunks only. The pest population was observed in the morning (8:00 am), mid-day (1:00 P.m.), and evening (6:00 PM) on leaves and tree trunks. During summer months, the population was higher on tree trunks at 1:00 pm, while in the winter, at 1:00 pm, the population was higher on the leaves. In the morning and evening, on tree canopy, the population is higher in the summer and lower in the winter. The population is higher on the stem in the morning and evening in winter. Hence, one spray in the summer on the tree trunk at 1:00 pm, 2nd whole tree spray after fruit harvest and a third spray during winter on tree trunks in the morning or evening minimised pest population during the fruiting season. Farmer yield and income are greatly enhanced with this strategy.*

Keywords: Mango Hopper, Ecology, Population Dynamics, Clothianidin, Flonicamid and Dinotefeuron

Introduction

Mango (*Mangifera indica*) (Anacardiaceae: Spindles) is a delicious, mono-embryonic, dicotyledon stone fruit grown in tropical regions including southeast Asia, east and west Africa, subtropical Americas, and the Caribbean regions. Mango is grown in a few places in Europe, the Canary Islands, and a few states of North America, Hawaii and Australia. Although some of the mangoes are grown in Florida USA, however, most of it is imported from Brazil, Mexico, Australia, Pakistan and India. In 2022, around 59 million tons of mangoes were produced. Among these, India is the leading producer of mangoes, followed by Indonesia, China, Pakistan, Mexico, and Brazil. In 2022, Pakistan ranked 4th in mango production. Although the Pakistani climate favours the production of mangoes, insect pest attacks pose a threat to production worldwide. Among these insect pests, the Mango hopper is a severe concern. This pest may reduce crop yield by 80-100 % if unmanaged.

Mango species *Armitodus Atkinson* (Leth), *Idioscopus clypeal* (Leth), and *I. niveosparasus* (intitules) (Leth.) are common in southeast Asia. (Rahman, 2007). Insecticides at various doses are recommended for the control of mango hoppers throughout the world (Munj, Reddy, Gundappa & Irulandi, 2020; Ghaffar, KHAN, Hameed, Iqbal, Ahmad, Raza, Imran, Muhammd, SHAH & RAZA, 2022). Most of these schedules were the first spray of insecticides at the panicle formation stage, followed by a second spray 21 days after the first and third sprays depending upon pest infestation before crop harvest. Many insecticides, viz., Acephate, lambda-cyhalothrin, spinosad, thiamethoxam, cypermethrin, DDT, BHC, and Endrin, were recommended (Singh & Mandal, 1969; Shawan, Rashed, Mitu & Jahan, 2018; Munj et al., 2020; Ghaffar et al., 2022). However, some problems were associated with these recommendations. The flowers are open 21 days after panicle formation; the pollinators at this stage are actively pollinating the flowers. Hence, pesticide exposure at this stage threatened the pollinator's population.(Drescher & Geusen-Pfister, 1990; Oyugi, Kibet & Adongo, 2024). Overusing the broad spectrum insecticides viz., acephate, imidacloprid, lambda-cyhalothrin, spinosad and deltamethrin is toxic to beneficial fauna. (Fernandes, Alves, Pereira, Aquino, Fernandes & Zanuncio, 2016; Jones, Duckworth & Robertson, 2018; Palkhade, Yadav, Mishra & Muhamed, 2018; Wang, Zhu & Li, 2020; Mota, de Lima Oliveira, Gonçalves, Vasconcelos, Miglioranza & de Castilhos Ghisi, 2023).

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In Pakistan, a few studies were carried out to determine the susceptibility of the cultivars and population dynamics of mango hoppers in Sindh province. (Talpur & Khuhro, 2003). However, more effort was needed to understand the pest's movement within the tree, including the canopy and trunk, during different times of the day. Hence, in the present experiment, we studied the movement behaviour of the pest within the tree at different times of the day and developed a strategy based on the pest movement behaviour and the pest population dynamics around the year in Punjab, Pakistan.

Methodology

Experimental layout:

This study was conducted at the Mango Research Institute, Multan, Pakistan experimental area. The experiment was laid out in a Randomized Complete Block Design (RCBD) with four modules (including control), each replicated thrice during two consecutive years, i.e. 2023-2024. The efficacy of different insecticides was evaluated through insecticide application at other times of crop season. The trees in the MRI medium density orchard are around 8-10 years of age of the cultivar Sufaid chance.

Impact of niche targeted spray on mango hopper population:

To understand the role of niche (specific place on mango tree) targeted spray in mango hopper population throughout the year, the insecticides were sprayed in different stages of crop growth. The mango hopper population resides on either the canopy of the trees and impacts plant vigour or the population rests on the tree trunk. Hence, the spray was done on specific sites where the population resides in the canopy or trunk, and its impact on the hopper population on a tree trunk and leaves was observed. The details of treatments are provided in Table 1. The conventional method is to spray the whole tree; hence, the pest population is ultimately killed. However, this spray application method has many disadvantages, including ecological imbalance among community organisms interaction. The experiment comprised eight treatments and four replicates in a randomised complete block design. The population was observed on stems and leaves. Spray was done through a knapsack sprayer on the trunk population. A tractor-mounted boom sprayer was used for conventional spray.

Table 1: Different insecticidal modules for the management of mango hopper.

Treatment	Method and time of application	Name of insecticide and dose
T1	No insecticide was applied	Control (No insecticide used)
T2	Spray only in summer (on stem)	Clothianidin (Trunk 20SC) @100ml/ 100L water (on stem)
T3	Spray only after fruit harvest (whole tree spray)	Dinotefuran (Oshin 20 SG) @50g / 100L water (whole tree)
T4	Spray only in winter (Stem spray)	Flonicamid (Ulala 50%DF) @80g/100L water
T5	Spray in summer (on stem) + post-harvest spray (whole tree)	Clothianidin (Trunk 20SC) @100ml/ 100L water (on stem)
		Dinotefuron (Oshin 20 SG) @50g / 100L water (whole tree)
T6	Spray in summer (on stem) + spray in winter on stem	Clothianidin (Telsta 20SC) @100ml/ 100L water
		Flonicamid (Ulala 50%DF) @80g/100L water
T7	Spray at post-harvest (whole tree) and spray in winter (on stem)	Dinotefuran (Oshin 20 SG) @50g / 100L water (whole tree)
		Flonicamid (Ulala 50%DF) @80g/100L water
T8	Spray in summer (on stem) + post-harvest spray (whole tree) + spray in winter (only on stem)	Clothianidin (Telsta 20SC) @100ml/ 100L water
		Dinotefuran (Oshin 20 SG) @ 50 g/100 L water
		Flonicamid (Ulala 50%DF) @80g/100L water

Population dynamics of mango hopper on tree trunks throughout the year:

To study the population dynamics of mango hoppers on tree trunks throughout the year (2023), one square foot area was marked on tree trunks and the population of mango hoppers was counted using a hand lens. The data was taken after a week interval.

Population dynamics of mango hopper on leaves throughout the year:

The population of mango hoppers on leaves was monitored throughout the year in each treatment (mentioned in Table 1). The data was taken by observing ten leaves per each cardinal direction. The data was taken each week, and the average population per replicate was calculated.

A graph was developed on the population dynamics of mango hoppers throughout the year using different treatments.

Average population of mango hopper on tree trunk and leaf surface throughout the year:

The average mango hopper population was taken at each niche throughout the year.

Population dynamics of mango hopper at different times of the day observed during 2023-2024 on tree trunks and leaves:

To determine the effect of the time of day on the hopper population, the mango hopper population was determined at weekly intervals from 2023 to 2024.

Effect of timings on the average population of mango hoppers throughout the year:

The average population at each time was calculated. Excel graphs on the population dynamics of mango hoppers throughout the year in different treatments were developed. The average population observed in each niche at a specific time was analysed through a split-plot ANOVA analysis with time as a sub-plot and the main plot niche. The interaction of niche and time was determined. The means

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were compared through Tukey HSD. The graph was developed through Excel.

Effect of spray applications on the population dynamics of pollinators during the flowering season:

In Pakistan, among the pollinator fauna, the dominant insect species are blue bottle flies, syrphid flies, house flies, native drones, zebra flies, flesh flies, wild bees, and stingless bees (Hameed, Karar, Ghaffar, Khan, Mubashir & Mustafa, 2022). About 1299 million US dollars is the economic value of pollination in mangoes (Hameed et al., 2022). Hence we studied the impact of three sprays on pollinators. In Pakistan, the honey bee species are not frequent visitors of mango inflorescence. Instead, blue bottle flies are dominant pollinators. The pollinator population develops when the flowers open. The flowering initiates in mid-February in Punjab, Pakistan. Hence, we recorded the pollinator population through a sweeping net from February onward. The population of pollinators was recorded after a week interval. The data record was initiated from the panicle formation (February 2024) until the pollination process and fruit set were complete (last week of May 2024).

Effect of spray applications on the average population of pollinators:

The average population of mango hoppers in each treatment throughout the pollination season was calculated from the 2nd last week of February to the previous week of May. The average of each treatment in each replicate was subjected to ANOVA analysis. The means were compared through Tukey HSD.

Statistical analysis:

To determine the impact of treatments on the hopper population, the variance was analysed through a randomised complete block design for each independent niche leaf or trunk. The means were compared through Tukey HSD at a 5 % significance level.

To determine the effect of the time of the day on the hopper population, the population of mango hopper was determined at weekly intervals throughout the years 2023 to 2024. The average population at each time was calculated. Graphs were developed through Excel on the population dynamics of mango hoppers throughout the year in different treatments. The average population observed in each niche at a specific time was analysed through a split-plot ANOVA analysis with time as a sub-plot and the main plot niche. The interaction of niche and time was determined. The means were compared through Tukey HSD. The graph was developed through Excel.

The average pollinator population was calculated, and a complete randomised block design ANOVA analysis was performed. The means were compared through Tukey HSD at 5%. All data was analysed through Statistica 8.1 (IBM). Standard error was calculated

Results

Population dynamics of mango hopper on tree trunks throughout the year:

During January 2023, the population of mango hoppers on tree trunks per square feet was almost similar in T1 (12-13 MH/ft^2), T2 (11-12 MH/ft^2), T3 (10-11 MH/ft^2), T4 (11-12 MH/ft^2), T5 (10-11 MH/ft^2), however, the lower population was observed in T6 (4-5 MH/ft^2), T7 (1-3 MH/ft^2), and T8 (1-2 MH/ft^2) (Fig 1). In February 2023, the population of mango hopper increased slightly in T1 (12-13 MH/ft^2), T2 (11-12 MH/ft^2), T3 (12-13 MH/ft^2), T4 (11-12 MH/ft^2), T5 (11-12 MH/ft^2), however the lowest population of mango hopper was observed in T8 (3.0-4.0 MH/ft^2). In March, the population of mango hoppers slightly declined on tree trunks, which may be because of the shifting of mango hoppers towards the canopy, new inflorescence and newly established fruits. Again, the population was lowest in March on twigs (5.0-6.0 MH/ft^2). In April 2023, the population was lower on tree trunks, perhaps due to movement to canopy leaves and fruits. The population was almost equal in T1 to T5. However, a slightly lower population was observed in T8. In May 2023, the population again increased on tree trunks in all treatments. However, higher population was observed in T1 (12-13 MH/ft^2), T2 (8-11 MH/ft^2), T3 (7-10 MH/ft^2), T4 (6-10 MH/ft^2), T5 (6-8 MH/ft^2). However, the lowest population was observed in T8 (3-5 MH/ft^2). In the last week of May, we sprayed insecticides on the stem population in T2, T5 and T8. Hence, the population suddenly declined to 1.67, 0.67 and 1.0, respectively.

In June 2023, the higher population was observed in T1 (13-15 MH/ft^2), T3 (10-13 MH/ft^2), and T4 (10-12 MH/ft^2). However, a lower population was observed in T5, T6, T7, and T8 due to insecticidal application. In July 2023, the population of mango hoppers was higher in control plots (16-18 MH/ft^2) of the branch. However, a slightly lower population was observed in T3 and T4. The population was lower in T5 (1-3 MH/ft^2), T6 (1-7 MH/ft^2), T7 (3-7 MH/ft^2) and T8 (0-2 MH/ft^2). In the 3rd week of July, the whole spray was done in T3, T5, and T8. The population of mango hoppers declined in these treatments to 1-13 MH/ft2, 1-3 MH/ft2, and 0.67 MH/ft2, respectively.

In August 2023, the higher population was observed in T1 (15-17 MH/ft^2), T2 (5-15 MH/ft^2), and T4 (15-17 MH/ft2). However, the lower population was present in T8 (1-3 MH/ft^2).

In September 2023, the higher population was observed in T1 (12-14 MH/ft^2), T2 (10-13 MH/ft^2), T4 (11-13 MH/ft^2). In September 2023, a higher population was observed in T1 (12-14 MH/ft2), T2 (10-13 MH/ft2), and T4 (11-13 MH/ft2). However, the population of mango hoppers was lowest in T8 (2.3-5.67 MH/ft^2). In October 2023, the higher population was observed in T1 (11.67-12.67 MH/ft^2), T2 (10.67-11.33 MH/ft^2), and T4 (11.67-12.33 MH/ft^2). However, the lowest population was observed in T8 (1-2.3). In November 2023, the population increased on tree trunks. The higher population of mango hopper was observed in T1 (13-16 MH/ft^2), T2 (11-13 MH/ft^2), T3 (11-14 MH/ft^2), T4 (13-14 MH/ft^2) however, the population of mango hopper was lower in T8 (2.67-4.0).

In December 2023, the mango hoppers increased in control plots on tree trunks (16-20 MH/ft^2).

Population dynamics of mango hopper on leaves throughout the year:

In January and February 2023, the population of mango hoppers on leaves was nil in all treatments, although a slight increase in the hopper population was observed at the end of February on 25.02. 2023, when 2-3 hoppers were observed in T1 (3-4 MH/leaf), T4 (1.8 MH/leaf), and T5

(1.5 MH/leaf), while the population was negligible in T8 (Fig 2). In March 2023, the population of mango hopper was higher in T1 (4-7 MH/leaf), T2 (1-2 MH/leaf), T3 (0-3 MH/leaf), T4 (2-3 MH/leaf), T6 (0 MH/leaf), T7 (0-0.8 MH/leaf), T8 (2-3 MH/leaf). In April 2023, the population of mango hopper increased in T1 (7-16 MH/leaf), T2 (3-9.5 MH/leaf), T3 (4-10.5 MH/leaf), T4 (3-5.1 MH/leaf), T5 (3.5-5 MH/leaf), T6 (0.6-2.9 MH/leaf), T7 (1-2.2 MH/leaf), T8 (2-2.5 MH/leaf).

In May 2023, the population of mango hopper declined on the canopy in T1 (8.3-0.75), T2 (10-0.8), T3 (7.3 - 0.5), T4 (10.8 - 7.2), T5 (5.7 – 2), T6 (2.25 – 0), T7 (2.5-1), T8 (3.8-0). In June 2023, the population of mango hoppers further declined in the canopy. As in T1, only the hopper (0-1) was visible per leaf. A similar case was observed with other treatments. In July 2023, the population of mango hoppers increased on leaves on new flushes. In T1, a sudden rise in population was observed (10-17.5). In T2, spray was done; hence, the population declined to 0.8. In T3, the population was lower (0.8-2.8). In T4, the population of mango hopper was low (1.5 -2.2), while in T5, the spray was done; hence the population decreased from 5.2 to 0.8. Similarly, in T8, the spray was done, which suddenly reduced the population to 0.8. In August 2023, the population of mango hoppers declined in T1 (17.3 to 9.1); however, in T2, the population was lower (0.6-1.5). In T3, a higher population (8.9-8.5) was observed compared to other treatments, although it was lower than the control (17.3-9.1).

In T4, T5, T6 and T7, the population was lower. In September 2023, the mango hopper population increased in T1 (9.5 to 10.5), while the population was lower in T2 (2-3.2) and T4 (3.5-5.1). T5 (2.1-2.5), T6 (3-0), T7 (2-2.8), T8 (2.2-0). In October 2023, the population of mango hoppers increased in T1 (11.2-13.1), while the population was negligible in T8. In November 2023, the population of mango hoppers decreased in control (15.1 to 10.5), while the population was negligible in T8 (0). In December 2023, the population of mango hoppers decreased in T1 (12.5 to 9.5), while the population was negligible in T8 (0). This might be due to winter spray in T8

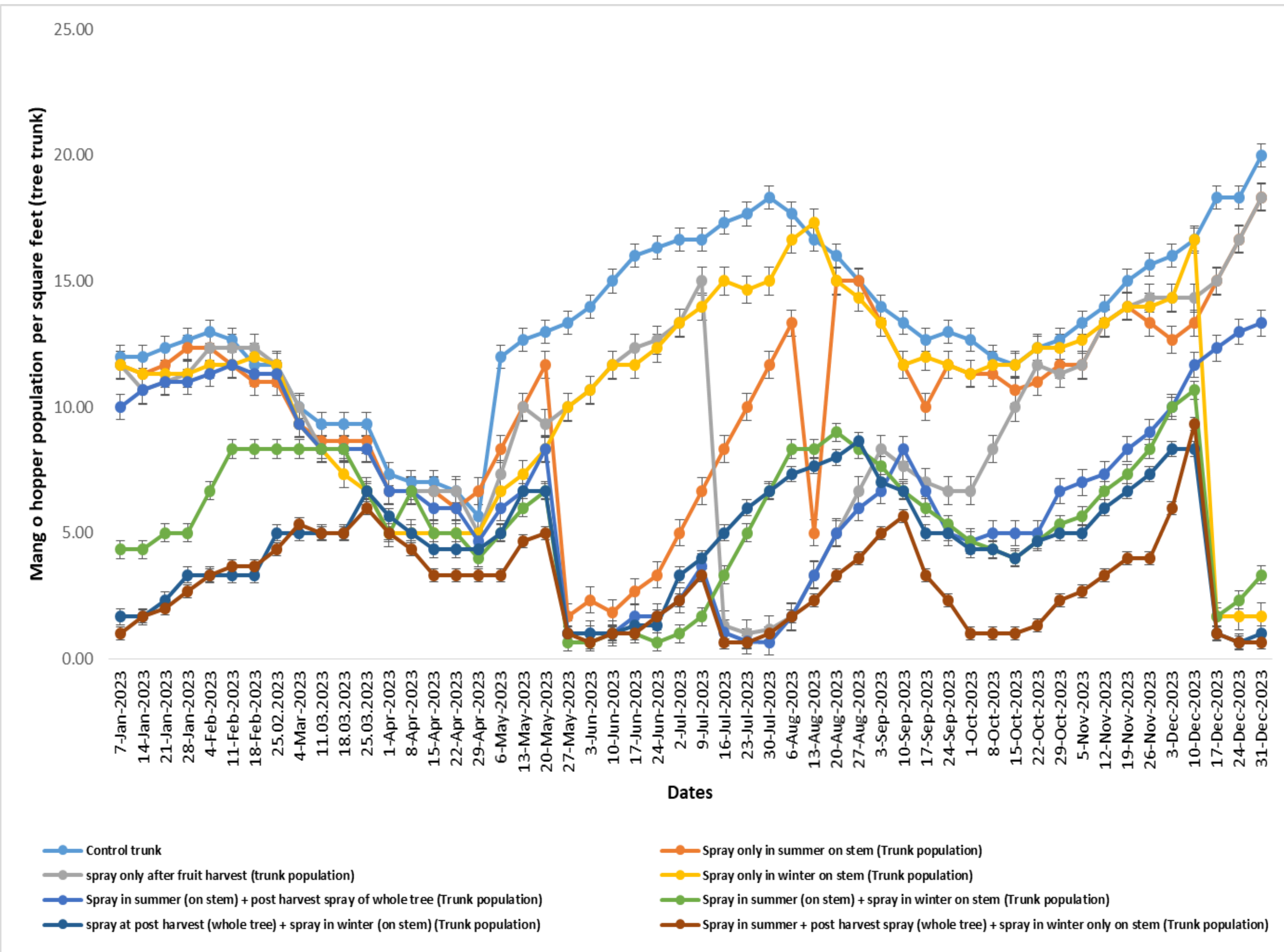

Figure 1: Population dynamics of mango hopper during 2023 on tree trunk. Here error bars represent standard error around mean.

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Average population of mango hopper on tree trunk and leaf surface throughout the year:

The one-way ANOVA analysis compared the population of mango hoppers on tree trunks per square foot throughout the year. A highly significant difference in pest population was observed (DF =7; F-value= 18.5; P <0.01) (Fig 3). The population of mango hopper was significantly higher in control (13.25 MH/ft^2), followed by T4 (10.75 MH/ft^2), T2 (10.5 MH/ft^2), T3 (9.5 MH/ft^2), T5 (6.75 MH/ft^2), T6 (5.5 MH/ft^2), T7 (4.75 MH/ft^2), and T8 (2.87 MH/ft^2).

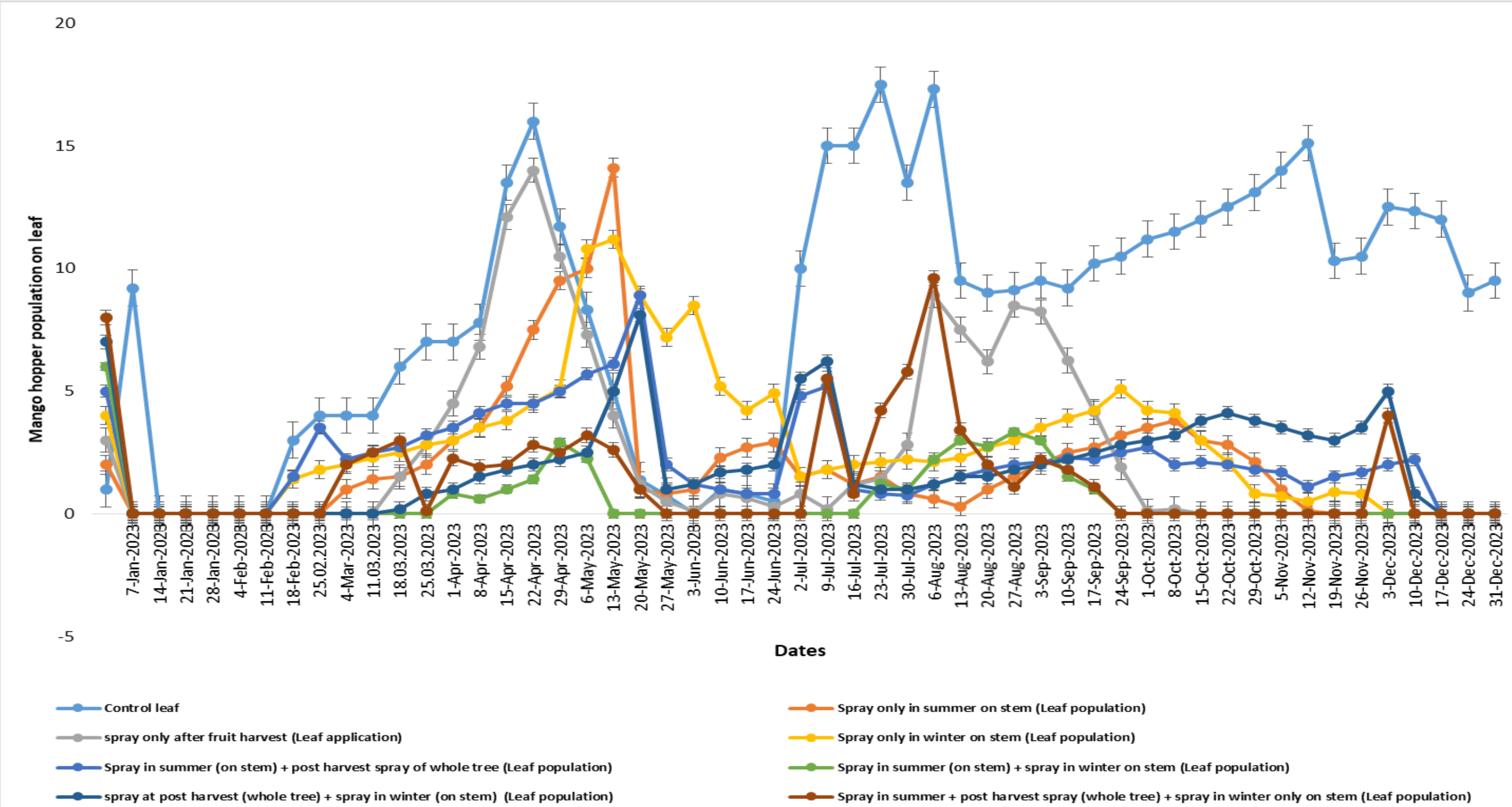

Figure 2. Population dynamics of mango hopper during 2023 on a leaf. Here error bars represent standard error around mean.

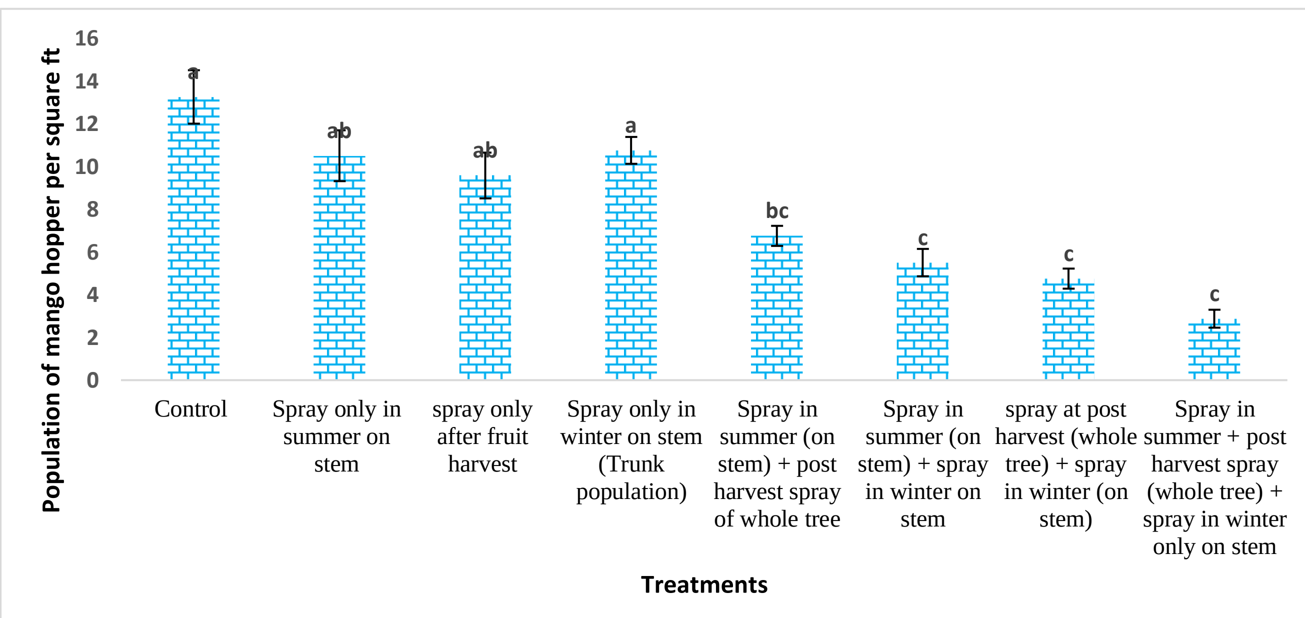

Figure 3: Comparison of hopper population on tree stem in all treatments. Here, the error bars represent the standard error around the mean. The letters represent the rank obtained through multiple pairwise comparisons through Tukey HSD at a 5% significance level.

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The one-way ANOVA analysis was done to compare the population of mango hoppers on leaf surfaces throughout the year. A significant difference in pest population was observed among treatments (DF =7; F-value = 22.63; P <0.01) (Fig 4). On the leaf surface, a higher population was observed in T1 (8.35 MH/leaf), followed by T4 (2.75 MH/leaf), T2 (2.5 MH/leaf), T2 (2.07 MH/leaf), T7 (1.92 MH/leaf), T6 (1.87 MH/leaf), T8 (1.37) and T8 (0.52 MH/leaf).

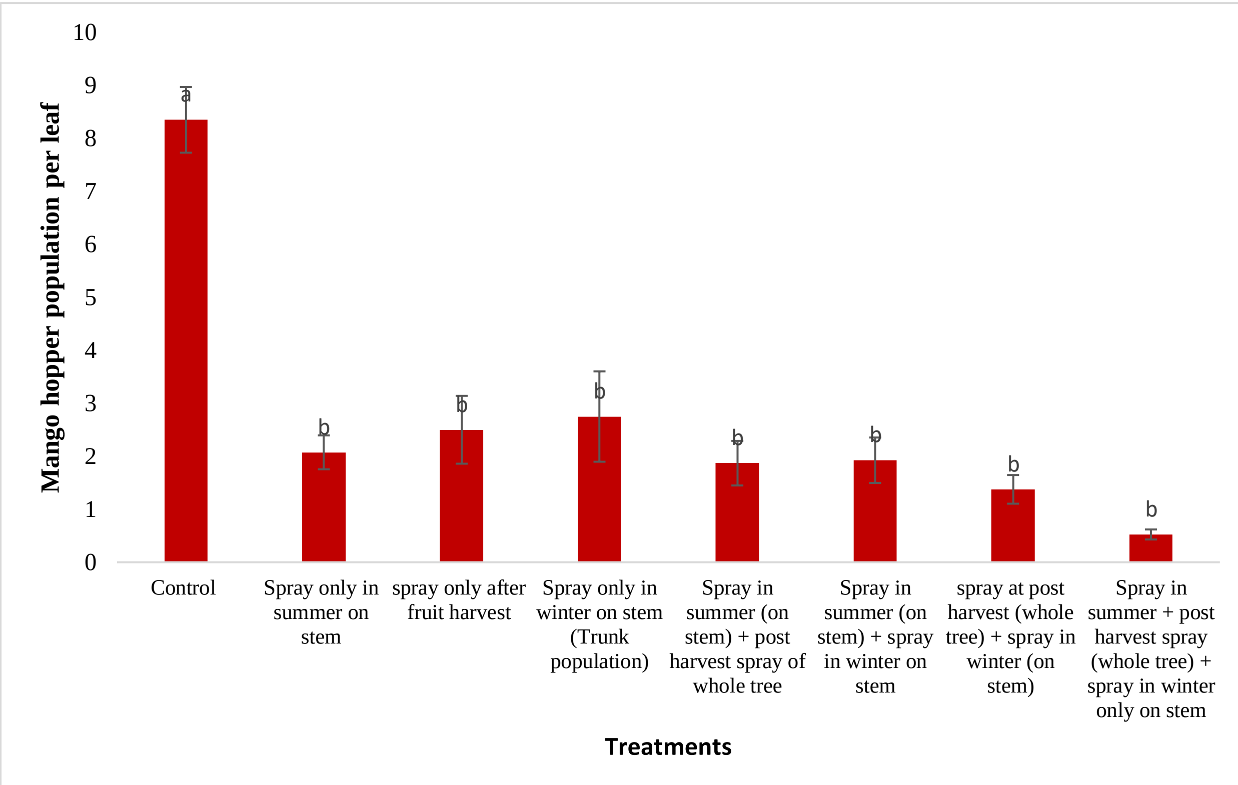

Figure 4: Comparison of Mango hopper population on a leaf through ANOVA analysis. Here, the error bars represent the standard error around the mean. The letters represent the rank obtained through multiple pairwise comparisons through Tukey HSD at a 5% significance level.

Population dynamics of mango hopper at different times of the day observed during 2023-2024 on tree trunks and leaves:

In July 2023, the population of mango hopper was higher (10-16 MH/leaf) on leaves at 8:00 am, while in the mid-day, the population was lower (0.8-1.0 MH/leaf) while at 6:00 PM, the population was again higher on the leaves (9-13.8 MH/leaf) (Fig 5). On the tree trunk at the same time, the population of mango hopper was higher at 1:00 PM (9-20 MH/ft^2), while the population was lower in the morning (1-2 MH/ft^2) and evening (0.8-1 MH/ft^2).

In August 2023, the population of mango hoppers was higher in the morning (16.2-18 MH/leaf). Similarly, the population of mango hoppers was higher in the evening (14.5-16.1 MH/leaf), while the population was lower in the day (1.8-0.5 MH/leaf). On tree trunks again, the population was higher mid-day (1:00 PM). The average population of mango hoppers ranged from (18.1-16 MH/ft2) in August, while the population of mango hoppers ranged from 2.0-5.0 and 1-3.0 in the morning and evening on the trunk in the same month.

In September 2023, the population of mango hopper was again higher on leaves in the morning (15-17.2 MH/leaf), while the population was lower in the mid-day (1:00 PM). The population of mango hoppers was lower on tree trunks in the morning (3.2-3.5 MH/ft^2). Similarly, the population of mango hoppers was lower in the evening on tree trunks (4.1-3.2 MH/ft2), while the population of mango hoppers was higher in the mid-day (1:00 PM) on tree trunks (16.2-15.7 MH/stem).

In October 2023, the population of mango hoppers was higher in the morning on leaves (10.9-6.8 MH/leaf), although the population of mango hoppers slowly declined. Around 16 hoppers per leaf were present in July, but this decreased to 6.8 in October. Similarly, in the evening, the population of mango hoppers was higher (16-6.8 MH/leaf) than the mid-day population (0.7-2.3 MH/leaf). On tree trunks, the population was higher during a mid day (18.0-17.3 MH/ft2), while in the morning and evening, the population of amino hopper was lower (1.2-1.8 MH/ft^2) and (2.1-2.3 MH/ft^2) respectively.

In November 2023, the population of mangoes further declined on leaves (5.2-3.2 MH/leaf). Although the population of mango hopper was slightly higher in the morning and evening (5.2-3.2 MH/leaf) and (5.1-5.2 MH/leaf) respectively. Meanwhile, the population of mango hoppers in the midday on leaves was slightly lower (2.5-4.2

MH/leaf). On tree trunks, the population declined at mid-day (18.21-8.7 MH/ft^2).

In December 2023, the population of mango hoppers declined to zero on leaves in the morning and evening, while the population was visible in the midday on leaves (2-3 MH/leaf). On tree trunks, the population in the midday declined to 2 hoppers, while 2.8-2.2 mango hoppers were visible in the morning and evening, respectively.

In January 2024, the mango hopper population on leaves was negligible in the morning and evening, while in the mid-day, 5-7 mango hoppers per leaf were recorded. Similarly, on tree trunks, the mango hopper population was higher (1.8-1.0 MH/ft2) in the morning and evening, while the population was zero in the mid-day.

In February 2024, the mango hopper population was lower, with almost zero mango hoppers in the morning and evening, while 7-9 mango hoppers were observed on leaves during the mid-day. On tree trunks (1-2 MH/ft^2) were visible in the morning. About 1-3 hoppers were present in the evening, while no hopper was observed mid-day. In February 2024, the population of mango hoppers was negligible in the morning and evening on leaves, while in the mid-day, the population was higher (7.0-9.0 MH/leaf) on tree trunks. On tree trunks, the hopper population was negligible in the mid-day and higher in the morning (1-2.5 MH/ft^2)) and evening (1-3 MH/ft^2).

In March 2024, the population of mango hopper was higher on the canopy in the mid-day (7-15 MH/leaf), while a lower population was observed in the morning (0-2.3 MH/leaf) and evening (0-3 MH/leaf). Similarly, on tree trunks, the population was visible in the morning (2-2.8 MH/ft2), mid-day (3-4 MH/ft^2) and evening (1.8-2.0 MH/ft^2).

In April 2024, the population of mango hoppers precedently increased in the morning (2.3-3.5 MH/leaf) and evening (2.2-3.3 MH/leaf), while the population was negligible on leaves in the mid-day. On tree trunks, the population of mango hopper increased rapidly (3-4.5 MH/ft2) in the mid-day, while a slightly lower population was observed in the morning (1-1.5 MH/ft^2) and evening (1-2.3 MH/ft^2).

In May and June 2024, the higher population gain was observed in the morning and evening on leaves (3.7-5.0 MH/leaf) and (0-2 MH/leaf), while the lower population was observed in the mid-day (0-2 MH/leaf). A higher population of mango hoppers was observed on tree trunks in the mid-day (2.9-7.5 MH/ft^2). The lower population was observed in the morning and evening on tree trunks 1.9-4.28 MH/ft^2 and 1.8-2.8 MH/ft^2 respectively.

Effect of timings on the average population of mango hoppers throughout the year:

The split-plot ANOVA analysis was done to determine the effect of time and site on the average population of mango hoppers (Fig 6). Overall, a significant impact of the site was observed (DF=3; F=11.21; p=0.04) and time of the day significantly affected the hopper population (DF=2; F=140.72; p=0.00). The interaction effect was highly significant (DF=2; F=60.52; p=0.0).

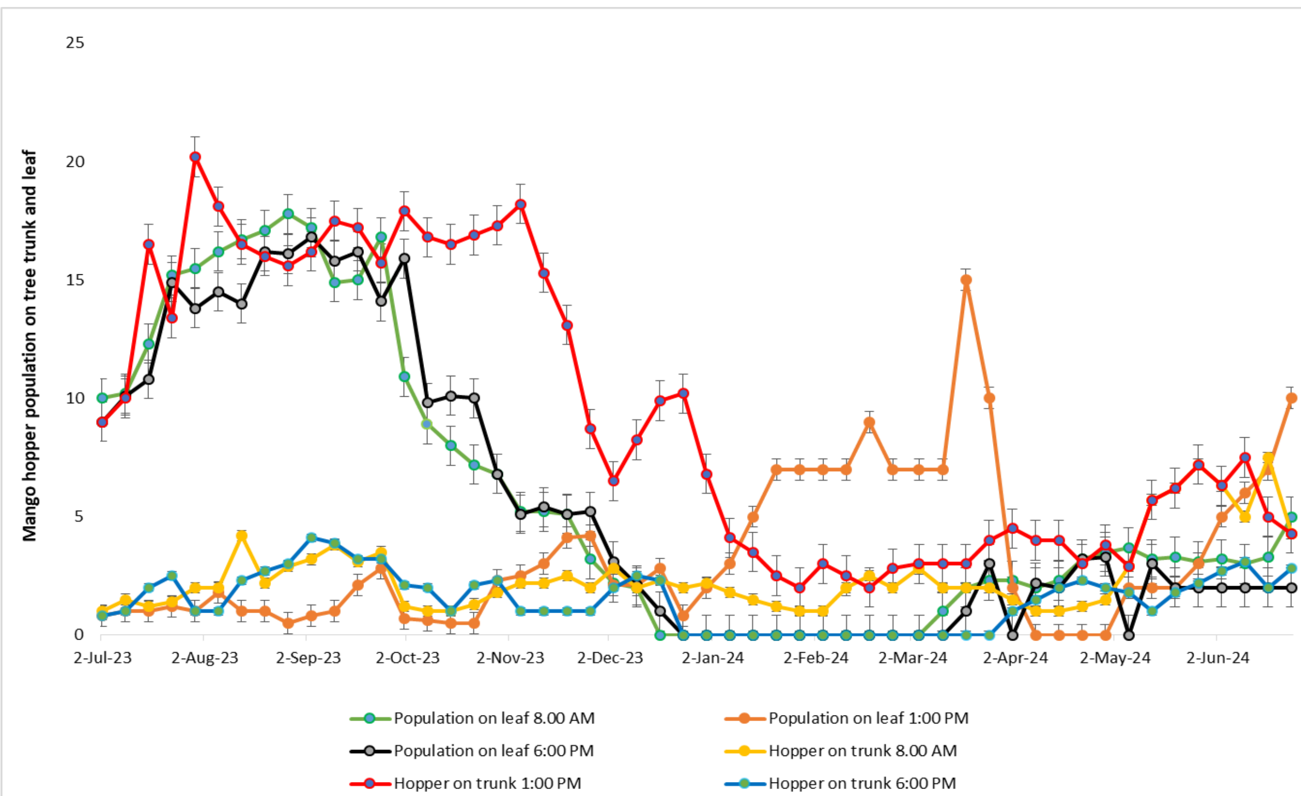

Figure 5. Population dynamics of mango hopper in different times of the day observed during 2023-2024 on tree trunks and leaves. Here error bars represent standard error around mean.

[Citation Hameed, A., Khan, A.H., Rehman, A.U., Muhammad, N., Iqbal, A., Mustafa, G., Ahmad, M., Hussain, R., Khizar, M., Bibi, F., Hussain, M., Imran, M., (2024). A pollinator friendly, cost effective, mango hopper management strategy developed based upon pest behavior. *Biol. Clin. Sci. Res. J.,* **2024***: 1112*. doi: https://doi.org/10.54112/bcsrj.v2024i1.1112]

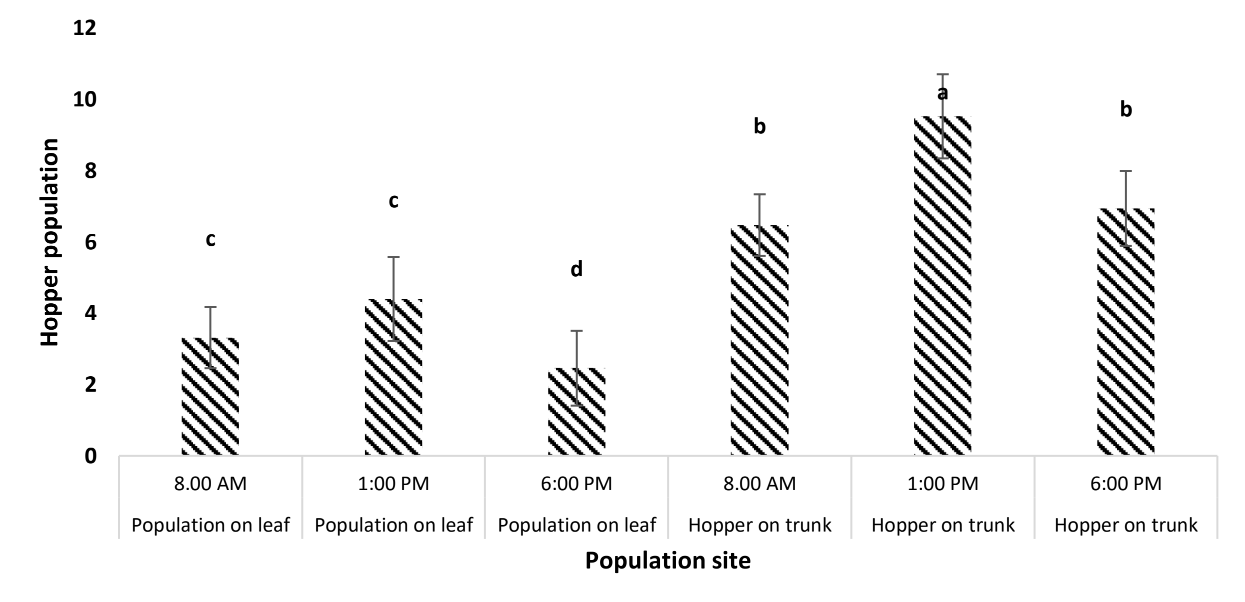

Figure 6: Effect of site location and timings on average population of mango hopper during 2023-2024 in control plots.

Effect of spray applications on the average population of pollinators:

The one-way ANOVA analysis through randomized complete block design was done to determine effect of treatments on the pollinator population . Overall, no significant difference in the pollinator population was observed among treatments (DF=7; F=2.01; $p > 0.05$) (Fig 7). Although a higher pollinator population was observed in control trees (4.80) followed by trees on which spray was done only in summer (4.637), trees on which spray was done only in winter (4.41), spray was done (4.05), trees on which spray was done after fruit harvest (whole tree spray) (3.98), spray was done only in summer on stem and whole tree spray after fruit harvest was done (3.16), trees sprayed in summer, after post harvest and winter sprayed (2.95) and trees where the spray was done after harvest, winter sprayed on tree trunks only (2.61).

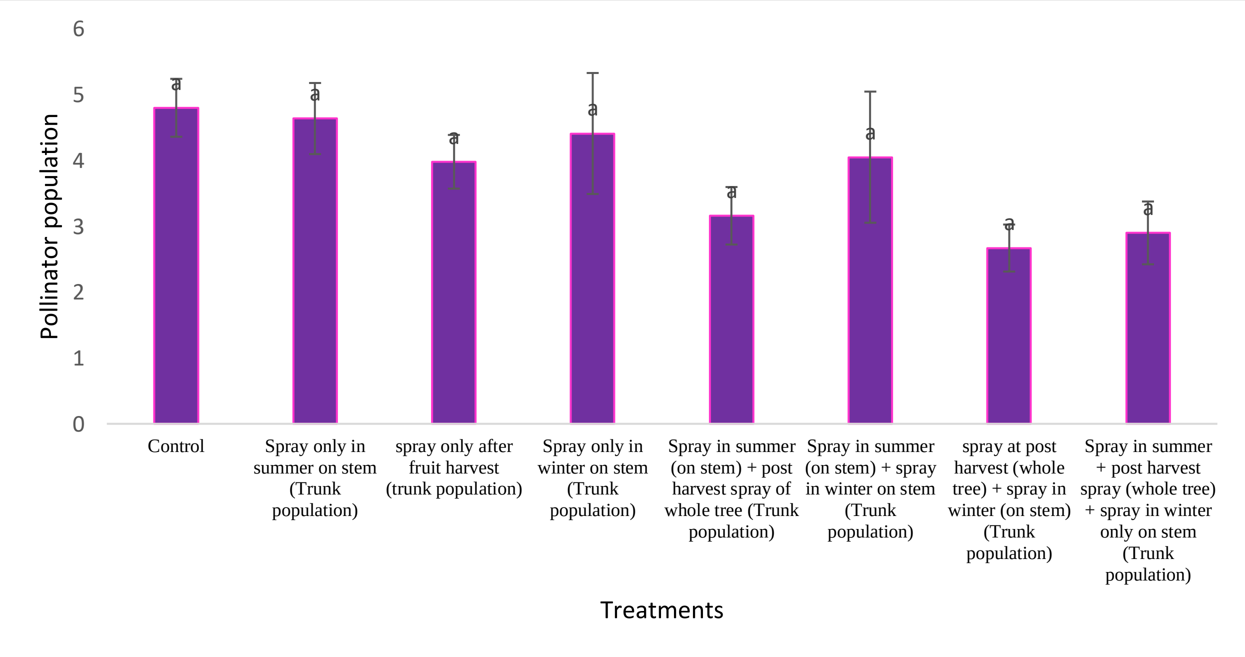

Figure 7: Effect of treatment application on pollinator population during 2024.

[Citation Hameed, A., Khan, A.H., Rehman, A.U., Muhammad, N., Iqbal, A., Mustafa, G., Ahmad, M., Hussain, R., Khizar, M., Bibi, F., Hussain, M., Imran, M., (2024). A pollinator friendly, cost effective, mango hopper management strategy developed based upon pest behavior. *Biol. Clin. Sci. Res. J.*, **2024***: 1112*. doi: https://doi.org/10.54112/bcsrj.v2024i1.1112]

Effect of spray applications on the population dynamics of pollinators during the flowering season:
The higher population of pollinator was observed in control trees. In the second last week of February 2024, almost the population of pollinators was same in all treatments except where the whole tree spray was done (Fig 8). The population of pollinators increased slowly and reached at peak in last week of March 2024. Finally the population declined in the mid-April as the fruit setting was complete.

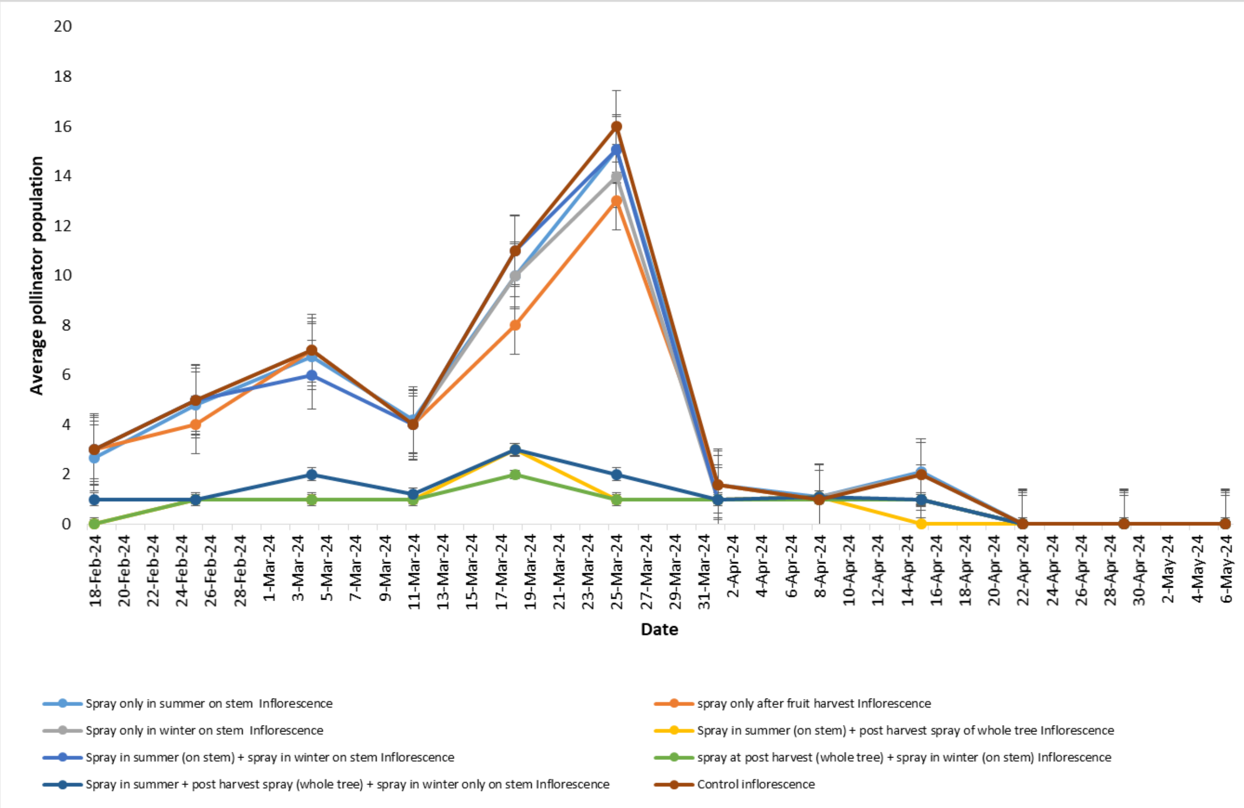

Figure 8. Population of pollinators during 2023-2024 on inflorescence. Here error bars represent standard error around mean.

Cost benefit ration of management strategy:
The cost benefit ration of management strategy was calculated through farmer interviews (table 2). Higher farmer net income was obtained in T8 while lower profit was obtained in T1.

Table 2: Cost Benefit ratio of management strategy

Treatment	Cost of insecticide (PKR)	Farmer Yield (Monds/acre)	Operational cost	Farmer Gross income	Farmer net income
T1	0	100	50,000	400000	350,000
T2	2700	128	50,000	512000	459,300
T3	4605	137	50,000	548000	493,395
T4	4920	145	50,000	580000	525,080
T5	7305	140	50,000	560000	502,695
T6	7620	205	50,000	820000	762,380
T7	9525	212	50,000	848000	788,475
T8	12225	237	50,000	948000	885,775

Discussion

In the present studies, the effect of niche targeted spray on mango hopper population was evaluated. Population dynamics of the mango hopper during different times of the day throughout the year was also studied. The effect of treatments on pollinator population was determined. Cost benefit ratio of management strategy suggests that three sprays enhance the fruit quality and overall farmer income. In the present studies we conclude that three sprays (summer on tree trunk, winter on stem in morning or evening and whole tree spray after harvest) is required to keep the population of mango hopper below threshold. We found that one spray in winter during December, on stem in morning or evening would reduce the pest overwintering population and reduce the pest numbers on new crop.

In Bangladesh, an experiment was conducted to determine the impact of insecticides and botanical extracts on hopper population (Adnan, Uddin, Alam, Islam, Kashem, Rafii & Latif, 2014). It was found that imidacloprid was highly effective in controlling hopper population while the cypermethrin was equally toxic to neem seed extract. Although in India, range of botanical insecticides and entomopathogens are used to control hopper population(Chaudhari, Sridharan & Sundar Singh, 2017), however in Pakistan only insecticides are used to control the pest population. The use of newer biopesticides like entomopathogens may reduce the environmental effects on beneficial fauna and decrease the insecticide resistance development among hoppers.

Seasonal population dynamics of mango hopper in subtropics was studied by Gundappa and Shukla (2016). They found that population of hopper developed rapidly between 10^{th} to 22^{nd} week of year, which is around mid-February to mid June. Our results were similar to Gundappa and Shukla (2016). We found that mango hopper population developed rapidly after the panicle formation which was similar to Gundappa and Shukla (2016).

In the present studies we report that mango hopper were abundant on tree trunks during the summer and hibernates in winter on tree trunk in cracks and crevices. Our results were similar to Talpur, Khuhro and Nizamani (2002), who reported that on mango crop the population of hopper has two peaks one in the spring when the panicle formation initiates and second after fruit harvest on the new leaves. Our results were also similar to (Anant, 2016) who determined the population of mango hopper hibernates in winter and reaches at peak during the spring and August.

Conclusion

Overall, we conclude that three sprays are required for mango hopper population management to ensure qualitative and quantitative mango production.

Declarations

Data Availability statement
All data generated or analyzed during the study are included in the manuscript.

Ethics approval and consent to participate
Approved by the department Concerned.

Consent for publication
Approved

Funding
Not applicable

Conflict of interest

Author contribution

All authors contributed equally

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