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THE IMPACT OF *PTEROPUS MEDIUS* ON GUAVA (*PSIDIUM GUAJAVA*) ORCHARD: EXAMINING DAMAGE AND MANAGEMENT STRATEGIES

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ABSTRACT

The present study was conducted in district Kasur, Pakistan to assess the guava fruit damage by *Pteropus medius* during summer and winter fruit ripening seasons in 2023-24. Artificial LED (AL) lights of 12W and 30W were used as a management strategy. Damage guava fruits by bats were collected for thirty days during both ripening seasons of guava (*Psidium gujava)* from three randomly selected acres in orchard, with and without artificial lights. After counting and weighing the collected damaged fruits, economic loss was calculated. The data indicated that on daily basis (WADF) of 1.97 ± 0.17 kg per acre ($p < 0.0001$) of actual fruit damage was observed in the winter season, while summer season faced 1.27 ± 0.09 kg per acre ($p < 0.0001$). Seasonal yield loss of 2.6% in summer and 16.14% in winter was estimated. The use of 12W and 30W LED lights as management strategy significantly reduced the fruit damage and economic losses. During winter season, 30WAL and 12WAL showed reduced damaged fruit per acre (0.36 ± 0.03 kg and 0.59 ± 0.05, respectively) as compared to orchard (4.97 ± 0.17 kg) with no artificial light (NAL). The yield loss (%) was significantly lower when the orchard was exposed to LED lights. The lowest yield loss was recorded with 30WALs during both summer (0.13 ± 0.01%) and winter (0.17 ± 0.01%) as compared to yield loss (1.30 ± 0.04%) in summer and (2.32 ± 0.08%) in winter with no artificial lights (NAL). The initial cost of light installation was considerable but the reduction in fruit loss made it economically worthwhile. In terms of cost-effectiveness, the 12WAL lights provided a higher return on investment, with a noteworthy positive net economic return during the winter season. It can be concluded that the installation of artificial lights is a practical and effective solution to manage bats related damage in guava orchards. The 12W AL lights offer a good balance between cost and effectiveness, making them a smart choice for orchard owners looking to minimize damage and maximize their profits without harming the bat population.

Keywords: Artificial Lights, Indian Flying Fox, *Pteropus medius*, Fruit damage, Conservation.

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INTRODUCTION

Fruit orchards play a dynamic role in agriculture across tropical and subtropical regions, where they provide humans with food and support local economies. Mangoes, guavas and bananas orchards play an important role in the export economies of many countries like Pakistan, India and Bangladesh (McEvoy *et al.,* 2021). Fruit orchards face many challenges from wildlife, especially due to fruit bats. One of the most important bat species in this respect is the Indian flying fox, *Pteropus medius*, weighing more than 1.6kg and having a wingspan that can reach up to 1.5m (Mahmood-ul-Hassan, 2009). These animals travel up to several kilometers each night in search of food and play a crucial role in pollination and seed dispersers of over 110 plant species (Wordley *et al.,* 2014; Gulraiz *et al.,* 2016; Ahmed *et al.,* 2023).

Pakistan is inhabited by four fruit-eating bats species including the Indian Flying Fox (*Pteropus medius*), short-nosed fruit bat (*Cynopterus sphinx*), Koler's fruit bat (*Rousettus leschenaultii*) and Egyptian fruit bat (*Rousettus aegyptiacus*) (Roberts and Bernhard, 1977; Mahmood-ul-Hassan *et al.,* 2009). Fruit bats play an important role in tropical and subtropical regions by pollinating plants and spreading seeds which helps keep ecosystems and farms healthy (Aziz *et al.,* 2016; Suripto, 2021). However, certain species like the Indian flying fox also feed on valuable fruits, resulting in profit loss for local farmers. In Pakistan, fruit farming is a large component of the economy as agriculture makes up around 23.7% of the country's GDP. This sector supports about 45% of the workforce with most workers living in rural areas (Fahad and Wang, 2020; Statista, 2024).

As farming practices expand into natural habitats and urban development closes in on traditional roosting areas, interactions between bats and fruit crops is becoming more frequent. Human-wildlife conflict intensifies in area where farming dominates and forests are shrinking. In Punjab, where guava is a major crop, farmers have reported losses due to *P. medius* feeding on guava fruit (Chakravarthy and Girish, 2003). According to the Crop Reporting Service, Punjab (2021), guava orchards cover about 55694 acres of area in Punjab. Studies from other countries such as Oleksy *et al.,* (2021) on the Mauritian flying fox (*Pteropus niger*) and Singh (2023) on the Indian flying fox (*Pteropus medius*) in *Litchi* orchards showed that fruit bats can damage fruits and have significant impact on fruit production. The human-wildlife conflict between bats and agriculture highlights the need for solutions that protect both bat populations and farmers' livelihoods (Kasso and Balakrishnan, 2013; Aziz *et al.,* 2017). Farmers around the globe have tried many ways to reduce crop damage by bats such as, netting around the fruit orchards or trees, culling of bats, loud sounds and chemicals. For example, netting has been reported as preventive measure to protect *Litchi* orchards in Madagascar (Tollington *et al.,* 2019). However, netting can be costly and is not always practical on larger orchards as well as potentially deadly for bats (Charerntantanakul *el al.,* 2023). Culling of bats will not increase the fruit production rather it endanger the bats (Florens and Baider, 2019). Many alternatives, such as artificial lights, have been reported to reduce the damage cause by bats without harming them (Singh, 2023). The use of artificial LED lights does not require labor-intensive activities on a daily basis and offers a more sustainable solution compared to other strategies like culling or netting. Moreover, artificial lights can be easily installed to an extensive range of orchard sizes and can be adapted to meet the specific needs of different fruit crops. Use of LED lights is an ecofriendly approach for protecting fruit crops across various agricultural settings with killing or destroying bat habitats and offering both efficiency and long-term effectiveness in reducing bat-related damage.

In district Kasur guava orchards cover an area of 2673 acres, producing substantial yields (Crop Reporting Service, Punjab 2021). However, these orchards are facing problems due to fruit predation by *P. medius*. There is a clear need to understand the economic impact of this damage and explore affordable and effective ways to protect both the crops and bats habitats. The aim of the present study was to address the existing research gap by assessing the level of damage caused by *Pteropus medius* to guava orchards and exploring sustainable, cost-effective methods to mitigate their negative impact on *Psidium guajava* production. One potential solution considered is the use of LED lights, which are known to deter fruit bats by exploiting their sensitivity to certain light frequencies, without harming the bats or destroying their roosting sites. This approach seeks to protect crops while conserving the *Pteropus medius* population by avoiding harmful practices such as killing the bats or disrupting their natural habitats.

MATERIALS AND METHODS

Study area: The present study was conducted on selected guava (*Psidium guajava*) orchard in district Kasur, Pakistan to evaluate the potential impact and damage caused by fruit bats (Indian Flying Fox - *Pteropus medius)* on fruit orchards during the fruit ripening seasons of year 2023 and 2024. Figure 1 shows the study area with GPS pin locations of selected fruit orchard and the nearest roosting sites of *Pteropus medius*. The distance between fruit trees and the total number of trees planted in one acre were noted. The selected fruit orchard was 5 years old and various other fruit orchards like mango (*Mangifera indica*), black mulberry (*Morus nigra*), malabar plum (*Syzygium cumini*), Indian plum (*Ziziphus mauritiana*), peach (*Prunus persica*), pear (*Pyrus communis*) and crop fields were present within 15km radius. The presence of other fruits were also foraging habitats for bats but not controlled by the current study, which is acknowledged as limitation. During each season, three random plots of one acre were selected in the middle of the orchard with equal number of fruit trees to maintain uniformity in treatments and to avoid from edge effect. Selected acres were not overlapping with each other to minimize lighting interference. These three plots represented each treatment: No Artificial Light-NAL (Control), 12W LED light treatment and 30W LED light treatment. Moreover, to reduce temporal bias all treatments were conducted simultaneously to ensure fruiting stage, weather and other factors remained comparable. Manual and herbicide methods were used to remove weeds under the trees in all selected plots. On a daily basis for 30 days, each plot was observed and damaged fruits were collected by observing each tree carefully early in the morning (Figure 2).

Assessment of damage caused by *Pteropus medius* in guava (*Psidium guajava*) orchard: To estimate fruit damage, two different fruiting seasons, summer and winter were observed for 30 days (1 month). Both fruit seasons are different in their fruiting period, summer fruit season stays for 2 months (July-August), while winter fruit season for 7 months (October to April). We observed damaged fruits by bats and calculated daily yield and economic loss for consecutive 30 days in all treatments. Later, we estimated monthly yield and economic loss. To calculate overall fruit loss and to compare the impact on fruit damage during summer and winter ripening seasons, we multiply the yield and economic loss of summer with 2 while winter with 7 according to their fruiting period. Variation in the period of fruit seasons is due to variations in temperature. Cooler temperatures during the winter contribute to slower fruit maturation, which stretches the season out, while during summer matures quickly due to the higher temperatures, thus leading to a shorter harvest season (Fischer and Melgarejo, 2021). All the damaged fruit by bats were collected from each plot. After counting, their weight was measured using a weighing balance. The weight of actual damage was calculated by first determining the number and weight of healthy fruits per kilogram (10-12 Guavas/Kg). That value was then multiplied by the number of damaged fruits from each plot separately. At the end of harvesting of fruits by workers from one acre for fruit markets, we weighed and recorded as yield per acre separately. Exclusion was made for damage caused by birds and other predators. Damage to fruits by bats is distinguishable from bird damage due to teeth marks of bats and consuming fruit juice and spitting out seeds and peel (Figure 2) (Raharimihaja *et al.,* 2016; Tollington *et al.,* 2019; Ali *et al.,* 2023). Total economic loss was calculated by the actual fruit damage to the price of guava fruit according to the rate list by the government office in the Division of Lahore-Punjab, Pakistan, during 2023-24. The percentage of damaged fruit and seasonal fruit loss (yield loss) was calculated by using the following formulas (Ali *et al.,* 2023).

$$\text{Damaged fruit (\%)} = \frac{\text{Weight of fruits damaged per acre}}{\text{Fruit yield per acre}} X\ 100$$

$$\text{Seasonal yield loss (\%)} = \frac{\text{Estimated weight of damaged fruits over season per acre}}{\text{Estimated Fruit yield over season per acre}} X\ 100$$

Management of *Pteropus medius* in fruit orchard using artificial light: Bats tend to avoid artificial lighting at night (ALAN) as reported by (Murugavel *et al.,* 2023). To examine the effect of artificial lights, white light was generated in the orchard using light-emitting diode (LED) lights of Factor Co. Ltd. Different wattages LED lights such as 12 and 30 watts were employed in each treatment. LED lights produce more white light and consume less electricity than incandescent or fluorescent lights but with variations in power of LED lights (i.e; 12W and 30W) the consumption of electricity was different (Table 2). During each fruit ripening season, 16 LED lights of 12W and 30W were positioned 50 feet apart and 5 feet above the center of the tree canopy in their relevant plot of one acre selected in guava fruit orchard. Long bamboo sticks (about one inch in diameter) was used to position the lights to cover the full tree canopy and adjacent trees facing downward. Electricity for the LED lights was sourced from nearby WAPDA (Water and Power Development Authority-Pakistan) power lines. The wires used were 1 mm thick and sufficient to handle the electricity load of the LED lights. Observations were conducted at night for 30 consecutive days to monitor if bats caused fruit damage on fruit trees and to ensure proper lighting conditions and any fused LED light was replaced instantly. The expenses related to installing LED lights, light (Bulb) holders, electric wires, switches and electricity consumption were calculated per acre on daily basis for one month (30 days). This data was used to analyze the effectiveness of this technique.

Net economic return calculation: Net economic returns (economic benefits) from a single acre of guava fruit orchard with LED lights was calculated by using the following formula for each treatment separately;

$$\begin{aligned}\text{Net Economic Return} &= (\text{Actual economic fruit loss without lights}) \\ &- (\text{Total expenditure for installation artificial lights} \\ &+ \text{Actual economic fruit loss on using artificial lights})\end{aligned}$$

Statistical analysis: Collected data were analyzed through factorial (2×3) ANOVA using PROC GLM in SAS software (version 9.1) considering fruit season and light as main effects and their interaction were tested, too. For the comparison of significant treatment means Duncan's Multiple Range test was applied considering $p \leq 0.05$.

RESULTS

The present study evaluated the damage caused by Indian Flying Foxes (*Pteropus medius)* in guava orchard across different season, on natural (without artificial lights) and lighting conditions. The results revealed the significant differences in fruit damage, yield losses and economic losses across two different seasons and conditions. One of the largest guava fruit orchards was selected in district Kasur (31° 7'45.73"N, 73°52'29.12"E), Punjab-Pakistan. Field surveys of three selected plots as, No Artificial Light- NAL (Control), 12W LED light treatment and 30W LED light treatment, were done for 30 days (1 month) on a daily basis and data regarding damaged fruits were noted on a logbook during each season separately for each plot.

Impact and estimation of fruit damage in guava (*Psidium guajava*) orchard: Table 1 summarizes the detailed assessment of damage caused by *P. medius* in selected plots of guava fruit orchard during both summer and winter seasons with all treatments. The statistical analysis revealed that daily total damage fruit per acre (TDF) caused in the winter season is significantly higher and more economic losses as compared to summer, when there were no artificial lights. Control group with no artificial lights, during the winter fruit season orchard faced a TDF of 13.81 ± 1.18 kg ($p < 0.0001$) and a monthly economic fruit loss (MEFL) of Rs. 5924.13 ±

506.64. Similarly, during the fruit ripening season in summer orchard had a daily total damage fruit (Kg) of 8.91 ± 0.65 ($p < 0.0001$) and a monthly economic loss of Rs. 3804.35 ± 280.88. During winter, the estimated weight of actual damaged fruit per acre (WADF) was recorded at 3.96 ± 0.13 kg per acre as compared to summer at 2.94 ± 0.08 kg (Table 1). During winter season it was noted that the absence of other fruits such as *Syzygium cumini, Morus alba, Litchi chinensis* and *Mangifera indica* around the study area within 15km. The winter months therefore resulted in more frequent and severe damage leading to a higher overall economic loss compared to summer season in absence of LED lights (Table 1). In addition, during the field surveys we also observed that more damage was on the taller trees with an average height 12 to 15 ft and more space between consecutive lines of fruit trees as compare to shorter trees (8 to 10 ft) and less space between trees in orchard.

Management of *Pteropus medius* in guava (*Psidium guajava*) orchard using LED artificial light method: The results from the treatment plots for the management of *P. medius* in guava fruit orchard using LED artificial light shown significant reduction in damage and economic losses when compared to orchard with no artificial light (NAL). The table 1 showing the data collected during the experimental period on the effectiveness of 12 Watt and 30 Watt artificial LED lights. The total damage fruits per acre (TDF) was lower in the plots exposed to LED lights, in winter 30WAL shown 2.55 ± 0.22 and 12WAL 4.10 ± 0.32 per acre as compared to no artificial light (NAL) which had 34.77 ± 1.16 damaged fruits per acre. Similarly, the weight of damaged fruit per acre (WDF) was significantly reduced (0.14 ± 0.01 kg) in winter with 30WAL and (0.20 ± 0.02 kg) as compared no artificial light (NAL) which had 2.09 ± 0.07 kg. The estimated weight of actual damaged fruit per acre (WADF) also followed the same pattern with winter 30WAL shown 0.36 ± 0.03 kg and 0.59 ± 0.05 with 12WAL, in contrast to 4.97 ± 0.17 kg with NAL (Table 1).

Similarly, yield loss (%) was significantly lower when orchard was exposed to LED lights. During winter 30WAL shown 0.17 ± 0.01% and 12WAL shown 0.27 ± 0.02% yield loss as compared to 2.32 ± 0.08% yield loss with NAL. This resulted in substantial reduction in economic losses. The daily economic fruit loss per acre (DEFL) was lower (Rs. 36.21 ± 3.14) in winter with 30WAL and (Rs. 59.04 ± 4.68) with 12WAL as compared to Rs. 497.16 ± 16.62 with NAL. Furthermore, monthly economic fruit loss per acre (MEFL) was significantly reduced in winter using 30WAL (Rs. 1086.30 ± 94.13) and 12WAL (Rs. 1771.20 ± 140.30) as compared Rs. 14914.90 ± 498.65 with NAL (Table 1).

Moreover, the reduction in fruit damage was also recorded when LED lights were installed in selected plots of orchard during summer. In summer 30WAL shown 2.02 ± 0.17 damaged fruits per acre, while 12WAL shown 4.13 ± 0.25 as compared to no artificial light (NAL) which had 20.57 ± 0.54 damaged fruits per acre. Correspondingly, the weight of damaged fruit per acre (WDF) was significantly reduced (1.06 ± 0.09 kg) with 30WAL and (0.20 ± 0.01) with 12WAL as compared with no artificial light (NAL) which had 1.02 ± 0.03 kg in summer. The estimated weight of actual damaged fruit per acre (WADF) during summer also followed the same pattern shown with 30WAL (0.27 ± 0.02 kg), 12WAL (0.59 ± 0.04 kg) in contrast to 2.94 ± 0.08 kg with NAL.

Similarly, yield loss (%) was significantly lower when orchard was exposed to LED lights during summer, 30WAL shown 0.15 ± 0.01% yield loss as compared to 0.27 ± 0.01% with 12WAL and 1.81 ± 0.06% yield loss with NAL. This resulted in a substantial reduction in economic losses in the summer fruit season. The daily economic fruit loss per acre (DEFL) was lower to (Rs. 21.72 ± 1.97) with 30WAL and (Rs. 59.07 ± 2.94) in presence of 12WAL as compared to Rs. 395.63 ± 13.03 with NAL. Furthermore, monthly economic fruit loss per acre (MEFL) was significantly reduced in summer using 30WAL (Rs. 951.53 ± 59.24) and 12WAL (Rs. 1772.20 ± 88.24) as compared Rs. 11869.00 ± 390.97 with NAL (Table 1).

After calculating yield loss for two months of summer and seven months of winter fruiting season, yield loss of 2.6% in summer and 16.14% in winter recorded from acre without artificial lights. One acre plot with 12WAL faces 0.5% yield loss in summer and 1.85% in winter. In contrast, plot with 30WAL calculated 0.5% and 1.17% yield loss in summer and winter respectively.

Net economic returns on installing artificial lights: The statistical analysis revealed that both seasonal variation and light management play a vital role in determining the extent of damage caused by *P. medius* as well as the associated economic impact on guava orchard. Table 2 summarizes the details on expenses and net economic return for installation of 12W and 30W LED lights. The total expenditure for installation includes the cost of materials such as bamboo sticks, electric wires, electric switches and the LED lights as well as the electricity costs for running the LED lights.

The seasonal expenditure for 12W LED lights was 11120 PKR in summer and 15920 PKR in winter while for 30W LED lights, the seasonal expenditure was 14200 PKR in summer and 24700 PKR in winter (Table 2). The net economic return after the installation of 12W and 30W LED lights showed mixed results. The monthly net economic return was negative in summer (-3110.2 PKR) but positive in winter (2979.6 PKR) for 12W LED lights. The seasonal net economic return was positive in both seasons with 2983.7 PKR in summer and 76085.9

PKR in winter. The monthly net economic return was also negative in summer (-4093.75 PKR) but positive in winter (1728.6 PKR) for 30W LED lights, The seasonal net economic return was positive in both seasons with 1812.5 PKR in summer and 72100.3 PKR in winter. The data indicated that installation of artificial LED lights had initial and operational costs but the reduction in fruit loss leads to a substantial net economic gain specifically in winter. Overall, the 12W LED lights appeared to be more cost-effective, yielding a higher seasonal return in winter as compared to the 30W lights.

Table 1. The fruit damage, yield loss and economic impact in guava (*Psidium guajava*) orchard during different seasons.

Fruit Season	N	TDF (N)	WDF	WADF	TFY	YL	DEFL	MEFL
Summer	180	8.91 ± 0.65^{b}	0.76 ± 0.04	1.27 ± 0.09^{b}	221.00 ± 1.60	0.57 ± 0.04^{b}	126.81 ± 9.36^{b}	3804.35 ± 280.88^{a}
Winter	180	13.81 ± 1.18^{a}	0.81 ± 0.07	1.97 ± 0.17^{a}	217.17 ± 1.62	0.92 ± 0.08^{a}	197.47 ± 16.89^{a}	5924.13 ± 506.64^{b}
Light								
12WAL	120	4.12 ± 0.21^{b}	0.20 ± 0.01^{c}	0.59 ± 0.03^{b}	219.83 ± 1.86	0.27 ± 0.01^{b}	59.07 ± 2.94^{b}	1772.20 ± 88.34^{b}
30WAL	120	2.28 ± 0.14^{c}	0.60 ± 0.06^{b}	0.32 ± 0.02^{c}	215.58 ± 2.00	0.15 ± 0.01^{c}	31.72 ± 1.97^{c}	951.53 ± 59.24^{c}
NAL	120	27.67 ± 0.91^{a}	1.55 ± 0.06^{a}	3.96 ± 0.13^{a}	221.83 ± 2.03	1.81 ± 0.06^{a}	395.63 ± 13.03^{a}	11869.00 ± 390.97^{a}
Season × Light								
Summer 12WAL	60	4.13 ± 0.25^{c}	0.20 ± 0.01^{c}	0.59 ± 0.04^{c}	219.67 ± 2.60^{b}	0.27 ± 0.02^{c}	59.11 ± 3.62^{c}	1773.2 ± 108.62^{c}
Summer 30WAL	60	2.02 ± 0.17^{d}	1.06 ± 0.09^{b}	0.27 ± 0.02^{d}	215.33 ± 2.84^{b}	0.13 ± 0.01^{d}	27.23 ± 2.28^{d}	816.75 ± 68.40^{d}
Summer NAL	60	20.57 ± 0.54^{b}	1.02 ± 0.03^{b}	2.94 ± 0.08^{b}	228.00 ± 2.64^{a}	1.30 ± 0.04^{b}	294.10 ± 7.71^{b}	8823.10 ± 231.26^{b}
Winter 12WAL	60	4.10 ± 0.32^{c}	0.20 ± 0.02^{c}	0.59 ± 0.05^{c}	220.00 ± 2.67^{b}	0.27 ± 0.02^{c}	59.04 ± 4.68^{c}	1771.20 ± 140.30^{c}
Winter 30WAL	60	2.55 ± 0.22^{cd}	0.14 ± 0.01^{c}	0.36 ± 0.03^{cd}	215.83 ± 2.84^{b}	0.17 ± 0.01^{cd}	36.21 ± 3.14^{cd}	1086.30 ± 94.13^{cd}
Winter NAL	60	34.77 ± 1.16^{a}	2.09 ± 0.07^{a}	4.97 ± 0.17^{a}	215.67 ± 2.90^{b}	2.32 ± 0.08^{a}	497.16 ± 16.62^{a}	14914.90 ± 498.65^{a}
ANOVA								
Fruit Season		<0.0001	0.2014	<0.0001	0.0889	<0.0001	<0.0001	<0.0001
Light		<0.0001	<0.0001	<0.0001	0.0693	<0.0001	<0.0001	<0.0001
Season × Light		<0.0001	<0.0001	<0.0001	0.0290	<0.0001	<0.0001	<0.0001

^{abcd}Superscripts on different means within column differ significantly at $p \leq 0.05$.

TDF (N): Total Damaged Fruit/ acre (N), **WDF**: Weight of Damage fruit/ acre (Kg), **WADF**: Estimated weight of actual damaged fruit/ acre (kg), **TFY**: Total fruit yield/ acre (kg), **YL**: Yield loss (%), **DEFL**: Daily economic fruit loss/ acre (Rs.), **MEFL**: Monthly economic fruit loss/ acre (Rs.)

Table 2: Details of expenses and net economic return on installation of LED lights.

Sr. No.	Details about Expenditure on Installation and Fruit loss	12W LED		30W LED	
		Summer	Winter	Summer	Winter
1	Total cost of 16 bamboo sticks (PKR)	2000	2000	2000	2000
2	Cost of electric wire (PKR)	3500	3500	3500	3500
3	Cost of electric switches, Holders etc (PKR)	1000	1000	1000	1000
4	Cost of 16 LED lights (PKR)	2700	2700	3500	3500
5	Cost of electricity used by 16 LED lights/ Night (PKR)	32	32	70	70
6	Cost of electricity used by 16 LED lights/ Month (PKR)	960	960	2100	2100
7	Cost of electricity used by 16 LED lights/ Season (PKR)	1920	6720	4200	14700
8	Total expenditure for installation of artificial lights/ Month (PKR)	10160	10160	12120	12120
9	Total expenditure for installation artificial lights/ Season (PKR)	11120	15920	14200	24700
12	Total Economic fruit loss with artificial lights/ Month (PKR)	1773.2	1771.2	816.75	1086.3
13	Total Economic fruit loss with artificial lights/ Season (PKR)	3546.4	12398.4	1633.5	7604.1

14	Total Net Economic return on first month (PKR)	-3110.2	2979.6	-4093.75	1728.6
15	Total Net Economic return at the end of fruit Season (PKR)	2983.7	76085.9	1812.5	72100.3

*Cost of 1 unit (1 Kwh) of electricity = PKR. 14.0 as per LESCO, Pakistan (Including all the tax charges to electricity meter by Water & Power Development Authority-Pakistan, 2023-24).

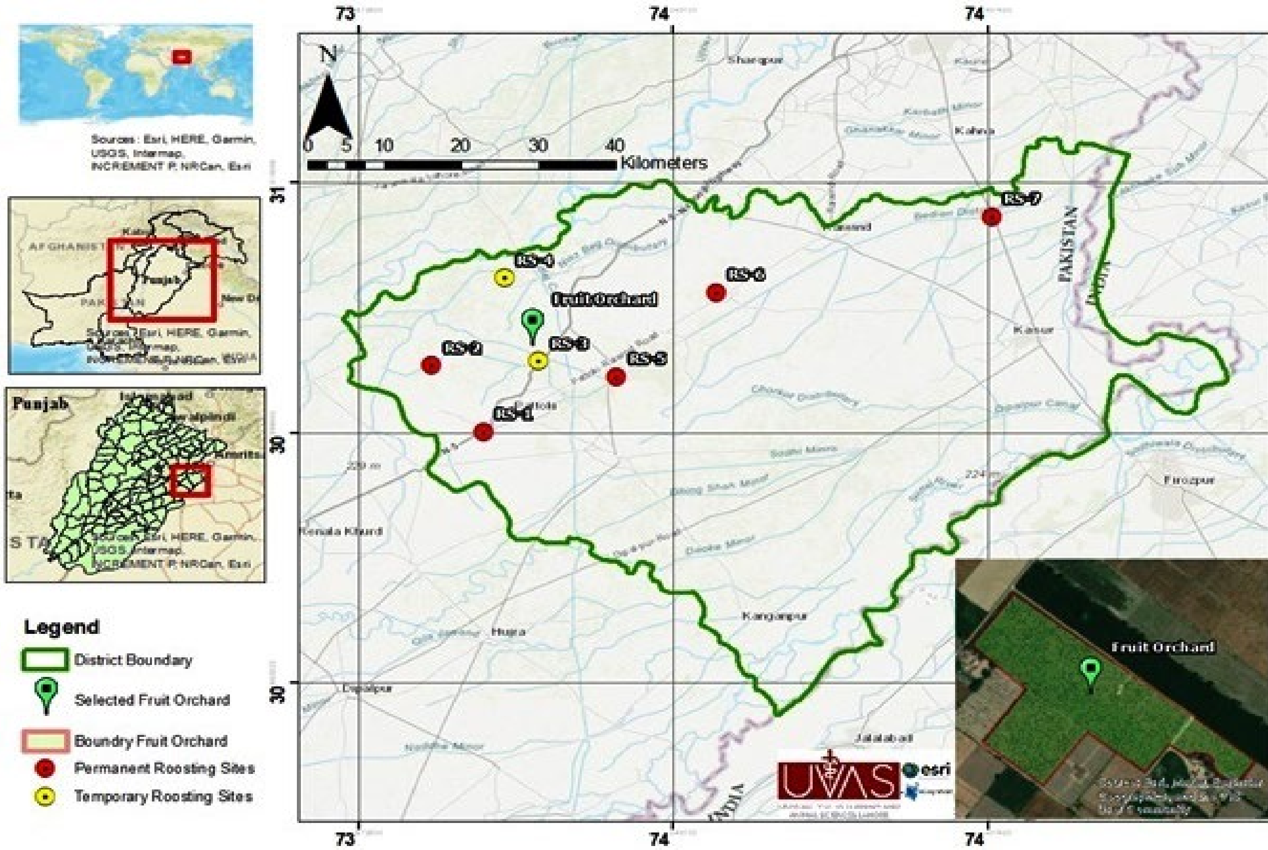

Figure 1. Map of study area showing permanent and temporary roosting sites in district Kasur.

Figure 2. Impact and damage caused by *Pteropus medius* in fruit orchard.

DISCUSSION

The results of the present study revealed that the damage caused by *Pteropus medius* was significantly higher in winter (2.32 ± 0.08%) than in summer (1.30 ± 0.04%) yield loss per acre on daily basis in fruit ripening seasons, this confirms the conclusions of Mahmood-ul-Hassan and Salim (2011), who highlighted that bat-related damage in horticultural districts of Pakistan often leads to substantial yield and financial losses for farmers. Which is also consistent with previous studies by Ali *et al.,* (2023) that have documented damage by *Pteropus medius* against the crop of ber (*Ziziphus jujube*) of 9.72% yield loss during the year 2017-18 and 11.26% yield loss in 2018-19 during fruit's ripening seasons. Singh *et al.,* (2022) reported that *P. medius* tend to cause damage to the *Litchi* (*Litchi chinensis*) ranged from ranged from 6.85 to 8.93% in 2018-19 and more damage in cooler months when their foraging area increases. Winter season may offer more active foraging opportunities in guava fruit orchards to *Pteorpus medius* due to a decrease in natural food sources. During the present study, the winter season showed nearly double the yield loss (2.32 ± 0.08%) compared to the summer (1.30 ± 0.01%) per acre daily. Moreover, seasonal yield loss is estimated as 2.6% in summer and 16.14% in winter by *P. medius*, without any managing strategy in current study. These findings revealed that fruit orchards are more vulnerable in winter and it is important to implement management efforts during winter season. According to Uma *et al.,* 2014 and Rizk *et al.,* 2023, change in environmental factors has resulted in increased fruit damage by bats during winter, which was linked to bat's behavior and foraging habits. Our findings are in line with Tollington *et al.,* (2019) who suspected bats cause about 42% of fruit damage in *Litchi* orchard but clarify the problems in assigning actual damage to a single cause in their assessments. In 2015 and 2016 Oleksy *et al.,* (2015) monitored fruit loss by *Pteropus niger* in 4 *Litchi chinensis,* 1 *Mangifera spp.* orchards and also 10 *Dimocarpus longan* trees. They reported 7-76% fruit loss by bats and birds including natural and fungal fruit loss.

The daily yield loss percentages in our study (1.30 ± 0.04% summer and 2.32 ± 0.08% in winter) during fruit ripening seasons may seem modest at first glance, the cumulative effect over an entire season, especially during winter, results in significant economic consequences for orchard owners. In the findings of Chakravarthy *et al.,* (2003), 28% of guava (*Psidium guajava*) fruit damage and 18% of arecanut (*Areca catechu*) fruit damage in the hilly fields of Chettalli and Uppinangadi areas of Karnataka-India were affected by bats during whole fruit ripening seasons. Our results are align with the findings of Rizk *et al.,* (2023) who reported the fruit damage to different fruit crops during their ripening seasons and substantial economic loss due to the Egyptian fruit bat (*Rousettus aegyptiacus*), the maximum average damage (11.1%) occurred in date palms (*Phoenix dactylifera*) from August to October, while the lowest (4.7%) was in apricots (*Prunus armeniaca*) during June and July. Mangoes (*Mangifera indica*) experienced 7.6% loss from June to August. Citrus (*Citrus sinensis*) crops saw damage starting from December to March, with an average loss of 7.0%, highlighting that fruit bats can cause severe fruit damage to more ripe and sweet fruits. In the studies of Charerntantanakul *et al.,* (2023) official archives and the public opinion poll indicated the fruit damage to tankan oranges (*Citrus tankan*) caused by Ryukyu flying fox (*Pteropus dasymallus*) accounted for 18–28% of the total damage in a typical year.

Orchard characteristics viz., tree height and space between tree rows, significantly affected the extent of damage caused by bats. Tall trees (12 to 15 feet) with more space between tree rows experienced more severe impact as this made it easier for bats to access and navigate the orchard. This observation is in line with the findings of Uma *et al.,* (2014), Oleksy *et al.,* (2021) and Rizk *et al.,* (2023) as they reported that fruit orchard design plays a critical role in facilitating bat access to fruit. Taller trees facilitate bats to land and fly again easily and more space between tree lines likely avoids bat entanglement in tree branches. Olesky *et al.,* (2015) also reported more damage on taller trees and reverse in shorter trees in *Litchi chinensis* orchards and damage caused by birds in independent of tree height. It is suggested that fruit orchard managers could reduce bat access by modifying orchard design. Planting trees of low height and increasing tree density could potentially discourage bat entry into orchard, although this may have other implications for orchard management and overall fruit production.

One of the keys aims of our study was to evaluate the effectiveness of LED lights as a management tool for reducing fruit damage by bats. Farmers often take traditional steps to protect their fruit crops from bats. They cut roosting trees, use smoke or fire to scare them away and install nets to prevent bats from getting in the orchard. While these methods help to control bats and prevent crop damage in the short term, they can harm bat populations in the long run. (Epstein *et al.* 2009; Mickleburg *et a.l* 2009; Harrison *et al.* 2011). The results clearly showed that the use of 12 Watt and 30 Watt LED lights reduced both the amount of fruit damage, and the economic loss associated with bat activity. The 30 Watt LED lights in particular were the most effective, reducing both fruit damage and economic loss more significantly than the 12 Watt LEDs but expensive in installing and operating cost. These results are consistent with studies by Oleksy (2015), Aziz *et al.,* (2016) and Ali *et al.,* (2023) who also reported that high intensity lights had a better effect in deterring bats. Lewanzik and Voigt (2014) reported that less food was explored in dim illuminated compartments as compared to dark. Moreover, they observed when trees were illuminated by streetlamps were less harvested by fruit eating bats as compared to when the trees were in natural darkness. According to Kumar *et al.,* (2024) streetlights greatly affected fruit eating bats. They observed *Cynopterus sphinx* foraging behavior and found that fewer bats visited fruit trees near light sources as compared to darker areas.

During the present study 30 Watt LEDs resulted in a net economic return of Rs. 1715 per acre in the winter season per month after recovering the capital cost and 82,625 per season suggested that LED lights can be a cost-effective and eco-friendly management strategy where bat activity is high to reduce fruit damage and bat conservation. The findings are in line with study of Oleksy *et al.,* (2021) who reported that the use of LED lights on commercial fruit farms can significantly reduce damage and yield losses. However, it is necessary to consider the cost of installation and electricity consumption must take into account. This highlights the need for a balanced approach where the cost-effectiveness of LED lights should be assessed against the level of bat damage and the overall cost of orchard management practices.

It is also important to note that LED lights helped to reduce damage, but they are not sufficient to remove all losses and attractive to many insects (Shimoda and Ki, 2013). This conclusion is similar to the findings of Aziz *et al.,* (2016); Olival (2016) and Singh (2023) who recommended integrating LED lighting with other management strategies, such as netting or sound deterrents to enhance effectiveness. Combining multiple control methods could provide a more comprehensive solution to the problem of bat damage, particularly in areas with high bat populations and larger orchards.

Conclusions and Recommendations: The present study shows that *P. medius* can cause significant damage to guava orchards in fruit ripening seasons (summer and winter). However, the fruit damage was particularly more in winter as compared to summer. The use of artificial LED lights has proven to be an effective management strategy. Both 12W and 30W LED lights significantly reduced fruit damage and economic losses as compared to orchard without lights. While the initial costs of installation were considerable, the reduction in fruit loss made it economically worthwhile, especially in winter. In terms of cost-effectiveness, the 12W LED lights provided a higher return on investment, with a noteworthy positive net economic return during the winter season. Even though the 30W lights had a stronger impact but their higher operating costs made them less profitable overall. In can be concluded that the installation of artificial lights is a practical and effective solution to manage bats related damage in guava orchards. The 12W LED lights, in particular, offer a good balance between cost and effectiveness, making them a smart choice for orchard owners looking to minimize damage and maximize their profits.

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