Research Article

Effect of Different Insect Pollinators Conservation Strategies on Fruit Yield Parameters of Pumpkin *Cucurbita pepo* L.

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Abstract | This study aimed to have a comparative evaluation of different insect pollinators' conservation strategies on fruit yield parameters of pumpkin *Cucurbita pepo* L. Treatments included the installation of a bee hotel (perforated wooden block) to support nesting solitary bees, an active honeybee (*Apis mellifera* L.) hive, inter-row planting of flowering plants (aster, verbena and hollyhocks), and these three treatments were compared with the control field receiving all conventional plant production practices. Parameters such as average fruit size, number of fruits per plant and edible fruit yield were recorded. Results of the study showed that pumpkin plants provided with honeybee hive showed a significant increase in number of fruits (17.7%), average fruit yield (33.90%), fruit weight (48.80%) and fruit size (24.90%) as compared to control treatment plants. Treatment plots provided with solitary bee hotels and floral intercropping also showed increased fruit yield parameters as compared to control although there was no statistical difference. Overall study findings demonstrated that the provision of different insect pollinators' conservation strategies such as installation of honeybee hives and solitary bee hotels and intercropping the field with different flowers boosted up the fruit yield parameters of pumpkin (*C. pepo*) crop and suggest that the use of honeybee hives can significantly enhance the pumpkin and other cucurbit crops yield.

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Introduction

Feeding exponentially increasing human population has been a major challenge for agricultural productions. Vegetable production is one of the most economical and profitable sectors of agricultural and horticultural industries. Pakistan owes a rich diversity and production of vegetables being cultivated all the year (Mahmood, 2014). Among various vegetables, pumpkin (*Cucurbita pepo* L) is considered as an important summer vegetable crop belonging to Cucurbitaceae family. Pumpkin fruits exhibit high nutritional value and contain different bioactive compounds including vitamins (A, C and E), antioxidants, lutein, phytosterols and carotenoids (El-Khatib and Muhieddine, 2019; Kulczynski and Gramza-Michałowska, 2019).

Pumpkin plants as other cucurbitaceous crops are entomophilous which exclusively depend on the insects for their pollination and fruit setting (Ali *et al*., 2014; Holland *et al*., 2020). Honeybees, solitary bees, bumble bees are most dominant insect pollinators. These provide a significant ecological service by enhancing the pollination of pumpkin crops (Garibaldi *et al*., 2020; Holland *et al*., 2020). Although solitary and bumble bees are more efficient pollinators as compared to honeybees because of their quick flower handling (Pfister *et al*., 2017), honeybees drop more pollens on the flowers with respect to other bees in measured visitations (Zhang *et al*., 2015).

Many pollination studies employ the visitation rate as a standard and it is commonly assumed that the effectiveness of a pollinator depends on its visits of a flower and floral exploitation (either gathering nectar or pollen) behavior (Olsson *et al*., 2015; Koch *et al*., 2017; Rollin and Garibaldi, 2019). In case of *C. pepo*, pollen load increases the fruit quantity and quality (Artz *et al*., 2011; Willis and Raine, 2021).

Nevertheless, a significant decline in population of insect pollinators have been observed in most of the agroecosystems due to many factors including anthropogenic disturbances, agricultural intensification and extensive of broad-spectrum synthetic pesticides particularly of neonicotinoids (Abrol, 2012; Wakgari and Yigezu, 2021; Willis and Raine, 2021; Nath *et al*., 2023). Moreover, floral resources within a one-kilometer range of bee hives in both summer and spring seasons play a critical role in maintaining bee diversity and quality, ensuring their survival and reproductive success over time (Image *et al*., 2022).

As increased abundance and diversity of indigenous insect pollinators have been shown to boost crop productivity in different crops such as in beans, oilseeds and cucurbits (Kevan *et al*., 1990; Tanda, 2019; Nath *et al*., 2023), this study was designed to assess the impact of different insect pollinators conservation techniques, such as the provision of bees hotel, honeybee hive and intercropping of cucurbit crop with different flowers, on the fruit yield parameters of pumpkin (*C. pepo*) crop.

Materials and Methods

Research was carried out in the vegetable research area of the Department of Horticulture, College of Agriculture, University of Sargodha in summer 2021. Experimental land was prepared by ploughing using rotavator and beds were prepared. The width and length of beds was 12 and 25 feet, respectively. Plant to plant and row to row distance was maintained as 2 and 12 feet, respectively.

Seeds of pumpkin (*C. pepo*) (Pumpkin No. 111 Hybrid Seed F1) were soaked in water for ten hours before sowing to break their dormancy and for uniform germination. After breaking dormancy, seeds were sown on beds. Choka method was used for seeding. Two seeds per hole were sown. Seed depth was about 1.5 to 2.5 cm. After germination, thinning was done to maintain proper plant population in each plot.

Experiment was laid out using randomized complete block design (RCBD) consisting of four treatments i.e., T1 (control), T2 (honeybee hive), T3 (bee hotel) and T4 (intercropping with seasonal flowers). A buffer zone of about 3 meters was maintained around and in between the treatment plots. Seeds of sorghum were sown in buffer zone to discourage the movement of visiting insect pollinators among the blocks. Honeybee hive and woody handmade bee hotels were purchased from nearby market. Bloomed flowers of aster, verbena and hollyhocks were procured from local plant nursery. Blooming period of pumpkin flowers started after 8-10 weeks of seedling germination. Male flowers appeared first than the female flowers. Female flowers appeared 10 days later then the male flowers. After blooming of pumpkin flowers, the placement of active honeybee (*Apis mellifera*) hive, installation of wooden bee hotel and intercropping of different flowers was done in their respective treatment plots.

In each plot, five plants were selected on random basis for the observation and collection of data. Numbers of flowers were counted on these selected plants from each bed. Insect visitation was observed for 15 minutes on one flower of the selected plants. Insect movement was observed continuously during blooming period. Observation was done twice a day, morning and evening time when insects were more active. Number and type of insects visiting the flowers in a day were noted. Finally crop yield was also recorded. After harvesting, the diameter of fruits was determined using digital vernier caliper and fruit weight was measured on digital electronic balance. During this experiment on pumpkin, spray of different pesticides was done according to the need.

The data of all recorded fruit parameters were analyzed by factorial analysis of variance (ANOVA) and the treatment means were compared using the least significant difference (LSD) test at standard level of probability *i.e.* $P \leq 0.05$.

Results and Discussion

Average number of fruits per C. pepo plant

Results of this field study revealed the impact of different insect pollinator conservation strategies such as of honeybee hives, bee hotels and floral intercropping on the number of fruits per pumpkin plant. A significant ($P < 0.05$) increase was observed in number of fruits in all three treatments as compared to control as shown in Figure 1. Moreover, the treatment (blocks) containing honeybee hives showed 17.7% increased fruit number per plant than that of control treatment. Similarly, the other treatments, containing bee hotels and intercropped flowers showed 5.20 and 9.34% increase in number of fruits per plant, respectively as compared to the control treatment.

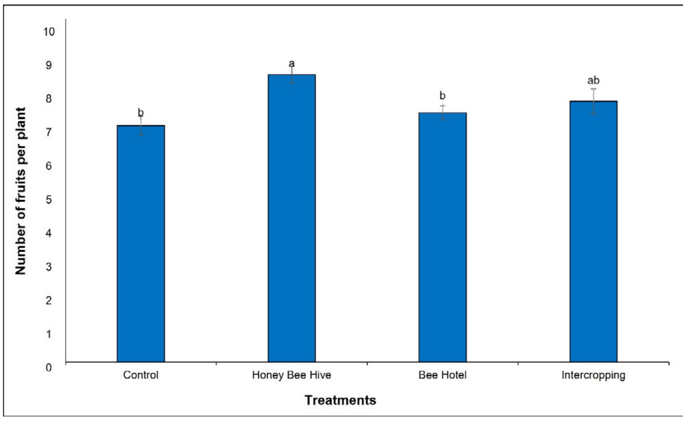

Figure 1: *Impact of different insect pollinators conservation strategies on the average number of fruits per plant of pumpkin (C. pepo). Bars and columns represent standard error and mean, respectively, of triplicate values. Alphabets at bar tops indicate significant difference among treatments (factorial ANOVA followed by LSD; α = 0.05).*

Average fruit yield per plant

Results of the study exhibited a differential impact of different insect pollinators conservation strategies (honeybee hives, bee hotels and floral intercropping) on the average marketable fruit yield per pumpkin plant, when grown under natural field conditions. A significant ($P < 0.05$) increase was observed in average fruit yield per plant of all treatments as compared to control (Figure 2). Moreover, the treatment (blocks) provided with honeybee hives showed a 33.90% increased average fruit yield per pumpkin plant than that of control treatment. Similarly, the other treatments, having bee hotels and floral intercropping showed 8.42% and 19.8% increase, respectively in the average fruit yield per plant as compared to control treatment (Figure 2).

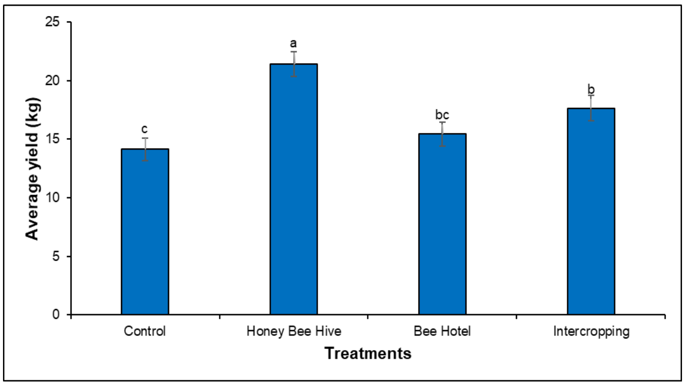

Figure 2: *Impact of different insect pollinators conservation strategies on the average fruit yield per plant of pumpkin (C. pepo). Bars and columns represent standard error and mean, respectively, of triplicate values. Alphabets at bar tops indicate significant difference among treatments (factorial ANOVA followed by LSD; α = 0.05).*

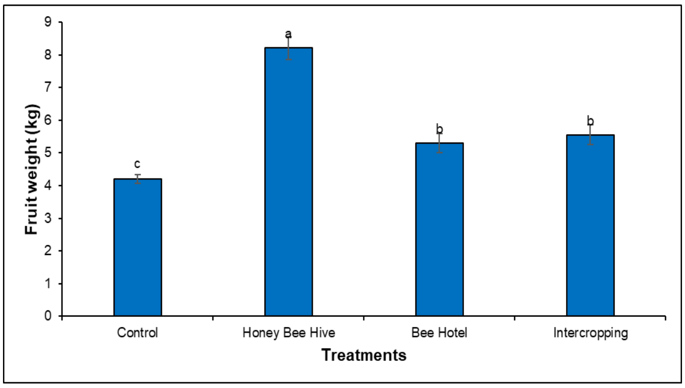

Figure 3: *Impact of different insect pollinators conservation strategies on the average fruit weight of pumpkin (C. pepo). Bars and columns represent standard error and mean, respectively, of triplicate values. Alphabets at bar tops indicate significant difference among treatments (factorial ANOVA followed by LSD; α = 0.05).*

Average fruit weight per plant

Average fruit weight of pumpkin was also significantly affected by different insect pollinators conservation strategies (honeybee hives, bee hotels and floral intercropping) on the fruit weight per pumpkin plant, when grown under natural conditions. A significant ($P < 0.05$) increase was observed in average fruit weight per pumpkin plant of all treatments as compared to control as shown in Figure 3. Moreover, the treatment (blocks) with honeybee hives showed 48.80% increased average fruit weight per plant than that of control treatment. Similarly, other treatments containing bee hotels and intercropped flowers showed 20.60% and 24.31% increase, respectively in average fruit weight per plant as compared to the control treatment (Figure 3).

Average fruit size

Similarly, the insect pollinators conservation strategies used in this field study *i.e.* provision of honeybee hives, bee hotels and floral intercropping in the treatment plots, exerted a significant effect on the average fruit size per pumpkin plant, when grown under natural conditions. A significant (P < 0.05) increase was observed in fruit size of all treatments as compared to control as it shown in Figure 4. Moreover, the treatment (blocks) containing honeybee hives showed 24.9% increased average fruit size per plant than that of control treatment. Similarly, the other treatments containing bee hotels and flowers showed 9.81% and 11.80% increase, respectively in average fruit size per plant as compared to the control treatment (Figure 4).

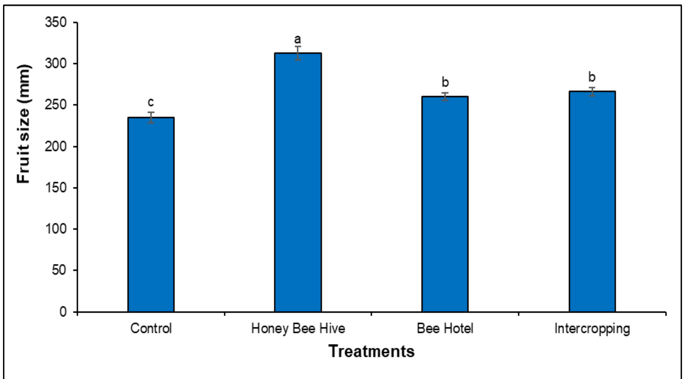

Figure 4: *Impact of different insect pollinators conservation strategies on the average fruit size (diameter) of pumpkin (C. pepo). Bars and columns represent standard error and mean, respectively, of triplicate values. Alphabets at bar tops indicate significant difference among treatments (factorial ANOVA followed by LSD; α = 0.05).*

Correlation analysis

A correlation analysis was performed to see if there is any association of different fruit yield parameters of pumpkin plants such as number of fruits, average fruit yield, fruit weight and fruit size (diameter) per plant. This correlation analysis showed that all the parameters were highly and positively associated with each other (Table 1). Average number of pumpkin fruits (per plant) were strongly correlated with the average fruit yield of pumpkin per plant. Similarly, the average fruit weight was also strongly correlated with the average yield of the pumpkin plant. Additionally, the average fruit size (diameter) was also strongly associated with the average number of fruits and average yield of pumpkin per plant (Table 1).

Table 1: *Correlation analyses regarding the impact of different insect pollinators conservation strategies on fruit yield parameters of pumpkin C. pepo.*

Study parameters	Average number of flowers	Average fruit yield	Average fruit weight	Average fruit size (diameter)
Average number of flowers	1			
Average fruit yield	**0.996	1		
Average fruit weight	**0.985	**0.975	1	
Average fruit size (diameter)	**0.989	**0.976	**0.997	1

*** highly positive correlation between the study parameters.*

Insects-mediated pollination is one of the essential aspects of entomophilous plants which rely exclusively on a wide variety of insect pollinators particularly on honeybees, solitary and bumble bees, wasps, moths, butterflies and files (Holland *et al*., 2020). In this study, we demonstrated the effectiveness of three strategies to attract and conserve insect pollinators and flower visiting insects on the fruit yield parameters of pumpkin *C. pepo* crop. Study results showed a significant increase in all studied fruit parameters of pumpkin plants as compared to control treatment. Particularly, plots provided with honeybee (*A. mellifera*) hive exhibited good quality marketable fruits. Our findings are in line with those of Ali *et al*. (2014), Abbasi *et al*. (2021) and David *et al*. (2022) who reported that the presence of honeybees in the immediate vicinity of the farm caused more pollination than other types of pollinators in pumpkin, sunflower and kiwifruits, respectively. Similarly, Artz *et al*. (2011) demonstrated that supplementation of pumpkin fields with live hives of *A. mellifera* caused significant a greater number of fruits and yield that non-supplemented pumpkin fields.

When plants are intercropped with other flowering plants, they also attract random visits of non-specific pollinators, and this might be due to the absence of native pollinator species because of the higher use of pesticides such as insecticides and weedicides that damage the targeted as well as non-targeted (insect pollinators) species (Willis and Raine, 2021). However, some other pollinator species that are observed in this study made less excursions to pistillate flowers, which may be connected to their lesser demands on pollen for larval development and adult maintenance, which might be substantial in proper pollination of flowers (Delgado-Carrillo *et al*., 2018; Bezerra *et al*., 2020).

Moreover, our results regarding higher average fruit yield in treatment plots are in accordance with the findings of Pereira *et al*. (2015) who also reported higher average fruit yield when plants were subjected to higher population of honeybees. The reason behind higher fruit yield is the successful pollination of maximum flowers by the native or attracted pollinators. The possible reason for higher fruit weight might be due the excessive visits of specific pollinators, higher contact time and presence of more blooming flowers (Zhang *et al*., 2015). Similarly, our findings of higher fruit size and fruit weight was in line with the results of Brar *et al*. (2020) and Noor *et al*. (2024) who also observed the higher fruit size and weight when they subjected their plants with frequent visits of honeybees. The reason would be the timely pollination of flowers by the nearby pollinators (in our case honeybees from beehives) that caused maximum pollination as compared to all other treatments. Similarly, the presence of bee hotels also attracted a vast variety of pollinating bees, but their visits were fewer. The other possible reason behind lower fruit weight and size in case of intercropping and control treatment might be due to the visits of pests like flies, beetles, leaf hoppers, aphids, thrips and plant bugs who damaged the flowers and leaves and even fruits that ultimately reduced the plant yield (Bhat *et al*., 2022).

The other reasons for the fewer production of fruits on plants might be due to the climatic factors such as higher temperature, fewer or higher rainfalls, thunderstorms that reduces the number of native pollinators. Another major factor is for higher production of fruits and average fruit yield is the contact time if a pollinators spend more time on a flower, there is more nectar accessibility. This enhances the possibility of more pollen deposition for successful pollination (Park *et al*., 2016; Lawson and Rands, 2019; Ramello *et al*., 2024). However, some bee species have small sizes and lack of hair, that reduced their capacity to effectively deposit pollen on flowers (Hargreaves *et al*., 2012; Pfister *et al*., 2017). Additionally, the disturbance of ecological balance by vast growing human populations (by building infrastructures and producing higher noise and air pollution) also the biggest cause of fewer pollinator visits. In addition, our findings need to be taken with caution due to the fact that the way we managed the bees throughout the scheduled visits may have had an effect on the pollen deposition (Lowenstein *et al*., 2015; Cecala *et al*., 2020).

Conclusions and Recommendations

Overall study results demonstrated the effectiveness of all three insect pollinators conservation strategies as compared to control and showed that supplementation of pumpkin fields with honeybee hives, bee hotels and floral intercropping enhanced the pumpkin fruit number, sized, weight and yield. Farmers should consider adopting these pollinator attraction and conservation techniques in order to boost the production of pumpkin and other entomophilous crops both in terms of quality and quantity.

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Novelty Statement

This field work has demonstrated that the provision and conservation of insect pollinators such as honeybees in cucurbit crops can significantly enhance the fruit yield parameters of round gourd *Cucurbita pepo* L.

Author's Contribution

Shahid Iqbal and Muhammad Zeeshan Majeed: Conceived the idea, prepared research protocol and supervised the research work.
Ghulam Haider, Faisal Noor and Muhammad Dawood: Conducted experiments and recorded data.
Ghulam Haider: Wrote the first draft.
Muhammad Zeeshan Majeed: Provided the technical support and revised the manuscript technically.
Umar Farooq and Muhammad Dawood: Analyzed the data and prepared results

Conflict of interest
The authors have declared no conflict of interest.

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