Research Article

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Pollinator Profile and Role of *Apis mellifera* on the Yield Enhancement in Sesame

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ABSTRACT

Insect pollinators contribute a major part in cross-pollination, few among them visit the sesame flowers that enhance the yield in terms of both qualitative and quantitative. The investigation took place at the oilseed research farm, National Agricultural Research Centre aiming to evaluate the pollinator profile of sesame and the impact of *Apis mellifera* on yield enhancement. Hymenopterans were the predominant floral visitors, constituting 90.81% of the total floral visitors, followed by the Dipterans and Coleopterans. Bees emerged as the most frequent floral visitors, with *Bombus haemorrhoidalis* being the most abundant at 27.16%, followed by *A. dorsata* (25.04%), *A. mellifera* (16.27%), and *A. florea* (9.34%). All the bee species started their activity before 09:00 am. *Bombus haemorrhoidalis*, *A. dorsata*, *A. cerana*, and *A. mellifera* attained their peak activity at 09:00 am whereas *A. florea* at 03:00 pm and *Xylocopa fenestrata* at 12:00 pm. The maximum number of pods with greater seed weight and yield was obtained in open-pollinated (41.53 pods/m^2, 3.44 gm/1000 seeds, and 91.97 gm/m^2 respectively) followed by *A. mellifera* and self-pollinated. This study concluded that honeybees especially *A. mellifera* play an important role in increasing the sesame yield. Further studies should focus on the impact of *Apis* and non-*Apis* bees on the reproductive success of sesame in terms of a single visit -as it is a tool for measuring the impact of pollinators on plant reproductive success- and the influence of climatic conditions like wind velocity, ambient temperature, light intensity, and relative humidity on the bee foraging activity.

Keywords: Sesame, yield, bees, Apis bees, pollinator profile

INTRODUCTION

Sesame (Pedaliaceae: *Sesamum indicum* L.) is considered among the oldest crop that seeds produce oil with a cultivation history spanning over 4,300 years in Babylon and Assyria [1, 2, 3]. About 90% of sesame is cultivated in Asia and Africa i.e., China, India, Pakistan, Bangladesh, Turkey, Thailand, Myanmar (Burma), Sudan, Nigeria, Ethiopia, and Mexico [4]. Sesame oil has high medicinal and nutritional properties and contains several minerals that are vital for human health and stability against oxidative rancidity [5, 6, 7, 8, 9]. Pakistan is currently grappling with a severe shortage of edible oil therefore, importing approximately 88% of its annual requirement, which amounts to 3.13 million tons [10, 11].

Therefore, the main reason for the cultivation of sesame seeds is primarily driven by its high oil content, which accounts for 50% [12]. According to the Pakistan Federal Bureau of Statistics [13], nearly 30,000 tons of sesame seeds during the 2017-18 period were produced from a sesame-cultivated area of 176 thousand acres.

Pollination serves as a regulating service, with animal pollination being crucial for the sexual reproduction of numerous crops, accounting for approximately 35% of global crop production and benefiting wild plants as well [14]. Insect pollinators contribute to pollination services for over 70% of the world's crops [15]. Throughout the latter half of the previous century, they played a pivotal role in increasing global food production by an estimated 15-30% through their invaluable regulatory services [16, 17, 18]. Among these pollinators, both wild and domesticated bees (*Apis mellifera* L.) represent the most crucial pollinator group, and their significance in pollination within natural and agroecosystems is progressively

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gaining recognition and acknowledgment [15, 19, 20, 21, 22, 23, 24, 25, 26, 27].

Sesame is primarily a self-pollinated crop, but it can exhibit some level of cross-pollination under certain conditions. The primary mode of pollination in sesame is autogamy, where the flowers are capable of self-pollinating without external assistance [1, 28]. Several studies have reported a significant increase in the yield of sesame when pollinated with insects [8, 29, 30, 31, 32, 33]. Some of the insects visit the flowers of sesame and transfer the pollen grains act as pollinators, and increase the yield of crops. The out-crossing rates of sesame exhibit variations ranging from less than 10% to 68%, influenced by climatic conditions and the activity of pollinators [34, 35]. Paleolog [36] found that insects play a key role in increasing the sesame seed yield up to 22% to 33%. A recent study conducted by Stein et al. [31] on the pollinator dependence of the sesame crop revealed that up to 59% of sesame yield increased by honeybee and wild bee pollination. Moreover, they concluded that pollinator deficiency in crops may lead to a yield gap between 50 and 87 percent. Several studies from throughout the world have reported the pollinator profile of sesame and the impact of insect pollination on yield-attributing components [32, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47], but the literature is scarce from Pakistan [48]. The aim of this study was to identify the local pollinators of sesame, their diversity, abundance, and diurnal fluctuation at 09:00, 12:00, and 15:00 hours throughout the blooming period. Moreover, the impact of *Apis mellifera* pollination on the reproductive success of sesame was also measured in terms of number of pods/m^2, seed weight of 1000 seeds, and yield/m^2.

MATERIALS AND METHODS

Experimental Area and Plant Species

The experiment was conducted at the Research Farm of Oil Seed Research Institute, National Agricultural Research Centre (33°40'16" N 73°07'42" E; 504 meters above sea level), Islamabad, Pakistan. The area is blessed with a subtropical humid climate characterized by hot summers and cold winters. The city encounters a maximum temperature of 42 degrees Celsius, a minimum temperature of one degree Celsius, the highest average wind speed of 5 meters per second, and a median cloud cover of 12%. The maximum rainfall in the months of July and August ranges from 620 to 647 millimtres [49].

The experimental plant species was sesame, *Sesamum indicum* (Pedaliaceae), sown in an area of four acres on 08 August 2022. The study lasted from September 2022 to November 2022 i.e., from the start of blooming until harvest.

Pollinator Community and Their Abundance To assess the pollinator community of *S. indicum*, two fields of at least three acres each were selected that were isolated three kilometers from each other. During the peak activity hours i.e., 09:00 am to 12:00 pm, the floral visitors were collected using a hand collection net. A two-day survey was conducted to collect floral visitors of *S. indicum*, with each field focused on a single day. All the collected floral visitors were identified up to the lower taxonomic level [50, 51, 52, 53, 54, 55, 56, 57, 58] and identified specimens were confirmed by the National Insect Museum, NARC (see acknowledgment).

The visitation frequency of floral visitors (i.e., the number of individuals of each species visited per one meter square per 120 seconds) and abundance every week was recorded at three observation times i.e., 09:00, 12:00, and 15:00 hours throughout the flowering period. Mostly the data was recorded from the center of the field, choosing the areas of one-meter square by random walk. Ten such observations were made at each observation time i.e., 09:00, 12:00, and 15:00 hours (30 observations/census). These observations were recorded using a stopwatch.

Pollinator Effectiveness

To measure the effectiveness of *A. mellifera* in terms of sesame reproductive success, three cages composed of metal covered by muslin cloth with a dimension of 2×2×4 meters were installed in the sesame field. These cages were installed before the initiation of flowering in *S. indicum*. For bee-pollination three cages were installed and a single nucleus colony of *A. mellifera* consisting of a queen, 1000 nurse bees, and 3000 forager bees was placed in each cage. For self-pollination (no insect visitation) three other such cages were installed without a nucleus colony of *A. mellifera*. Whereas, for open pollination (unrestricted insect visitation), three areas of 2×2 meters each were selected [32]. After the maturation of the crop, the resultant pods were harvested and the number of pods, seed weight/1000 seeds, and yield/m^2 were recorded as the measures of pollination effectiveness.

Statistical Analysis

One-way Analysis of Variance (ANOVA) was used to measure the significant difference in the number of pods/m^2, yield/m^2, and seed weight/1000 seeds among *A. mellifera* pollinated, self-pollinated, and open-pollinated pods. Means were compared by using the Least Significance Difference (LSD) post hoc test at alpha 0.05. A computer-based software IBM SPSS Statistics 26 was used to perform the analysis of the data.

RESULTS

A total of 707 individuals from 13 species including 6 species of bees, 3 species of wasps (Order Hymenoptera), 2 species of flies (Diptera), and 2 species of beetles (Coleoptera) visited the flowers of *S. indicum*. Among these floral visitors, Hymenopterans were the most dominant, comprising 90.81% of the floral visitors, followed by Dipterans at 6.08% and Coleopterans at 3.11%. Among bee species, *Bombus haemorrhoidalis* was the most dominant visitor of *S. indicum* flowers and consisting 27.16% of all the floral visitors followed by *Apis dorsata* (25.04%), *A. mellifera* (16.27%) and *A. florea* (9.34%). Among wasp species, *Polistes wattii* was the most dominant (2.26%) floral visitor followed by *Antepipona* sp. (0.99%) and *Vespa velutina* (0.85%). Among syrphid flies and beetles, *Eristalinus tabanoides* (3.54%) and *Aulacophora foveicollis* (1.84%) were the most dominant floral visitors respectively (Table 1).

Table 1. Floral visitors' abundance and species percentage on *Sesamum indicum*

Order	Species	Abundance	Species percentage	Order percentage
Hymenoptera	*Apis florea*	66	9.34	90.81
	Apis cerana	54	7.64	
	Apis dorsata	177	25.04	
	Apis mellifera	115	16.27	
	Bombus haemorrhoidalis	192	27.16	
	Xylocopa fenestrata	9	1.27	
	Antepipona sp.	7	0.99	
	Vespa velutina	6	0.85	
	Polites wattii	16	2.26	
Diptera	*Eristalinus tabanoides*	25	3.54	6.08
	Eristalinus arvorum	18	2.55	
Coleoptera	*Coccinella septempunctata*	9	1.27	3.11
	Aulacophora foveicollis	13	1.84	

The results showed that all the species of honeybees started their activity before 09:00 am. *Apis dorsata*, *A. mellifera*, and *A. cerana* attained their peak activity at 09:00 am and gradually declined until 03:00 pm. However, *A. florea* attained their peak activity at 03:00 pm (Fig. 1). In the case of non-Apis bees, activity also started before 09:00 am. *Bombus haemorrhoidalis* attained their peak activity at 09:00 am and gradually declined until 03:00 pm. While *Xylocopa fenestrata* attained their peak activity at 12:00 pm (Fig. 2).

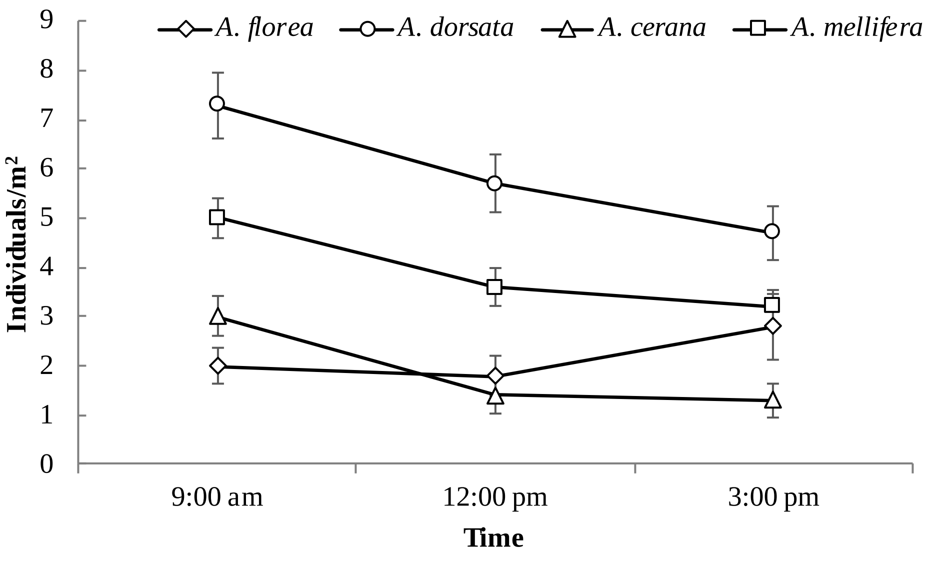

Figure 1. Variations in the diurnal abundance of *Apis* spp. at three different observation times

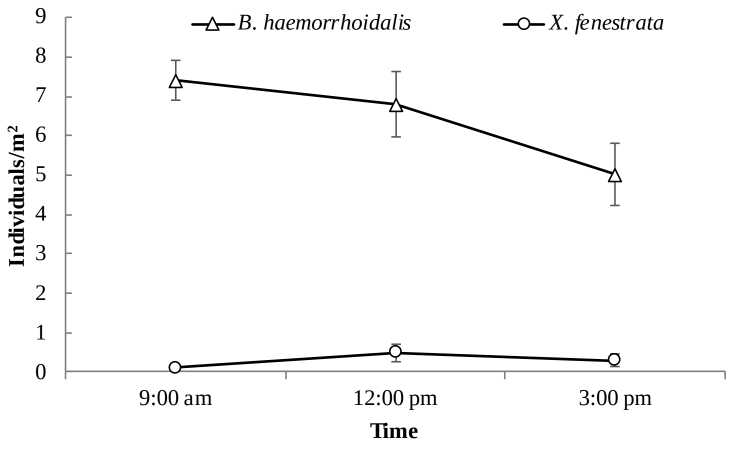

Figure 2. Variations in the diurnal abundance of non-*Apis* spp. at three different observation times

In the case of wasps, the activity of *Polistes wattii* and *Antepipona* sp. started before 09:00 am. *Vespa velutina* and *P. wattii* attained their peak activity at 12:00 pm and gradually declined until 03:00 pm. Whereas *Antepipona* sp. attained its peak activity at 09:00 am and gradually declined until 03:00 pm (Fig. 3). In the case of syrphid flies, activity also started before 09:00 am. Both species i.e., *Eristalinus tabanoides* and *Eristalinus arvorum* attained their peak activity at 12:00 pm and gradually declined until 03:00 pm (Fig. 4). In the case of beetles, activity also started before 09:00 am. *Aulacophora foveicollis* attained their peak activity at 12:00 pm whereas the activity of *Coccinella septempunctata* gradually increased attaining a peak at 03:00 pm (Fig. 5).

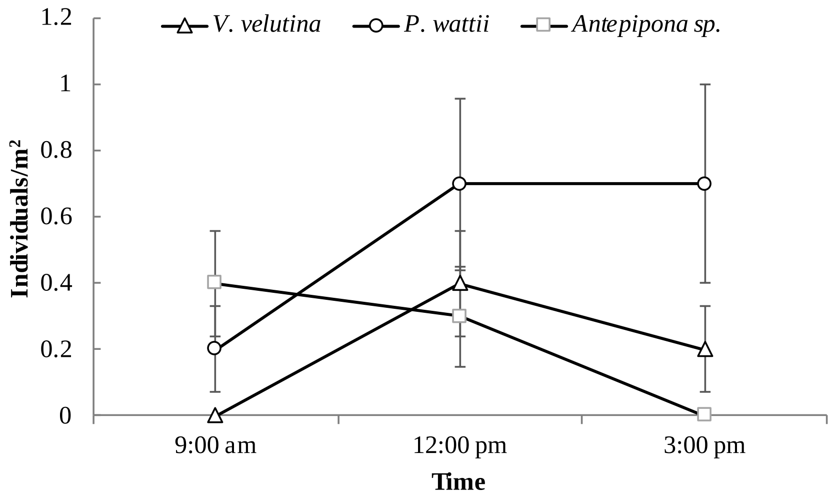

Figure 3. Variations in the diurnal abundance of wasps at three different observation times

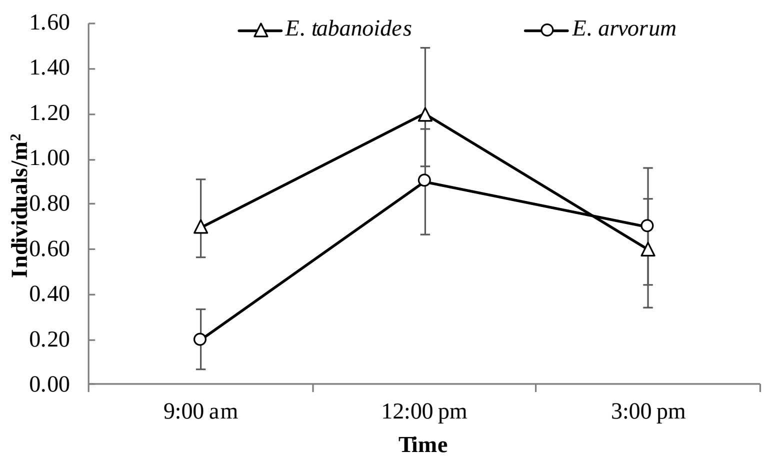

Figure 4. Variations in the diurnal abundance of syrphid flies at three different observation times

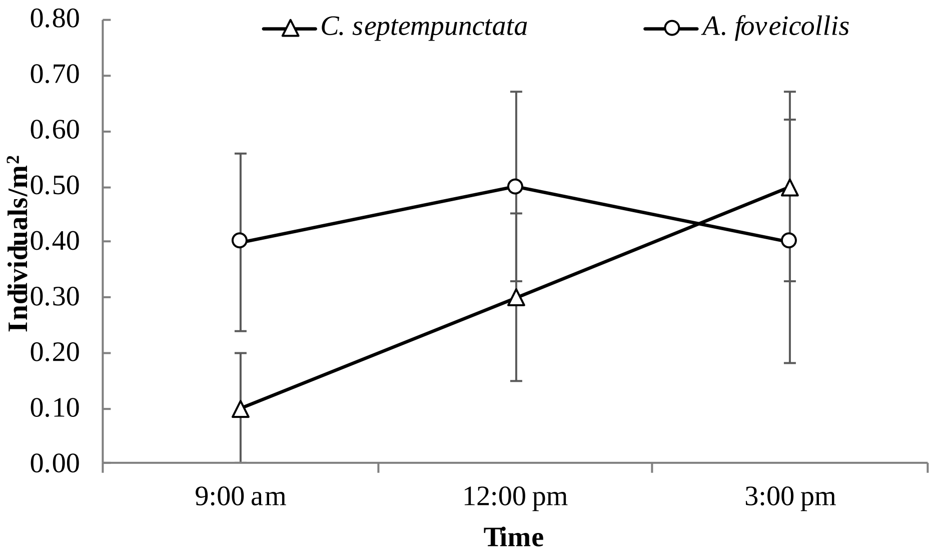

Figure 5. Variations in the diurnal abundance of beetles at three different observation times

There was a statistically significant difference among open-pollinated, *A. mellifera*, and self-pollinated treatments in terms of number of pods/m^2, seed weight/1000 seeds (gm), and yield (gm/m^2). The maximum number of pods with greater seed weight and highest yield was obtained in open-pollinated (41.53 pods/m^2, 3.44 gm/1000 seeds, and 91.97 gm/m^2, respectively) followed by *A. mellifera* and self-pollinated (Table 2).

Table 2. Number of pods, 1000 seed weight, and yield/m^2 resulting from open, *Apis mellifera* and self-pollination

Treatments	No. of Pods/m^2	Yield (gm/m^2)	Seed weight/1000 seeds (gm)
Open	41.53 ± 1.75 a	91.67 ± 2.03 a	3.44 ± 0.07 a
Apis mellifera	35.80 ± 2.21 b	77.33 ± 2.60 b	3.14 ± 0.05 b
Self-pollinated	22.33 ± 1.23 c	59.33 ± 2.33 c	2.90 ± 0.05 c
Results of One-Way ANOVA			
F	30.8	48.2	21.5
df	2	2	2
P-value	0.0001	0.0002	0.0001

DISCUSSION

The sesame crop is able to auto pollinate and benefit from both self-pollination and cross-pollination [30]. The extent of cross-pollination varies from 0.5-65 percent, influenced by factors such as the foraging activity of pollinators, the presence of other vegetation, and environmental conditions [39]. In Nigeria, Ashri [59] observed cross-pollination rates ranging from 2.7-51.7 percent. In the present study, 13 species of floral visitors were recorded. Hymenopterans were the most abundant floral visitors and among them, bees were the most dominant floral visitors of *S. indicum*. Kamel et al. [45] reported 29 species of pollinators from the orders Hymenoptera, Diptera, Lepidoptera, and Coleoptera on sesame. A total of 31 species of pollinators from four orders i.e., Coleoptera, Diptera, Hymenoptera, and Lepidoptera were reported by Mahmoud [44]. Thirteen species of pollinators from different orders on *S. indicum* were reported by Patil and Viraktamath [40] from Karnataka, India. Nine species of pollinators on sesame were reported by Kamel [38]. Furthermore, they also concluded that Hymenopterans were the most abundant and frequent pollinators of sesame. Most of the studies have also reported that hymenopterans were the most abundant and frequent floral visitors of sesame flowers followed by lepidopterans, dipterans, and coleopterans [32, 41, 43, 48].

Sesame flowers contain five petals, with the lowermost petal extended to create a special structure which is called the lip. This lowermost petal or lip initially overlaps the flower, upholding its closure until almost dawn. After opening the flower, the lip makes a constant stripe that serves as a pathway for pollinators especially bees [60]. These characteristics of sesame flowers i.e., the morphology of the lower lip and diameter of the corolla facilitate cozy landing and entry in flower for most of the bees, hence increasing the rate of cross-pollination [61] and might make them the most predominant floral visitors of sesame [48]. In the present study, *B. haemorrhoidalis* was the most dominant visitor of *S. indicum* flowers and consisting 26.16% of all the floral visitors followed by *A. dorsata*, *A. mellifera*, and *A. florea*. Kumar and Lenin [39] documented that the superfamily Apoidea was the most dominant floral visitor of sesame comprising 96%. It has been reported that honey bees served as the primary pollinators for sesame, demonstrating a higher frequency of bee visits per square meter per minute [37, 42]. Contrary to our findings, most of the studies have reported that *A. mellifera* was the most abundant floral visitor of sesame than other bee species [32, 39, 46]. Few studies have found that *A. cerana* was the most dominant pollinator of sesame [47, 63] whereas *A. mellifera* with low abundance [64]. Some studies reported *A. dorsata* as the predominant pollinator species as compared to other honeybees [41, 42, 65].

In the present study, all the species of bees started their activity before 09:00 am. *Apis dorsata*, *A. cerana*, and *A. mellifera* attained their peak activity at 09:00 am whereas *A. florea* attained its peak activity at 03:00 pm. In the case of non-Apis bees, *B. haemorrhoidalis* attained its peak activity at 09:00 am whereas, *X. fenestrata* at 12:00 pm. It has been reported from that the hymenopteran species attained their peak abundance between 9:00 am to 11:00 am, gradually declining as the day progresses [32, 43]. Moreover, the least number of pollinators were recorded during the mid-day at 02:00 pm to 03:00 pm [32]. In contrast, Munir and Aslam [66] observed the peak foraging activity from 08:00 am to 09:00 am. Said et al. [46] found that bees-initiated foraging on sesame flowers from 09:00 am to 11:00 am with 2.4 bees per meter square per five minutes. Furthermore, they also found that the highest foraging activity of bees (9.8 bees/m^2/5 minutes) was recorded from 1300 hours to 1500. Only a few studies have reported the peak foraging activity of *A. mellifera* and *A. cerana* from 09:00 am to 11:00 am [43, 47]. This peak in the foraging activity of bees might be due to the ample nectar flow in the flowers of sesame mostly during the morning hours [30]. Later, the nectar concentration slowly reduces, explaining the fluctuations in the foraging activity of pollinators [30]. Thus, to obtain a higher yield of sesame, the crucial time period for the pollination ranges from 0700 hours to 1100 hours.

In the present study, the maximum number of pods with greater seed weight and highest seed yield/m^2 was recorded in open-pollinated flowers followed by *A. mellifera* and self-pollinated flowers. Insect pollinators play a key role in the cross pollination that ultimately increases the crop yield [30]. Several studies have shown similar results i.e., Blal et al. [8] recorded the higher pod weight, the number of seeds per pod, the weight of 1000 seeds, and yield per plant in open-pollinated pods as compared to self-pollinated pods. Das and Jha [67] reported a higher seed yield of sesame under open-pollinated conditions followed by honeybee (*A. mellifera*) pollinated and self-pollinated conditions. In open-pollinated conditions, the higher yield of sesame might be due to the visitation of a variety of wild pollinators. Mahmoud [44] similarly reported that insect visits to sesame flowers led to a significantly higher yield compared to self-pollinated flowers. Rahman [68] also reported similar findings by conducted a study on different modes of pollination in sesame crops. He revealed that both open-pollination and caged pollination with honeybees significantly enhanced the number of pods per plant, the number of seeds per pod, and the weight of 1000 seeds compared to self-pollination. Contrarily, a study reported that *A. mellifera* pollinated plots were higher in sesame yield than the open-pollinated plots [32].

Conclusion

According to the current study's findings, pollinators particularly honeybees -*Apis mellifera*- had a significant role in the enhancement of sesame seed yield. It is concluded that unrestricted or open-pollinated flowers were better than honeybee-pollinated flowers in terms of plant reproductive success i.e., maximum number of pods with greater seed weight and highest yield/m^2. So, to obtain better crop yield, honeybees ought to be supported by wild pollinators.

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Conflict of Interest:

The authors declare that they have no conflict of interest that could have appeared to influence the work reported in this paper.

Author Contributions:

W.A., S.A., and Z.H.D. conceived the research. G.S. and A.U.K. designed the experiments. R.M., N.I., and M.K.R. collected and prepared the materials. G.S., W.A., and Z.H.D. conducted experiments and collected data. G.S. supervised the experiments. W.A., A.U.K., and M.K.R. G.S., W.A., and S.A. wrote the manuscript. All authors have read and agreed to the published version of the manuscript.

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