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Research Article

Effect of pollination on fruit set and quality of sweet cherry (*Prunus avium* L.) in Kashmir Valley, India

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Abstract
Pollinators play a crucial role in the reproduction of cherries, ensuring successful fruit set and enhancing the quality and yield of cherries. The study aimed to highlight the crucial role of insect pollinators in enhancing the fruit set and quality of sweet cherries (*Prunus avium* L.) in orchards of the Kashmir Valley, with significant implications for sustainable horticultural practices. Utilizing a Randomized Block Design (RBD) with six treatments and three replications, the contributions of three key pollinators *Apis mellifera*, *Apis cerana*, and *Eristalis tenax* were systematically evaluated. While all pollination treatments resulted in 100% fruit set, notable differences in fruit quality were observed based on pollinator species and visit frequency. *A. mellifera* emerged as the most effective pollinator, attributed to its high foraging rate (1.65 flowers per second) and strong fidelity. It produced the largest fruits (18.00 mm), highest fruit weight (8.82 g), lowest acidity (1.12% citric acid), and highest TSS (17.90°Brix). *A. cerana* also contributed significantly, particularly under multiple visit scenarios, yielding fruit size of 17.10 mm, weight of 7.22 g, acidity of 1.44%, and total soluble solids (TSS) of 16.57°Brix. Though *E. tenax* exhibited lower efficiency, it still played a supplemental role, improving fruit characteristics moderately with repeated visits. Foraging efficiency, measured as time spent per flower, further reinforced the dominance of *A. mellifera* (8.34 seconds/minute/flower) over *A. cerana* (9.38 seconds/minute/flower) and *E. tenax* (11.34 seconds/flower).

Keywords: Acidity, Cherry, Fruit set, Foraging time, Fruit size, Fruit weight, Foraging speed, Total soluble solids (TSS)

INTRODUCTION

Pollination is pivotal in agricultural productivity, especially for crops such as cherry (*Prunus avium* L.), where fruit set and quality largely depend on effective cross-pollination. While cherries possess some self-fertility, cross-pollination, particularly by insect pollinators, is crucial for optimal fruit production (Osterman *et al.,* 2024). The global cherry industry is highly reliant on insect pollinators to ensure the success of its yields, with several studies demonstrating the positive impact of pollinator activity on both fruit quantity and quality (Hünicken *et al.,* 2021). Among the insect pollinators, bees, including honeybees (*Apis mellifera*), bumblebees (*Bombus* spp.), and solitary bees, are recognised as the most efficient agents of cherry pollination. These insects facilitate the transfer of pollen between flowers, thereby enhancing fertilisation and ultimately increasing fruit set (Khalifa *et al.,* 2021). In many parts of the world, particularly in Europe and North America, extensive research has been conducted to evaluate the role of these pollinators in cherry orchards(Rosas-Ramos, Baños-Picón, Tormos and Asís, 2020). For instance, honeybees are known to be highly effective due to their abundance and ability to forage in large numbers. At the same time, bumblebees are valued for their ability to pollinate under cooler temperatures, which is advantageous during the cherry flowering season in temperate regions. Solitary bees, such as Osmia spp., have also been identified as important contributors, with some species showing remarkable efficiency in pollinating cherry blossoms (Khalifa *et al.,* 2021).

Furthermore, studies have shown that orchards with diverse pollinators tend to exhibit better fruit sets and higher-quality cherries, as pollinator diversity ensures greater cross-pollination (Katumo *et al.,* 2022). However, in many regions, including the Kashmir Valley in India, the role of insect pollinators in cherry orchards is less well understood, despite cherries being a key horticultural crop in the region (Tanda, 2022). Kashmir is one of the largest producers of sweet cherries in India, and its unique climate, characterized by cold winters and temperate summers, provides ideal conditions for cherry cultivation (Ahmad *et al.,* 2021). The cherry orchards in Kashmir are predominantly smallholder systems where traditional practices are often employed. In recent years, there has been growing interest in the contribution of insect pollinators to fruit production, particularly as the agricultural sector in the region faces challenges from changing climate patterns and environmental stressors (Dar, 2021). In the Kashmir Valley, wild and managed honeybees are the primary pollinators in cherry orchards. Due to the cooler climate during the cherry bloom period, other pollinators, such as bumblebees, also play an essential role. Their ability to forage in cooler conditions can complement the activity of honeybees, especially during early spring when temperatures may not be optimal for honeybee activity (Paray *et al.,* 2015). However, research on the diversity and abundance of pollinators in Kashmiri cherry orchards is still in its infancy. The traditional reliance on honeybees in the region has led to the largely overlooked status of other insect pollinators, such as solitary bees and flies (Katumo *et al.,* 2022). This has led to a gap in understanding the full range of pollinators that contribute to cherry fruit set and quality in this specific agroecosystem. One of the critical ways that insect pollinators enhance fruit set in cherries is by promoting cross-pollination (Osterman *et al.,* 2024).

Cherries exhibit a degree of self-incompatibility, meaning pollen from the same plant or clone is less likely to result in successful fertilization. Cross-pollination, facilitated by insect pollinators, ensures genetic diversity and higher fertilisation rates, resulting in a greater proportion of flowers developing into fruits (Muñoz-Sanz *et al.,* 2020). Furthermore, pollinator activity influences the number of fruits and their quality. Well-pollinated cherries tend to be larger, more uniform and have better flavor and shelf life, all of which are important factors in commercial cherry production (Osterman *et al.,* 2024). The importance of pollinators in enhancing cherry fruit quality cannot be overstated, especially in regions like Kashmir, where agriculture is a significant part of the local economy. Poor pollination can lead to a range of problems, such as smaller fruit size, increased fruit drop, and reduced market value (Khalifa *et al.,* 2021). Moreover, cherries that do not receive adequate pollination often have lower sugar content and inferior overall quality, which directly affects their appeal in both local and export markets. In this context, maintaining healthy populations of insect pollinators is crucial for ensuring high-quality fruit yields that meet the demands of both domestic and international consumers (Khalifa *et al.,* 2021). Thus, insect pollinators play a critical role in the successful cultivation of cherries worldwide, enhancing both fruit set and quality. In regions like Kashmir, where cherry production is a significant economic activity, understanding and supporting pollinator populations is crucial for sustaining yields and ensuring high -quality fruit production (Klaus *et al.,* 2024).

The present study aimed to investigate the role of major insect pollinators in cherry orchards, focusing on their effectiveness in improving fruit set and quality. The study aimed to assess the effectiveness of different insect pollinators, including honeybees (*Apis mellifera* and *Apis cerana)* and *Syrphid flies (e.g., Eristalis tenax*), on the fruit set and the quality of cherries *(Prunus avium L.*).

MATERIALS AND METHODS

The present study was undertaken at 04 districts of Kashmir valley viz, Srinagar, Ganderbal, Baramullah and Shopian and the collection sites (Districts) were selected based on the maximum land under cherry orchard cultivation in Kashmir Division (Fig. 1). The contributions of three key pollinators *Apis mellifera*, *Apis cerana*, and *Eristalis tenax* on the fruit set and fruit quality of sweet cherry were systematically evaluated during the study.

Experimental design

The study employed a randomized block design (RBD) to ensure rigorous and reliable results, thereby minimising variability and enhancing statistical accuracy. The experimental setup consisted of six distinct treatments, and each replicated three times to facilitate meaningful comparisons and statistical validation. Three cherry trees were randomly chosen within the selected experimental cherry orchards, and three flowering twigs were selected from each tree for the treatments. This meticulous approach ensured representative sampling and consistent application of treatments. The six treatments were designed to examine how varying numbers of pollinator visits influenced key parameters such as fruit set, weight, size, total soluble solids (TSS), and acidity,

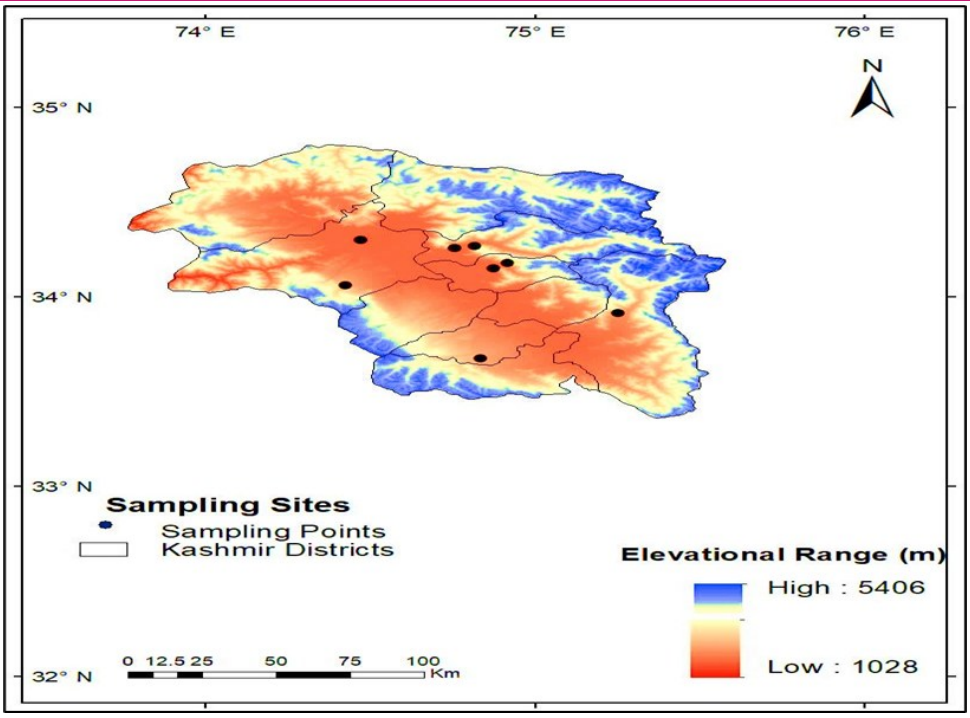

Fig. 1. *Study area map illustrating the geographical layout of the Kashmir Valley region, emphasizing the four districts viz; Srinagar, Ganderbal, Baramullah, and Shopian, significant for cherry cultivation; Each district is distinctly marked, showcasing two locations in each district, selected based on the maximum land under cherry cultivation*

following the previous methodology (Montiel, Serrano, Martinez-Romero, and Alburquerque, 2010). To eliminate competition from other pollinators and maintain controlled conditions, *Apis mellifera* and *Apis cerana* colonies were strategically placed near selected trees in cherry orchards. These cherry trees were subjected to the treatments and continuously monitored from flowering until fruit set.

On the other hand, Syrphid flies were collected from almond trees two to three days before the onset of cherry bloom, and due to the difficulty of identifying *Eristalis tenax* in the field, specimens were transported to the laboratory for accurate identification by experts based on external morphology, confirming 35 specimens. These flies were housed in insect-ventilated containers (25 cm x 25 cm x 25 cm) with access to sugar solution or honey water, placed on moist cotton balls. To maintain their active state, hoverflies were allowed to feed and groom in a Thermostatic Entomological Chamber to ensure their health and longevity. Syrphid flies, being ectothermic insects, thus remain most active and exhibit better feeding, grooming, and longevity between 12 and 27°C (Morgan *et al.,* 1987). During pre-bloom, cherry buds were bagged to control pollination, with treatments labelled from T_1 to T_6. Six treatments and three replications per tree were given, and *Eristalis tenax*, *Apis mellifera*, and *Apis cerana* were introduced for pollination. The treatments included T_1 (pollinator exclusion), T_2 (single pollination visit), and T_3 (double pollination visit) till T_6 (multiple visits) with bags opened and closed accordingly to ensure visits. Colonies of *Apis cerana* and *Apis mellifera* were placed inside netted enclosures, and the same pollination process was applied. After pollination, flowers were re-bagged to prevent further pollination visits by pollinators, and once fruit began to form, the bags were removed to allow sunlight exposure. Fruits were tagged, left to ripen on the tree, and harvested at full ripeness for quality analysis. This systematic approach allowed the study to draw meaningful insights into the role of pollinators in improving cherry fruit yield and quality.

Pollinator observation and Data collection

The study focused on detailed observations of pollinator behaviour to assess their effectiveness in pollination of cherries. During the peak flowering period, researchers monitored insect activity daily for three hours in the morning (when pollinator activity is typically highest). The following metrics were recorded for each treatment:

Pollinator visits per flower

The number of individual pollinator visits per flower was counted for each treatment. Observers recorded the number of times a pollinator landed on a flower, a key indicator of pollination potential (Shiguo *et al.,* 2012).

Duration of pollinator visits

The time each pollinator spent on a flower during each visit was recorded using a stopwatch. This helped assess the thoroughness of pollination, as longer visit durations generally suggest greater pollen transfer

(Paul *et al.,* 2024).

Fruit set and fruit quality measurements

The study focused on evaluating both fruit set and quality. To assess the fruit set, we meticulously counted the number of flowers produced on each cherry tree and recorded the number of fruits that subsequently developed. This measurement provided a direct and quantifiable indication of the effectiveness of pollination for each treatment group. By comparing the number of flowers to the number of fruits, the researchers were able to gauge the success rate of pollination, allowing for a clear understanding of how different pollination strategies influenced fruit development. After data collection, the results underwent rigorous statistical analysis to discern the effectiveness of the various pollinator groups involved in the study. Analysis of Variance (ANOVA) was employed as the primary statistical tool to evaluate significant differences across multiple treatment groups using PAST (PAleontological Statistics, version 4.x+) software. ANOVA allowed the researchers to assess variations in fruit set, size, weight, and sugar content (measured in terms of Total Soluble Solids (TSS) among the different treatments, comprehensively comparing how each pollinator group's activity contributed to the overall fruit quality and yield.

RESULTS

The findings on the contributions of three major pollinators *Apis mellifera*, *Apis cerana*, and *Eristalis tenax* revealed the indispensable role of these pollinators in cherry production, as evidenced by the lack of fruit set and quality in control treatments where pollinators were excluded. While all pollination treatments achieved a 100% fruit set, significant differences in fruit quality parameters were observed (Fig. 1 and Fig. 2), reflecting the influence of each pollinator species and the frequency of their visits.

Among the pollinators, *Apis mellifera* emerged as the most effective, producing the largest fruit size, the highest fruit weight, the lowest acidity, and the highest TSS, owing to its efficient foraging behaviour and strong flower constancy. These results highlight the critical role of *Apis mellifera* and *Apis cerana* in optimizing pollination efficiency and improving fruit quality in cherry orchards.

Table 1 represents the quantitative parameters of cherry fruit, including fruit set, fruit size, fruit weight, total soluble solids (TSS), and acidity, which were measured under various pollination treatments by *Apis cerana*. No fruit development occurred without pollinators (pollinator exclusion), as evidenced by zero values (0.000 ± 0.000) for all parameters.

A single visit by *Apis cerana* resulted in a small fruit size of 16.657 mm, a weight of 5.423 g, a TSS of 12.400 ± 0.611°Brix, and an acidity of 1.740 ± 0.021 pH, indicating some effect of pollination. After two visits, the fruit size increased to 16.860 ± 0.421 mm, the weight increased to 5.837 ± 0.018 g, the TSS increased to 14.233 ± 0.088°Brix, and the acidity decreased slightly to 1.670 ± 0.015 pH. Following three visits, further improvements were noted, including a fruit size of 16.850 ± 0.252 mm, a weight of 6.257 ± 0.009 g, a TSS of 14.333 ± 0.088°Brix, and a reduced acidity of 1.597 ± 0.029 pH. A quadruple visit increased the fruit size to 17.103 ± 0.180 mm, weight to 6.497 ± 0.009 g, TSS to 15.400 ± 0.208°Brix, and lowered acidity further to 1.540 ± 0.038 pH. The most significant improvements were observed with multiple visits by *Apis cerana*, re-

Table 1. Quantitative parameters of cherry fruit *viz*., fruit set, fruit weight, fruit size, total soluble solids (TSS), and acidity with pollination treatments by *Apis cerana*

Treatment	Fruit Set	Fruit Size (mm)	Fruit Weight (g)	**TSS** (°Brix)	Acidity (Citric acid pH)
Pollinator Exclusion	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Single Visit by *Apis cerana*	0.010±0.000	16.657±0.633	5.423±0.402	12.400±0.611	1.740±0.021
Double Visit by *Apis cerana*	0.010±0.000	16.860±0.421	5.837±0.018	14.233±0.088	1.670±0.015
Triple Visit by *Apis cerana*	0.010±0.000	16.850±0.252	6.257±0.009	14.333±0.088	1.597±0.029
Quadruple Visit by *Apis cerana*	0.010±0.000	17.103±0.180	6.497±0.009	15.400±0.208	1.540±0.038
Multiple Visits by *Apis cerana*	0.010±0.000	17.927±0.015	7.220±0.012	16.567±0.285	1.443±0.064
		SD: 0.821 CD: 0.694 CV: 5.77 SE(m): 0.250	SD: 0.403 CD: 0.208 CV: 7.74 SE(m): 0.075	SD: 0.716 CD: 0.592 CV: 5.89 SE(m): 0.213	SD: 0.084 CD: 0.077 CV: 6.30 SE(m): 0.028

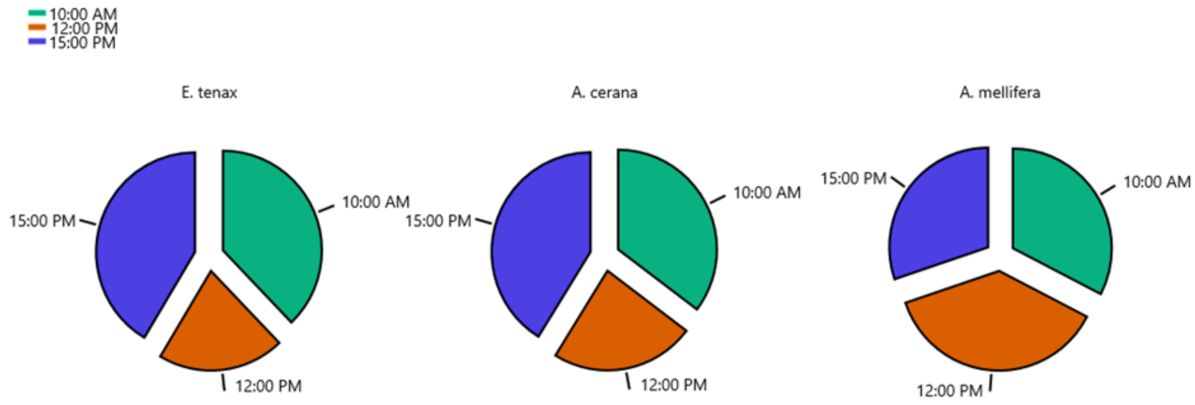

Fig. 2. *Illustrating the foraging rates of three key insect pollinators Apis mellifera, Apis cerana, and Eristalis tenax in cherry orchards. The foraging rate is measured as the average number of flowers visited per second or minute during three specific times: 10:00 a.m., 12:00 p.m., and 3:00 p.m. Among the pollinators, A. mellifera exhibiting the highest foraging rate, visiting the maximum number of flowers, making it the most efficient pollinator. It is followed by A. cerana and E. tenax with the lowest rate*

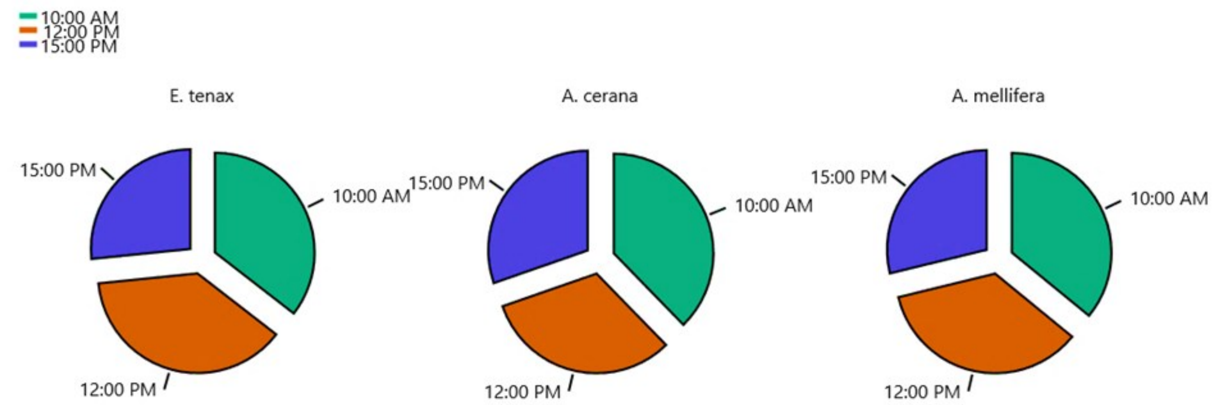

Fig. 3. *Showing the foraging speed of insect pollinators of cherry, measured as Time spent/flower/minute. These charts highlight the variation in time spent per flower across different hours for each pollinator species. The data imply that A. mellifera is the most effective pollinator in terms of foraging speed, as it spends the least amount of time on each flower, followed by A. cerana and E. tenax, which spend more time per flower*

sulting in a fruit size of 17.927 ± 0.015 mm, weight of 7.220 ± 0.012 g, TSS of 16.567 ± 0.285°Brix, and the lowest acidity of 1.443 ± 0.064 pH.

Statistical analysis revealed the following: for fruit size, , the critical difference (CD) was 0.694, the coefficient of variation (CV) was 5.77%, and the standard error (SE) was 0.250. For fruit weight, the coefficient of determination (CD) was 0.208, the coefficient of variation (CV) was 7.74%, and the standard error (SE) was 0.075. The TSS parameter had a standard deviation (SD) of 0.716, coefficient of determination (CD) of 0.592, coefficient of variation (CV) of 5.89%, and standard error (SE) of 0.213. For acidity, CD was 0.077, CV was 6.30%, and SE was 0.028. These results underscore the importance of *Apis cerana* as a pollinator, with multiple visits showing significant increases in cherry fruit quality and yield, particularly in terms of fruit size, weight, and total soluble solids (TSS). The statistical values confirm the reliability and consistency of the data.

Table 2 represents the quantitative parameters of cherry fruit, including fruit set, fruit size, fruit weight, total soluble solids (TSS), and acidity, which were analysed under varying pollination treatments by *Apis mellifera*. No fruit development occurred without pollinators (pollinator exclusion), as reflected in the zero values (0.000 ± 0.000) for all parameters. A single visit by *Apis mellifera* resulted in the initial fruit set, with fruit sizes of 16.820 ± 0.500 mm, weights of 5.120 ± 0.300 g, total soluble solids (TSS) of 13.600 ± 0.550°Brix, and acidity levels of 1.520 ± 0.018 pH. Doubling the visits led to slight improvements, with a fruit size of 17.020 ± 0.400 mm, weight of 8.820 ± 0.020 g, TSS of 14.500 ± 0.080° Brix, and acidity reduced to 1.450 ± 0.014 pH. With triple visits, the parameters improved further, yielding a fruit size of 17.100 ± 0.250 mm, a weight of 5.650 ± 0.010 g, a TSS of 15.700 ± 0.085°Brix, and an acidity of 1.380 ± 0.026 pH. Quadruple visits further enhanced

Table 2. Quantitative parameters of cherry fruit *viz.*, fruit set, fruit weight, fruit size, totalsoluble solids (TSS), and acidity with pollination treatments by *Apis mellifera.*

Treatment	Fruit Set	Fruit Size (mm)	Fruit Weight (g)	TSS (°Brix)	Acidity (Citric acid pH)
Pollinator Exclusion	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Single Visit by *Apis mellifera*	0.010±0.000	16.820±0.500	5.120±0.300	13.600±0.550	1.520±0.018
Double Visit by *Apis mellifera*	0.010±0.000	17.020±0.400	5.520±0.020	14.500±0.080	1.450±0.014
Triple Visit by *Apis mellifera*	0.010±0.000	17.100±0.250	6.650±0.010	15.700±0.085	1.380±0.026
Quadruple Visit by *Apis mellifera*	0.010±0.000	17.250±0.200	7.700±0.010	16.800±0.200	1.220±0.035
Multiple Visits by *Apis mellifera*	0.010±0.000	18.000±0.010	8.820±0.011	17.900±0.270	1.120±0.062
		SD: 0.716 CD: 0.34 CV: 4.98 SE(m): 0.292	SD: 0.301 CD: 0.09 CV: 6.50 SE(m): 0.123	SD: 0.655 CD: 0.29 CV: 5.01 SE(m):0.267	SD: 0.079 CD: 0.038 CV: 7.01 SE(m): 0.032

Table 3. Quantitative parameters of cherry fruit *viz.*, fruit set, fruit weight, fruit size, total soluble solids (TSS), and acidity with pollination treatments by *Eristalis tenax*

Treatment	Fruit Set	Fruit Size (mm)	Fruit Weight (g)	TSS (°Brix)	Acidity (Citric acid pH)
Pollinator Exclusion	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000	0.000±0.000
Single Visit by *Eristalis tenax*	0.010±0.000	14.000±0.600	4.000±0.300	8.000±0.500	2.800±0.020
Double Visit by *Eristalis tenax*	0.010±0.000	15.000±0.500	4.200±0.200	9.500±0.400	2.750±0.018
Triple Visit by *Eristalis tenax*	0.010±0.000	15.500±0.400	4.400±0.100	10.500±0.300	2.300±0.015
Quadruple Visit by *Eris-talis tenax*	0.010±0.000	16.000±0.300	4.500±0.100	11.000±0.200	2.000±0.010
Multiple Visits by *Eristalis tenax*	0.010±0.000	16.500±0.200	4.600±0.100	12.000±0.200	1.970±0.010
		SD: 0.33 CD: 0.38 CV: 2.60 SE(m): 0.14	SD: 0.13 CD: 0.15 CV: 3.64 SE(m): 0.05	SD: 0.27 CD: 0.30 CV: 3.14 SE(m): 0.11	SD: 0.012 CD: 0.014 CV: 0.62 SE(m): 0.005

the metrics, achieving a fruit size of 17.250 ± 0.200 mm, a weight of 5.700 ± 0.010 g, a TSS of 16.800 ± 0.200°Brix, and an acidity level lowered to 1.220 ± 0.035 pH. Multiple visits by *Apis mellifera* produced the best results, with a fruit size of 18.000 ± 0.010 mm, weight of 5.820 ± 0.011 g, TSS of 17.900 ± 0.270°Brix, and the lowest acidity of 1.120 ± 0.062 pH.

Statistical analysis confirmed the trends, with the following observations: a critical difference (CD) of 0.34, a coefficient of variation (CV) of 4.98%, and a standard error (SE) of 0.292 were recorded for fruit size. For fruit weight, the coefficient of determination (CD) was 0.09, the coefficient of variation (CV) was 6.50%, and the standard error (SE) was 0.123. Similarly, TSS exhibited an SD of 0.655, a CD of 0.29, a CV of 5.01%, and an SE of 0.267. Acidity parameters showed a coefficient of determination (CD) of 0.038, a coefficient of variation (CV) of 7.01%, and a standard error (SE) of 0.032. These results highlight the crucial role of *Apis mellifera* in enhancing cherry fruit quality and yield, with multiple pollination visits yielding the most significant improvements across all parameters.

Table 3 represents the quantitative parameters of cherry fruit, including fruit set, fruit size, fruit weight, total soluble solids (TSS), and acidity, which were examined under pollination treatments by *Eristalis tenax*. No fruit development occurred without pollinators (pollinator exclusion), as indicated by zero values (0.000 ± 0.000) across all parameters. A single visit by *Eristalis tenax* resulted in an initial fruit set, with fruit sizes of 14.000 ± 0.600 mm, weights of 4.000 ± 0.300 g, TSS of 8.000 ± 0.500°Brix, and acidity of 2.800 ± 0.020 pH. Doubling the visits improved these values, with a fruit size of 15,000 ± 0.500 mm, a weight of 4,200 ± 0.200 g, a TSS of 9,500 ± 0.400°Brix, and a slight reduction in acidity to 2.750 ± 0.018 pH. With triple visits, further enhancement was observed, recording a fruit size of 15.500 ± 0.400 mm, weight of 4.400 ± 0.100 g, TSS of 10.500 ±

0.300°Brix, and acidity reduced to 2.300 ± 0.015 pH. Quadruple visits yielded even better results, achieving a fruit size of 16,000 ± 0.300 mm, a weight of 4,500 ± 0.100 g, a TSS of 11,000 ± 0.200°Brix, and a further drop in acidity to 2.000 ± 0.010 pH. The best results were observed with multiple visits by *Eristalis tenax*, which produced fruit with a size of 16.500 ± 0.200 mm, a weight of 4.600 ± 0.100 g, a TSS of 12.000 ± 0.200° Brix, and the lowest acidity at 1.970 ± 0.010 pH.

Statistical analysis supported these findings. For fruit size, the critical difference (CD) was 0.38, the coefficient of variation (CV) was 2.60%, and the standard error (SE) was 0.14. For fruit weight, the coefficient of determination (CD) was 0.15, the coefficient of variation (CV) was 3.64%, and the standard error (SE) was 0.05. The TSS results showed a CD of 0.30, a CV of 3.14%, and an SE of 0.11. For acidity, the CD was 0.014, the CV was 0.62%, and the SE was 0.005.These results highlight the role of *Eristalis tenax* in cherry fruit development, with multiple visits providing significant improvements across all parameters. However, compared to *Apis cerana* and *Apis mellifera*, the overall contributions of *Eristalis tenax* were relatively modest, emphasizing the importance of species-specific pollination efficiencies.

DISCUSSION

The results of this study highlight the vital contribution of insect pollinators to enhancing both fruit set and fruit quality in cherry orchards, reinforcing their importance for sustainable horticultural systems (Bartomeus *et al.,* 2014). The lack of fruit set and optimal quality in control treatments clearly emphasizes the essential role of biotic pollination, a finding consistent with prior research on the dependency of temperate fruits on insect pollinators (Hünicken *et al.,* 2021). While all pollination treatments resulted in complete fruit set (100%), significant variations in fruit quality metrics were recorded depending on the pollinator species and the frequency of their visits. Among the tested pollinators, *Apis mellifera* proved to be the most effective, yielding the largest fruit (18.00 mm), highest fruit weight (8.82 g), lowest acidity (1.12% citric acid), and the highest sugar content (TSS, 17.90°Brix). These results are attributed to its superior foraging efficiency and strong floral constancy. This is also in conformity with the results of various pollination methods on fertilization processes and fruit yield in passion fruit where Chinese bee pollination facilitated fruit development, enhanced both external and internal fruit quality, and improved amino acid content. (Pan *et al.,* 2025). *Apis cerana* also made noteworthy contributions, particularly under conditions of repeated visits, improving both fruit size (17.10 mm) and weight (7.22 g), as well as acidity (1.44%) and total soluble solids (TSS) (17.90°Brix). Although *Eristalis tenax* performed less effectively in comparison, its role as an auxiliary pollinator was evident. Repeated visits by this species resulted in improved fruit size (16.50 mm), weight (4.60 g), acidity (1.97%), and total soluble solids (TSS) (12.00°Brix), aligning with earlier studies on the valuable pollination services offered by the order Diptera (Osterman *et al.,* 2021). Additionally, all pollinator treatments showed a consistent decline in fruit acidity with increasing visits, further enhancing fruit quality and market appeal. Temporal foraging dynamics also significantly influenced pollination success. As illustrated in Fig. 2, *Apis mellifera* exhibited the highest foraging rate during the cooler morning and midday hours, while *Apis cerana* showed peak activity in the afternoon. *Apis mellifera* maintained consistent activity, but with a noticeable decline during midday, likely due to its sensitivity to temperature and light intensity, as has been shown in studies on honey bees' response to heat and temperature (Jhawar *et al.,* 2019). This temporal variation highlights the complementary roles of different pollinator species, indicating that diverse pollinator populations are crucial for ensuring continuous and efficient pollination throughout the day.The findings presented in Figs. 2 and 3 emphasize the critical role of *Apis mellifera* in the pollination dynamics of cherry orchards. Although *Eristalis tenax* exhibited higher foraging rates during the morning and midday hours, *A. mellifera* demonstrated consistent and reliable pollination throughout the day. At 10:00 AM, *A. mellifera* recorded a foraging rate of 1.62, greater than *E. tenax* (1.32), and its foraging rate remained consistent throughout the afternoon (1.50 at 3:00 PM). Despite the varying environmental conditions, this consistency in foraging activity highlights *A. mellifera*'s adaptability to different times of day and its role as a steady contributor to cherry pollination. The foraging speed data further illustrates *A. mellifera*'s importance as a reliable pollinator. *A. mellifera* spent less time per flower (8.34 seconds on average) than *E. tenax* (11.73 seconds). This faster rate makes bees efficient pollinators, as they gather nectar and pollen more rapidly, which is particularly beneficial in ensuring the quality and success of pollination. This is based on the statement that, on average, bee-pollinated plants produce 40% more fruits than artificially pollinated plants (Sáez *et al.,* 2019). In the context of the orchard ecosystem, *A. mellifera* and *A. cerana* play a crucial role by providing consistent pollination across the day, contributing to the overall health and productivity of the orchard. This highlights the necessity of *A. mellifera* as an indispensable pollinator for cherry orchards, where its presence helps to balance pollination efforts across varying environmental conditions. The results of this provides valuable insights into optimising pollination services in cherry orchards, thereby contributing to both ecological conservation and agricultural productivity. By understanding which pollinators are most efficient and how they influence the reproductive success of cherry trees, we can develop targeted strategies to promote sustainable fruit production in future.

Conclusion

This study highlights the crucial role of insect pollinators in enhancing both fruit set and quality in cherry orchards, providing valuable insights for sustainable horticultural practices. Using a carefully designed Randomised Block Design (RBD) with six treatments and three replications, the research assessed the contributions of three key pollinators *Apis mellifera*, *Apis cerana*, and *Eristalis tenax* highlighting the indispensable role these pollinators play in cherry production. The lack of fruit set and quality in control treatments strongly reinforced the necessity of pollinators for successful cherry cultivation. Among the three studied pollinators, *Apis mellifera* proved most effective, producing the largest fruits with highest weight, more total soluble solids (TSS), and lowest acidity due to its efficient foraging behavior and high flower constancy. *Apis cerana* significantly enhanced fruit quality through multiple visits, while *Eristalis tenax* served as a valuable supplementary pollinator. Their complementary foraging schedules (with *E. tenax* most active in morning and midday, *A. cerana* peaking in afternoon, and *A. mellifera* foraging consistently all day) ensured steady rate of pollination coverage. Notably, *A. mellifera* showed superior pollination efficiency with the highest foraging rate and lowest foraging speed. These findings highlight that maintaining pollinator diversity, by incorporating *Apis mellifera* and *Apis cerana* into their orchard management strategies, growers can optimise pollination efficiency, enhance fruit quality, and contribute to the long-term sustainability of cherry production. This research further reinforces the essential role of *Apis* species in cherry orchards, emphasizing their reliability and consistency in supporting orchard productivity across varying environmental conditions.

Conflict of interest

The authors declare that they have no conflict of interest.

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