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RESEARCH ARTICLE
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The Kinds and Abundance of Flower-Visiting Insects and their Impact on the Yield of Cashew (*Anacardium occidentale* L.)

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ABSTRACT

Pollination significantly influences cashew (*Anacardium occidentale L.*) productivity, yet research on pollinating insects in Indonesia remains limited. Through field surveys, this study identified the diversity, abundance, and roles of flower-visiting insects on cashew flowers. Weekly observations of insect activity on flower panicles were conducted to assess their foraging behaviours and impact on fruit set. Open pollination was compared with insect-excluded pollination using nylon mesh bagging. A total of 24 genera from four orders (Hymenoptera, Lepidoptera, Diptera, and Coleoptera) were identified, with *Braunsapis* sp. (48%) and *Eumenes* sp. (26.2%) as the dominant pollinators. Diurnal activity peaked in the morning and declined in the afternoon. No fruit set occurred in bagged flowers, while open pollination achieved a 32% fruit set. These findings highlight the critical role of insect-mediated pollination in cashew production and underscore the need for pollinator-friendly agricultural practices to enhance yield and sustainability.

Keywords: Pollination, Fruit Set, *Braunsapis* sp., Cashew, Yield.

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INTRODUCTION

Cashew (*Anacardium occidentale* L.), a tropical tree crop of the family Anacardiaceae, is widely recognized for its economic and nutritional significance (Salehi et al., 2019; Dakuyo et al., 2022). Cashew nuts are an excellent source of healthy fats, including monounsaturated and polyunsaturated fatty acids, which contribute to heart health (Rico et al., 2016). They are also rich in essential nutrients such as magnesium, copper, and zinc, which play vital roles in bone health, immune function, and metabolism (Fusco et al., 2020). According to recent market analyses, the cashew industry is projected to grow annually, reflecting its economic importance and widespread utilization in food and cosmetic industries (Benevides et al., 2023; Ahmad, 2024).

Native to northeastern Brazil, the cashew tree is now cultivated in numerous tropical and subtropical regions globally (Asna & Menon, 2024). It plays a pivotal role in the economies of cashew-producing countries due to the increasing global demand for its nuts and by-products. According to Jeyavishnu et al. (2021), the surge in global demand for cashew nuts has driven significant improvements in cultivation practices, production systems, and value-added processing. In Indonesia, cashew exports increased from 77,000 tons in 2020 to 102,000 tons in 2021, underlining its economic importance. Despite these advancements, low fruit set and yield instability remain major challenges in cashew production. Factors such as suboptimal pollination, premature fruit drop, and other environmental and biological constraints contribute to these issues, threatening sustainable production (Aliyu, 2008; Olubode et al., 2018).

Pollination is a fundamental ecosystem service that directly impacts crop productivity (Supriyadi et al., 2021; Supriyadi & Bashir, 2024). In cashew, pollination involves the transfer of pollen from the anthers of male flowers to the stigmas of hermaphroditic flowers, a process that relies heavily on insect activity. Cashew flowers produce nectar and emit specific floral cues to attract pollinators, including bees, wasps, and other insects (Kuukyi & Wiafe, 2016; ZariMan et al., 2022). The reliance on insect pollinators

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makes understanding their behavior and interaction with cashew flowers critical for improving fruit set and yield. Cashew flowers, organized into panicles, consist of male and hermaphroditic flowers, with only a small percentage (7.3%) developing into fruits (Pereira et al., 2023). This low fruit set is primarily attributed to inadequate pollination (Eradasappa & Mohana, 2016; Palei et al., 2019). Although cashew flowers are capable of self-pollination, cross-pollination mediated by insect pollinators is essential for enhancing fruit set and overall productivity (Freitas & Paxton, 1998; Layek et al., 2021). Evidence suggests that promoting pollinator activity can substantially improve cashew yields. For instance, the introduction of beehives in cashew orchards has been reported to significantly enhance pollination efficiency in several regions, including Africa and Asia (Layek et al., 2021; Silué et al., 2021).

The role of insect pollinators in cashew production is both critical and multifaceted. Insects not only facilitate pollen transfer but also influence the reproductive success of cashew flowers. Key insect pollinators include members of Hymenoptera, Diptera, Lepidoptera, and Coleoptera. Within Hymenoptera, bees such as Braunsapis sp. and Eumenes sp. are among the most significant, given their abundance and frequent visitation to cashew flowers (Vanitha & Raviprasad, 2019; Silué et al., 2021). Studies have demonstrated that insect pollinators exhibit preferences based on flower sex and age, further underscoring the complexity of cashew pollination ecology (Eradasappa & Mohana, 2016). However, the diversity and abundance of flower-visiting insects in cashew plantations are influenced by various factors, including floral characteristics, surrounding vegetation, and agroecological practices (Freitas & Paxton, 1998; Supriyadi et al., 2024).

Indonesia's cashew sector faces unique challenges that highlight the need for localized research on pollination dynamics (Hidayati et al., 2021). Despite being a major producer, studies on the types and roles of flower-visiting insects in Indonesia remain scarce. Understanding the relationship between insect activity and cashew yield is crucial for devising effective management strategies to enhance pollination services. As noted by Silué et al. (2022), optimizing pollination in agricultural systems requires a comprehensive understanding of the interactions between plants and their pollinators, particularly under varying environmental conditions.

Recent research has emphasized the importance of pollinator-friendly practices in improving cashew yields. For example, planting nectar-rich companion crops and minimizing pesticide usage have been shown to enhance pollinator populations in orchards (Layek et al., 2021). Additionally, the preservation of natural habitats surrounding cashew plantations is critical for maintaining pollinator diversity and abundance. In Côte d'Ivoire, Silué et al. (2022) observed that proximity to natural habitats significantly increased the diversity of flower-visiting insects, resulting in improved fruit set. These findings underscore the need to integrate ecological considerations into cashew farming practices.

Climate change further complicates the relationship between pollinators and cashew production. Rising temperatures, altered precipitation patterns, and habitat loss pose significant threats to pollinator populations globally (Lawson & Rands, 2019; Janousek et al., 2023; Brunet & Fragoso, 2024). In tropical regions like Indonesia, such climatic shifts may disrupt the timing of cashew flowering and pollinator activity, leading to reduced yields. Thus, understanding how environmental stressors affect pollinator behavior and plant-pollinator interactions is essential for developing resilient agricultural systems.

The present study aims to address the knowledge gap by identifying the types and abundance of insect visitors to cashew flowers in Indonesia and assessing their contributions to fruit set formation. Unlike previous studies conducted in other regions, this research focuses on the specific conditions and challenges of cashew farming in Indonesia. By documenting the diversity, abundance, and activity patterns of flower-visiting insects, this study seeks to provide insights into the ecological requirements of cashew pollination. Furthermore, it highlights the potential of targeted pollination management practices to enhance cashew productivity sustainably.

MATERIALS & METHODS

Research Location

The research was conducted in a local cashew plantation in Gemawang Village, Wonogiri, Central Java, located at 7°52'45.7"S latitude and 111°01'44.4"E longitude (Fig. 1). The cashew trees in this plantation are between 15 and 25 years old. Fertilization was done between the cashew trees, where seasonal crops were also planted. No pesticides were sprayed on either the seasonal crops or the cashews. Observations were carried out from September to November 2023, during the peak of flowering, when more than 50% of the trees were blooming simultaneously.

Kind and Abundance of Flower Visiting Insects

Observations of flower-visiting insects were carried out using field surveys following the method of Silué et al. (2021), by recording the types and numbers of insects exhibiting activity in search of nectar or pollen in cashew flowers. Twenty-five inflorescences were randomly selected from 25 cashew plants, observing both male and hermaphroditic flowers. Observations were conducted in the morning (08:00–10:30 am), midday (11:30 am–14:00 pm), and afternoon (15:00 pm–17:30 pm), with each observation lasting threemin per sample unit. Identification of flower-visiting insects was based on descriptions from Borror et al. (1992), Marsh (1994) and Plowes & Patrock (2000) and their status as cashew flower visitors was confirmed according to Vanitha & Raviprasad (2019).

Insect Visit Activity

Observations of diurnal insect activity on cashew flowers were conducted following the method of Silué et al. (2022), with modifications to the observation times. The time each insect visitor spent on a single flower was recorded (from arrival to departure). The duration of visits was visually measured using a stopwatch, starting from the first day the flower bloomed (one day old) until the flower wilted.

Fig. 1: Map showing the research location in Gemawang Village, Wonogiri, Central Java, Indonesia (7°52'45.7"S, 111°01'44.4"E), where the study on flower-visiting insects of cashew (*Anacardium occidentale L.*) was conducted.

The diurnal activity of flower-visiting insects was also recorded by dividing the observation periods into morning (08:00–10:30 am), midday (11:30 am–14:00 pm), and afternoon (15:00–17:30 pm). Additionally, insect visits were identified based on the flower's age stage (from blooming to wilting).

Effect of Insect Pollinators

The impact of insect pollinators on fruit set was estimated by comparing open pollination with pollination under insect exclusion. Insect exclusion was conducted by bagging the inflorescences, while open pollination was observed without bagging. Twenty-five inflorescences were covered with nylon gauze one week before calyx formation and kept covered until all petals had fallen, following the method of Supriyadi et al. (2021).

Data Analysis

Descriptive analysis was based on the identification of insects at the genus level. Population abundance data were presented graphically to express the percentage of each genus of flower-visiting insects, using the formula:

$$RA = \frac{ni}{N}\ x\ 100\%$$

Where: RA = Relative Abundance; ni = Number of individuals of genus n; N = Total number of individuals.

The data on diurnal insect activity on cashews, including the number of insect visits, the average duration of visits, and the number of visits to male and hermaphrodite flowers, were presented using histograms created in Excel 2013 (Windows 10). A pie chart, also created in Excel 2013 (Windows 10), illustrated the percentage of fruit set formation.

RESULTS

Diversity and Abundance of Flower-Visiting Insects

In this study, a total of 24 genera of flower-visiting insects were recorded on cashew (*Anacardium occidentale L.*) flowers, belonging to four orders: Hymenoptera, Lepidoptera, Diptera, and Coleoptera. These insects were further classified into 16 families. The highest diversity of genera was observed within the order Hymenoptera, which included key genera such as *Braunsapis* sp., *Eumenes* sp., and *Allorhynchium* sp. (Table 1). Among all insect genera, *Braunsapis* sp. (Apidae) accounted for the highest relative abundance at 48%, followed by *Eumenes* sp. (Vespidae) at 26.2% (Fig. 2). Genera such as *Paratrechina* sp., *Lucilia* sp., and *Ammophila* sp. exhibited lower relative abundances, with less than 10% representation each.

Table 1: Diversity and flower visitation status of insects observed on cashew (*Anacardium occidentale L.*) during the flowering period. The table lists insect genera grouped by their taxonomic orders and families, along with their visitation behavior on male and hermaphrodite flowers

Order	Family	Genus	Status of Flower Visitation	
			Male	Hermaphrodite
Hymenoptera	Apidae:	Braunsapis	V	V
		Xylocopa	NV	V
	Vespidae:	Eumenes	V	V
		Allorhynchim	V	V
		Phimenes	NV	V
	Sphecidae:	Ammophila	V	V
	Formicidae:	Tetraponera	V	V
		Polyrhachis	V	V
		Paratrechina	NV	V
	Scoliidae:	Campsomeris	V	V
	Halictidae:	Pseudapis	NV	V
Lepidoptera	Lycaenidae:	Leptotes	NV	V
		Rapala	NV	V
	Nymphalidae:	Hypolimnas	NV	V
		Ideopsis	V	NV
	Zygaenidae	Artona	V	NV
	Pieridae	Eurema	V	NV
	Hesperiidae	Pelopidas	V	NV
Diptera	Syrphidae	Ischiodon	NV	V
		Asarkina	V	NV
	Calliphoridae	Lucilia	V	NV
	Bombyliidae	Exoprosopa	V	NV
Coleoptera	Chrysomelidae	Colaspoides	V	V
	Coccinellidae	Menochilus	V	V

Note: Visitation status is denoted as "V" (visited) or "NV" (not visited), indicating whether the insect exhibited nectar or pollen foraging activities.

Diurnal Activity of Flower-Visiting Insects

The diurnal activity patterns of flower-visiting insects were assessed across three time intervals: morning (08:00–10:30), midday (11:30–14:00) and afternoon (15:00–17:30). The results indicated that insect activity was highest in the morning, with *Braunsapis* sp. and *Eumenes* sp. being the dominant visitors during this period. Their activity gradually declined through midday and was lowest in the afternoon (Fig. 3). This trend suggests that environmental factors such as temperature and light intensity may influence insect behavior. Other genera, such as *Paratrechina* sp. and *Lucilia* sp., showed limited activity in the morning and almost negligible activity in the afternoon.

Impact of Floral Maturity on Insect Activity

The age of the cashew flowers strongly influenced the number of insect visits and the duration of their visits. On the first day of blooming, an average of 1.64 insects visited each flower per three-minute observation period, with an average visit duration of 0.2min per individual insect (Fig. 4). However, insect activity declined sharply after the second day of blooming and was minimal by the sixth and seventh days of floral maturity. This pattern highlights the short effective pollination period of cashew flowers, which is a critical factor for fruit set formation.

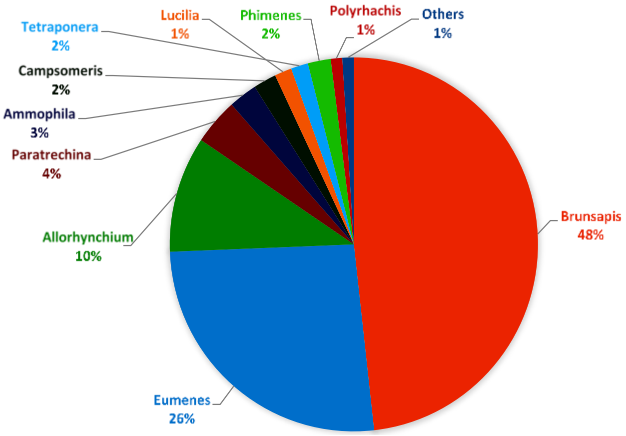

Fig. 2: Relative abundance of flower-visiting insect genera observed on cashew (*Anacardium occidentale L.*) during the flowering period.

Preferences Based on Flower Sex

Insects exhibited differential visitation rates to male and hermaphroditic flowers. The average number of visits to male flowers was recorded at 1.76 visits per three-minute interval, compared to 1.37 visits for hermaphroditic flowers (Fig. 5). However, the average visit duration was longer for hermaphroditic flowers (0.25min) than for male flowers (0.4min). This suggests that hermaphroditic flowers may offer more attractive nectar or pollen rewards, potentially enhancing their role in cross-pollination.

Effect of Pollination on Fruit Set Formation

The impact of insect pollinators on fruit set was evaluated by comparing open pollination with bagging treatments to exclude insects. The results revealed a significant difference in fruit set between the two treatments. In open pollination, 32% of flowers successfully developed into fruit, while no fruit set was observed in the bagged inflorescences (Fig. 6). Among the open-pollinated flowers, 62% experienced premature fruit drop, and 6% were damaged by pests or other factors. These findings confirm the indispensable role of insect pollinators in ensuring successful fruit formation in cashew.

DISCUSSION

The findings of this study highlight the critical role of flower-visiting insects in the pollination and productivity of cashew (*Anacardium occidentale L.*). The diversity and abundance of pollinators observed, particularly the dominance of *Braunsapis* sp. and *Eumenes* sp. (Table 1, Fig. 1), underscore the importance of maintaining robust pollinator populations for successful cashew cultivation. These results align with previous studies that emphasize the reliance of cashew flowers on insect-mediated cross-pollination to achieve optimal fruit set (Vanitha & Raviprasad, 2019; Silué et al., 2021, 2022).

Identifying 24 genera from four orders—Hymenoptera, Lepidoptera, Diptera, and Coleoptera—demonstrates the ecological complexity of cashew pollination systems. Hymenoptera was the most diverse and abundant order, with *Braunsapis* sp. contributing 48% of the total relative abundance. This dominance of Apidae aligns with findings from studies in Côte d'Ivoire and India, where bee species were identified as the primary pollinators of cashews (Layek et al., 2021; Silué et al., 2022). The observed abundance of *Eumenes* sp. (26.2%) further highlights the role of Vespidae in pollination. These results suggest that conservation efforts targeting Hymenoptera, particularly Apidae and Vespidae families, could significantly benefit cashew productivity. The limited representation of Diptera, Lepidoptera, and Coleoptera aligns with earlier observations that these groups play secondary roles in cashew pollination (Freitas & Paxton, 1998). However, their contribution should not be underestimated, as diverse pollinator assemblages enhance pollination resilience under varying environmental conditions (Knop et al., 2018). This underscores the need for strategies that support a broad spectrum of insect pollinators.

The diurnal activity patterns observed in this study (Fig. 3) showed peak insect activity in the morning, with a gradual decline toward midday and afternoon. These findings are consistent with previous reports indicating that cooler morning temperatures and moderate light levels favor pollinator activity (Yilangai et al., 2015; Silué et al., 2021). The high activity of *Braunsapis* sp. and *Eumenes* sp. during the morning highlights their role as efficient pollinators under favorable environmental conditions. Environmental factors such as temperature and humidity have been shown to significantly influence pollinator behavior (Lawson & Rands, 2019; Janousek et al., 2023; Brunet & Fragoso, 2024). In tropical climates like Indonesia, rising midday temperatures may reduce insect activity, as observed in this study. This highlights the importance of optimizing agricultural practices, such as intercropping with shade-providing plants, to create favorable microclimates for pollinators (Layek et al., 2021).

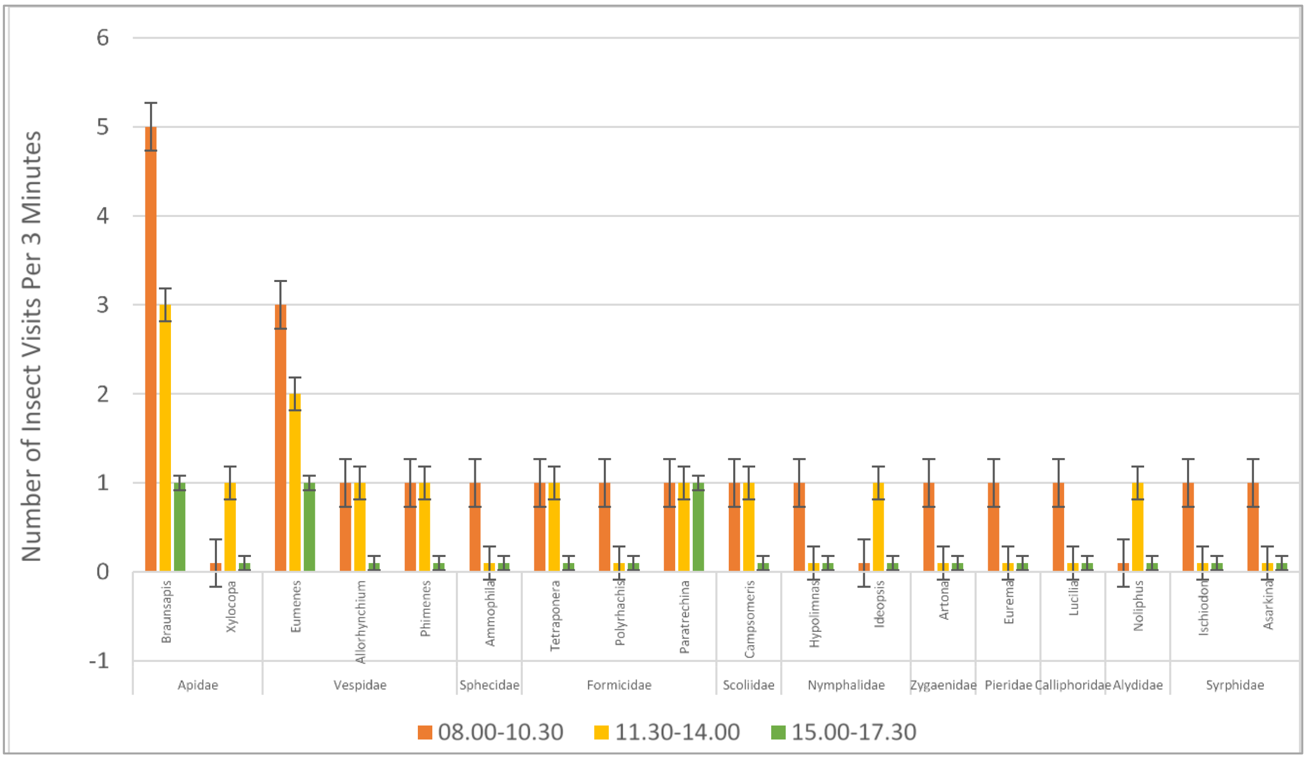

Fig. 3: Diurnal activity of flower-visiting insects on cashew (*Anacardium occidentale L.*) inflorescences observed across three-time intervals: morning (08:00–10:30), midday (11:30–14:00), and afternoon (15:00–17:30).

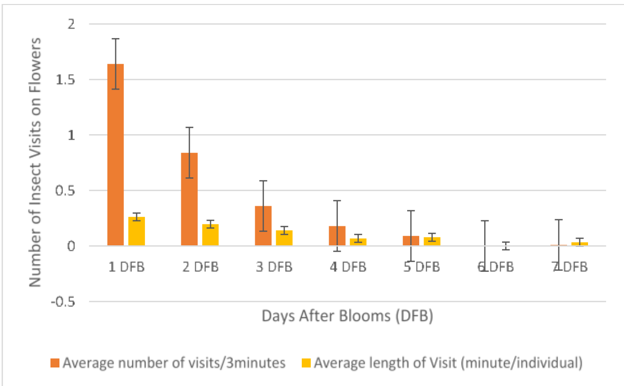

Fig. 4: Number of insect visits (per 3min interval) and the average duration of visits (in min) across different stages of floral maturity, from the day of bloom to flower senescence.

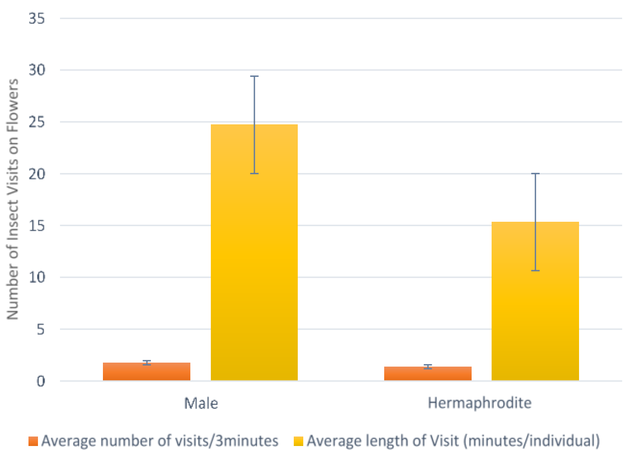

Fig. 5: Average number of insect visits to male and hermaphrodite flowers of cashew (*Anacardium occidentale L.*), and the differences in visitation frequency between flower sexes.

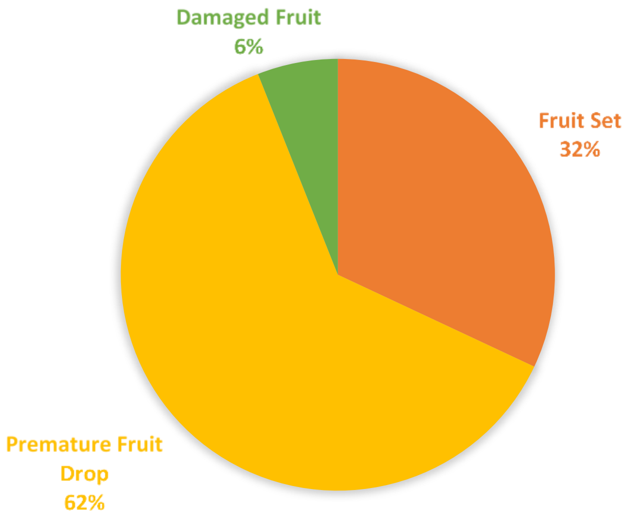

Fig. 6: Percentage of fruit set formation under open pollination conditions in cashew (*Anacardium occidentale L.*), showing the proportion of flowers successfully developing into fruits without controlled pollination methods.

The study revealed interaction between floral maturity and insect activity (Fig. 4). The number of insect visits and visit durations were highest on the first day of blooming, declining sharply after the second day. This finding underscores the importance of the effective pollination period, which is limited to the early stages of floral maturity. Similar results have been reported in studies on other entomophilous crops, where flower age significantly influences nectar and pollen availability, thereby affecting pollinator visitation rates (Eradasappa & Mohana, 2016). The differential visitation rates to male and hermaphroditic flowers observed in this study further emphasize the complex dynamics of cashew pollination. While male flowers received more visits, hermaphroditic flowers had longer visit durations, possibly due to higher nectar or pollen rewards. These findings are consistent with the resource allocation hypothesis, which suggests that flowers offering greater rewards attract longer visits (Silué et al., 2021; Pereira et al., 2023). Understanding these dynamics is crucial for breeding programs aimed at enhancing the attractiveness of hermaphroditic flowers to improve cross-pollination rates.

The significant difference in fruit set between open-pollinated and bagged inflorescences (Fig. 6) highlights the indispensable role of insect-mediated pollination in cashew. The absence of fruit set in bagged treatments aligns with earlier studies demonstrating the reliance of cashew flowers on insect pollinators for successful fertilization (Freitas & Paxton, 1998; Silué et al., 2022). The observed fruit set rate of 32% under open pollination is comparable to findings from other regions, reinforcing the importance of maintaining pollinator populations to ensure crop productivity (Vanitha & Raviprasad, 2019). Premature fruit drop, which affected 62% of open-pollinated flowers, remains a major challenge in cashew production. Factors contributing to fruit drop include inadequate pollination, environmental stressors, and pest damage (Aliyu et al., 2014). Strategies to mitigate fruit drop should focus on enhancing pollinator efficiency and addressing abiotic and biotic stressors.

The findings of this study have important implications for pollinator management in cashew plantations. Promoting pollinator-friendly practices, such as planting nectar-rich companion crops and reducing pesticide use, can enhance pollinator diversity and abundance. Recent studies have shown that integrating wildflower strips and native vegetation into agricultural landscapes can significantly boost pollinator populations (Knop et al., 2018; Silué et al., 2021). In addition to habitat management, addressing climate change impacts is critical for sustaining pollinator activity. Rising temperatures and altered precipitation patterns pose significant threats to pollinator populations and their interactions with cashew flowers (Lawson & Rands, 2019; Janousek et al., 2023; Brunet & Fragoso, 2024). Adaptive strategies, such as introducing climate-resilient pollinator species and implementing agroforestry systems, could mitigate these impacts (Layek et al., 2021).

While this study provides valuable insights into the dynamics of cashew pollination in Indonesia, several limitations should be acknowledged. The observational nature of the study precludes causal inferences regarding specific pollinator behaviors and their effects on fruit set. Future research should focus on experimental approaches, such as controlled pollination studies, to elucidate the mechanisms underlying pollinator preferences and efficiency. Additionally, the influence of landscape-level factors, such as proximity to natural habitats and land-use changes, on pollinator populations warrants further investigation. Studies integrating remote sensing and ecological modeling could provide a more comprehensive understanding of these factors (Knop et al., 2018). Finally, the role of less abundant pollinator taxa, such as Diptera and Coleoptera, in cashew pollination remains poorly understood and should be explored in greater detail.

Conclusion

This study highlights the critical role of insect pollinators in cashew (*Anacardium occidentale* L.) productivity. Pollinator diversity, comprising 24 genera across four insect orders, underscores the ecological complexity of cashew pollination. The dominance of Braunsapis sp. (48%) and Eumenes sp. (26.2%) demonstrates their significance as key pollinators. Diurnal activity peaked in the morning, with both genera exhibiting consistent visitation across floral maturity stages. The absence of fruit set in bagged inflorescences confirms the indispensable role of insect-mediated pollination, with open pollination achieving a 32% fruit set. These findings emphasize the need for pollinator-friendly practices, such as conserving natural habitats and reducing pesticide use, to sustain pollinator populations. Addressing challenges like premature fruit drop and climate change impacts is essential for enhancing cashew yields. Future research should prioritize strategies to improve pollination efficiency and develop resilient agricultural systems for long-term productivity.

Conflict of Interests: The authors declare that there is no conflict of interest.

Author's Contribution: All authors contributed equally to this research work.

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