BIOGENESIS Jurnal Ilmiah Biologi

pISSN 2302-1616, eISSN 2580-2909
Vol 12, No. 1, June 2024, pp. 47-55
Available online http://journal.uin-alauddin.ac.id/index.php/biogenesis
DOI https://doi.org/10.24252/bio.v12i1.42864

The relationship between environmental factors and the diversity and abundance of flower-visitor insects on chili pepper in dry season

Fahma Wardah Sururin[1], Kahar Muzakhar[1], Nida An Khafiyya[1], Purwatiningsih[1*]
[1]Department of Biology, Faculty of Mathematics and Natural Science, Universitas Jember
Jl. Kalimantan No. 37, Sumbersari, Jember, Indonesia. 68121
*Email: purwatiningsih.fmipa@unej.ac.id

ABSTRACT. Approximately 80% of flowering plants are highly dependent on insect pollination, including the chili pepper (*Capsicum frutescens*). Environmental conditions serve as parameters for insects in their activities. Therefore, this study was conducted to determine the diversity and abundance of flower-visiting insects in *C. frutescens* and their environmental factors. Field observations of flower-visiting insects were conducted during the dry season utilizing aerial capture methods. The data was analyzed using diversity, abundance, evenness, and dominance indices equations. Multiple linear regression analysis was also conducted to determine the abiotic and biotic factors (environmental factors) that influence the abundance of flower-visiting insects. The analysis results showed that a moderate trend in the diversity of insect and as many as 33% of the total recorded insect individuals belong to the Vespidae family. The *Allorhynchium argentatum* showed the highest species abundance (27% individuals). Based on the multiple regression analysis results, environmental factors had a non-significant native influence on the abundance of flower-visiting insects. Environmental conditions during the dry season have a weak influence on insect interactions with plants.

Keywords: *Allorhynchium argentatum*; chili pepper; flower-visiting insect; insect diversity; multiple regression

Article History: Received 20 November 2023; Received in revised form 16 May 2024; Accepted 30 May 2024; Available online 30 June 2024.
How to Cite This Article: Sururin FW, Muzakhar K, Khafiyya NA, Purwatiningsih P. 2024. The relationship between environmental factors and the diversity and abundance of flower-visitor insects on chili pepper in dry season. *Biogenesis: Jurnal Ilmiah Biologi*. vol 12(1): 47–55. doi: https://doi.org/10.24252/bio.v12i1.42864.

INTRODUCTION

Pollination is a crucial ecosystem service for both natural ecosystems and agriculture. Reproduction, plant propagation, and fruit development are influenced by the process of pollination (Pardo & Borges, 2020). Insects are a group of animals that inhabit various ecosystems and help the pollination process of plants (Nicholls et al., 2013; Noriega et al., 2018), especially flower-visiting insects. The process of pollination is not only important for plants but also indirectly impacts human food security. Several studies have revealed that global agricultural land productivity is highly dependent on insect pollination (Anoosha et al., 2018; Tolera & Ballantyne).

Approximately 80% of wild flowering plants depend on insect pollination (Hussain et al., 2023). Meanwhile, around 70% (±1500) of plant species are directly utilized by humans as food sources (Pardo & Borges, 2020; Vasiliev & Greenwood, 2020). According to Dunn *et al.,* (2020), harvests dependent on insects were estimated to generate USD 361 billion worldwide in 2012. However, simultaneously, the population of pollinating insects is declining due to climate change, landscape fragmentation, and agricultural intensification (Dun *et al.,* 2020). The composition and species variation of insect communities and their abundance become crucial aspects that can influence their interactions with plants (Goodwin *et al.,* 2021).

Not all flower-visiting insects are pollinators, but most are capable of pollinating (Salisbury *et al.,* 2015). Bees, flies, beetles, butterflies, and moths are common insects that visit flowers (Ollerton, 2017). They collect nectar and pollen, or even just search for prey. These activities have the potential to help pollen fall and adhere to the stigma. The process of flower pollination interaction by insects and the diversity of insects themselves are influenced by several factors, one of which is environmental conditions (Siregar *et al.,* 2016; Goodwin *et al.,* 2021), and climate change (Adams *et al.,* 2020; Outhwaite *et al.,* 2022).

Weather or local environmental conditions directly or indirectly affect insects (Shrestha *et al.*, 2018; Lawson & Rands, 2019; Plos *et al.,* 2023). This is because insects are ectothermic animals (Shrestha *et al.,* 2018). Insects, especially flower-visiting insects, require warm environmental conditions to find food. If the conditions do not allow it, the insects will slow down their body regulation and reduce their activity. Thus, in this case, environmental conditions directly affect insects to consider the energy expended with the food they successfully obtain (Shrestha *et al.* 2018; Lawson & Rands, 2019). In addition, environmental conditions can affect the frequency, behavior, and effectiveness of insects to fly and find food (Shrestha *et al*., 2018). Therefore, we assume that several environmental factors (temperature, humidity, wind speed, rainfall, and light intensity) also affect the diversity and abundance of flower-visiting insects.

Our study focuses on the chili pepper (*C. frutescens*), which is a high-value horticultural crop. This plant is highly favored by Indonesian people as a food ingredient (Olatunji & Afolayan, 2018; Supriadi *et al.,* 2018). The chili flower is a hermaphroditic flower that is capable of self-pollination. However, the chili flower requires insects for cross-pollination to enhance the quality and quantity of its fruit (Chesaria & Syukur, 2018). Therefore, flower-visiting insects become potential pollinator agents for chili pollination. Specific information regarding the diversity of flower-visiting insects on chili pepper (*C. frutescens*) has been limited. Similarly, the relationship between the changing global environmental conditions in Indonesia has not been extensively discussed. Shifting environmental conditions, including rising temperatures and unpredictable rainfall, threaten flowering plants by impacting their bloom times, resource production, and overall diversity (Wolf et al., 2017; Iler et al., 2019). Therefore, climate change could alter insect behavior and pose a potential major threat to pollinator populations, leading to reduced productivity and food security. Based on these considerations, this study aims to analyze the diversity and abundance of flower-visiting insects on *C. frutescens* plants and the influence of biotic and abiotic factors (microclimate) on the abundance of flower-visiting insects. This study establishes a baseline for chili pepper pollination in Indonesia to predict the impact of climate change on pollinator populations and future food security.

MATERIALS AND METHODS

Study area. This research was conducted in Taman Village, Grujugan District, Bondowoso Regency, East Java, Indonesia. The study was carried out in a 1500 m^2 chili plantation with a total of 4000 plants for 5 weeks, starting from October to November 2022 (Fig. 1). The plantation used as the research site was a monoculture plantation planted solely with *C. frutescens* var. Bara. However, around the *C. frutescens* plants, several wild herbaceous plants were growing, dominated by wild grasses. In addition to the wild grasses, two sides of the plantation were covered with elephant grass (*Pennisetum* sp.) and dense creeping plants, while the other two sides border directly with other agricultural fields (corn and rice).

Collection of flower-visiting insect data. The flower-visiting insect data was collected using the scan sampling method to determine the diversity and abundance of flower-visiting insect. Insects were directly collected using an insect net with the sweep method. Insect sampling was conducted weekly from 8.00 am to 2.00 pm (WIB) on sunny days during the study period. Data collection began when the plants were 3 months old until the chili flowers reached the unproductive stage or when approximately 90% of the flowers per plant were no longer forming. The collected insect samples were then identified. Insect identification was conducted by observing insect morphology through the antennae, wings, thorax, and abdomen. Identification was carried out to the family level using the identification keys (Triplehorn & Johnson, 2005; Goulet & Hubber, 1993). Identification to the species level was performed using identification keys and matching the insect collection of the Laboratory of Entomology, National Research and Innovation Agency (BRIN). The collected and identified insects were then counted to determine the number of individuals of each species.

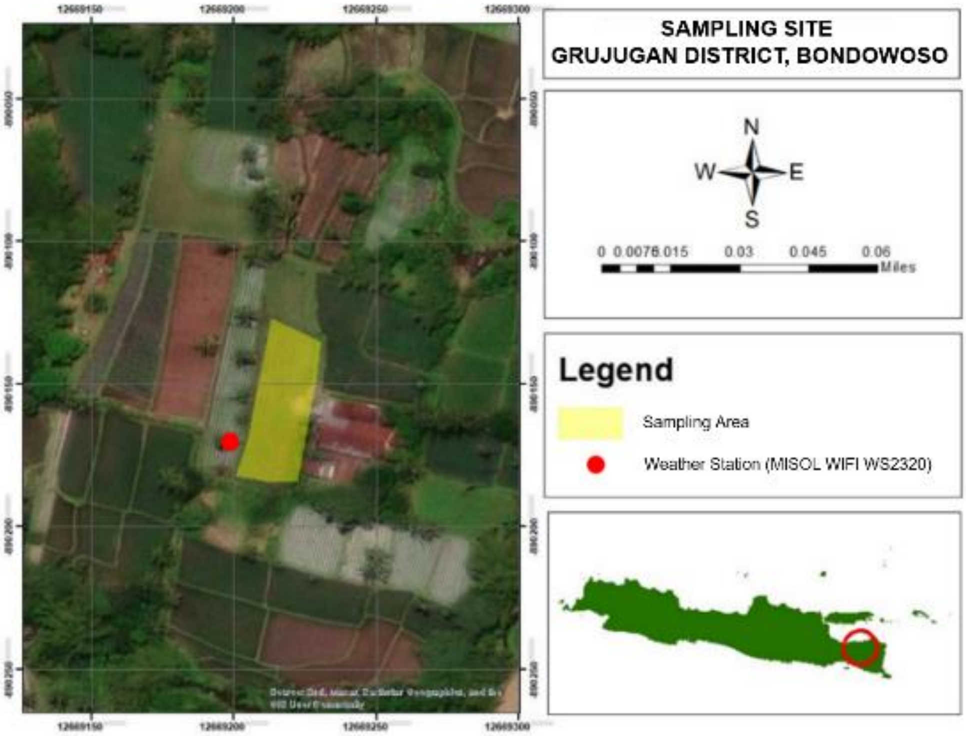

Fig. 1. Location of the data collection

Biotic data collection. Flowers as the focal point for insect visitation on *C. frutescens* were also considered as a biotic factor for flower-visiting insect visitation. The counting was conducted by dividing the land into 5 plots, each consisting of 20 plants. The counted flowers included both fully bloomed and unopened (not bud) flowers. The number of fully bloomed flowers indicates the potential number of flowers for insect visitation. Flower observations and counting were conducted every week during the daytime or after collecting to optimize the count of bloomed flowers.

Abiotic data collection. Abiotic data measurements were conducted using a Weather Station device (MISOL Wifi WS2320) installed at the research site. The observed variables included temperature, humidity, wind speed, rainfall, and light intensity. This weather station has sensors that record all weather changes directly and process them in a microprocessor on the data logger. The processed data results are stored in a logger format (log file). The saved log file contains weather data that can be viewed in an Excel file or visualized in the form of graphs using Ecowitt Weather software. The abiotic data measurements were scheduled to collect data every 5 min over 24 h. The data collected for this study was within the time frame of insect data collection.

Data analysis. The number of flower-visiting insects was then quantitatively analyzed using the Shannon-Wiener diversity index (H'), Relative abundance (Ri), Pielou's evenness index (J'), and Simpson dominance index (D) (Odum, 1993). The daily insect abundance data was analyzed to determine the influence of abiotic and biotic factors on the abundance of flower-visiting insects. The impact of abiotic factors was analyzed through multiple regression analysis while the influence of biotic factors was analyzed through linear regression analysis using R software version 4.1.3.

RESULTS AND DISCUSSION

Diversity and abundance flower-visiting insect. The observation results recorded 33 individual flower-visiting insects on *C. frutescens.* The total flower-visiting insects were divided into 14 species belonging to 5 families, including Apidae, Halictidae, Vespidae, Syrphidae, and Coccinellidae. The Vespidae family was the family with the most individuals found (33%) from 2 species among the community (Table 1).

Table 1. Species and number of flowers visitor insect chili pepper (*Capsicum frutescens*)

Order	Families	Species	Number of Individual	Relative abundance (%)
Hymenoptera	Apidae	*Amegilla* sp.	1	3.03
		Ceratina sp. 12	2	6.06
	Halictidae	*Nomia* sp.	7	21.21
		Nomia strigata	2	6.06
	Vespidae	*Alloryhnchium argentatum*	9	27.27
		Rhynchium haemorhoidalis	2	6.06
Individual subtotals			23	
Species subtotals			6	
Diptera	Syrphidae	*Paragus* sp.	4	12.12
Individual subtotals			4	
Species subtotals			1	
Coleoptera	Coccinellidae	*Coelophora* sp.	1	3.03
		Coelophora maculata ab. Iridea	2	6.06
		Ryszardia deepiens	1	3.03
		Coccinella tranversalis	1	3.03
		Coccinellidae A	1	3.03
Individual subtotals			5	
Species subtotals			5	
Individual total			33	
Species total (S)			12	
Diversity (H’)			2.148	
Evenness (J)			0.865	
Dominance (D)			0.153	

Vespidae is a diurnal, solitary, and social insect in its activity of visiting flowers (Qasim *et al.*, 2022; Palupi *et al.*, 2023). As a pollinator, Vespidae often becomes a secondary pollinator and a specialist pollinator on some types of flowering plants in the ecosystem. Vespidae has a wide range of flower preferences, in line with its characteristics and behavior in visiting flowers (Koneri *et al.*, 2021; Hussain *et al.*, 2023). Meanwhile, the flower-visiting insect with low individual abundance and species number is the Syrphidae family. In this family, only 1 species (*Paragus* sp.) with 12% abundance was recorded. Syrphidae is a family where most of its species are pollinators and predators of small insects, such as aphids and thrips (Dunn *et al.*, 2020; Finch & Cook, 2020). Therefore, its abundance is also influenced by the population of its prey (Dunn *et al.*, 2020; Soli *et al.*, 2020).

The Shannon-Wiener diversity index (H’) of flower-visiting insects in this chili crop indicates moderate diversity (because the value 1<H’>3, H’=2.148). Pielou’s evenness index (J’) shows high evenness with a value of 0.865 (>0.7) and a low dominance value of 0.153 (<1) (Table 1). This moderate diversity is due to the presence of wild flowering plants can be an alternative food source for insects (Purwantiningsih *et al.* 2012; Alfawwaz *et al.*, 2022). Some of these wild flowering plant species include *Acmella* sp., *Cleome rutidosperma*, and *Mazus pumilus.* In addition, the presence of aphid and thrips populations also attracts some flower-visiting insects that are predators, such as Syrphidae (Dunn *et al.*, 2020; Finch & Cook, 2020; Soli *et al.*, 2020) and Coccinellidae (Mishra & Kanwat, 2018; Gnatiuk *et al.*, 2023).

The stability of evenness is also supported by its low dominance value. According to Alfawwaz *et al.*, (2022), evenness is related to dominance; if evenness is stable, the dominance will be low. Low dominance indicates the absence of any dominating insect in the distribution of the flower-visiting insect population, resulting in relatively stable evenness in the community. Moderate diversity, stable evenness, and low dominance in the chili pepper crop of the same genus, *Capsicum annuum* crop.

Alingan *et al.*, (2023) reported that *Capsicum annuum* crop also has moderate diversity, stable evenness, and low dominance.

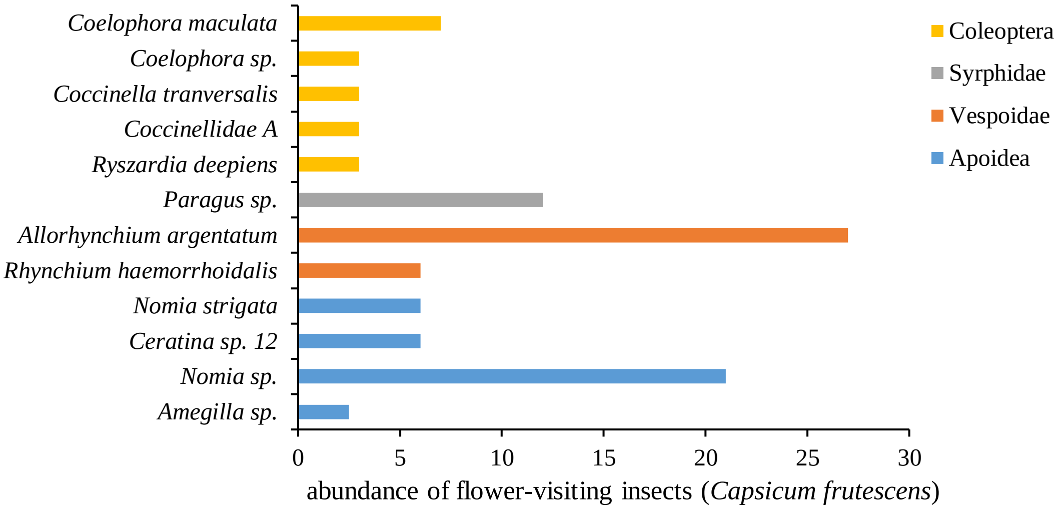

Fig. 2. The abundance of insect species visiting insect *Capsicum frutescens* flowers

The highest abundance is shown by *Allorhynchium argentatum* (23.6%), while the lowest is *Amegilla* sp. and most species in the Coccinellidae family (2.33%) (Table 1, Fig. 2). *A. argentatum* is a solitary bee species known as the potter wasp (Hussain *et al.*, 2023). During its visit, *A. argentatum* can spend an average of 5-10 seconds per flower. *Allorhynchium argentatum* has never been reported to visit flowers on plants in agricultural ecosystems. Koneri *et al.* (2021), and Hussain *et al.* (2023) mentioned that *A. argentatum* is often found in forest ecosystems as a generalist pollinator. This is also supported by the morphology of *A. argentatum*, which has fine hairs on its head, thorax, and abdomen. The fine hairs on the head and thorax of this Vespidae are used as a place for pollen attachment (Palupi *et al.*, 2023). So, the abundance of insects visiting flowers is likely related to the number of flowers.

Regression analysis showed that insect abundance had a non-significant negative effect on insect abundance (Table 2). This contradicts the findings of Cholis *et al.*, (2020), who explained that a higher number of flowers leads to a stronger attractant that draws visiting insects. The non-significant negative effect in this study may be due to the relatively low number of insect individuals found, and the peak period of flower abundance and insect presence may not have been observed.

Table 2. Result of regression test on the abundance of flower-visiting insects and the number of flowers

Variable	Estimate	Std. Error	t value	p-value
(Intercept)	28.078	4.308	6.518	0.00734**
Flower	-0.0106	0.0052	-2.056	0.13206

Note: ** (significant 0.001)

Vespidae and other species of Hymenoptera are attracted to yellow and white flowers. The visual perception ability of Vespidae can only see colors in the wavelength range of 300-500 nm (represents purple-blue-green) (Van der Kooi *et al.*, 2021). White flowers can absorb UV light, so they will appear purple to Vespidae and other insects (Papiorek *et al.*, 2016; Narbona *et al.* 2021). In addition to attracting Vespidae this purple wavelength can also attract other insect groups in the Hymenoptera and Diptera orders (Van der Kooi *et al.*, 2021). The abundance and diversity of insects are also likely influenced by volatile compounds in floral nectar (FN) that plants release to signal pollinating insects. FN contains carbohydrates and amino acids that insects need (Heil, 2011).

Insect abundance and environmental factors. Environmental factors recorded during the study were humidity in the 82-91% range, temperature 24-25°C, wind speed 0.2-0.8 m/s, rainfall 0-7 mm/day, and light intensity 16400-27875 lux. Based on the analysis, all environmental factors had a non-significant negative effect on insect abundance. This is indicated by negative estimate values and a p-value of more than 0.05 (Table 3).

Table 3. Result of multiple regression test on the abundance of flower-visiting insects and abiotic factors

	Estimate	Std. error	z value	p-value
(Intercept)	2.08059	86.108	0.024	0.981
Temperature (°C)	-1.2978	62.123	-0.021	0.983
Humidity (%)	-0.0022	0.0187	-0.119	0.905
Wind Speed (m/s)	-0.7158	4.2897	-0.167	0.867
Rainfall (mm)	-0.3584	3.9726	-0.090	0.928
Light Intensity (lux)	-0.4260	7.0070	-0.061	0.952

Temperature and humidity are very influential on insects to balance body temperature and water content in the insect body when flying (Jaworski & Hilszczanski, 2013; Alfawwaz *et al.*, 2022). Based on the results of the analysis, temperature has a negative and non-significant effect (Table 3). It is also seen in the graph (Fig. 3) that the line formed has a small distance difference. According to Plos *et al.*, (2023) explained that the higher the temperature, the insects will be enactive or reduce their activity. Temperature has a relationship with insect flight mechanisms, which are effective when the body temperature is 30°C as in the study site is the optimal temperature for pollinator insects to visit flowers. While in flowers, the lower the air temperature and the higher the humidity, the volume of nectar increases and its viscosity decreases (Hendriksma *et al.*, 2019; Bareke *et al.*, 2021; Descamps *et al.*, 2021; Harrison & Rands, 2022). This condition of nectar is generally not favored by insects because it has a low energy content (Harrison & Rands, 2022). The low energy content of each nectar encourages insects to visit more flowers to get enough energy. According to Shrestha *et al.* (2018), also that cool ambient temperatures can benefit insects by saving energy and without having to select flowers.

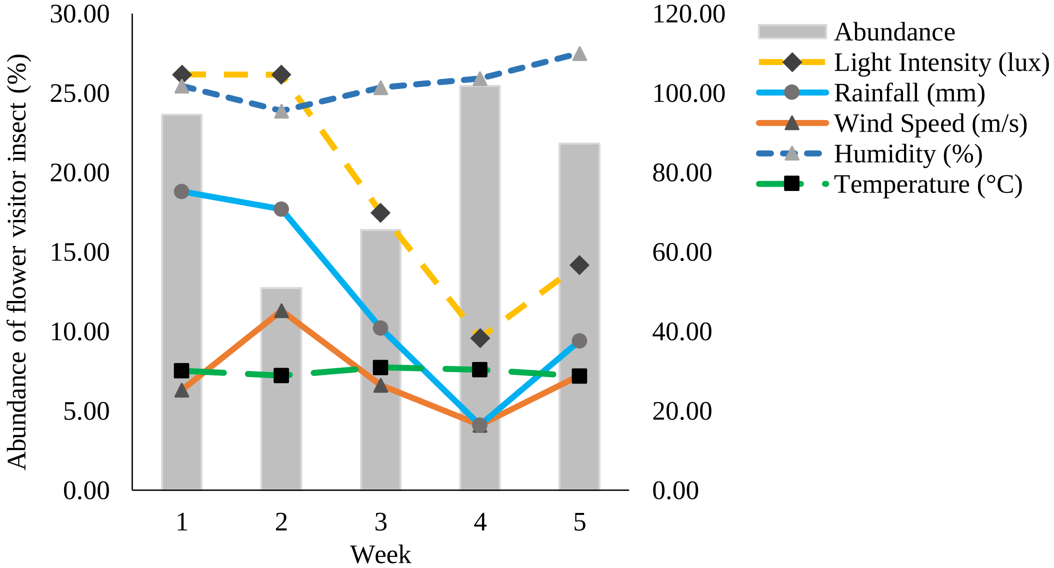

Fig. 3. The abundance of insect species visiting insect *Capsicum frutescens* flowers

Light intensity can also increase insect body temperature. Similar to temperature, light intensity has a negative effect, meaning that by increasing the light intensity, an insect will reduce their activity (Cholis *et al.*, 2020; Owens et al., 2020). The light intensity can accelerate the increase in insect body temperature to start flying. Light intensity also helps insect vision (visual navigation) and signals to forage food (Kendall *et al.*, 2021). Wind speed also has a negative non-significant on insect abundance (Table 3, Fig. 3), this is following studies conducted by Koneri *et al.,* (2021). Wind speed can affect insects in food search and pollination activities (Polatto et al., 2014; Koneri *et al.*, 2021). Insects will invest more energy to pollinate and can reduce pollination efficiency when wind speeds are high (Bentrup *et al.,* 2019). According to Widhiono (2015), wind speed will affect pollinating insect activity at 24-32 km/hour. Rainfall during the dry season is quite infrequent and low in intensity compared to the wet season. However, when rain does occur, it can cause pollen loss, nectar dilution, and eliminate attractant signals that attract insects to flowers (Lawson & Rands, 2019). Rainwater can also increase insect body weight during flight (Jaworski *et al.*, 2022), so when it rains insects can be interrupted from interacting with target plants.

CONCLUSION

The diversity of flower visitor insects in chili pepper (*C. frutescens*) plants has moderate diversity (H'=2.148), stable evenness (E=0.865), and low dominance (D=0.153). *Allorhynchium argentatum* is the insect species with the highest abundance in chili pepper. Environmental factors and the availability of food sources (flowers) in the dry season have a non-significant effect (p-value >0.05) on insect abundance. Further research is warranted to investigate the impact of flower-visiting insect abundance on pollen count and nectar concentration specifically within *C. frutescens* over a single growing season. By knowing these relationships, we can understand the environmental conditions that produce quality nectar and pollen, and increase insect diversity in agricultural ecosystems, potentially leading to increased crop productivity.

ACKNOWLEDGEMENTS

This research was fully funded by the Institute for Research and Community Service (LP2M) of Universitas Jember through the Postgraduate Grant (3288/UN25.3.1/LT/2023). Our gratitude also goes to the local community around the area study and the entomology research team who helped in field data collecting.

REFERENCES

Adams BJ, Li E, Bahlai CA, Meineke EK, McGlynn TP, Brown BV. 2020. Local- and landscape-scale variables shape insect diversity in an urban biodiversity hot spot. *Ecological Applications*. vol 30(4): 1–14. doi: https://doi.org/10.1002/eap.2089.

Alfawwaz M, Permana, AD, Putra RE. 2022. Diversity and abundance of insect pollinator of chayote (*Sechium edule* (Jacq.) Swartz. *Jurnal Biodjati.* vol 7(1): 36–44. doi: https://doi.org/10.15575/biodjati.

Alingan P, Sataral M, Qodri A. 2023. Diversity of insect flower visitors of cayenne pepper in agricultural landscapes, Banggai, Central Sulawesi. *Celebes Agricultural*. vol 3(2): 100–114. doi: https://doi.org/10.52045/jca.v3i2.411.

Anoosha V, Saini S, Kaushik HD, Yadav S. 2018. Diversity of insect pollinators on medicinal tree, baheda (*Terminalia bellirica* Roxb.) in southern Haryana. *Journal of Entomology and Zoology Studies*. vol 6(4): 429–432.

Bareke T, Abera T, Addi A. 2021. Nectar secretion of *Callistemon citrinus* (Curtis) Skeels, Myrtaceae: potential for honey production. *Plants and Environment*. vol 3(2): 30–36. doi: https://doi.org/10.22271/2582-3744.2021.jun.30.

Bentrup G, Hopwood J, Adamson NL, Vaughan M. 2019. Temperate agroforestry systems and insect pollinators: a review. *In Forests.* vol 10(11): 1–20. doi: https://doi.org/10.3390/f10110981.

Chesaria N, Syukur SM. 2018. Analisis keragaan cabai rawit merah (*Capsicum frutescens*) lokal asal Kediri dan Jember. *Buletin Agrohorti*. vol 6(3): 388–396. doi: https://doi.org/10.29244/agrob.v6i3.21107.

Cholis M, Atmowidi T, Kahono S. 2020. The diversity and abundance of visitor insects on pummelo (*Citrus maxima* (burm) Merr) cv. nambangan. *Journal of Entomology and Zoology Studies*. vol 8(4): 344–351.

Descamps C, Jambrek A, Quinet M, Jacquemart AL. 2021. Warm temperatures reduce flower attractiveness and bumblebee foraging. *Insects*. vol 12(6): 1–13. doi: https://doi.org/10.3390/insects12060493.

Dunn L, Lequerica M, Reid CR, Latty T. 2020. Dual ecosystem services of syrphid flies (Diptera: Syrphidae): pollinators and biological control agents. *Pest Management Science*. vol 76(6): 1973–1979. doi: https://doi.org/10.1002/ps.5807.

Finch JTD, Cook JM. 2020. Flies on vacation: evidence for the migration of Australian Syrphidae (Diptera). *Ecological Entomology.* vol 45(4): 896–900. doi: https://doi.org/10.1111/EEN.12856.

Gnatiuk AM, Gaponenko MB, Honchar HY, Gaponenko AM. 2023. Diversity of *Epipactis palustris* (L.) Crantz (Orchidaceae) pollinators and visitors in conditions of Kyiv city (Ukraine). *Hacquetia.* vol 22(2): 247–262. doi: https://doi.org/10.2478/HACQ-2022-0018.

Goodwin EK, Rader R, Encinas-Viso F, Saunders ME. 2021. Weather conditions affect the visitation frequency, richness and detectability of insect flower visitors in the Australian alpine zone. *Environmental Entomology*. vol 50(2): 348–358. doi: https://doi.org/10.1093/ee/nvaa180.

Goulet H, Huber JT. 1993. Hymenoptera of the world: an identification guide to families. Canada: Research Branch, Agriculture Canada. pp 668.

Harrison AS, Rands SA. 2022. The ability of bumblebees *Bombus terrestris* (Hymenoptera: Apidae) to detect floral humidity is dependent upon environmental humidity. *Environmental Entomology*. vol 51(5): 1010–1019. doi: https://doi.org/10.1093/ee/nvac049.

Heil M. 2011. Nectar: generation, regulation and ecological functions. *Trends in Plant Science*. vol 16(4): 191–200. doi: https://doi.org/10.1016/j.tplants.2011.01.003.

Hendriksma HP, Toth AL, Shafir S. 2019. Individual and colony level foraging decisions of bumble bees and honey bees in relation to balancing of nutrient needs. *Frontiers in Ecology and Evolution*. vol 7: 1–12. doi: https://doi.org/10.3389/fevo.2019.00177.

Hussain M, Liaqat H, Malik MF, Aftab K, Batool M, Iqbal R, Liaqat S. 2023. Distribution patterns of insect pollinator assemblages at Deva Vatala National Park, Bhimber, Azad Jammu and Kashmir. *Pakistan Journal of Zoology*. vol 56: 1–13. doi: https://dx.doi.org/10.17582/journal.pjz/20221004171007.

Iler AM, Compagnoni A, Inouye DW, Williams JL, CaraDonna PJ, Anderson A, Miller TE. 2019. Reproductive losses due to climate change-induced earlier flowering are not the primary threat to plant population viability in a perennial herb. *Journal of Ecology*. vol 107(4): 1931–1943. doi: https://doi.org/10.1111/1365-2745.13146.

Jaworski T, Hilszczanski J. 2013. The effect of temperature and humidity changes on insects development their impact on forest ecosystems in the expected climate change. *Lesne Prace Badawcze*. vol 74(4): 345–355. doi: https://doi.org/10.2478/frp-2013-0033.

Jaworski CC, Geslin B, Zakardjian M, Lecareux C, Caillault P, Nève G, Meunier JY, Dupouyet S, Sweeney ACT, Lewis OT, Dicks LV, Fernandez C. 2022. Long-term experimental drought alters floral scent and pollinator visits in a Mediterranean plant community despite overall limited impacts on plant phenotype and reproduction. *Journal of Ecology*. vol 110(11): 2628–2648. doi: https://doi.org/10.1111/1365-2745.13974.

Kendall LK, Evans LJ, Gee M, Smith TJ, Gagic V, Lobaton JD, Hall MA, Jones J, Kirkland L, Saunders ME, Sonter C, Cutting BT, Parks S, Hogendoorn K, Spurr C, Gracie A, Simpson M, Rader R. 2021. The effect of protective covers on pollinator health and pollination service delivery. *Agriculture, Ecosystems and Environment*. vol 319: 1–15. doi: https://doi.org/10.1016/j.agee.2021.107556.

Koneri R, Nangoy MJ, Wakhid. 2021. Richness and diversity of insect pollinators in various habitats around Bogani Nani Wartabone National Park, North Sulawesi, Indonesia. *Biodiversitas Journal of Biological Diversity*. vol 22(1): 288–297. doi: https://doi.org/10.13057/biodiv/d220135.

Lawson DA, Rands SA. 2019. The effects of rainfall on plant–pollinator interactions. *Arthropod-Plant Interactions*. vol 13(4): 561–569. doi: https://doi.org/10.1007/s11829-019-09686-z.

Mishra SK, Kanwat PM. 2018. Seasonal incidence of mustard aphid, Lipaphis erysimi (Kalt) and its major predator on mustard and their correlation with abiotic factors. *Journal of Entomology and Zoology Studies*. vol 6(3): 831–836.

Narbona E, del-Valle JC, Whittal JB. 2021. Painting the green canvas: how pigments produce flower colours. *The Biochemist*. vol 43(2): 6–12. doi: https://doi.org/10.1042/bio_2021_137.

Nicholls CI, Altieri MA. 2013. Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. *Agronomy for Sustainable Development*. vol 33: 257–274. doi: 10.1007/s13593-012-0092-y.

Noriega JA, Hortal J, Azcárate FM, Berg MP, Bonada N, Briones MJ, Del Toro I, Goulson D, Ibanez S, Landis DA, Moretti M, Potts SG, Slade EM, Stout JC, Ulyshen MD, Wackers FL, Woodcock BA, Santos AM. 2018. Research trends in ecosystem services provided by insects. *Basic and Applied Ecology*. vol 26: 8–23. doi: https://doi.org/10.1016/j.baae.2017.09.006.

Odum EP. 1993. Dasar-Dasar Ekologi. 3rd Edition. Yogyakarta: Gadjah Mada University Press.

Olatunji TL, Afolayan AJ. 2018. The suitability of chili pepper (*Capsicum annuum* L.) for alleviating human micronutrient dietary deficiencies: a review. *Food science & nutrition*. vol 6(8): 2239–2251. doi: https://doi.org/10.1002%2Ffsn3.790.

Ollerton J. 2017. Pollinator diversity: distribution, ecological function, and conservation. *Annual Review of Ecology, Evolution, and Systematics*. vol 48: 353–376. doi: https://doi.org/10.1146/annurev-ecolsys-110316-022919.

Outhwaite CL, McCann P, Newbold T. 2022. Agriculture and climate change are reshaping insect biodiversity worldwide. *Nature*. vol 605: vol 97–102. doi: https://doi.org/10.1038/s41586-022-04644-x.

Owens AC, Cochard P, Durrant J, Farnworth B, Perkin EK, Seymoure B. 2020. Light pollution is a driver of insect declines. *Biological Conservation*. vol 241: 1–9. doi: https://doi.org/10.1016/j.biocon.2019.108259.

Palupi ER, Sudarsono S, Sadjad S, Solihin DD, Owens JN. 2023. The behavior of insect pollinators in a teak (*Tectona grandis* L. f.) clonal seed orchard with weedy understory in East Java. *Forest Science and Technology*. vol 19(3): 241–249. doi: https://doi.org/10.1080/21580103.2023.2241497.

Papiorek S, Junker SS, Alves-dos-Santos I, Melo GA, Amaral-Neto LP, Sazima M, Wolowski M, Freitas L, Lunau K. 2016. Bees, birds and yellow flowers: Pollinator-dependent convergent evolution of UV-patterns. *Plant Biology*. vol 18(1): 46–55. doi: https://doi.org/10.1111/plb.12322.

Pardo A, Borges PA. 2020. Worldwide importance of insect pollination in apple orchards: A review. *Agriculture, Ecosystems & Environment*. vol 293: 1–17. doi: https://doi.org/10.1016/j.agee.2020.106839.

Plos C, Stelbrink N, Römermann C, Knight TM, Hensen I. 2023. Abiotic conditions affect nectar properties and flower visitation in four herbaceous plant species. *Flora: Morphology, Distribution, Functional Ecology of Plants*. vol 303: 1–10. https://doi.org/10.1016/j.flora.2023.152279.

Polatto LP, Chaud-Netto J, Alves-Junior VV. 2014. Influence of abiotic factors and floral resource availability on daily foraging activity of bees: influence of abiotic and biotic factors on bees. *Journal of Insect Behavior*. vol 27: 593–612. doi: https://doi.org/10.1007/s10905-014-9452-6.

Purwantiningsih B, Leksono AS, Yanuwiadi B. 2012. Kajian komposisi serangga polinator pada tumbuhan penutup tanah di Poncokusumo-Malang. *Berkala Penelitian Hayati*. vol 17(2): 165–172. doi: https://doi.org/10.23869/bphjbr.27.2.20127.

Qasim M, Carpenter JM, Bokhari H, Khan MR. 2022. Vespidae (Insecta: Hymenoptera) of multan region, *Pakistan. Oriental Sciences.* vol 56(3): 1–32. doi: http://dx.doi.org/10.1080/00305316.2021.2024465.

Salisbury A, Armitage J, Bostock H, Perry J, Tatchell M, Thompson K. 2015. Enhancing gardens as habitats for flower-visiting aerial insects (pollinators): Should we plant native or exotic species?. *Journal of Applied Ecology*. vol 52(5): 1156–1164. doi: https://doi.org/10.1111/1365-2664.12499.

Shrestha M, Garcia JE, Bukovac Z, Dorin A, Dyer AG. 2018. Pollination in a new climate: assessing the potential influence of flower temperature variation on insect pollinator behaviour. *Plos One*. vol 13(8): 1–24. doi: https://doi.org/10.1371/journal.pone.0200549.

Siregar EH, Atmowidi T, Kahono S. 2016. Diversity and abundance of insect pollinators in different agricultural lands in Jambi, Sumatera. *Hayati Journal of Biosciences*. vol 23(1): 13–17. doi: https://doi.org/10.1016/j.hjb.2015.11.002.

Soli E, Gladys KO, Esther NK. 2020. Insect pollinator diversity and their influence on yield and quality of *Capsicum annuum* (Solanaceae), Machakos, Kenya. *Open Journal of Animal Sciences*. vol 10(03): 545–559. doi: https://doi.org/10.4236/ojas.2020.103035.

Supriadi DR, Susila AD, Sulistyono E. 2018. Penetapan kebutuhan air tanaman cabai merah (*Capsicum annuum* L.) dan cabai rawit (*Capsicum frutescens* L.). *Jurnal Holtikultura Indonesia*. vol 9(1): 38–46. doi: https://doi.org/10.29244/jhi.9.1.38-46.

Tolera K, Ballantyne G. 2021. Insect pollination and sustainable agriculture in Sub-Saharan Africa. *Journal of Pollination Ecology*. vol 27: 36–46. doi: https://doi.org/10.26786/1920-7603(2021)615.

Triplehorn CA, Johnson NF. 2005. Borror and Delong's Introduction to the Study of Insects 7th Edition. Boston: Cengage Learning. p 888.

Van der Kooi CJ, Stavenga DG, Arikawa K, Belušič G, Kelber A. 2021. Evolution of insect color vision: from spectral sensitivity to visual ecology. *Annual Review of Entomology*. vol 66(1): 435–461. doi: https://doi.org/10.1146/annurev-ento-061720-071644.

Vasiliev D, Greenwood S. 2020. Pollinator biodiversity and crop pollination in temperate ecosystems, implications for national pollinator conservation strategies: Mini review. *Science of the Total Environment*. vol 744: 1–7. doi: https://doi.org/10.1016/j.scitotenv.2020.140880.

Widhiono I. 2015. Diversity of butterflies in four different forest types in Mount Slamet, Central Java, Indonesia. *Biodiversitas Journal of Biological Diversity*. vol 16(2): 196–204. doi: https://doi.org/10.13057/biodiv/d160215.

Wolf AA, Zavaleta ES, Selmants PC. 2017. Flowering phenology shifts in response to biodiversity loss. *Proceedings of the National Academy of Sciences.* vol 114(13): 3463–3468. doi: https://doi.org/10.1073/pnas.1608357114.