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Pollination biology of yellow passion fruit (*Passiflora edulis* forma flavicarpa) at typical Indonesian small-scale farming

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Abstract. *Putra RE, Wibisana G, Kinasih I, Raffiudin R, Soesilohadi RCH, Purnobasuki H. 2023. Pollination biology of yellow passion fruit (*Passiflora edulis *forma flavicarpa) at typical Indonesian small-scale farming. Biodiversitas 24: 2179-2188.* Yellow passion fruit (*Passiflora edulis* forma flavicarpa) has been considered one of the potential local fruits targeted as the export commodity of Indonesia. However, this fruit production level is relatively unstable, which lowers their potency as cash crops and makes them secondary fruits for small-scale farmers. One of the possible factors related to this condition is pollination success. This research aimed to study the pollination biology of yellow passion fruit in terms of flower interaction with insects and the morphological aspect of flowers. The observation was conducted in four sites at Kampung Organik Beji, Wonogiri District, between January-February 2022. Pollinators' census was done by scan sampling while flower-visiting insect activities were monitored by focal sampling. This study found 26 species of flower-visiting insects which can be grouped into 5 Ordo and 12 Families with moderate diversity index (H'=2.15), evenly distributed (J'=0.66), and low domination (D=0.32). Among identified insects, carpenter bees (*Xylocopa latipes*), stingless bees (*Tetragonula laeviceps*), and Asiatic honey bees (*Apis cerana*) were considered as pollinators in which X. latipes (Vt=11.81±7.44 second, Fvr=2.41±1.55) visited flower (Vt) on shorter times, and more flower visitation rate (Fvr) than T. laeviceps (Vt=12.36±8.32 second, Fvr=1.10±0.30). Furthermore, this study found that the benefit of natural pollination was better than hand cross-pollination. However, the benefit was hampered by a lack of plant protection and soil fertility management. This study may be applied as baseline information to create pollinator protection zones in the area near the plantation zone to ensure the pollination services for crops.

Keywords: Carpenter bees, ecosystem services, insects, interactions, local fruits, stingless bees

INTRODUCTION

Generally, to fulfill their nutrition needs, human gathers and cultivate various plants, most flowering plants, through agriculture (Nicole 2015; Garibaldi et al. 2022). Due to their importance, heavy investments in technology, energy, and finances have been made to improve agricultural productivity (Rosegrant et al. 2022). Interestingly, although large and industrial-scale agriculture produces significantly large amounts of food, there are indications that most food systems highly depend on small-scale farming. High dependency on small-scale farming can be found in many countries and regions where there is a lack of suitable open, flat, and irrigated land, especially in Asia and Africa (Lowder et al. 2016; van Loon et al. 2020). In these regions, small-scale farming is the prominent farm model, which becomes a major income for the local population. Furtherly, there are indications due to the degradation of land, population growth, and demographical changes; small-scale farming will be grown significantly in the future (Giller et al. 2021; Miranda et al. 2022).

One of the emerging markets for Asian agriculture products is exotic fruits, such as Passion fruit, a woody, perennial, and climbing plant that belongs to the Passifloraceae family (Banu et al. 2009). Although 50 passion fruit species (*Passiflora edulis*) are edible, only two types are widely cultivated. The cultivation purpose is to meet the needs of fresh fruit or the juice industry, namely *P. edulis* Sims (purple passion fruit) and *P. edulis* f. flavicarpa (yellow passion fruit) (Ramaiya et al. 2020) and possibly application for functional food (He et al. 2020). Passion fruit production in Indonesia in 2016-2020 was relatively unstable and tended to decline, from 101,964 tons (2016) to 53,319 tons (2020) (Badan Pusat Statistik, 2020), despite a global market. In Indonesia, most passion fruit plantations are considered small-scale farming primarily due to a lack of suitable areas for planting.

One major characteristic of small-scale farming is their high dependency on the surrounding area and all biotic and abiotic interactions related to the crops, known as ecosystem services (Sawe et al. 2020; Timberlake et al. 2022). Biotic interactions significantly impact these farms, especially insect interactions (Pywell et al. 2015). Insects have lived on earth since approximately 350 million years ago and are adaptable to various habitats after evolving numerous times (Triplehorn and Johnson 2005). In their habitats, which can be found in almost all ecosystems, insects have diverse roles that affect the local community and involve various biological interactions (Bellamy et al. 2018). Interactions between insects and plants can be mutualism, which benefits both parties, e.g., the pollination process provides food resources for the flower-visiting insect and assists in sexual reproduction for the host plants (Arnold et al. 2018; Bugin et al. 2022). In contrast, interaction also can be antagonistic e.g., pests can destroy plant tissues (Moreira et al. 2018). Furthermore, the presence of insects can affect the development of plants through pollination, galling, and interactions with herbivores (Hillier et al. 2018).

In tropical regions, the yellow passion fruit (*P. edulis* f. flavicarpa), which is self-incompatible (Souza et al. 2010), is the most dominant cultivated species. In nature, yellow passion fruit strongly depends on wild pollinators, especially insects (Yamamoto et al. 2012). This is due to the stickiness of the pollen, causing pollination by the wind to be ineffective (Das et al. 2013). Therefore, pollination is essential in fruit production (Das et al. 2013; Junqueira et al. 2013) and has become the main focus of this study. Studies and reports from Brazil, the passion fruit market leader, showed that passion fruit's pollination depends on its most effective pollinator, carpenter bees, and human pollination (Junqueira and Augusto 2017; Martarello et al. 2021). Between these, manual cross-pollination is the most commonly applied due to the loss of carpenter bees (Yamamoto et al. 2012). Unfortunately, global changes in environmental conditions produce a decline in biodiversity, causing interference with interactions between plants and their pollinators, resulting in the loss of pollination services (Bezerra et al. 2019; Powney et al. 2019; Millard et al. 2021) and increasing the application of manual cross-pollination. In the long term, this condition will alter farm management, especially for small-scale farms, due to increased production costs to compensate for the loss of pollination services.

This study is based on three research questions, (i) Do local insects act as pollinators for yellow passion fruit, (ii) Does the local insect community suitable for maintaining the pollination ecosystem services for sustainable fruit production, and (iii) Is pollination the essential factor affecting the fruit production of yellow passion fruit in small scale farm?

MATERIALS AND METHODS

Study area and period

The study was conducted at "Kampung Organik Beji" (Beji Organic Village), one of the role model areas for organic farming, located in Nguntoronadi Sub-district, Wonogiri District, Central Java Province, Indonesia. The study area selection was also based on the low possibility of behavioral alteration and death due to insecticide exposure. One of the main commodities cultivated on the market demand is passion fruit. This research was conducted from January-February 2022 at four plots, A (07°53.854'S and 110°58.345'E), B (07°53.670'S and 110°58.486'E), C (07°54.739'S and 110°58.406'E), and D (07°53.631'S and 110°58.445'E) (Figure 1.), which elevated at 356-418 meters above sea level. The sampling plots were an area where yellow passion fruit was cultivated as part of the home garden and small farm system (the average size was 100 m^2), which was introduced as economic development program during the cashew revitalization.

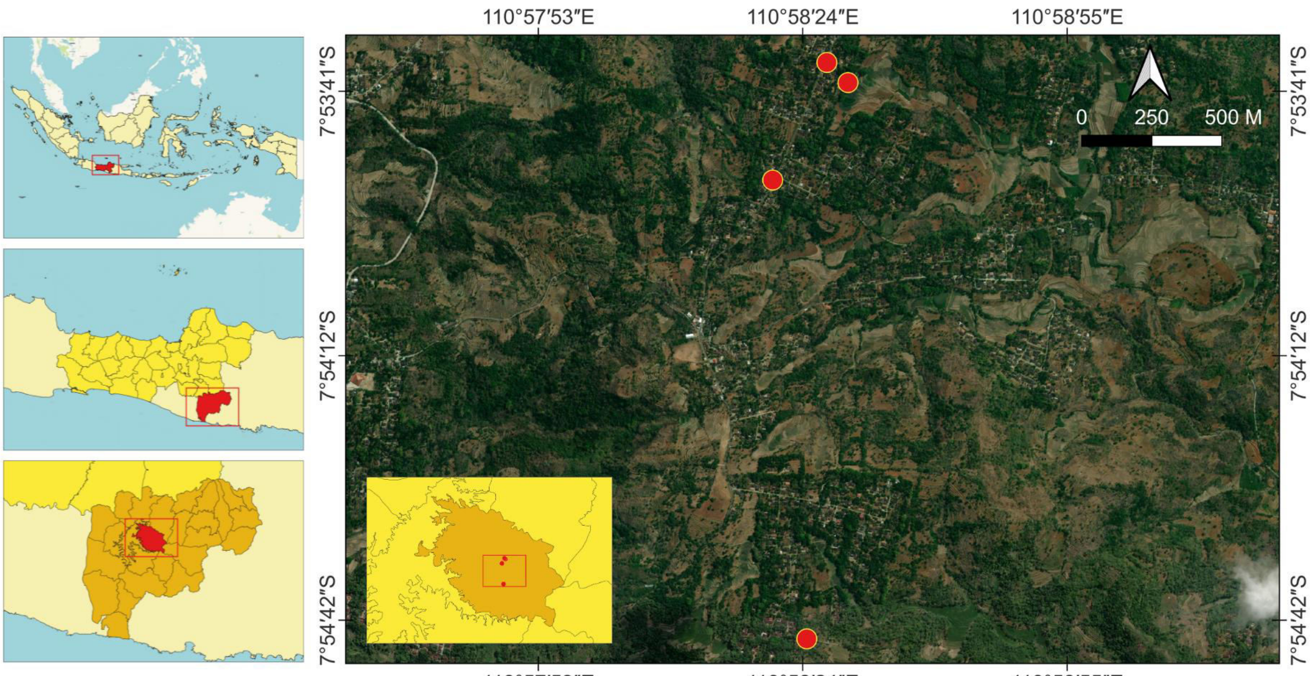

Figure 1. Research location map in Beji Organic Village, Nguntoronadi Sub-district, Wonogiri District, Central Java, Indonesia

Flower-visiting insect observation

Direct observations of insect visitors on open flowers were carried out by walking along the yellow passion fruit vines during rainless daylight (12:30-14.30 PM) and afternoon (16:00-18:00 PM) based on flower anthesis times and stigma receptivity (Yamamoto et al. 2012). Diversity observation was done using the scan sampling method while flower-visiting insect activities were monitored by the focal sampling method (Thompson et al. 2021). The total number of flowers observed was 135 flowers. The observation was conducted continuously for three days, with a total observation period was 48 hours. The flower-visiting insect activities recorded in this study were: (i) Resource collection which determined whether the insect collected nectar, pollen or extrafloral-nectaries/EFN, (ii) Visitation time (Vt) which recorded time spent on flower from first alight to flight (Vt), (iii) Flower visitation rate per one minute (Fvr).

Unidentified visitor insects were collected using a sweeping net, then killed in a container moistened with ethyl acetate for further identification. Each collected insect will be identified using the morphospecies approach according to key identification and pictures (Borror et al. 2005) up to the family stages. Further identification up to genus or species, according to James (2017), Trianto and Purwanto (2020), and Nazarreta et al. (2021).

Pollination success

The pollination on fruit production impact was observed on 135 flowers divided among three groups of pollination regimes evenly, namely: (i) Open pollination (OP) group - flowers were not covered by a pollination bag made of nylon mesh with a mesh diameter of 1 mm (Figure 2). (ii) Self-pollination (SP) group - flowers were covered by a pollination bag made of nylon mesh with a mesh diameter of 1 mm (Figure 3). (iii) Hand cross-pollination (HCP) group - hand-pollinating flower by applying pollen from a different flower. The flower was covered with nylon mesh before and after hand pollination (Figure 4).

The effects of insect on pollination was measured based on:

Fruit set. Determinaton of the fruit set was conducted on the 4th day after flower anthesis (Shahbani et al. 2020) when the fruit formed. Fruit set level was calculated by formula:

Fruit set (%) = (total numbers of fruit / total numbers of flower) x 100%

Fruit mortality. Fruit mortality was calculated as the percentage of aborted fruit prior harvest period at 60 days after flower anthesis (Shahbani et al. 2020).

Percentage of abnormal fruit. Percentage of abnormal fruit (Figure 5) was calculated at 60 days after flower anthesis

Fruit length and diameter. Fruit length and diameter, only measured on normal fruit, were measured by a digital caliper.

Fruit weight. Fruit weight was measured by a digital weighing scale

Seed numbers. Seed numbers were calculated manually from normal mature fruits

Total soluble solute (TSS). Total soluble solute was measured by digital brixmeter (ATAGO)

Figure 2. Experiment procedure for open-pollination group. A. Selected flower, B. Thread used to mark the flower, C. Full bloom flower

Figure 3. Experiment procedure for self pollination group. A. Selected unbloom flower, B. Unbloom flower covered by pollination bag, C. Full bloom flower inside pollination bag

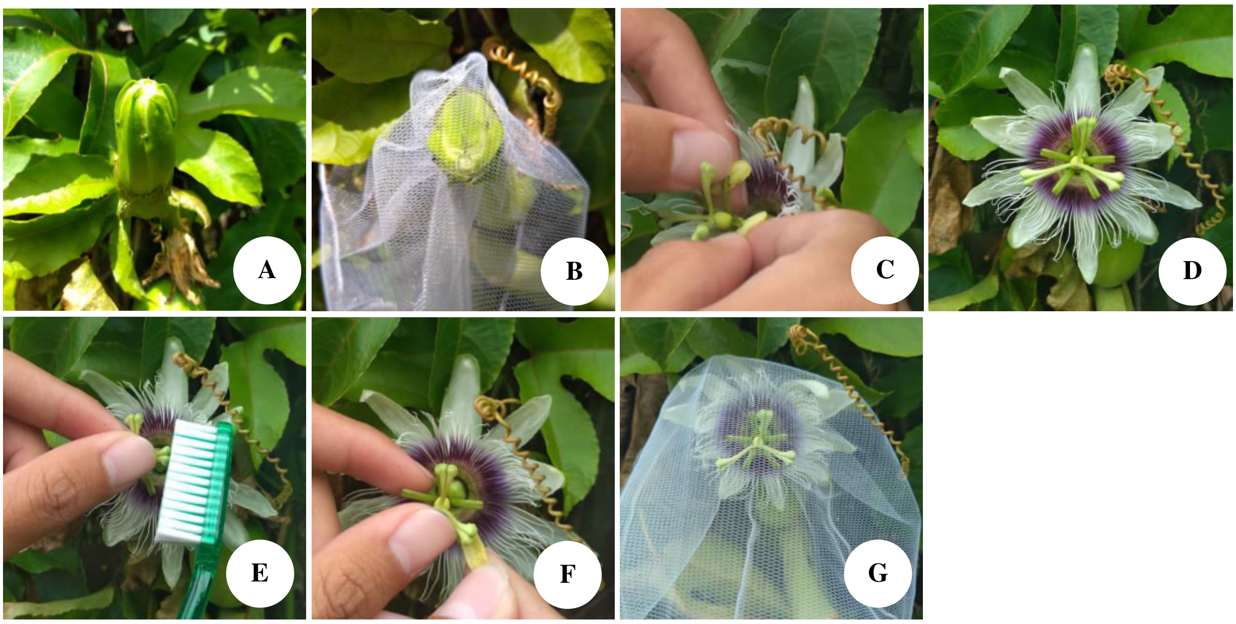

Figure 4. Experiment procedure for hand cross-pollination group. A. Selected unbloom flower, B. Unbloom flower covered by pollination bag, C. Pollination bag remove when flower started blooming, D. Full bloom flower, E. Cleaning the stigma, F. Transfer the pollen from other flowers, G. Pollinated flower covered by pollination bag

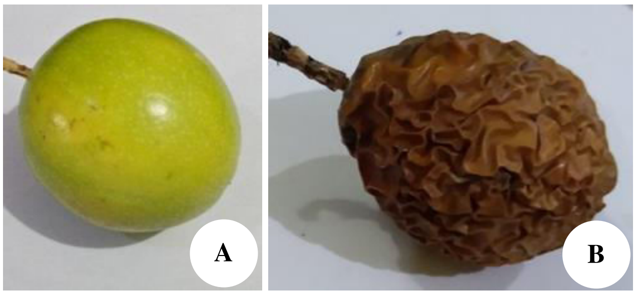

Figure 5. Comparison between normal and abnormal fruit. A. Normal fruit, B. Abnormal fruit

Data analysis

Flower-visiting insect community

The flower-visiting insect communities data were analyzed further using the Shannon-Wiener diversity index (H'), Pielou evenness index (J'), Berger-Parker domination index (D), and relative abundance (RA) by following information and formulas:

$$H' = -\sum_{i=1}^{s} \left(\frac{ni}{N}\right) \ln\left(\frac{ni}{N}\right)$$

$$J' = \frac{H'}{In(S)}$$

$$D = \frac{Nmax}{N}$$

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

Where:
ni : number of species i
N : number of all individual
ln : Natural logarithm
S : Morphospecies number
Nmax : Individual number of the most abundant species

The analyzed data follows the criteria value provided in Table 1.

Table 1. Analysis category

Analysis type	Value ranges	Categories
Shannon-Wiener diversity index (H')	H' < 1	Low diversity
	1 ≤ H'≤ 3	Moderate diversity
	H'> 3	High diversity
Pielou evenness index (J')	J'> 0.5	Evenly distributed
	J' < 0.5	Uneven distributed
Berger-Parker domination index (D)	D < 0.5	Low domination
	D > 0.5	High domination

RESULTS AND DISCUSSION

Insects pollinators for yellow passion fruit

This study collected 256 individual flower-visiting insects and identified 26 species (of 17 genera) from 5 Orders and 12 Families through morphospecies approaches (Table 2). Among the visitor insect, four species with high individual abundance were *Xylocopa latipes* (81 individuals), *Dolichoderus* sp. (45 individuals), and *Drosophilidae* sp3. (43 individuals), and *Tetragonula laeviceps* (33 individuals) comprised 78.9% of the composition of all visitor insects. Only Drosopihildae sp3. and *Xylocopa latipes* were found in all areas (Table 2).

Table 2. Species and number of individual flower-visiting insects

Order Family Species	Individual Number					Relative abundance (RA) (%)	Role
	A	B	C	D	Total		
Coleoptera							
Anobiidae							
Anobiidae sp1.	1	0	0	0	1	0.39	Visitor/Unknown
Diptera							
Calliphoridae							
Calliphoridae sp1.	0	0	0	2	2	0.78	Visitor/Unknown
Drosophilidae							
Drosophilidae sp1.	3	0	0	0	4	1.56	Saprophage
Drosophilidae sp2.	1	0	0	0	1	0.39	Saprophage
Drosophilidae sp3.	22	5	7	9	43	16.8	Saprophage
Drosophilidae sp4.	1	0	0	0	1	0.39	Saprophage
Drosophilidae sp5.	1	0	0	0	1	0.39	Saprophage
Drosophilidae sp6.	0	0	1	0	1	0.39	Saprophage
Lonchaeidae							
Lonchaeidae sp1.	0	0	0	2	2	0.78	Pest
Muscidae							
Muscidae sp1.	0	2	0	0	2	0.78	Visitor/Unknown
Scathophagidae							
Scathophagidae sp1.	0	1	0	9	10	3.91	Phytophage
Stratiomyidae							
Stratiomyidae sp1.	0	0	0	1	1	0.39	Phytophage
Tephritidae							
Bactrocera sp.	0	0	1	0	1	0.39	Pest
Tephritidae sp1.	1	1	0	0	2	0.78	Pest
Hemiptera							
Pentatomidae							
Plautia sp.	1	0	0	0	1	0.39	Phytophage
Hymenoptera							
Apidae							
Apis cerana	0	0	1	0	1	0.39	Pollinator
Tetragonula laeviceps	0	2	0	31	33	12.89	Pollinator
Xylocopa latipes	9	13	32	27	81	31.64	Pollinator
Formicidae							
Camponotus sp.	2	0	0	0	2	0.78	Predator
Dolichoderus sp.	9	0	33	3	45	17.58	Predator
Iridomyrmex sp.	2	0	0	0	2	0.78	Predator
Monomorium sp.	0	9	0	0	9	3.52	Predator
Philidris sp.	6	1	0	0	7	2.73	Predator
Lepidoptera							
Erebidae							
Amata huebneri	1	0	0	0	1	0.39	Visitor/Unknown
Euproctis sp.	0	0	1	0	1	0.39	Phytophage
Erebidae sp1.	0	0	0	1	1	0.39	Phytophage
Individual number	60	34	76	86	256	100	
Species number	14	8	7	10	26		

Based on family, insects with the highest relative abundance were from the Apidae family (RA= 44.92%), which were classified as pollinators (Yamamoto et al. 2012), followed by *Formicidae* insects (RA= 25.39%) as predators (Izaguirre et al. 2013), and *Drosophilidae* insects (RA= 19.92%) as saprophage (Çatal et al. 2021). The composition of pollinating insects was much higher than harmful insects, such as pests (RA = 1.95%) and phytophagous (RA = 5.42%).

The high visitation frequency of Xylocopa was recorded during the study following a report from Brazil on the insect that visited passion fruit flowers (Yamamoto et al. 2012). The availability of Xylocopa at all sampling areas indicated the healthy environmental condition of the cultivation area, as *Xylocopa* requires a specific woody structure for nesting (Junqueira and Augusto 2017).

Also, plenty of alternative food plants are commonly available in Indonesia's typical home garden (Motzke et al. 2016; Wahyuningsih et al. 2022). Therefore, the result also could be interpreted as the potency of passion fruit to be applied as part of *Xylocopa* and other big-size wild bees conservation programs as a food plant. Meanwhile, in this study, we also found that *T. laeviceps* and *Apis cerana* were very active in visiting flowers on agricultural land not applied to pesticides. These results support previous studies on bees' insecticide residue avoidance behavior (Easton and Goulson 2013; Thomson et al. 2014), who also visited passion fruit flowers. Furthermore, these two types of bees can be used as an alternative pollinating insects on yellow passion fruit, as both species could be domesticated. In this study, the high visitation of *X. latipes* and *T. laeviceps* could be related to the availability of the Xylocopa nest and Tetragonula hive around the trees. In contrast, *A. cerana* bees' nests were not found nearby.

Plot A had the highest number of flower-visiting insect species (14 species) due to more variety and abundance of flowering plants as a food source than other plots. In comparison, plot C had the least species (7). The diversity of flower-visiting insects is related to flowers' abundance (Hevia et al. 2021; Abrahamczyk et al. 2022). In addition, a low number of visitor insect species in plot C could also be related to the presence of predatory ants *Dolichoderus* sp. Furthermore, it seems to prevent the visit of small-bodied insects but did not prevent the presence of the much larger *X. latipes* bee. Although the presence of predatory ants is beneficial for host plants in preventing pest visits (Melati and Leal 2018), it has a negative effect by preventing pollinating insects that use visual senses, such as bees (Melati and Leal 2018; Nogueira et al. 2021). Therefore, this can reduce pollination services and result in a decline in fruit production (Calixto et al. 2018).

Moreover, the dominant flower-visiting insects (RA > 10%, Drosophilidae sp3. (RA = 16.8%), Dolichoderus sp. (RA = 17.58%), *T. laeviceps* (RA = 12.89%), and *X. latipes* (RA = 31.64%)) show different patterns of resources collection and stigma contact (Table 2). As pollination requires active stigma contact, only two species (*X. latipes* and *Tetragonula laeviceps*) could be considered pollinators with slightly different patterns of pollination activities (Table 3).

There were different patterns of the resources collected by the dominant flower-visiting insect. For example, Drosophila collected nectar and pollen as feed resources, as shown by the licking behavior of adult Drosophila in nectar or pollen-rich flower parts surfaces such as petals and anthers (Ishikawa et al. 2022). On the other hand, *Dolichoderus* sp. collected all resources flowers provide, particularly extrafloral nectaries (EFN). The EFN located in the sepals, petiole, and leaf margin of yellow passion fruit play indirect role mechanisms of anti-herbivores as it attracts predatory arthropods such as ant (Izaguirre et al. 2013).

Social bee *T. laeviceps* and solitary bee *X. latipes* differ in resources collected. For example, the *T. laeviceps* collected pollen, while *X. latipes* collected nectar. Nectar is a source of energy for the queen and worker bees, while pollen is a protein provider for the development of larvae, young worker bees, and queens (Konzmann and Lunau 2014). The visitation time (Vt) of *X. latipes* was slightly shorter (average 11.81±7.44 seconds, varied between 1.87 to 31.38 seconds) than *T. laeviceps* (12.36±8, 32 seconds, varied between 2.31 to 33.13 seconds). The resource-gathering behavior influences the length of the bee's visit to the flower (Rodriguez-Saona et al. 2011). For example, the *Xylocopa latipes* will land on the flower's corona, approach the nectar chamber, stick out its proboscis, collect the nectar, and move around. The time required to do this behavior is much shorter than *T. laeviceps* which perches on the stamen or stigma to collect pollen, then walks to the adjacent stigma when the style curves up to the stamen.

The *Xylocopa latipes* visited more flowers per minute (2.41±1.55) than *T. laeviceps* (1.10±0.30). Bees will generally increase the frequency of visits to flowers with higher quality and quantity of resources. *Xylocopa latipes* had a higher flower visitation rate than *T. laeviceps* could be associated with more significant energy requirements in *Xylocopa* due to its bigger body size. Furtherly *Passiflora* flowers, nectar is secreted in small amounts but continuously (Varassin et al. 2001), encouraging *Xylocopa* to visit more flowers to fulfill their energy requirement.

Local insect community for pollination and sustainable fruit production

The passion flower-visiting insect community in Kampung Organik Beji has a moderate diversity index (H'=2.15), evenly distributed (J'=0.66), and low domination (D=0.32). The diversity index value in all study sites was moderate, with the highest recorded in plot A (H'=2.02) (Figure 6).

The diversity value in plot A was higher than other plots due to its location bordering heterogeneous natural forests and the large number of flowering plants growing in and around the research plot. This condition leads to an increasing variety of visitor insects essential for pollination (Silva et al. 2019). Moreover, plot A had plenty of rotten yellow passion fruit, which strongly attracted various species of *Drosophila* (Dweck et al. 2018). The variety of visitor insects can increase the diversity index value due to increasing species richness and evenness (Jost 2010). However, this condition may increase the potency of fruit fly infestation due to the increasing availability of breeding sites.

Table 3. Dominant flower-visiting and pollinator insect activities

Species	Observed activities			
	Dominant insect activities		Pollinator insect activities	
	Resources collection	Stigma contact (%)	Visitation time (second)	Flower visitation rate (unit)
Drosophilidae sp3.	Nectar, pollen	20.93	-	-
Dolichoderus sp.	Extrafloral nectaries/EFN, nectar, pollen	2.22	-	-
Tetragonula laeviceps	Pollen	60.61	12.36±8.32 (n=25)	1.10±0.30 (n=32)
Xylocopa latipes	Nectar	66.67	11.81±7.44 (n=68)	2.41±1.55 (n=79)

Compared to other plots, plot C had the lowest number of species (7), the lowest diversity value (H'=1.17), the lowest evenness value (J'=0.6), and the highest dominance (D = 0.43). The value of diversity can affect the value of evenness, where both values are inversely proportional to the value of dominance (Ulfah et al. 2019). The low evenness and high dominance values were due to the unevenly distributed number of visitor insects due to the dominance of the predatory ant *Dolichoderus* sp., which is a threat to insect visitors.

Biodiversity decline could be caused by habitat destruction (mainly changes in agricultural management practice), pollution by agrichemical, invasive alien species, and climate changes (Khaliq et al. 2014; Bezerra et al. 2019). Although it needs to be interpreted carefully, diversity value may reflect environmental stability. Our findings on the diversity of flower-visiting insects, particularly the high abundance of native bee visits and the presence of nests around the study area, may serve as bioindicators indicating a relatively low environmental disturbance in the study area. Concerning bee pollination, conserved native bees may sustain and even promote pollination services (Yamamoto et al. 2012), which is beneficial in fruit production.

Is pollination the essential factor affecting the fruit production of yellow passion fruit on small-scale farms?

This study showed the importance of pollination for yellow passion fruit production, as reported by similar studies from various regions (Krause et al. 2012; Silveira et al. 2012; Yamamoto et al. 2012; Arias-Suarez 2014; Shahbani et al. 2020; Martarello et al. 2021). The result showed the fruit set level by natural pollination at 56.7% (Figure 7), which is higher than previous studies that reported the fruit set level between 14.3 to 53.85% (Hoffmann et al. 2000; Malerbo-Souza et al. 2002; Freitas and de Oliveira Filho 2003; Cobra et al. 2015).

Generally, the natural (open) pollination produced a higher fruit set which indicated a healthy pollination system of the local cultivation area. That also provides ample visits of the most effective pollinator (*X. latipes*) and flower availability to support cross-pollination (Yamamoto et al. 2010; Lowenstein and Minor 2015). In our study area, most houses in residential areas are typical villages built with hardwood and surrounded by old decaying cashew trees (*Anacardium occidentale*), which provide a suitable nest for *Xylocopa* species (He et al. 2020). On the other hand, lower fruit set of hand cross-pollination could be caused by lack of experience, weather conditions, variation in pollen quality, and unmatched pollen deposition to the receptive period of stigma (Souza et al. 2004; Mondo et al. 2022). This study showed the importance of the availability of conserved natural habitats for local pollinators along with the diverse forage plants to maintain effective pollination services, as yellow passion fruit only provides nectar as resources on small-scale farms (Kishore et al. 2010; Silveira et al. 2012; Varassin et al. 2018). Loss of the service will force this farm to adopt manual cross-pollination, which could increase the production cost due to the extra cost of hiring pollination workers (Krause et al. 2012; Cobra et al. 2015; Wurz et al. 2021).

More fruit mortality on open pollination than on hand cross-pollination, although the proportion of abnormal fruits was slightly lower. Furtherly, hand cross-pollination also produced more seeds and slightly bigger fruit. On the other hand, natural (open) pollination produced better fruit quality in terms of weight and the TSS (related to sweetness) (Table 4).

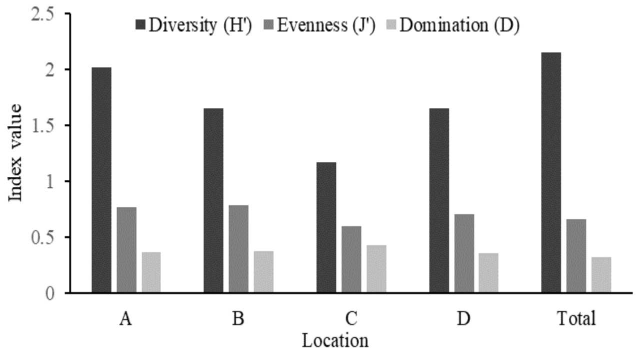

Figure 6. Diversity, evenness, and domination index in four research locations

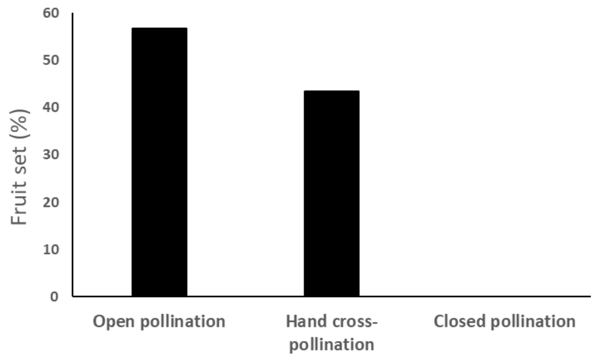

Figure 7. Fruit set of yellow passion fruit on different pollination regime

Table 4. Fruit characteristics produced by open and hand cross-pollination

Fruit parameter	Open pollination	Hand cross-pollination
Fruit mortality (%)	53	38
Abnormal fruit (%)	5	7
Length (cm)	6.82±0.75[a]	6.71±0.68[a]
Diameter (cm)	5.78±0.55[a]	5.91±0.47[a]
Weight (gr)	104.14±38.15[a]	94.43±23.49[a]
Seed number	206.28±87.36[a]	229.71±96.06[a]
Total Soluble Solute (TSS) (°BRIX)	11.97±2.67[a]	9.8±4.19[a]

This study showed another concern related to yellow passion fruit cultivation in the study area: the mortality of developed fruits. This condition was caused by the pest and pathogenic attack (personal observation, data not shown), which could have originated from the surrounding area, consisting of open fields, an old cashew plantation, and rotten passion fruits. The high fruit mortality caused by pathogenic and pest attacks is hindering the benefit of pollination (Bartomeus et al. 2015). Other factors that may be related to high fruit mortality are (1) soil fertility (Llorens et al. 2018) and (2) farm management (Yamamoto et al. 2010; Uchoa et al. 2018; Galvao et al. 2020). Unfortunately, both these factors are usually neglected in the basic organic setup of many villages in Indonesia and usually hamper the adaptation of pollination management practices for cash crops.

In conclusion, small-scale farming for yellow passion fruit is the potential to be developed as part conservation program due to its strong dependency on natural pollination by local insects and the sensitivity of small-scale farms to cost savings. Although yellow passion fruit production highly depends on pollination, good management of pathogenic and pest control and soil fertility are crucial for the sustainability of small-scale farming of yellow passion fruit. Therefore, it is necessary to develop the right balance between maintaining ecosystem service and providing suitable plant protection and nutrition to maximize its benefit.

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