Enhancing Flower-Visiting Insects by Planting of Sunn Hemp (*Crotalaria juncea* L.) in the Ecosystem of Coffee

Supriyadi SUPRIYADI (✉)
Retno WIJAYANTI
Retna Bandriyati ARNIPUTRI
Ria AYUDYA

Summary

The production of coffee fruit set depends on cross-pollination, but a few studies have examined the role of insect pollinators in the coffee ecosystem in Indonesia. The relationships between the planting of a flowering plant, sunn hemp (*Crotalaria juncea* L.) in the coffee ecosystem and flower-visiting insects were examined in this study. The study was carried out by planting *C. juncea* in the coffee plantation to record the diversity and abundance of flower-visiting insects and their effects on the fruit set of coffee. The insects were recorded weekly on flower panicles/clustered flowers, during the flowering period. The influence of wild pollinators was assessed by comparing the number of fruit sets of coffee in open pollination and wind pollination by bagging the flower panicle using nylon mesh gauze one week before the petals opened until all petals had dried and/or fallen off. The results showed that the diversity of flower-visiting insects increased during the flowering period, both on coffee and *C. juncea*. Belonging to two orders, 10 families, and 12 genera, the insects were actually observed by watching their feeding behaviors at flowers. The abundance of flower-visiting insects was 2.5-fold higher in the coffee ecosystem with *C. juncea* than in the control plot. The abundance was also influenced by the distance of *C. juncea* from the coffee. The average percentages of fruit set of coffee by open pollination were 58.83% in the coffee plot with *C. juncea* and 55.53% in the control plot. These values were higher than observed by wind pollination, in which the average percentages were only 32.01% and 21% in the coffee plot with *C. juncea* and in the control plot, respectively.

Key words

flowering plant, insect pollinator, coffee fruit set

Department of Agrotechnology, Faculty of Agriculture, University of Sebelas Maret Jl. Ir. Sutami 36A, Kentingan, Surakarta 57126, Indonesia

✉ Corresponding author: supriyadi58@staff.uns.ac.id

Received: July 7, 2020 | Accepted: January 19, 2021

Introduction

Coffee, *Coffea canephora* Pierre ex Froehner, syn. *Coffea robusta* L. is an important cash crop in Indonesia. With more than 1.29 million ha of coffee plantation and producing 633.991 tons of coffee per year, Indonesia is considered as one of the important coffee producers after Brazil, Vietnam, and Colombia (Ministry of Industry of the Republic of Indonesia, 2013; Foreign Agricultural Service, 2018). However, the average productivity of coffee in Indonesia is 700 kg per ha (Sunanto et al., 2019), both for robusta and arabica, which is lower than the 1500 kg per ha of coffee productivity in Vietnam (Ministry of Industry of the Republic of Indonesia, 2013).

The low average productivity of coffee in Indonesia is related to less intensive cultivation practices (Purba et al., 2012). The pollination of coffee flowers is one aspect that needs concerns to increase coffee productivity (Geeraert et al., 2019). The study showed that diversity and abundance of insect pollinators that visit during the flowering season lead to the increase of coffee bean yields (Klein et al., 2003; Vergara and Badano, 2009; Ngo et al., 2011; Hipolito et al., 2018), which may increase more than 50% compared to pollination by wind only (Krishnan et al., 2012). Hipolito et al. (2018) also recorded a more than 30% increase in coffee yield by the management of biodiversity pollinators. Therefore, the implementation of coffee ecosystem management strategies to conserve insect pollinators is necessary. Farmers should adopt eco-friendly agriculture practices, including the encouraging role of insect pollinators, as conducted at coffee plantations in Mexico (Vergara and Badano, 2009).

Effort to encourage coffee cultivation which is eco-friendly to insect pollinators is needed. The study revealed that planting of flowering plant, sunn hem (*C. juncea*) may increase the diversity and population of flower-visiting insect on soybean (Rahayu et al., 2018) and the abundance of insect predators and parasitoid on coffee plantation (Supriyadi et al., 2019). Flowering plants produce nectar and/or pollen as a food source for pollinator insects, including adult insect predatory and parasitoids (Jervis et al., 1993; Landis et al., 2000).

Nectar is a plant secretion composed mainly of sugar and other compounds, including amino acids, proteins, fats, vitamins, secondary metabolites, organic compounds, and minerals in low content (Nicolson and Thornburg, 2007), whereas pollen is rich in nitrogen and has a 2.5–60% protein content (Roulston and Cane, 2000; Weiner et al., 2010). The availability of flowering plants is an important factor to enhance the role of insect pollinators. Therefore, this study was conducted to examine the relationship between planting *C. juncea* in the coffee ecosystem and flower-visiting insects and its contributions to coffee yields.

Material and Methods

Material and study sites

The study was conducted from May 2016 to February 2017 at the Coffee Plantation, Ungaran, Central Java, Indonesia (the elevation is approximately 515 m above sea level at the coordinates of 7°10'32.9" S and 110°23'52.8" E, and daily precipitation ranges between 12.75 and 16.38 mm). All coffee plants were fertilized regularly, and weeds were manually cut every 3 months.The size of each experiment and the control plot was 7200 m^2. The sunn hemp (*C. juncea*) was planted (size 4×10 m^2) in the center of the experiment plot as a source of pollen and nectar. No pesticide was applied during the study.

Sampling of Flower-Visiting Insects

The diversity and abundance of flower-visiting insects were recorded directly by visual inspection on the flower in the treatment plot (coffee with *C. juncea*) and control plot (coffee without *C. juncea*). The insects were recorded on 30 different plants in two minutes per sample (selected on flower panicles/ clustered flowers on two branches), from 08.00 a.m. - 10.30 a.m. The samples were taken every week during the flowering period.

The effects of *C. juncea* distances as a source of nectar and pollen on the diversity and abundance of insect visitors on flower coffee were also identified. The sample was determined at different distances (adjacent to 5, 10, 15, 20, 25, and 30 m) from *C. juncea* flowers to the coffee flowers, into four transect lines quadrants. For each insect visitor, the category 'crawling' and/or 'flying' that displayed feeding behaviors on the flowers of coffee was recorded visually (Erniwati and Kahono, 2009; Widhiono and Sudiana, 2015). The insect specimens were identified to the genus level according to the guideline for the identification of insects in the laboratory.

Duration of Visits and Daily Activity of Pollinators

The time it takes for a pollinator to handle each flower panicle may be related to its efficiency at cross-pollination. The duration of each pollinator per visit in one flower panicle was recorded directly by visual inspection. The observation of the length of time of pollinator's visit was conducted between 08:00 a.m. to 10:00 a.m. (the high activity of insect pollinator) on newly blooming coffee flowers (one night before the observation day). The visitation time of each pollinator per visit was measured by using a digital stopwatch. The observation of diurnal activity of each species insect pollinators was carried out sequentially on the same day, i.e., in the morning (08:00 a.m. -11:00 a.m.), midday (12:00 a.m. - 14:00 p.m.), and afternoon (15:00 p.m. - 17:00 p.m.), during the flower bloom of coffee.

Percentage of Fruit Set

To assess the influence of wild pollinators, four flower panicles (clustered flowers) on one branch were selected from 30 trees of coffee (in total 120 panicles). The influence of wild pollinators was assessed by comparing the number of fruit set of coffee in open pollination (by wild pollinators) and wind pollination (excluded wild pollinators). The exclusion of wild pollinators was carried out by bagging the flower panicle using nylon mesh gauze (0.25-mm mesh), but this did not exclude wind pollination (Willmer and Stone, 1989). The bag was fixed around the flowers one week before the petals opened. After petals had dried and/or fallen off, the nylon gauze was removed. The numbers of coffee fruit set in each panicle of coffee (green swollen ovules) were counted as described by Vergara and Badano (2009).

Data Analysis

The kinds and population of flower-visiting insects on a flower of coffee and *C. juncea* were analyzed descriptively using tables. A simple regression analysis was performed to examine the independent variable of flowering plant of *C. juncea* distance to the coffee and dependent variables of diversity and abundance of flower-visiting insects by using SPSS software (10.0J) for statistical analysis. The Statistical analysis (t-test) using SPSS software (10.0J) was also conducted to compare the means of fruit set produced by open pollination (wild pollinators) and wind pollination (excluding wild pollinator).

Results

Flower-Visiting Insects

Two orders of flower-visiting insects were recorded that showed feeding activity on coffee flowers, namely Hymenoptera and Lepidoptera. Seven families belonging to Hymenoptera were Apidae, Halictidae, Scoliidae, Megachilidae, Andrenidae, Vespidae, Ichneumonidae, while two families of Lepidoptera were Lycaenidae and Pieridae. There were three genera recorded of Apidae, namely *Apis, Xylocopa*, and *Thyreus*, while only one genus from another family was recorded as visiting the coffee flower (Table 1). This research showed that coffee visiting insects consist of real pollinator (bee/Apidae), predaceous insects of Halictidae, parasitic insects (Ichneumonidae and Scoliidae), and herbivore insects of Lycaenidae and Pieridae.

The average of flower-visiting insects on the plot with *C. juncea* was 4.8 (71.64%) higher than 1.9 (28.36%) on a plot without C. *juncea* per coffee branch in two minutes. The peak of population abundance of the flower visiting insects, particularly bees, was observed in the flower-coffee blooming period. Social bees of Apidae (Hymenoptera) were the dominant insect visitors. An average of 2.8 bees (Apidae) per branch per two minutes visited the coffee plot with *C. juncea*, which is 70% higher than in the control plot. The prevalent bees were in the genera *Apis* and *Xylocopa*. The abundance of flower-visiting insects also tend to decline ($F = 1.157$, $r^2 = 0.23$, $n = 30$; $P > 0.05$)) by increasing distance from the flowering plant *C. juncea* to coffee (Fig. 1).

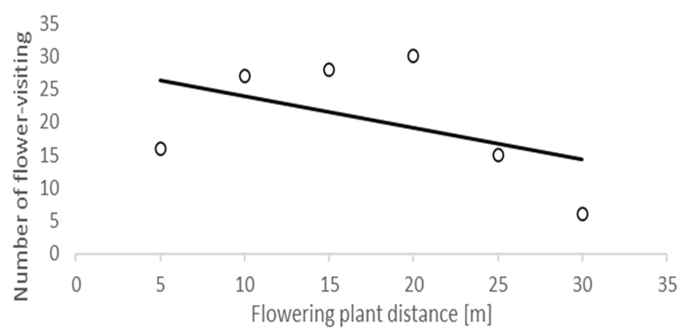

Figure 1. Relationship between the number of flower-visiting insects and *Crotalaria juncea* L. distance to coffee ($y = 28.73 - 0.48x$, $F = 1.157$, $r^2 = 0.23$, $n = 30$; $P > 0.05$)

Table 1. Diversity and abundance of flower-visiting insects on coffee with and without flowering plants *Crotalaria juncea* per branch in two minutes

Order	Family	Genera	With flowering-plant		Without flowering-plant	
			No of individuals per branch	(%)	No. of individuals per branch	(%)
Hymenoptera	Apidae	*Apis*	2.8	70	1.2	30
		Xylocopa	0.5	71.42	0.2	28.78
		Thyreus	-	-	0.1	100
	Halictidae	*Augochloropsis*	0.4	100	-	-
	Scoliidae	*Campsomeris*	0.1	50	0.1	50
	Megachilidae	*Stelis*	0.1	100	-	-
	Andrenidae	*Andrena*	0.2	100	-	-
	Vespidae	*Polistes*	0.1	100	-	-
	Formicidae	*Dolichoderus*	0.4	66.67	0,2	33.33
	Ichneumonidae	*Hoplocryptus*	0.1	100	-	-
Lepidoptera	Lycaenidae	*Strymon*	-	-	0.1	100
	Pieridae	*Phoebis*	0.1	100	-	-
Total			4.8	71.64	1.9	28.36

Most of the flower-visiting insects on *C. juncea* and coffee flowers were similar, but two families and five genera on *C. juncea* were not recorded on coffee and one family and three genera on coffee were not recorded on *C. junce* (Table 1 and Table 2). The insects on *C. juncea* belonged to two orders, 11 families, and 14 genera that visited the flowers of *C. juncea* (Table 2). Social bees (Apidae) were also the dominant insect visitors on the flowers of *C. juncea*. This study also observed few herbivore insects, namely Pieridae, Lycaenidae, Papilionidae) on *C. Juncea*.

Length of Time of the Pollinator's Visit and Diurnal Activity

In general, the activity of coffee flower visitor insects begins in the morning at 08:00 a.m and reaches its peak at 08.00 a.m. - 11.00 a.m. The daily activity decreases rapidly during the day (12.00 a.m - 14.00 p.m), and there is low activity in the afternoon from 15:00 p.m. until the end activity (Table 3).

Table 2. Diversity and abundance of flower-visiting insects on *Crotalaria juncea* per plant in two minutes

Order	Family	Genera	No. of individuals per plant	(%)
	Apidae	*Apis*	2.1	21.87
		Xylocopa	2.9	30.56
Hymenoptera	Megachilidae	*Stelis*	0.97	10.07
	Vespidae	*Polistes*	1.2	12.5
		Polybia	0.03	0.34
	Andrenidae	*Andrena*	0.97	10.07
	Halictidae	*Augochloropsis*	0.43	4.51
	Pompilidae	*Priocnemis*	0.03	0.35
	Ichneumonidae	*Hoplocyptus*	0.13	1.39
	Scoliidae	*Campsomeris*	0.27	2.78
Lepidoptera	Pieridae	*Colias*	0.2	2.08
		Ascia	0.13	1.38
	Lycaenidae	*Strymon*	0.06	0.69
	Papilionidae	*Battus*	0.1	1.04

Table 3. Average lenght of visitation time and daily visit activity of insect pollinators on coffee flowers

Order	Family	Genera	Lenght in one visitation and daily visit activity			
			Lenght of time	Time of visitation		
				08.00 – 11 am	12.00 – 02 pm	03.00 – 05 pm
Hymenoptera	Apidae	*Apis*	1':44"	√	√	√
		Xylocopa	16"	√		
	Halictidae	*Augochloropsis*	20"	√	√	
		Andrena	27"	√	√	
	Scoliidae	*Campsomeris*	7"	√	√	√
Lepidoptera	Pieridae	*Ascia*	16"	√		
	Lycaenidae	*Strymon*	19"	√	√	

Note: √: present

The daily visitation activity of bees (Apidae) on coffee flowers occurs throughout the day. Meanwhile, the activity of other visitor insects occurs in the morning and afternoon, except Scoliidae that showed activity in the afternoon. In this study, the longest visitation time of insect pollinators on the coffee flowers was recorded for bees (Apidae) and was more than one minute (Table 3), while the length of time of other visitor insects was less than one minute.

Percentage of Fruit Set of *C. Canephora*

The study showed that the fruit set of coffee in open pollination increased with the abundance of flower-visiting insects. The percentage of fruit set of coffee in the plot with *C. juncea* was 58.8% higher than 51.5% in the control plot without *C. juncea* ($P < 0.1$). Moreover, the averages of fruit set of coffee by open pollination were 58.83% in the plot with *C. juncea* and 55.53% in the control plot. These values were higher than by wind pollination alone, for which the averages were 32.01% in the treatment plot with *C. juncea* and 21% in the control plot (Fig. 2).

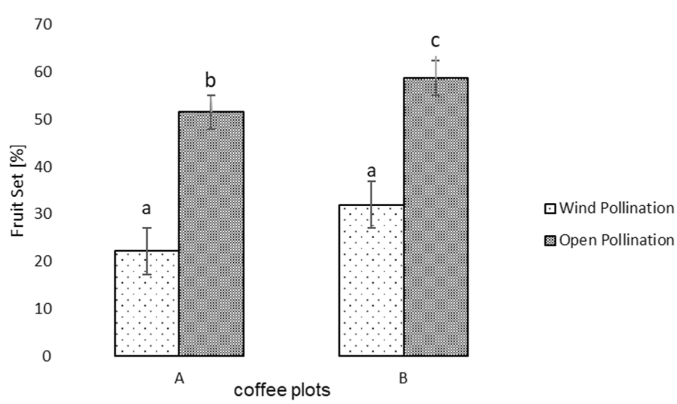

Figure 2. Percentage of fruit set *Coffea canephora* Pierre ex Froehner after different pollination treatments, open pollination (wind and wild pollinators) and wind pollination. (A). Coffee plot without *Crotalaria juncea* L. and (B). Coffee plot with *C. juncea*

Discussion

In this study, flower-visiting insects were 2.5-fold more abundant in the coffee plot with *C. juncea* but did not differ in diversity. The abundance of insects increased during the flowering period, both on coffee and *C. juncea*. An increase in the diversity and abundance of pollinator insects in coffee ecosystems with flowering plants was also reported by Boreux et al. (2013) and Klein et al. (2008). As this study shows, the presence of flowering plants of *C. juncea* with coffee leads to an increased abundance of flower-visiting bees. The bee (Hymenopter: Apidae) is a dominant insect pollinator in coffee plots with *C. juncea*. Bees (Apidae) were abundant on the coffee flowers and *C. juncea*. This indicates that *C. juncea* invites bee pollinators. Similar results were obtained by Rahayu et al. (2018) proving that sunn hem (*C. juncea*) may increase the population of bees on soybean flowers. This is important because approximately 97% of coffee pollination is conducted by bees (Krishnan et al., 2012).

Ants (Formicidae) were included as a group of flower-visiting insects because of their high abundance on flower panicles, which may contribute to cross-pollination (Huda et al., 2015). All flower-visiting insects recorded in this study have not been previously reported as pests on coffee (Kalshoven, 1981), and they visit the flowers mainly to obtain nectar and pollen. Moreover, among the *C. juncea* flower-visiting insects, parasitoid insects (Ichneumonidae and Scoliidae) and predaceous insects (Halictidae) were also recorded. This suggests that *C. juncea* is suitable for parasitoid and predatory insects. The parasitoid and predatory insects require an extra food source of nectar and pollen produced by flowering plants (Infante et al., 2008; Landis et al., 2000).

The *C. juncea* flowers were also visited by insect pollinators, including predators and parasitoids, but there is no record of a coffee pest. Heimpel and Jervis (2005) suggest that flowering plants invite many pollinators, including natural enemies, but are not always suitable for pests. Therefore, information related to choosing flowering plants that provide beneficial nutrients to parasitoids and predators (but are not suitable for coffee pests) is important. Principally, the food resources of flowering plants in the agroecosystems may be the main plant itself and/or other plants that are integrated with the cropping system (Supriyadi, 2014).

In this study, the population of flower-visiting insects was influenced by the distance of *C. juncea* as a food source for the coffee flowers. The abundance of insects, which is important for pollination effectiveness, may decrease by increasing coffee distance to *C. juncea*. Therefore, the length of visitation time may contribute to cross-pollination. Based on the length of visitation time and daily visit activity, bees (Apidae) were considered as effective pollinators in coffee flower. The bees (Apidae) more actively visit from flower to flower in/or other coffee compared to other insects. However, the influence of light intensity and temperature have not been examined in this study. Additionally, the behavior and diurnal activity of insect pollinators, particularly bees (Apidae), may change with changing light intensity and temperature (Klein et al., 2008, Supriyadi et al., 2020).

In this study, the abundance of flower-visiting insects in the ecosystem of coffee with *C. juncea* led to an increased fruit set of coffee. The average fruit set of coffee by open pollination (by wind and wild pollinators) was higher than that by excluding wild pollinators (by wind pollination). Klein et al. (2003a) also record that open pollination increases the average of fruit set of coffee by up to 16% higher compared to wind pollination. However, the difference in the bee pollinators' activities between solitary and social has not been evaluated in this study. The fruit set of highland coffee, *C. arabica*, was shown to be correlated with bee diversity, but not abundance (Klein et al., 2003b). Roubik (2002) also found that fruit set of coffee increased by more than 50% through pollination by non-native honey bees in Panama.

The results suggest that the management strategies used in coffee production should be encouraged by pollinator-friendly practices to increase coffee production. Although this study has not evaluated the pollination effectiveness of each insect visitor, this has been widely demonstrated in previous studies. Therefore, future production systems of coffee should consider the importance of flowering plants to sustain pollination services.

Conclusion

The coffee ecosystem with the flowering plant of *C. juncea* may increase the number of flower-visiting insects, but not insect diversity. The abundance of flower-visiting insects on coffee was increased during the flowering period, both on coffee and *C. juncea*. The bees of Apidae (Hymenoptera) were the dominant flower-visiting insects, and thus *C. juncea* in the ecosystem of coffee may lead to an increased abundance of effective pollinators. The *C. juncea* also did not invite coffee pests. The fruit set of coffee was influenced indirectly by the increase in insect pollinators at open-pollinated flowers. Therefore, this study suggests the planting of sunn hemp (*C. juncea*) in the ecosystem of coffee to increase the fruit set of coffee.

Acknowledgements

Financial support for the research was obtained from the Directorate Research and Public Service, Ministry of Research, Technology and Higher Education of the Republic of Indonesia (DIPA Grant No. 873/UN27.21/PP/2017), which we gratefully acknowledge.

References

Boreux V., Kushalappa C. G., Vaast P., Ghazoul J. (2013). Interactive Effects among Ecosystem Services and Management Practices on Crop Production: Pollination in Coffee Agroforestry Systems. PNAS 110 (21): 8387–8392. doi: 10.1073/pnas.1210590110

Erniwati, Kahono S. (2009). The Role of the Wild Plants in Relation to the Conservation of the Hymenopteran Pollinators. J Teknol Ling 10 (2): 195-203 (in Indonesian)

Foreign Agricultural Service (2018). Coffee: World Markets and Trade, December 2018. Available at: https://downloads.usda.library.cornell.edu/usdaesmis/files/m900nt40f/41687n67f/ nk322j622/coffee.pdf [Accessed 16/02/2020]

Geeraert L., Aerts R., Berecha G., Daba G., De Fruyt N., D'hollander J., Kenny H., Hanna S., Olivier H. (2019). Effects of Landscape Composition on Bee Communities and Coffee Pollination in *Coffea arabica* Production Forests in Southwestern Ethiopia. Agric Ecosyst Environ 288. doi:10.1016/j.agee.2019.106706

Heimpel G., Jervis M. (2005). Does Floral Nectar Improve Biological Control by Parasitoids? In Wäckers F., Van Rijn P., Bruin J. (Eds.), Plant-Provided Food for Carnivorous Insects: A Protective Mutualism and its Applications. Cambridge University Press, Cambridge, pp. 267-304

Hipólito J., Boscolo D., Viana B. F. (2018). Landscape and Crop Management Strategies to Conserve Pollination Services and Increase Yields in Tropical Coffee Farms. Agric Ecosyst Environ 256: 218–225. doi: 10.1016/j.agee.2017.09.038

Huda A. N., Salmah M. C., Hassan A. A., Hamdan A., Razak M. A. (2015). Pollination Services of Mango Flower Pollinators. J Insect Sci 15 (13): 113. doi: 10.1093/jisesa/iev090

Infante F., Mumford J., Baker P., Fowler S. (2008). Interspecific Competition between *Cephalonomia stephanoderis* and *Prorops nasuta* (Hym, Bethylidae), Parasitoids of the Coffee Berry Borer, *Hypothenemus hampei* (Col., Scolytidae). J Appl Entomol 125: 63–70

Jervis M., Kidd N., Fitton M., Huddleston T., Dawah H. (1993). Flower-Visiting by Hymenopteran Parasitoids. J Nat Hist 27: 67-105. doi: 10.1080/00222939300770051

Kalshoven L. G. E. (1981). Pests of Crops in Indonesia. PT. Ichtiar Baru-Van Hoeve, Jakarta.

Klein A. M, Steffan-Dewente I., Tscharntke T. (2003a). Pollination of *Coffea canephora* in Relation to Local and Regional Agroforestry Management. J Appl Ecol 40: 837–845

Klein A. M., Steffan-Dewente I., Tscharntke, T. (2003b). Fruit Set of Highland Coffee Increases with the Diversity of Pollinating Bees, in: Proc R Soc Lond. London, pp. 955–961

Klein A. M., Cunningham S. A., Bos M., Steffan-Dewente I. (2008). Advances in Pollination Ecology from Tropical Plantation Crops. Ecology 89: 935–943. doi: 10.1890/07-0088.1

Krishnan S., Kushalappa C. G., Shaanker R. U., Ghazoul J. (2012). Status of Pollinators and Their Efficiency in Coffee Fruit Set in a Fragmented Landscape Mosaic in South India. Basic Appl Ecol 13: 277–285

Landis D., Wratten S., Gurr G. (2000). Habitat Management to Conserve Natural Enemies of Arthropod Pests in Agriculture. Annu Rev Entomol 45:175–201. doi: 10.1146/annurev.ento.45.1.175

Ministry of Industry, Republic of Indonesia. (2013). Press Release: The Third Largest Domestic Coffee Production in the World. Available at: https://www.kemenperin.go.id/artikel/6611/Produksi-Kopi-Nusantara-Ketiga-Terbesar-Di-Dunia [Accessed 16/02/2019]

Ngo H., Mojica A., Packer L. (2011). Coffee Plant – Pollinator Interactions: A Review. Can J Zool 89 (8):647–660

Nicolson S., Thornburg R. (2007). Nectar Chemistry (Chapter 5), in: Nicolson S. W., Nepi M., Pacini E. (Eds.), Nectaries and Nectar. Springer-Verlag, pp. :215–263

Purba O. M., Toekidjo, Prajitno J. (2012). The Productivity of Arabica Coffee (*Coffea arabica* L.) in Raya Subdistrict Simalungun Regency. Vegetalika 1(2): 1-11 (in Indonesian)

Rahayu S. K., Supriyadi S, Supriyono, Wijayanti R., Arniputri R. B. (2018). Diversity of Flower Visiting Insects on Intercropping between Soybean and Sunn Hemp (*Crotalaria juncea*). J Entomol Indon 15:23–30 (in Indonesian)

Roubik D. (2002). Feral African Bees Augment Neotropical Coffee Yield, in: Kevan, P., Imperatriz-Fonseca, V. (Eds.), Pollinating Bees. The Conservation Link Between Agriculture and Nature, Ministry of Environment, Brasília, pp. 255-266

Roulston T. H., Cane J. H. (2000). Pollen Nutritional Content and Digestibility for Animals. Plant Syst Evol 222: 187–209. doi: 10.1007/BF00984102

Sunanto, Salim, Rauf A. W. (2019). Analysis of Agreement of Increasing Productivity of Arabican Coffee in Area Development in Toraja Utara Regence. J Sos Ekon Pertan 15 (1): 42-55 (in Indonesian)

Supriyadi S., Dzikrillah F. D., Arniputri R. B., Wijayanti R. (2020). The Effect of Shade Trees in the Coffee Ecosystem to the Population and Diurnal Activity of Insect Pollinators. Int J Adv Sci Eng Inf Technol 10:1743-1749. doi: 10.18517/ijaseit.10.4.12167

Supriyadi S., Wijayanti R., Arniputri B., Puspitarini N., Dwiyatno M. H. (2019). The effect of *Crotalaria juncea* Plant in Coffee Ecosystem to the Diversity and Abundance of Predators and Parasitoid Insects. IOP Conf. Ser.: Earth Environ Sci. 250-012018

Supriyadi S. (2014). Diversity of Flowering Plants in Agro-Ecosystems to Improve Ecological Service. In Proceeding of Annual Symposium and Seminar of Indonesian Agronomy Association (Purwanto E., Yunus A., Samanhudi, eds). Surakarta, Indonesia, pp. 157-161

Vergara C. H., Badano E. I. (2009). Pollinator Diversity Increases Fruit Production in Mexican Coffee Plantations: The Importance of Rustic Management Systems. Agric Ecosyst Environ 129: 117–123. doi: 10.1016/j.agee.2008.08.001

Weiner C.N., Hilpert A., Werner M., Linsenmair K. E., Blüthgen N. (2010). Pollen Amino Acids and Flower Specialisation in Solitary Bees. Apidologie 41:476–487. doi: 10.1051/apido/2009083

Widhiono I., Sudiana E. (2015). The Role of Wild Plants in the Conservation of Pollinating Insects of the Order Hymenoptera. In: Prosiding Seminar Nasional, Masyarakat Biodiversitas Indonesia 1, pp. 1586–1590

Willmer P., Stone G. (1989). Incidence of Entomophilous Pollination of Lowland Coffee (*Coffea canephora*); the Role of Leaf Cutter Bees in Papua New Guinea. Entomol Exp Appl 50(2): 113–124

---

aCS86_14