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Pollen species resources for Carpenter bees (*Xylocopa* spp.) in Central Sulawesi, Indonesia

SAMSURIZAL M. SULEMAN♥, MANAP TRIANTO, DIRHAM, LESTARI M. P. ALIBASYAH, HAYYATUN MAWADDAH
Department of Biology Education, Faculty of Teacher Training and Education, Universitas Tadulako. Jl. Soekarno Hatta KM. 9, Palu 94148, Central Sulawesi, Indonesia. Tel./fax.: +62-451-422611, ♥email: biosamriz@gmail.com

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Abstract. *Suleman SM, Trianto M, Dirham, Alibasyah LMP, Mawaddah H. 2025. Pollen species resources for Carpenter bees* (Xylocopa *spp.*) *in Central Sulawesi, Indonesia. Biodiversitas 26: 1503-1510.* Pollen represents the microgametophyte generation in seed plants and plays a crucial role in their life cycle. Carpenter bees (*Xylocopa* spp.), known for their preference for forage plants with specific aroma and visual characteristics, play a significant role in the pollination process This study aimed to identify the plants producing pollen for carpenter bees in three districts of Central Sulawesi, Indonesia. The sampling of carpenter bees was carried out using the roaming method. The pollen samples from each bee leg were prepared using the acetolysis method to clear the pollen walls. Quantitative analysis was performed by counting 200-300 pollen grains in a single slide. *Xylocopa confusa* collects pollen from a diverse range of plant families, including Asteraceae, Arecaceae, Fabaceae, Poaceae, and others, while *X. latipes* relies on a more limited selection. *Cocos nucifera* serves as the predominant pollen source for both bee species. Additionally, *X. confusa* utilizes several Important Minor (IM) pollen sources, such as *Desmodium adscendens, Euphorbia hirta*, and *Tetracera scandens*, while Minor (M) pollen sources include *Ageratum conyzoides, Sphagneticola trilobata*, and others. Morphologically, most pollen grains are circular in polar view, with variations in equatorial shape, including prolate, subprolate, and semicircular forms. The highest pollen percentage is recorded for *C. nucifera* in both bee species.

Keywords: Carpenter bees, pollen morphology, pollen sources, Sulawesi, *Xylocopa* spp.

INTRODUCTION

Indonesia is one of the tropical countries blessed with abundant natural wealth, including diverse flora and fauna. One of the fauna beneficial to humans is carpenter bees (*Xylocopa* spp.) (Hymenoptera: Anthophoridae) (Christenhusz and Byng 2016). A key factor influencing the life of carpenter bees is the availability of food sources (Doaigey et al. 2018), such as fruit trees, vegetables, ornamental plants, crops, forest plants, and plantation crops (Kajornjit et al. 2018; Sudarmono 2020). The flowers of these plants contain nectar and pollen, which are crucial to the life of carpenter bees (Saensouk and Saensouk 2021).

All species of flowering plants that contain nectar, pollen, and propolis can be utilized as food sources for all bees (Doaigey et al. 2018). Propolis, a resinous substance collected by bees from tree buds, sap flows, or other botanical sources, plays a crucial role in bee nutrition and hive health. Hugg et al. (2020) revealed that the food sources for bees, particularly *Apis indica* (Fabricius, 1798), include ornamental plants, legumes, certain fruit plants, coconut, and vegetables. Plants can produce both nectar and pollen, but some only produce one or the other (Jalil 2014; Ya'akob et al. 2018). According to Octavia et al. (2015), bees can visit several hundred flowers to gather enough nectar or pollen as their food source. Approximately 25,000 bee species have been identified in the worldwide (Michener 2007). Bees are drawn to pollen due to its protein content and to nectar because of its sugar content; the higher the sugar content in nectar, the more frequently bees will visit the flower (Barker et al. 2016).

Carpenter bees are bees that have a large size and are hairy (Nugroho and Soesilohadi 2014). These bees are also called wood bees, because, in their lives, they make nests in dead wood and bamboo (except for the subgenus *Proxylocopa*, which makes nests on the ground) (Azmi et al. 2015; Bisui et al. 2019). These bees have an important role in helping the success of the pollination process of several plant species, such as long beans, cucumber, eggplant, and tomatoes (Jayuli et al. 2018; Pratama et al. 2018; Hugg et al. 2020), highlighting their ecological significance. Their foraging behavior facilitates efficient pollen transfer, supporting the reproduction of wild and cultivated plants. These bees also show preferences for certain floral resources, shaping plant-pollinator interactions within ecosystems. Recognizing their ecological significance is crucial for biodiversity conservation and sustainable agriculture, as they contribute to maintaining plant diversity and enhancing crop yields (Pratama et al. 2018). Indonesia has four species of carpenter bees that are widely distributed across almost all islands (Hugg et al. 2020). Three species of carpenter bees were reported in Bogor and Sukabumi (Java), namely *Xylocopa confusa* (Pérez, 1905), *X. latipes* (Drury, 1773), and *X. caerulea* (Fabricius, 1804). Furthermore, in Bali, West Sumatra, and Central Sulawesi two species were reported, namely *X. confusa* and *X. latipes*. Based on their biological characteristics, wood bees are a type of bee that can be found in almost all types of habitats, such as primary forests, secondary forests, urban and rural areas, which have different environmental characteristics (Abbas and Sucianto 2020; Windarsih and Trianto 2021).

Pollen-producing plants collected by carpenter bees as food sources include *Acacia* sp., *Ageratum houstonianum* Mill., *Calliandra brevipes* Benth., *Capsicum* sp., *Carica papaya* L., *Cocos nucifera* L., *Helianthus* sp., *Impatiens balsamina* L., *Mimosa pudica* L., and *Psidium guajava* L. (Abbas and Sucianto 2020). Morphological characteristics of pollen, such as symmetry, size and shape, exine, and aperture ornamentation, indicate from which plant the pollen originated (Salamah et al. 2019). This study aimed to identify plants producing pollen from carpenter bees *Xylocopa* spp. in Central Sulawesi, Indonesia.

MATERIALS AND METHODS

Study area

This research was carried out from October to December 2023 in three districts of Central Sulawesi Province, Indonesia, i.e. This research was carried out from October to December 2023 in three districts of Central Sulawesi Province, Indonesia, i.e. (i) Nambaru, Parigi Moutong District, (ii) Towale, Donggala District, and (iii) Sidondo, Sigi District (Figure 1, Table 1).

Procedures

Sampling stage and identification of Xylocopa *spp.*

The sampling of *Xylocopa* spp. was carried out using the roaming method (Bookhout 1996). Surveys of the sampling locations in each observation area was conducted by walking through residential areas and gathering information about the presence of nests from local residents. The coordinates of the nests found will be recorded using a Garmin etrex 20 Global Positioning System (GPS) (Table 1). The collection of *Xylocopa* spp. in their natural habitat will follow the method by Trianto and Purwanto (2020). On the first day, 10 sampling points were established, each spaced 100 m apart. A sugar water solution will then be sprayed on bushes or plants, covering an area of 1 × 1 m. Plastic string was tied to each sampling point as markers. On the second day, the established sampling points were revisited and checked three times: at 7:00 AM, 1:00 PM, and 4:30 PM local time. After the morning check, the sampling points were sprayed with sugar water again. After the midday check, the points were sprayed again, and after the final check in the afternoon, the sugar water was reapplied. *Xylocopa* spp. found during the checks will be captured using an insect net. Identification was carried out using available references, such as Hurd and Moure (1963) and Maa (1970).

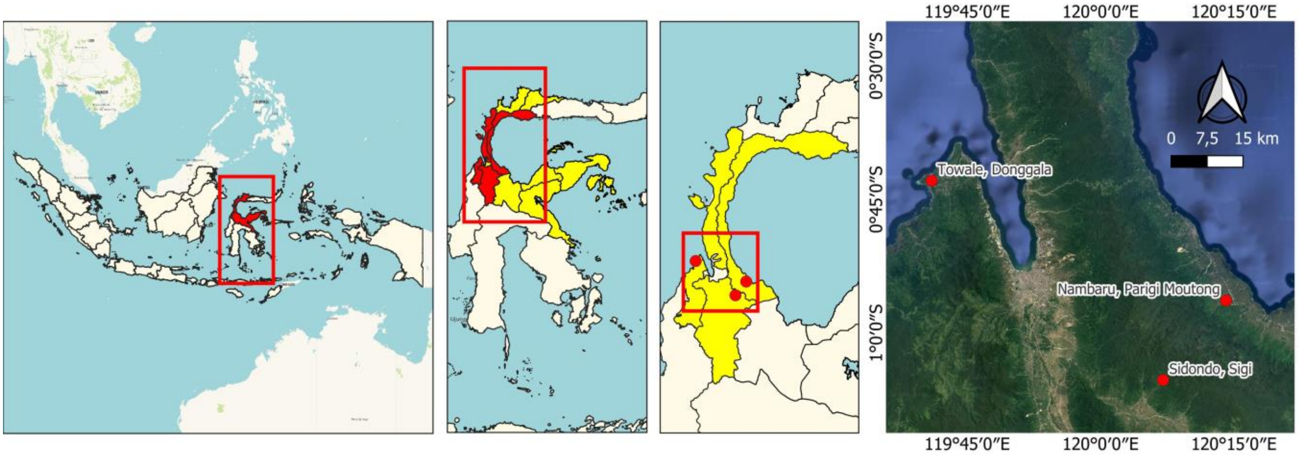

Figure 1. Study sites in the Central Sulawesi Province, Indonesia

Table 1. Study sites employed for the sampling of *Xylocopa* spp.

Location	Coordinate	Environmental condition
Nambaru, Parigi Moutong	0°56'20" S 120°14'08" E	Forest area: natural ecosystems dominated by dense tree cover. It has high biodiversity, including various flowering plants that serve as food sources for pollinators. This habitat supports a stable ecosystem with complex interactions between flora and fauna
Towale, Donggala	0°25'31" S 120°04'11" E	Plantation: cultivated lands managed by humans, such as coconut, cocoa, or oil palm plantations. Plant diversity is lower compared to natural forests, but it still provides nectar and pollen sources for some bee species and other pollinators. Agricultural practices and human activities may influence insect populations and their behavior in this area
Sidondo, Sigi	1°05'17" S 120 °07'04" E	Forest area: disturbed forests due to human activities or environmental changes. Although it still provides habitat for various plant and animal species, its biodiversity may be lower than that of primary forests. However, this area remains important for maintaining bee populations and local ecosystem sustainability

Pollen samples from each bee leg were prepared using the acetolysis method to clear the pollen walls. The acetolysis method used followed the procedure of Wrońska-Pilarek et al. (2015). Pollen samples were placed in 1.5 mL tubes. Then 1 mL of acetolysis solution was added, which consisted of a mixture of acetic anhydride ($C_4H_6O_3$) (M = 102.09 g/mol) and H_2SO_4 (M = 98.08 g/mol) in a 9:1 ratio, where H_2SO_4 was added to the acetic anhydride. The acetolysis mixture generates heat, so it was left for 10 minutes before being added to the sample. The sample was then heated in a GFL water bath at 80°C for 5 minutes with the tube lid open. After that, the solution in the tube was centrifuged at 3,500 rpm for 10 minutes. The acetolysis solution was discarded, and 1 mL of distilled water was added and centrifuged again at 3,500 rpm for 10 minutes to rinse the pollen in the tube. This process was repeated 2-3 times until clear. The sedimented pollen was stored in an oven at 60°C for 24 hours, then 1 mL of 30% glycerin was added and stirred with a toothpick to prevent clumping. A drop of the pollen sample was then taken using a pipette, placed on a microscope slide, and covered with a coverslip. Nail polish was applied to the edges of the coverslip to serve as an adhesive.

Identification of pollen types

Pollen identification involves analyzing the morphology of pollen grains under a microscope to classify them into specific types (Huang 1972). The selection of six key characteristics in pollen identification, i.e. shape, size, apertures, exine ornamentation, color, and surface sculpturing is based on their taxonomic significance and role in distinguishing species as well as their ecological adaptations (Punt et al. 2007; Halbritter et al. 2018). These characteristics are used because they can indicate evolutionary relationships, dispersal mechanisms, compatibility with pollinators, and specific features that differentiate taxa at the genus or species level (Hesse et al. 2009).

Data analysis

All characters observed were compared with known pollen type references in pollen atlas and database (https://www.paldat.org), which specific to different regions and plant families. Percentage of pollen type was conducted by counting 200-300 pollen grains per slide according to Halbritter et al. (2018) as follows:

$$\text{Percentage of Pollen Type } (\%) = \left(\frac{\text{Number of Grains of a Specific Pollen Type}}{\text{Total Number of Pollen Grains Identified}} \right) \times 100$$

RESULTS AND DISCUSSION

Species diversity of *Xylocopa* spp.

Carpenter bees (*Xylocopa* spp.) are large, robust bees known for their role as important pollinators in various ecosystems. They are characterized by their strong mandibles, which they use to excavate nests in wood, and their distinctive glossy black or metallic-colored bodies. The species within this genus exhibit variations in body size, coloration, and wing iridescence, adapting to different environmental conditions. The following are descriptions of two *Xylocopa* species identified in the research site:

Xylocopa confusa *(Pérez, 1905)*

Xylocopa confusa is a large carpenter bee species with a body length ranging from 20 to 25 mm. Its body is predominantly glossy black, often displaying a metallic blue or green sheen, particularly on the thorax and abdomen. The head is broad and robust, featuring large compound eyes positioned laterally. The antennae are of moderate length, segmented, and slightly curved at the tips. It possesses strong mandibles, which are adapted for excavating nests in soft wood. The thorax is covered with short, sparse hairs (setae) and is typically black, sometimes reflecting metallic hues depending on the angle of light. The wings are dark brown to black, with a characteristic purplish or greenish iridescence. The abdomen is elongated and cylindrical, with a relatively smooth surface compared to social bees like *Apis* or *Bombus*. The legs are sturdy and well-adapted for clinging to surfaces and digging into wood.

Xylocopa latipes *(Drury, 1773)*

Xylocopa latipes is one of the largest species of carpenter bees, with a body length reaching 28-32 mm. It has a predominantly black, glossy body with a characteristic metallic blue or purple sheen on the thorax and abdomen. The head is broad and robust, equipped with large compound eyes positioned laterally. The antennae are moderately long, slightly curved at the tips, and consist of multiple segments. The mandibles are strong and adapted for excavating wood to create nesting sites. The thorax is covered with short and sparse hairs (setae), primarily black, with a noticeable metallic reflection depending on the lighting. The wings are dark brown to black with a distinctive purplish or bluish iridescence. The abdomen is elongated and cylindrical, with a smooth and glossy surface.

Pollen diversity found in *Xylocopa* spp.

The identification of 12 pollen types obtained from 5 samples of *X. confusa* revealed the presence of Gramineae-type pollen (originating from plants in the family Gramineae). All the pollen types collected by *X. confusa* were classified as small-sized pollen (10-25 µm), except for Gramineae-type pollen and coconut pollen (*C. nucifera*), which were classified as large-sized pollen (50-100 µm). The morphological variations of the pollen types collected by *X. confusa* include the following polar view shapes (circular, circular-lobate, spheroidal, and semiangular), equatorial view shapes (spheroidal, subprolate, prolate, compressed oval, and oblate), apertures (tricolporate, tricolpate, monocolpate/sulcate, monoporate, and tetrad), and exine ornamentation (psilate, scabrate, reticulate, verrucate, striate, and echinate). The most common aperture type found in the pollen collected by *X. confusa* was tricolporate. At the same time, the most frequent polar view shape was circular, and the equatorial view shapes were predominantly spheroidal and subprolate. Furthermore, the observation of pollen from 3 samples of *X. latipes* revealed only one type of pollen, which is coconut pollen (*C. nucifera*), which was classified as large-sized pollen (50-100 µm). The characteristics of *C. nucifera* pollen include polar view shape (circular), equatorial view shape (prolate/compressed oval), aperture (monocolpate/sulcate), and exine ornamentation (psilate) (Figure 2; Table 2).

The diversity of pollen types obtained from bee pollen samples indicates that *X. confusa* utilizes a wider range of plant species for pollen sources compared to the *X. latipes* colony. *Xylocopa confusa* collects pollen from various plant species, categorized as predominant, important minor, and minor pollen sources. In contrast, *X. latipes* collects pollen from only one plant species, which is categorized as a predominant pollen source (Table 2). *Xylocopa confusa* and *X. latipes* use *C. nucifera* as a predominant pollen source. The majority of pollen collected by *X. confusa* is *C. nucifera*, accounting for 49.68%, while *X. latipes* collects 95.05% of its pollen from *C. nucifera*.

Xylocopa confusa collects pollen from a diverse array of plant species, including *C. nucifera*, which serves as a predominant pollen source. In addition to *C. nucifera*, *X. confusa* gathers several important minor pollen types, such as *Desmodium adscendens* (Sw.) DC., *Euphorbia hirta* L., and *Tetracera scandens* (L.) Merr. The bee also collects minor pollen from *Ageratum conyzoides* L., *Lannea coromandelica* (Houtt.) Merr., *M. pudica*, *Saurauia oligolepis* Miq., and *Sphagneticola trilobata* (L.) Pruski. This varied pollen collection indicates a broad foraging behavior in *X. confusa*, contrasting with the more specialized pollen collection observed in *X. latipes*.

Discussion

The results indicate a significant difference in the diversity of pollen types collected by *X. confusa* and *X. latipes*. *Xylocopa confusa* collects pollen from 12 different plant species, whereas *X. latipes* gathers pollen from three species. This variation reflects a notable strategic difference in the foraging patterns of these two bee species (Table 2). *Xylocopa confusa* exhibits the ability to gather pollen from a diverse array of sources, including various plant species from the family Gramineae, as well as *D. adscendens*, *E. hirta*, *T. scandens*, and others (Table 2). This suggests that *X. confusa* has a flexible and adaptive foraging strategy, providing a significant ecological advantage (Dellinger et al. 2021). This advantage of flexibility provides a significant ecological advantage, which allows *X. confusa* to utilize various food sources depending on their availability (Dellinger et al. 2019). This is crucial in dynamic ecosystems where pollen availability may vary seasonally or due to other environmental changes (Peeters and Ito 2021). In contrast, *X. latipes* exclusively collects pollen from *C. nucifera*, indicating a high level of specialization in foraging. This specialization may offer greater efficiency in gathering and processing pollen from a focused source (Li et al. 2023), but also carries risks, especially if the primary source, *C. nucifera*, experiences a decline in quantity or quality. *Xylocopa latipes* may be more vulnerable to environmental changes or disturbances affecting coconut plants, which in turn could impact the survival of this species.

The morphological analysis of the pollen collected by *X. confusa* reveals a fascinating array of features. The pollen types collected include polar views, such as circular, circular-lobate, spheroidal, and semiangular shapes, as well as equatorial views like spheroidal, subprolate, prolate, compressed oval, and oblate. Additionally, the most commonly found pollen aperture is tricolporate, while exine ornamentation varies between psilate, scabrate, reticulate, verrucate, striate, and echinate (Table 2).

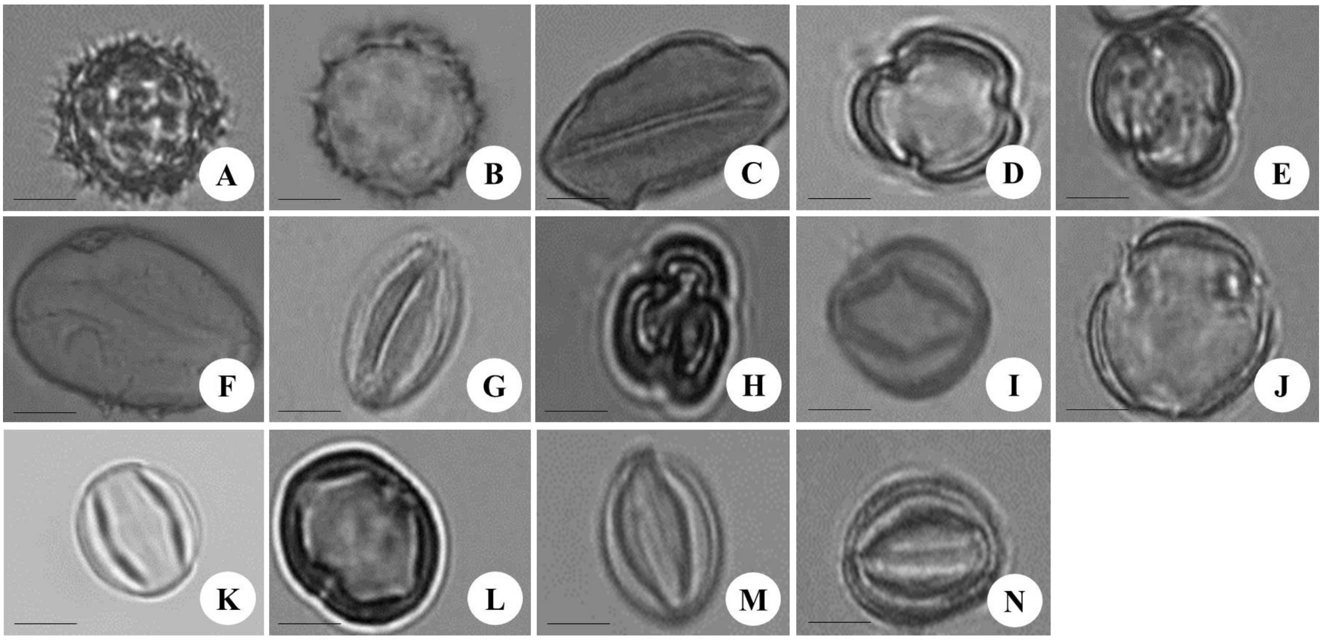

Figure 2. The diversity of pollen types obtained from bee pollen samples was collected from the legs of *X. confusa* and *X. latipes*: A. *Ageratum conyzoides*; B. *Sphagneticola trilobata*; C. *Cocos nucifera*; D. *Lannea coromandelica*; E. *Mimosa pudica*; F. *Imperata cylindrica*; G. *Tetracera scandens*; H. *Lithocarpus glutinosus*; I. *Desmodium adscendens*; J. *Euphorbia hirta*; K. *Saurauia oligolepis*; L. *Saurauia vulcani*; M. *Tetracera scandens*; N. *Tetracera indica*. Scale bar: 5.0 µm

Table 2. Pollen types, morphological characteristics, and pollen percentage of bee pollen collected from *X. confusa* and *X. latipes* samples

Family	Species	Polar side	Equatorial side	Aperture	Exine ornament	Polar size (height × width) µm	Equatorial size (height × width) µm	Pollen percentage (%)	Category
***Xylocopa confusa* (Pérez, 1905)**									
Asteraceae	*Ageratum conyzoides* L.	Circular	Spheroidal	Tricolporate	Echinate	14.54-15.31 × 13.21-13.76	15.22-15.89 × 13.04-13.41	1.55	M
Asteraceae	*Sphagneticola trilobata* (L.) Pruski	Circular	Spheroidal	Tricolporate	Echinate	15.67-16.42 × 16.66-17.08	17.66-17.56 × 17.96-17.97	3.83	M
Arecaceae	*Cocos nucifera* L.	Circular	Compressed oval	Sulcate	Psilate	63.03-85.75 × 58.53-77.59	67.50-93.64 × 44.52-67.38	49.68	P
Anacardiaceae	*Lannea coromandelica* (Houtt.) Merr.	Circular	Prolate	Tricolporate	Striate	13.03-15.26 × 13.98-17.02	22.54-52.43 × 15.47-16.54	3.48	M
Fabaceae	*Mimosa pudica* L.	Circular	Oblate	Tetrad	Psilate	12.28-12.51 × 13.19-14.05	13.30-13.49 × 13.49-14.17	5.50	M
Poaceae	*Imperata cylindrica* (L.) Raeusch.	Circular	Spheroidal	Monoporate	Scabrate	76.38-86-69 × 70.01-72.84	77.18-81.05 × 63.12-65.55	8.25	IM
Dilleniaceae	*Tetracera scandens* (L.) Merr.	Circular	Subprolate	Tricolpate	Reticulate	16.67-18.59 × 16.14-16.83	16.76-18.90 × 13.75-13.35	6.87	IM
Fagaceae	*Lithocarpus glutinosus* (Blume) Soepadmo	Circular	Subprolate	Tricolporate	Reticulate	11.64-11.72 × 11.25-11.28	13.24-13.56 × 13.52-13.71	5.87	M
Fabaceae	*Grona adscendens* (Sw.) H.Ohashi & K.Ohashi	Circular	Subprolate	Tricolporate	Reticulate	16.07-16.97 × 15.98-16.02	14.95-15.43 × 12.82-13.56	10.00	IM
Euphorbiaceae	*Euphorbia hirta* L.	Circular	Subprolate	Tricolporate	Reticulate	16.08-21.02 × 16.88-20.79	16.19-20.42 × 13.74-16.39	4.63	IM
Actinidiaceae	*Saurauia oligolepis* Miq.	Circular	Subprolate	Tricolporate	Psilate	14.78-15.24 × 14.52-15.77	15.61-15.01 × 13.33-14.21	0.25	M
Actinidiaceae	*Saurauia vulcani* Korth.	Circular	Subprolate	Tricolpate	Scabrate	16.94-18.38 × 15.95-17.53	17.82-18.92 × 11.74-14.43	0.09	IM
***Xylocopa latipes* (Drury, 1773)**									
Arecaceae	*Cocos nucifera* L.	Circular	Prolate	Monocolpate	Psilate	52.89-83.54 × 46.41-75.37	65.3-91.42 × 31.29-65.96	95.05	P
Dilleniaceae	*Tetracera scandens* (L.) Merr.	Circular	Subprolate	Tricolpate	Reticulate	16.66-18.59 × 16.24-16.82	16.76-18.96 × 12.75-13.35	4.92	IM
Dilleniaceae	*Tetracera indica* (L.) Merr. .	Semiangular	Prolate	Tricolpate	Verrucate	14.73-16.75 × 14.52-16.45	18.25-19.41 × 16.06-16.24	0.03	IM

Note: M: Minor; IM: Important Minor; P: Predominant

This phenomenon occurs because each plant species produces pollen with unique shapes and structural characteristics, observable from different angles (polar or equatorial views). This morphological variation results from adaptive evolution aimed at enhancing reproductive success, as pollen structure plays a critical role in protecting genetic material and facilitating attachment to pollinators, such as bees. Polar shapes, such as circular, circular-lobate, spheroidal, and semiangular as well as equatorial shapes like spheroidal, subprolate, prolate, compressed oval, and oblate, help pollen adhere more effectively to pollinators or reach a plant's stigma surface (Araújo et al. 2021). The common tricolporate aperture (with three furrows or pores) is a widespread adaptation that facilitates the release of male gametes onto the plant's stigma, thereby expediting fertilization. Variations in exine ornamentation, including psilate, scabrate, reticulate, verrucate, striate, and echinate textures, enhance pollen adhesion to pollinators or stigmas, while also protecting pollen from environmental stressors such as extreme temperatures, humidity, and pathogens. These variations, therefore, are not merely morphological differences; they are integral to a plant's reproductive strategy, involving morphological and ecological diversity to ensure successful fertilization (Geier et al. 2024).

This variation reflects the bee's ability to gather pollen from various plant species with different morphological characteristics (Portman et al. 2019). The diversity in pollen morphology indicates that *X. confusa* can adapt to different types of pollen, allowing this species to collect and utilize pollen from a wide range of sources. In terms of size, *X. confusa* tends to collect smaller pollen (10-25 µm), except for pollen from the family Gramineae and *C. nucifera*, which fall into the large size category (50-100 µm). This preference for smaller pollen may be related to the morphology of *X. confusa* mouthparts and body structure, which may be more efficient in collecting small-sized pollen from a variety of plant types (Agostini et al. 2024). The ability to handle various pollen sizes provides an additional advantage in exploiting food sources (He and Zhu 2020). On the contrary, *X. latipes* collects pollen exclusively from *C. nucifera*, which is larger (50-100 µm). The pollen morphology of *C. nucifera* collected by *X. latipes* includes circular polar views and prolate/compressed oval equatorial views, with monocolpate/sulcate apertures and psilate exine ornamentation. The consistency in the morphology and size of this pollen indicates that *X. latipes* is specifically adapted to handling pollen from this single plant species (Mahmoud and Shebl 2024). This suggests that *X. latipes* likely possesses a body structure highly suited for collecting large pollen, and this specialization provides an advantage in the efficiency of collecting and processing pollen from *C. nucifera*.

The diversity of pollen sources collected by *X. confusa* indicates that this species adopts a broad and varied pollen-gathering strategy. By collecting pollen from a wide range of plant species, *X. confusa* functions as a generalist pollinator capable of adapting to environmental changes and pollen availability (Geier et al. 2024). This generalist strategy allows *X. confusa* to take advantage of various pollen sources that may have different flowering periods, thereby increasing its chances of survival in fluctuating conditions (Araújo et al. 2021). For instance, *X. confusa* gathers pollen from *D. adscendens, E. hirta, T. scandens*, and *I. cylindrica*, all of which may have different blooming periods and availability. This shows that *X. confusa* can utilize different food sources depending on the season or availability. This ability also reflects a more flexible and adaptive foraging strategy, where *X. confusa* can exploit a variety of pollen types to meet its nutritional needs. In contrast, *X. latipes* has a highly specific foraging strategy, exclusively collecting pollen from *C. nucifera*. This specialization may offer an advantage in terms of efficiency in gathering pollen from a single plant species (Silva et al. 2024); however, this specialization also poses a significant risk. Relying on one pollen source can also be a disadvantage, especially if the primary source, *C. nucifera*, experiences a decline or disruption. If coconut populations decrease due to environmental changes or other threats, *X. latipes* may struggle to find alternative pollen sources, potentially affecting the survival of the species.

The differences in foraging strategies and the diversity of pollen collected by *X. confusa* and *X. latipes* have significant ecological implications. As a generalist species, *X. confusa* plays an important ecological role in maintaining plant diversity within ecosystems (Jankauski et al. 2022). Its ability to utilize various pollen sources allows *X. confusa* to contribute to the pollination of a wide range of plant species, which in turn helps sustain biodiversity (Tang et al. 2020). The presence of *X. confusa* in ecosystems with high plant diversity contributes to ecosystem stability and overall environmental health. In contrast, *X. latipes* functions as a specialist that heavily relies on *C. nucifera*. This dependence on a single pollen source indicates that *X. latipes* plays a specific role in the pollination of coconut plants. While this specialization allows for efficiency in pollen collection and processing, it also makes *X. latipes* more vulnerable to changes that affect coconut populations. Therefore, it is essential to consider conservation efforts not only for bee species but also for their primary pollen sources, in this case, *C. nucifera*. Conserving diverse habitats and pollen sources is crucial for supporting generalist bee species like *X. confusa*, which depend on a variety of plants for their pollen needs. Preserving plant diversity within natural habitats will help maintain healthy *X. confusa* populations and enhance pollination effectiveness in these ecosystems (Ya'akob et al. 2018). On the other hand, conserving key plant species such as *C. nucifera* is equally important for supporting specialist bee species like *X. latipes*. Conservation efforts should focus on protecting habitats that provide a variety of pollen sources and safeguarding key plant species that are critical for pollen specialists (Silva et al. 2024).

The difference in pollen-gathering strategies between *X. confusa* and *X. latipes* reflects their distinct adaptations to their environments. *Xylocopa confusa*, with its diverse pollen sources and varying pollen morphology, demonstrates a high level of adaptation to changing environmental conditions (Dellinger et al. 2021). Its ability to utilize pollen from various plant species allows *X.*

confusa to remain flexible and resilient in a range of environmental situations. This adaptability offers an advantage in terms of being able to locate and exploit available food sources, ensuring survival even in uncertain conditions (Araújo et al. 2021). On the other hand, *X. latipes* exhibit a more specialized adaptation, relying heavily on *C. nucifera*. While this specialization enables greater efficiency in collecting pollen from a single source, it also creates a stronger dependence on the availability of *C. nucifera*. If the primary pollen source declines or is disrupted, *X. latipes* may struggle to find alternative food sources, potentially threatening the species' survival. This specific adaptation highlights the importance of monitoring and protecting the plant species that serve as the primary pollen source for specialist bee species (He and Zhu 2020).

In conclusion, *X. confusa* exhibits a preference for a diverse range of plant species, collecting pollen from multiple plant families, including Asteraceae, Arecaceae, Fabaceae, Poaceae, and others. In contrast, *X. latipes* shows a higher level of specialization, exclusively collecting pollen from a single plant species, *C. nucifera*. The morphological variations of the collected pollen reflect the different foraging adaptations of these bee species. *X. confusa* is a generalist species, utilizing pollen from various sources categorized as predominant, important minor, and minor pollen sources. Meanwhile, *X. latipes* is a specialist species, heavily relying on *C. nucifera* as its primary pollen source. These findings highlight the importance of habitat conservation and the availability of pollen resources for the sustainability of *Xylocopa* spp. populations in Central Sulawesi. The diverse pollen sources utilized by *X. confusa* demonstrate its foraging flexibility, whereas the dependency of *X. latipes* on a single plant species emphasizes the need for preserving *C. nucifera* populations within the ecosystem.

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REFERENCES

Abbas M, Sucianto E. 2020. Feed resources determination based on pollen diversity in *Trigona* bees (*Trigona* sp.) colony. Biosaintifika 12 (3): 478-487. DOI: 10.15294/biosaintifika.v12i3.26603.

Agostini JC, Françoso E, Arias MC, Zanella FCV. 2024. Morphological and molecular evidence for considering *Xylocopa nigrocincta* as the senior synonym of *Xylocopa suspecta* (Apidae: Xylocopini). Apidologie 55: 18. DOI: 10.1007/s13592-024-01057-9.

Araújo TN, Pires LP, Meireles DAL, Augusto SC. 2021. Individual-resource network between *Xylocopa* bees and plant resources: Generalist species, specialist individuals? Ecol Entomol 46 (6): 1273-1282. DOI: 10.1111/een.13072.

Azmi WA, Zulqurnain NS, Ghazi R. 2015. Melissopalynology and foraging activity of stingless bees, *Lepidotrigona terminata* (Hymenoptera: Apidae) from an apiary in Besut, Terengganu. J Sustain Sci Manag 10 (1): 27-35.

Barker MS, Li Z, Kidder TI, Reardon CR, Lai Z, Oliveira LO, Scascitelli M, Rieseberg LH. 2016. Most Compositae (Asteraceae) are descendants of a paleohexaploid and all share a paleotetraploid ancestor with the Calyceraceae. Am J Bot 103 (7): 1203-1211. DOI: 10.3732/ajb.1600113.

Bisui S, Layek U, Karmakar P. 2019. Comparing the pollen forage pattern of stingless bee (*Trigona iridipennis* Smith) between rural and semi-urban areas of West Bengal, India. J Asia-Pac Entomol 22 (3): 714-722. DOI: 10.1016/j.aspen.2019.05.008.

Bookhout TA. 1996. Research and Management Techniques for Wildlife and Habitats. Allen Press Inc., Kansas.

Christenhusz MJM, Byng JW. 2016. The number of known plants species in the world and its annual increase. Phytotaxa 261 (3): 201-217. DOI: 10.11646/phytotaxa.261.3.1.

Dellinger AS, Artuso S, Fernández-Fernández DM, Schönenberger J. 2021. Stamen dimorphism in bird-pollinated flowers: Investigating alternative hypotheses on the evolution of heteranthery. Evolution 75 (10): 2589-2599. DOI: 10.1111/evo.14260.

Dellinger AS, Artuso S, Pamperl S, Michelangeli FA, Penneys DS, Fernández-Fernández DM, Alvear M, Almeda F, Armbruster WS, Staedler Y, Schönenberger J. 2019. Modularity increases rate of floral evolution and adaptive success for functionally specialized pollination systems. Commun Biol 2: 453. DOI: 10.1038/s42003-019-0697-7.

Doaigey AR, El-Zaidy M, Alfarhan A, El-Salam Milagy A, Jacob T. 2018. Pollen morphology of certain species of the family Lamiaceae in Saudi Arabia. Saudi J Biol Sci 25 (2): 354-360. DOI: 10.1016/j.sjbs.2017.03.001.

Geier C, Engel MS, Bouchal JM, Ulrich S, Grímsson F, Wedmann S, Wappler T. 2024. The earliest large carpenter bee (*Xylocopa*) and its adhering pollen (Araliaceae, Theaceae). Palaeobiodivers Palaeoenviron 104 (4): 949-962. DOI: 10.1007/s12549-024-00604-7.

Halbritter H, Ulrich S, Grímsson F, Weber M, Zetter R, Hesse M, Buchner R, Svojtka M, Frosch-Radivo A. 2018. Illustrated Pollen Terminology. Spinger, Cham. DOI: 10.1007/978-3-319-71365-6.

He C, Zhu C. 2020. Nesting and foraging behavior of *Xylocopa valga* in the Ejina Oasis, China. PLoS One 15 (7): e0235769. DOI: 10.1371/journal.pone.0235769.

Hesse M, Halbritter H, Weber M. 2009. *Beschorneria yuccoides* and *Asimina triloba* (L.) Dun: Examples for proximal polar germinating pollen in angiosperms. Grana 48 (3): 151-159. DOI: 10.1080/00173130903024343.

Huang TC. 1972. Pollen Flora of Taiwan. National Taiwan University Press., Taipei.

Hugg TT, Tuokila M, Korkonen S, Weckström J, Jaakkola MS, Jaakkola JJK. 2020. The effect of sampling height on grass pollen concentrations in different urban environments in the Helsinki Metropolitan Area, Finland. PLoS One 15 (9): e0239726. DOI: 10.1371/journal.pone.0239726.

Hurd PD, Moure JS. 1963. A Classification of the Large Carpenter Bees (Xylocopini) (Hymenoptera: Apoidae) Vol 29-30. University of California Press, California.

Jalil AH. 2014. Beescape for Melipones: Conservation of Indo-Malayan Stingless Bess. Partridge Publishing, Singapore.

Jankauski M, Casey C, Heveran C, Busby MK, Buchmann S. 2022. Carpenter bee thorax vibration and force generation inform pollen release mechanisms during floral buzzing. Sci Rep 12 (1): 12654. DOI: 10.1038/s41598-022-16859-z.

Jayuli M, Junus M, Nursita IW. 2018. Effect of land altitude on pollen diameter *Apis cerana* in Malang District. J Trop Anim Prod 19 (1): 9-21. DOI: 10.21776/ub.jtapro.2018.019.01.2. [Indonesian]

Kajornjit P, Saensouk S, Saensouk P. 2018. Pollen and anatomy of the genus *Globba* in Thailand. ScienceAsia 44 (3): 146-161. DOI: 10.2306/scienceasia1513-1874.2018.44.146.

Li Z, Meng S, Qin F, Wang S, Liang J, He X, Lu J. 2023. Host root exudates initiate a foraging preference by the root parasite *Santalum album*. Tree Physiol 43 (2): 301-314. DOI: 10.1093/treephys/tpac116.

Maa TC. 1970. Revision of the subgenus *Ctenoxylocopa* (Hymenoptera: Anthophoridae). Pac Insects 12 (4): 723-752.

Mahmoud KM, Shebl MA. 2024. Morphological and histological structure of adexinal glands of some solitary bee species (Hymenoptera-Apoidea). Sociobiology 71 (2): e10405. DOI: 10.13102/sociobiology.v71i2.10405.

Michener CD. 2007. The Beess of The World. Second Edition. The Johns Hopkins Univ. Press, Baltimore.

Nugroho RB, Soesilohadi RCH. 2014. Identification foods sources of stingless bee, *Trigona* sp. (Hymenoptera: Apidae) in Gunungkidul District. Biomedika 7 (2): 42-45. DOI: 10.31001/biomedika.v7i2.184. [Indonesian]

Octavia RS, Sulasmi ES, Sulisetijono. 2015. Pollen characterization of Asteraceae family in Malang Raya. J Online Universitas Negeri Malang 1: 1-9. [Indonesian]

Peeters C, Ito F. 2021. Colony dispersal and the evolution of queen morphology in social Hymenoptera. Ann Rev Entomol 46: 601-630. DOI: 10.1146/annurev.ento.46.1.601.

Portman ZM, Orr MC, Griswold T. 2019. A review and updated classification of pollen gathering behavior in bees (Hymenoptera, Apoidea). J Hymenopt Res 71: 171-208. DOI: 10.3897/jhr.71.32671.

Pratama IPNE, Watiningsih NL, Ginantra IK. 2018. The effect of different altitude to the pollen types that *Trigona* collected. J Biologi Udayana 22: 42-48. DOI: 10.24843/jbiounud.2018.v22.i01.p06. [Indonesian]

Punt W, Hoen PP, Blackmore S, Nilsson S, Le Thomas A. 2007. Glossary of pollen and spore terminology. Rev Palaeobot Palynol 143 (1-2): 1-81. DOI: 10.1016/j.revpalbo.2006.06.008.

Saensouk P, Saensouk S. 2021. Diversity and cytological studies on the genus *Amomum* Roxb. former *Elettariopsis* Baker (Zingiberaceae) in Thailand. Biodiversitas 22 (6): 3209-3218. DOI: 10.13057/biodiv/d220624.

Salamah A, Luthfikasari R, Dwiranti A. 2019. Pollen morphology of eight tribes of Asteraceae from Universitas Indonesia Campus, Depok, Indonesia. Biodiversitas 20 (1): 152-159. DOI: 10.13057/biodiv/d200118.

Silva LL, Cossolin JFS, Kloss TG, Alvim JRL, Reis AB, Zanuncio JC, de Castro e Castro BM, Serrão JE. 2024. Anatomy and histology of the male reproductive tract of the parasitoid wasp *Hymenoepimecis bicolor* (Brullé, 1846) (Hymenoptera: Ichneumonidae). Acta Zool 106 (1): 100-108. DOI: 10.1111/azo.12500.

Sudarmono S. 2020. Short Communication: Pollen diversity in the Bogor Botanic Gardens, Indonesia. Biodiversitas 20 (4): 931-936. DOI: 10.13057/biodiv/d200401.

Tang R, Li Y, Xu Y, Schinnerl J, Sun W, Chen G. 2020. In-situ and ex situ pollination biology of the four threatened plant species and the significance for conservation. Biodivers Conserv 29: 381-391. DOI: 10.1007/s10531-019-01887-5.

Trianto M, Purwanto H. 2020. Morphological characteristics and morphometrics of stingless bees (Hymenoptera: Meliponini) in Yogyakarta, Indonesia. Biodiversitas 21 (6): 2619-2628. DOI: 10.13057/biodiv/d210633.

Windarsih Y, Trianto M. 2021. Morphometrics variations of carpenter bees *Xylocopa confusa* Latreille and *Xylocopa latipes* Drury from different habitats in Central Sulawesi. J Biologi Tropis 21 (1): 191-198. DOI: 10.29303/jbt.v21i1.2472. [Indonesian]

Wrońska-Pilarek D, Jagodziński AM, Bocianowski J, Janyszek M. 2015. The optimal sample size in pollen morphological studies using the example of *Rosa canina* L. (Rosaceae). Palynology 39 (1): 56-75. DOI: 10.1080/01916122.2014.933748.

Ya'akob H, Norhisham NF, Mohamed M, Sadek N, Endrini S. 2018. Evaluation of physicochemical properties of *Trigona* sp. stingless bee honey from various Districts of Johor. J Kejuruteraan SI 2 (1): 59-67. DOI: 10.17576/jkukm-2019-si2(1)-08.