BIODIVERSITAS ISSN: 1412-033X
Volume 25, Number 6, June 2024 E-ISSN: 2085-4722
Pages: 2747-2756 DOI: 10.13057/biodiv/d250645

Food source diversity and honey production in stingless bee meliponiculture, Ogan Komering Ulu Timur, South Sumatra, Indonesia

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Manuscript received: 12 May 2024. Revision accepted: 28 June 2024.

Abstract. *Rahmad B, Damiri N, Hanafiah Z, Adriani D, Hanum L. 2024. Food source diversity and honey production in stingless bee meliponiculture, Ogan Komering Ulu Timur, South Sumatra, Indonesia. Biodiversitas 25: 2747-2756.* This research, conducted with meticulous care, aims to collect data on the diversity of food source plants and analyze vegetation, honey production, and quality in stingless bee (*Trigona* sp.) cultivation (meliponiculture) in East Ogan Komering Ulu District (OKUT), South Sumatra Province, Indonesia. The research was carried out using a comprehensive survey method with a qualitative and quantitative approach. The qualitative methods record the type of stingless bee food sources, while qualitative methods are used for honey quality. Direct observation, questionnaires, and in-depth interviews with beekeepers were carried out to collect data on honey production. The investigation involved observing food-supply plants in the meliponiculture area designated as the research site. Meliponiculture area location is the presence of beekeepers actively engaged in producing honey. The results of the inventory of food plant types at the meliponiculture location showed that the composition of food source plants consisted of six species of forestry plants, three species of plantation plants, seven species of MPTs, one species of crop plant, eight species of home garden and four species of shrubs. The planting pattern of plantation and forestry possesses the highest honey yield, which is 360 kg per year. Cultivated honey products have good quality and comply with Indonesian National Standards (SNI), which include organoleptic tests and laboratory tests, with results: Water content 27.14% w/w, reducing sugar content 62.05% w/w, degree of acidity 101.64 ml NaOH Kg, Total solids insoluble in water 0,066% w/w, Ash Content 0.24% w/w, and acidity degree (pH) 3.25.

Keywords: Food source, honey, meliponiculture, stingless bee

INTRODUCTION

Stingless bees (Hymenoptera: Apididae, Meloponini) are social bees with a eusocial structure, comprising over 600 species mainly inhabiting tropical and subtropical areas. The stingless bees live in colonies of queens, several worker bees, and drones. Despite their name, stingless bees do not possess the ability to sting, but they retain a non-functional and vestigial sting. The stingless bees play important roles in ecology, economy, pharmacy, and socio-culture. They play a crucial role as pollinators for essential tropical plants and crops. The stingless bees produce several chemical compounds in their product (Engel et al. 2018; Roubik 2023). Stingless bees produce honey, propolis, and pollen, which are of high economic value in their honey, yield and beneficial for health (Lavinas et al. 2019; Trianto and Purwanto 2021). Indonesia is a country that has very high biodiversity both in the form of natural plants and cultivated plants, so it is not surprising that this condition provides sufficient food for the development of bees. There are 3 groups of bees in Indonesia, namely honey bees, stingless bees, and bumble bees, which all produce honey (Kahono et al. 2018). *Trigona* is a genus of stingless bees that is widely meliponicultivated.

Feed is a very important requirement for the sustainability of stingless bee farming, and the lack of feed will be a serious problem. It can hamper the development of the honey bee farming business, decreasing the production of honey, pollen, and royal jelly, thereby reducing the beekeeper's income. In addition, lack of food can cause honey bee colonies to become weak, the small number of worker bees, low production of honey, pollen, and royal jelly, and queen bee productivity decreases due to low nectar and pollen food supplies as a source of carbohydrates and protein sources (De-lima et al. 2019; Paray et al. 2021).

The main food sources for bees are pollen (pollen) and nectar (sugar solution that comes from plants), where pollen is a source of protein, while nectar is a source of carbohydrates. Bees consume these two types of food from plants, especially flowers. However, in certain plants, like rubber (*Ficus elastica* Roxb) and acacia (*Acacia* sp.), nectar is not secreted from glands at the base of the flower but from young leaf buds and the base of the leaves. Also, stingless bees can obtain carbohydrates from honeydew, a sugary liquid secreted by plants through the intermediary of plant-sucking insects (Schrader et al. 2017).

Around 20,000 species of flowering plants grow and develop well in Indonesia. The very large diversity of these plant types makes it possible to provide nectar and pollen throughout the year. Therefore, information about these plants, whether from shrubs, agricultural plants, plantation plants, or forestry, is very important (Kusmana and Hikmat 2015). Food plants (bee forage) are the key factor determining the bee cultivation business's success, and the availability of nectar and plant pollen production determines the development of a stingless bee colony. Thus, suitable food source plants to support the colony's development must be abundant so that the cultivation can produce good harvests with honey quality that meets standards. Therefore, the first and most important factor must be collecting information on the availability and abundance of food plants to start a stingless bee cultivation business. Furthermore, it is important to carry out an inventory of the types, potential, and location of potential food source plants to determine where honey bee cultivation activities are (Henry and Rodet 2018). This research aimed to study the planting patterns in stingless bee (*Trigona* sp.) farming, areas production, and the quality of the honey produced in East Ogan Komering Ulu District, South Sumatra, Indonesia.

MATERIALS AND METHODS

Description of the study area

The research was conducted from January to June 2023 at meliponiculture locations of *Trigona* sp. in Sukaraja Village, Buay Madang Sub-district, and Batumarta X Village, Madang SK III Sub-district, South Sumatra Province. The selected location considered the presence of forest farmer groups cultivating stingless bees in those areas. The spatial research location is shown in Figure 1.

Methods

This research employed a combination of qualitative and qualitative survey methods. The qualitative methods record the type of stingless bee food sources according to Creswell and Creswell (2017); the qualitative methods used for honey quality. Direct observation, questionnaires, and in-depth interviews with beekeepers were carried out to collect data on honey production (Jamshed 2014). The investigation involved observing food-supply plants in the meliponiculture area designated as the research site. Meliponiculture location is the presence of beekeepers actively engaged in producing honey.

Vegetation analysis

Identification of food source plant type is accomplished by creating a 20×20 meter measurement plot and monitoring the food plants visited by stingless bees. Plots are used to identify the plant types that provide food for stingless bees. The plot has dimensions of 20×20 meters, with the cultivation box positioned in the center, and this plot size considers the optimal distance for *Trigona* sp. bees to search for food. Their body size strongly influences the distance bees travel to find food. The longer a bee can fly, the larger its body. *Trigona* sp. has a size of 5 cm and can fly roughly 600 m (Lukman et al. 2021).

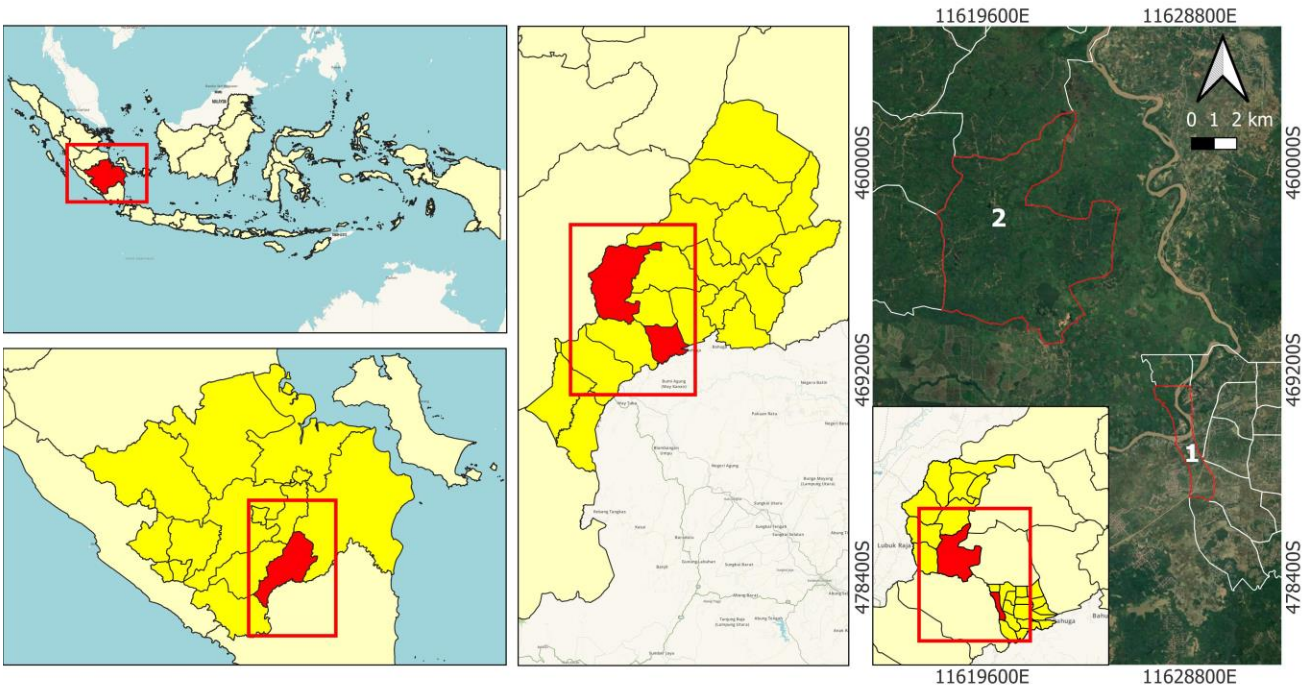

Figure 1. Research location in Ogan Komering Ulu Timur (OKUT) District, South Sumatra Province, Indonesia. Note: 1. Sukaraja Village, Sub-district Buay Madang; 2. Batumarta X Village, Sub-district Madang SK III

Vegetation analysis was carried out to examine the characteristics of the arrangement (species composition) and shape (structure) of vegetation that is closely related to the diet of stingless bees (*Trigona* sp.) in agroforestry systems managed by farmers. The parameters observed include species importance value index (IVI), which is the sum of relative density (RD), relative frequency (RF), and relative dominance (RD_o), whose maximum value of 300%. In this case, the IVI of a community is determined by density, frequency, and relative dominance (Agbelade et al. 2017).

Relative density describes the size of the population in a community; relative frequency describes the growth/planting pattern of a plant species (scattered or spatial) in a community. The relative dominance indicates the area where it grows or the basal area of a species in a community. The species importance index, according to Agbelade et al. (2017), is as follows:

$$Importance\ Value\ Index\ (IVI)\ for\ trees = RD + RF + RD_0$$

$$Density\ (D) = \frac{\text{Number of individuals of a species}}{\text{Area of sample plot}}$$

$$Relative\ Density = \frac{\text{Number of individuals of a species}}{\text{JNumber of individuals of a all species}} \times 100\%$$

$$Frequency = \frac{\text{Number of plots found for a species}}{\text{Number of all plots}}$$

$$Relative\ Frequency = \frac{\text{Frequency of a species}}{\text{Sum of frequencies of all species}} \times 100\%$$

$$Dominance = \frac{\text{Basal area of a species}}{\text{Total of Basal area of all species}}$$

$$Relative\ Dominance = \frac{\text{Dominance of a species}}{\text{Total of Dominance of all species}} \times 100\%$$

Species diversity index

The species diversity index (H') was computed using the Shannon-Wiener diversity index in the following equation (Wiser 2016):

$$H' = -\sum_{i=1}^{s} (Pi)(\ln Pi)$$

Where:
H' : Shanon-wiener diversity index;
s : the total number of species in the community
P_i : proportion of s made up the species and $l_{n=}$ natural logarithm

Species richness

Species richness was calculated using the Margalef formula (Magurran 2005) as follows:

$$RMg = \frac{S-1}{\ln N}$$

Where:
RMg : Margalef index
S : Total number of species
N : total number of individual species

Honey quality analysis

The quality parameters of *Trigona* sp. honey that are considered in international trade are smell (typical of honey), taste (typical of honey), water content (%), ash content, acidity (mL NaOH/kg), water-insoluble solids (%), reducing sugar (glucose and fructose) (%) and sucrose (%) (Ridoni et al. 2020).

RESULTS AND DISCUSSION

Diversity of food sources

Using the collected data, we identified various food source plant categories within the research site. The plants sustaining stingless bees encompassed forestry plants, plantation plants, Multi-purpose Tree Species (MPTS), crops, home gardens, and shrubs. The plant's food source composition at the research location can be seen in Table 1.

Based on Table 1, the composition of food source plants consists of 6 species of forestry plants, 3 species of plantation plants, 7 species of MPTs, 1 species of crop plant, 8 species of home garden plants, and 4 species of shrubs. Given their smaller size, stingless bees gather nectar from a more varied array of flowers, encompassing a broad size spectrum (Bisui et al. 2019). The utility of the type of plant influences beekeepers' preferences in establishing food source plants. Fruit plants, which are also Multi-Purpose Tree species (MPTs), are often planted to improve food supplies in stingless bees. Apart from providing a source of nectar, pollen, and resin for stingless bees, the MPTs plant can also produce fruit of great economic value, and the wood and leaves can be used. Aside from that, MPTs plants have a variety of flower colors and a fragrant perfume, making it simpler to attract worker bees collecting nectar and pollen. Flower color can entice bees to return to the same flower species if the plant's nectar or pollen supply is abundant. Similarly, the stimulus produced by flowers in the form of aroma can also stimulate bees for a brief duration, but this can cause bees to remember it for several months, if not their entire lives (Layek et al. 2016). Manggo (*M. indica*) are the only plants producing nectar, resin, and pollen in the research area. These plants are significant sources of propolis, as bees can gather two different substances from mango trees for propolis production: a reddish-brown resin from the bark and latex from the fruit (Popova et al. 2021); the resin has been found to contain triterpenes, particularly cycloartane and includes cardol as well (Herrera-Lopez et al. 2020). In contrast, latex is rich in monoterpenes with a distinctive mango aroma, cardol, carbohydrates, and small amounts of protein (Karunanayake 2019).

The next most popular option is home garden flowers, with ornamental plants chosen being that flower virtually all year. *Air mata pengantin* (*Antigonon leptopus*), *kaliandra* (*Calliandra calothyrsus*), and santos lemon (*Xanthostemon chrysanthus),* for example. Beekeepers profit from home garden flowers in various ways, including providing nectar and pollen as a food source for stingless bees. The red flower *C. calothyrsus* plant has long been utilized as a food source by beekeepers, and it has even become the primary choice for free-range (pastoral) system beekeepers. Calliandra plants have long-lasting flowers and a high nectar content, making them ideal for honey bee nectar supply. As a result, a mutually beneficial link between the physical characteristics of flowers and insects hunting for nectar and the '‘intermediary’' duty of bees as pollinators is required. In this manner, a mutually beneficial partnership can be developed to achieve the best results (Nasution 2022; Obeng-Darko et al. 2022).

Table 1. Composition of plant food sources at the research location OKUT District, South Sumatra Province, Indonesia

Plant groups	Plant species	Source of nectar/resin/pollen	Flowering season
Forestry Plant	*Vitex pinnata* Linn.	Nectar + Pollen	August-October
	Schima wallichii (DC) Korth	Nectar + Pollen	August-October
	Albizzia falcataria L Nielsen	Nectar	June-September
	Acacia mangium Wild.	Nectar	January-December
	Tectona grandis Linn.	Nectar + Pollen	Mei-August
	Peronema canescens Jack.	Nectar	February and August
Plantation Plant	*Hevea brasiliensis* Mull.Arg	Nectar + Pollen	September -October
	Coffea canephora Mull.Arg.	Nectar	May-June
	Cocos nucifera A. Froechner.	Nectar + Pollen	January-December
MPTs	*Dimocarpus longan* Lour.	Nectar + Pollen	September-November
	Nephelium lappaceum Linnaeus.	Nectar	October-November
	Citrus sinensis (L) Osbeck.	Nectar + Pollen	August-November
	Salacca zalacca (Gaertn.) Voss.	Pollen	Januari-December
	Mangifera indica Linn	Nectar+Resin+Pollen	May-October
	Musa paradisiaca Linn	Nectar + Pollen	Depends on planting period
	Archidendron pauciflorum (Benth) Kosterm	Pollen	May-June
Crops plant	*Amaranthus caudatus* Linn	Nectar	Depends on planting period
Home garden plant	*Calliandra calothyrsus* Meisn.	Nectar	January-December
	Antigonon leptopus Hook & Arn	Nectar	January-December
	Dombeya ledermannii(Lindl).Benth.&Hook	Nectar	January-December
	Xanthostemon chrysanthus (Muell)Benth	Nectar + Pollen	January-December
	Murraya paniculata (L.) Jack	Nectar	January-December
	Cyrtostachys lakka Becc	Pollen	January-December
	Celosia cristata Linn	Pollen	January-December
	Saraca asoca (Roxb) Wilde	Nectar	January-December
Shrub	*Melastoma malabathricum* Linn	Nectar	January-December
	Mikania micrantha Kunth	Pollen	January-December
	Lantana camara Linn	Nectar	January-December
	Spilanthes paniculata Wall. Ex DC	Pollen	January-December

Many forestry plants are also selected as food sources for stingless bees. Forest plants produce a wide range of floral and extra nectar. Despite being affected by the flowering season, the supply of nectar, pollen, and resin from forestry plants is quite abundant in nature. The *Acacia* is popular among beekeepers for its ability to increase honey supply. *Acacia* can secrete nectar along the leaf stalks, and almost all acacia leaf bases secrete nectar all year, making it a potentially abundant and sustainable source of honey for bees. Furthermore, acacia blooms can produce seasonal pollen that honey bees can eat (Syaifuddin et al. 2021). Bees collect nectar and pollen from flowering plants to meet their needs for energy and protein (Obeng-Darko et al. 2023).

Rubber plantations are breeding grounds for stingless bees in practically all research locations. This is inextricably linked to the presence of rubber plants as nectar, pollen, and resin sources for stingless bees. Stingless bees are not discovered gathering pollen from herbaceous plants located around rubber plantations. This is supposed to be because rubber flowers are appealing. Rubber flowers are brilliant yellow and tiny, generating nectar and resin (Umar et al. 2017). Rubber plantation is a potential pollen source (Ramadani et al. 2021). Furthermore, the peak time for stingless bee pollen collection activities is thought to correspond to the flowering time for rubber and oil palm trees. Rubber flowers bloom from around 09.30 AM till noon, around 02.30 PM, with a peak bloom in the afternoon, around 1.30 PM (Umar et al. 2017).

Honey output typically decreases during the forestry crop season, when plantation crops finish flowering. This tough period for food is known as the lean season, and it is indicated by a drop in tin the honey yield produced by the stingless bees. To prepare for this dry period, growers typically utilize a variety of bush plants as a source of nectar and pollen. Breeders prefer *Melastoma malabathricum*, *Mikania micrantha*, *Lantana camara*, and *Spilanthes paniculata*. These invasive species are typically not intentionally planted but grow spontaneously and become weeds in staple crops. These bushes, however, are left alive by beekeepers and are only thinned when they get too numerous. Rubber and multi-purpose plants such as Durian, Mango, and Petai all flower around the same period, from June (6) to October (10), while Rambutan blooms from October (10) to December (12).

Vegetation analysis

The results of vegetation analysis at the meliponiculture site in OKUT District are presented in Table 2. Plants for food sources are planted in plantations near settlements by beekeepers; therefore, MPTs influence the availability of nectar, pollen, and resin. The vegetation analysis at meliponiculture places in the OKUT District shows the following plants have the highest IVI, i.e.: *Hevea brasiliensis* (59.38%), *Peronema canescens* (41.60%), *M. malabathricum* (35.68%), *A. leptopus* (16.80%), and *Archidendron pauciflorum* (11.31%). The main reason beekeepers set bee colony stands in rubber plantations near residential areas is easier to monitor, care for, and harvest. Aside from that, the presence of long-established forestry plants like *P. canescens* and MPTs plants like *A. pauciflorum*, *Dimocarpus longan*, and *Nephelium lappaceum* adds to the variety of plants that supply nectar, pollen, and resin. Aside from the plants already stated, the presence of settlements allows farmers to plant ornamental plants, which have various benefits, including supplying nectar and adding to the attractiveness of the houseyard.

Antigonon leptopus, *X. chrysanthus*, *Celosia cristata*, *Dombeya ledermannii*, and *C. calothyrsus* are among the home garden planted. *A. leptopus* has long been known and believed to be a bee-food source plant capable of producing nectar all year. Stingless bees are interested in the bridal tears and shrub's pink and white blossom. *A. leptopus* flower has a lovely pink color; therefore, its attractive flowers are favored by pollinating insects, including butterflies, bees, ants, and beetles. These flowers bloom year-round, independent of the seasons, and feature a climbing mechanism that helps draw bees for pollination (Reddy 2020; Raju et al. 2023). The allure of the *A. leptopus* flower is essential in attracting bees to gather nectar. Interestingly, these flowers only produce nectar on the first blooming, providing both pollen and fresh nectar. In contrast, on the second day, they offer any remaining nectar to foraging insects (Raju et al. 2023).

Honey bees are vital in pollinating various plant species, yet their ability to do so effectively depends on their colony health. This health depends significantly on the availability of bee-supportive plants in the area. Enhancing the diversity of potential food plants is crucial for promoting honey bee cultivation, as it impacts the bees'' development and the production of honey, propolis, and bee bread (Pande and Gi 2018; Al-Ghamdi and Al-Sagher 2023). Stingless bees require resin to build nests, defend nests from germs and fungi, and generate propolis (Hasan et al. 2019).

Plants between or around the main plant are known as filler plants. Typically, the goal of planting filler plants is to use open ground that could be planted. The presence of nectar, pollen, and resin, which must always be present in meliponiculture, is considered in the selection of filler plants because the nectar and pollen from the main plant truly depend on the flowering season. Filler plants were not usually put on purpose in numerous research sites. Some develop naturally and are left to flourish to provide nectar and pollen. For example, shrubs or herbaceous plants grow naturally in plantations. They are then left to survive with appropriate arrangements that do not affect the primary plants but may still offer the nectar and pollen that stingless bee colonies require.

According to Hoover and Ovinge (2018), the time of autumn and the availability of natural pollen influence the formation of bee daughter cells in an *Apis mellifera* colony. Furthermore, pollen regulates not only the pace of creation of baby bee cells but is also a significant factor in the formation of hypopharyngeal glands in freshly hatched worker bees. Furthermore, Fine et al. (2018) discovered that queen bees fed bread or fresh bee pollen and bread or frozen bee pollen generated considerably more eggs and modified the cell structure of the bee offspring than those fed solely artificial pollen. Meliponiculture in the OKUT District can be seen in Figure 2.

Table 2. Analysis of the Importance of Forage Plant Types in OKUT District, South Sumatra Province, Indonesia

Plant species	Amount	RD	RF	RD_o	IVI
A. leptopus	20	1.58	8.7	6.53	16.8
V. pinnata	8	0.632	4.35	2.83	7.81
S. wallichii	4	0.316	2.17	2.52	5.01
C. canephora	6	0.474	2.17	0.14	2.79
D. longan	2	0.158	2.17	1.71	4.04
A. falcataria	8	0.632	4.35	2.23	7.21
A. mangium	4	0.316	2.17	0.56	3.05
M. malabathricum	361	28.515	6.52	0.65	35.68
M. micrantha	79	6.240	4.35	0.49	11.08
C. calothyrsus	18	1.422	4.35	0.14	5.91
H. brasiliensis	537	42.417	10.87	6.09	59.38
C. nucifera	17	1.343	4.35	1.47	7.16
L. camara	28	2.212	2.17	6.09	10.48
T. grandis	12	0.948	2.17	6.53	9.65
D. ledermannii	9	0.711	4.35	0.49	5.55
X. chrysanthus	16	1.264	4.35	0.31	5.93
M. paniculata	7	0.553	2.17	0.65	3.37
A. pauciflorum	11	0.869	4.35	6.09	11.31
C. lakka	4	0.316	2.17	0.71	3.20
P. canescens	16	1.264	4.35	35.99	41.60
S. paniculata	7	0.553	2.17	1.06	3.78
N. lappaceum	18	1.422	2.17	2.23	5.83
A. caudatus	17	1.343	2.17	0.14	3.66
C. sinensis	13	1.027	2.17	0.02	3.22
S. zalacca	12	0.948	2.17	0.65	3.77
C. cristata	21	1.659	2.17	6.09	9.92
M. indica	6	0.474	2.17	6.53	9.18
M.paradisiaca	5	0.395	2.17	1.06	3.63

Note: RD: Relative Density; RF: Relative frequency; RD_o: Relative Dominance; IVI: Importance Value Index

Figure 2. Meliponiculture pattern in OKUT District, South Sumatra Province, Indonesia

Based on interviews with cultivators, meliponiculture is identified as a profit-driven venture that integrates environmental conservation by enhancing plant diversity for multiple business purposes, including food production. Beyond the primary honey product in traditional beekeeping, practitioners in meliponiculture can also yield various forest products such as fruits, sap, leaves, tubers, and stems from stingless bees. The diverse species of stingless bees exemplify the potential for a biodiversity-driven economy. Notably, the honey produced by stingless bees commands a higher price compared to honey from *Apis* spp. Bee. Effectively harnessing the potential of stingless bees could significantly contribute to the local economy, especially for communities residing near forested areas. A Food and Agriculture Organization (FAO) study underscores that beekeeping is one of the most promising economic activities for populations near forest regions (Schouten and Llyod 2019).

Honey production

The flora surrounding an apiary can greatly influence the yield of honey. Some specific plants can enhance bee vitality, broaden their food sources, and even enhance the flavor and caliber of the honey they produce. The study's findings indicate seven planting patterns identified within the beekeeping region in OKUT. These include pairings such as plantations with forestry, plantations with shrubbery, plantations with ornamental plants, plantations with palm trees, plantations with fruit-bearing plants, plantation and fruit crops, plantation, forestry, fruit crops, and ornamental plants, as well as a mix of plantations, forestry, and ornamental vegetation. The relationship between crop patterns and honey production of stingless bee is presented in Table 3.

Table 3 shows that the planting pattern of plantation and forestry possesses the highest yield of honey, which was 360 kg/year. This planting pattern was significantly different from other planting patterns. Based on the research results, plantation plants, in particular, *H. brasiliensis*, forest plants of *A. mangium*, and multi-purpose trees (source of fruits and timber), are the dominant nectar-producing plants. The main needs of bees for their growth and development are nectar, extra nutritional nectar, and pollen. This food source must be available every month, every season, and the plant's location must be suitable (Thomas et al. 2017). The composition of landscapes and the proximity to forests impact the richness and abundance of meliponine species. Most landscape-level elements significantly affect both the diversity and population size of stingless bees (Wayo et al. 2020). The honey production of a bee plant species relies on factors such as the quality and quantity of its nectar, its flowering pattern, and its abundance. Plants mostly create nectar to reward visits to their flowers. Its production is a complicated physiological process mostly controlled by abiotic environmental factors and the phenology of the flower. It is strongly impacted by the shape, size, and position of individual flowers within the species (Filipiak et al. 2022). Nectar is the primary ingredient for honey, though not all flowering plants produce it, and honey bees may not collect all available nectar (Affek 2018). The rubber tree, which has extrafloral nectaries, flowers, and to a lesser extent, latex, including in propolis, offers stingless bees a vital source of nectar and a favorable environment to flourish. These extrafloral nectaries on the rubber tree serve as valuable nectar and pollen sources (Erwan et al. 2023).

Acacias, substantial woody plants prevalent in numerous tropical and subtropical arid regions globally, play a crucial role in biomass production. This plant is well-known for its use as food, fuel, firewood, lumber, forage, gum, tannins and traditional medicine. Additionally, acacias contribute to environmental protection and conservating water and soil. Furthermore, acacias are home to several species of nectarivorous insects and a vast variety of herbivorous animals and invertebrates (Adgaba et al. 2016). Nectar-producing acacia trees attract large and more diverse groups of flower-seekers. Most acacia trees have long-lasting blooms that open first as female flowers without a set daily schedule for visitors or rewards. However, many acacia flowers last only a day, opening first as a male flower, and they show a clear daily pattern in rewarding visitors (Awad et al. 2017). Many factors influence the release of nectar in plants. Some important factors include: temperature, humidity, soil properties, wind, and plant age. From flowering plants, nectar and pollen are available when the plant's flowers are blooming (Chatt et al. 2017).

Multi-purpose trees are the most significant melliferous plant in South Sumatra and benefit from their combined fruit and timber production. Nectar secretion, flower phenology, foraging, and honey potential measurements examined multi-purpose trees'' interaction with the honeybees. Trees with multiple uses have a remarkable ability to secret nectar, possibly due to their scattered flowering schedule, with only a few flowers or clusters per day for up to three months. This strategy could be a way for the plant to attract sufficient pollinators during its flowering period. Another reason for the extended flowering duration might be the tree's method of generating adequate sugar for daily photosynthesis in its leaves to produce nectar.

Table 3. The relationship between plantation patterns and honey production of stingless bee in OKUT, South Sumatra, Indonesia

Planting pattern	**Honey production average (kg/year)**	**$LSD_{0,05}$= 39.45**
Plantations with palm trees	120 ± 8.66	a
Plantations, forestry, and ornamental vegetation	182.25 ± 5.41	b
Plantation, forestry, fruit crops, and ornamental plants	197 ± 4.16	b
Plantations and fruit crops	240 ± 26.83	c
Plantations and ornamental plants	275 ± 61.94	c
Plantations with bush plants	300.25 ± 38.74	c
Plantation and forestry	360 ± 0.00	d

The plant's deep roots also enable it to access underground water, ensuring it can produce nectar without moisture stress (Adgaba et al. 2017). Bee foraging for nectar and pollen was low during the early morning; it peaked in the afternoon. Remarkable foraging activity was recorded during high temperature (35°C) and low humidity (20%) conditions. Foraging for nectar collection was more distinct than pollen. The flowering of *Ziziphus nummularia* (source of fruits and timber) was gradual. It was characterized by some flowers opening and secreting nectar early before sunrise, whereas others remained open until sunrise (Alqarni 2015).

Honey bee quality analysis

Stingless bee honey products will be more valuable if their quality and safety meet the SNI quality guidelines. According to SNI 8664:2018 (BSN 2018), stingless bee honey (*Trigona* sp.) is a natural liquid with a pleasant flavor produced by both wild and cultivated from plant flower nectar or other portions of plants (floral extract) (National Standardization Agency 2018). Environmental factors such as regional origin, variations in seasons, bee types, sources of nectar plants, how the bees live (cultivated or wild), how to collect, and post-harvest methods will all impact the quality of the honey produced. Therefore, honey quality parameters have also been established for those variations.

The stingless bee honey quality test was conducted at the Pekanbaru Industrial Services Standardization and Policy Agency (BSKJI). At the time of data collection, honey samples were gathered from the harvest of beekeepers, ensuring that the sample analyzed was from meliponiculture locales and was authentic to pure honey. The acquired samples are examined and analyzed for many test parameters in data processing. Organoleptic testing consists of honey smell and taste tests, while laboratory tests are for water content, sugar levels, acidity, water-insoluble particles, ash content, and acidity levels. Table 4 shows the results of the quality test for stingless bee honey of stingless bee.

Organoleptic smell and taste examination

According to organoleptic tests, stingless bee honey and wild honey have a distinct honey smell and flavor. When compared to forest honey, stingless bee honey has a unique, sour-sweet flavor. Stingless bee honey is distinct from honey produced by stinging bees such as *A. mellifera*. The fundamental difference is that stingless bee honey contains more water, has lower diastase enzyme activity, and has a distinct sugar spectrum (Ramadhan et al. 2020).

Moreover, the acidity of stingless bee honey is affected by its high water content. The acidity of stingless bee honey is affected by its high water content. The high water content facilitates the fermentation process, which raises the acidity value. Fermentation by Zygosaccharomyces yeast changes the flavor of honey owing to the creation of alcohol, which interacts with air, causing free acids to arise (Hakim et al. 2021). These acids, which include oxalic acid and acetic acid, can influence the honey's flavor, acidity, and scent (Savitri et al. 2017). The presence of alcohol gas in honey can be used to determine the fermentation process (Budiono et al. 2023). One of the uniqueness of stingless bee honey is its high acidity. Water content, hydrogen ion dissociation in water, bee food sources, and mineral concentration in honey all impact honey acidity (Evahelda et al. 2017); honey with a low pH helps prevent bacterial development.

Water content examination

The water content of stingless bee honey simplicia was determined to be 27.14% (Table 4). This result meets the quality standards for stingless bee honey based on SNI 8664:2018, which are no more than 27.5%. Water content that exceeds the criteria for honey quality might cause the honey to deteriorate fast. The relative humidity of the air can affect the water content of stingless bee honey. If the air's relative humidity exceeds stingless bee honey, water vapor will be absorbed, increasing the water content (Evahelda et al. 2017). The moisture content of stingless bee honey can also be altered by poor post-harvest treatment, the type of nectar sucked, and the honey's maturation stage. Additionally, stingless bee honey products must be prepared quickly after harvesting to avoid contact with air since it is hygroscopic, which means they rapidly collect water vapor (Evahelda et al. 2017).

Reducing sugar test

SNI 8664:2018 requires a minimum of 55% reducing sugar test results, while the test results for stingless bee honey samples are 62.05%, greater than the minimum limit to meet the minimal criteria (Table 4). Cold-temperature honey can reduce sugar levels much more effectively than room-temperature honey. Water content, humidity, and harvest period all impact honey's lowering sugar content. Aside from the health advantages of honey, people like its sweet flavor. Honey's reduced sugar content influences this sweet flavor, and the proportion of various sugars depends on the type of flowers consumed by bees (Feknous et al. 2022).

The entire quantity of fructose and glucose in honey is described as total reducing sugars. *H. brasiliensis* honey and *Dalbergia latifolia* honey have a lower fructose percentage than glucose. Therefore, lowering the reducing-sugar content can increase the content of long-chain sugars (oligosaccharides and polysaccharides), which can be produced by enzyme activity and the acid reversal process (Ridoni et al. 2020).

Table 4. The honey quality of stingless bees from meliponiculture in OKUT District, South Sumatra, Indonesia

Parameter	Quality requirements	Test result	Unit
Odor	Typical honey	Typical honey	-
Taste	Typical honey	Typical honey	-
Water content	Max 27.5%	27.14%	% w/w
Reducing sugar	Min 55%	62.05%	% w/w
Acidity	Max 200%	101.64	MI-NaOH.kg
Insluble solid in water	Max 0.7%	0.066%	% w/w
Ash content	Max 0.5%	0.24%	% w/w
Acidity degree	-	3.25	-

Acidity examination

Honey acidity is one of the factors used to assess honey quality, so stingless bee honey has a unique and more acidic flavor than *Apis* honey. The acidity of honey samples from the research area was tested and found to be 101.64 mL NaOH/Kg, much below the necessary 200 mL NaOH/Kg standard value (Table 4). This demonstrates that honey from stingless bee cultivation has a sweet and sour flavor that is nonetheless marketable.

The acidity of honey is dictated by the dissociation of hydrogen ions in the water solution, and most of it also contains minerals (such as Ca, Na, and K). Honey with a greater mineral content has a higher pH. Acetic, butyric, formic, gluconic, lactic, malic, maleic, oxalic, pyroglutamic, citric, succinic, glycolic, and aketoglutaral acids are also found in honey. The total sugar content of honey varies according to quality, ranging from 76 to 83 (Silva et al. 2016). This test is performed to assess the quality of honey so that the honey ingested is safe and meets official regulations (Ridoni et al. 2020).

Insoluble solids in water test

The insoluble solids test in water reveals that dirt-derived items, such as sand, leaf fragments, insects, etc., cannot expand or dissolve after entering the water. The water-insoluble solids standard in SNI 8664:2018 is 0.7% w/w, whereas the test findings for honey samples from the research area were 0.066% w/w (Table 4). These findings suggest that water-insoluble solids in the honey sample are still within the acceptable range.

Ash content test

The total ash content was determined using the gravimetric technique and the concept of oxidation of organic compounds by heating to 500-600°C, and the residual inorganic chemicals were weighed after the combustion process (Rahmawati et al. 2023). The total ash content of stingless bee honey indicates the number of minerals in the honey derived from nectar and pollen-derived nectar (Gela et al. 2021). This study determined the total ash content of stingless bee honey simplicia was 0.24% (Table 4). This result meets the quality standards for stingless bee honey based on SNI 8664:2018, which are no more than 0.5%.

The type of nectar and pollen-producing plants, the location of plant development, soil composition, and bee species may all impact ash content. Stingless bee honey has much more ash than *Apis* bee honey. The difference in ash concentration between stingless honey and *Apis* bee honey is due to the honey's origin, specifically the bee's dietary supply. Stingless bees reside where their food sources develop in soil with more minerals than *Apis* bees (Gela et al. 2021). Potassium, iron, phosphorus, calcium, sodium, magnesium, and zinc are all minerals in stingless bee honey. Honey's key minerals include calcium, potassium, sodium, and magnesium (Hakim et al. 2021).

Acidic degrees test (pH)

In this investigation, the pH of stingless bee honey simplicia was 3.25 (Table 4). No Indonesian National Standard (SNI) specifies the pH of stingless bee honey. However, according to the Malaysian standard, excellent stingless bee honey has a pH of 2.5-3.8 (Hakim et al. 2021). The stingless bee honey in this study meets the quality standards for stingless bee honey based on this standard.

Ramadhan et al. (2020) investigated the pH of stingless bee honey from East and North Kalimantan. According to the study's findings, the pH of stingless bee honey in 11 honey samples ranged from 3 to 4. Stingless bee honey is distinct from honey produced by stinging bees such as *A. mellifera*. The fundamental difference between these two kinds of honey is that stingless bee honey has more water and less diastase enzyme activity, and the sugar spectrum of the two kinds of honey differs. The acidity of stingless bee honey is affected by its high water content, which facilitates the fermentation process and increases the acidity value.

In conclusion, the vegetation analysis at meliponiculture in the OKUT district showed that the following plants were found to have the highest Importance Value Index (IVI), i.e.: *H. brasiliensis* (59.38%), *P. canescens* (41.60%), *M. malabathricum* (35.68%), *A. leptopus* (16.80%), and *A. pauciflorum* (11.31%). All research sites use a polyculture or mixed crop planting design, demonstrating that the availability of varied plant sources is one of the factors considered while creating meliponiculture. The plantation crop planted in the cultivation region dominates crop type, and most farmers employ plantation crops such as rubber and oil palm. The planting pattern of plantation and forestry possesses a high honey yield of 360 kg per year. This planting pattern was significantly different from other planting patterns. Cultivated honey products have good quality and comply with Indonesian National Standards (SNI), which include organoleptic tests and laboratory tests, with results: Water content 27.14% w/w, reducing sugar content 62.05% w/w, degree of acidity 101.64 mL NaOH Kg, Total Solids insoluble in water 0.066% w/w, Ash Content 0.24% w/w, and acidity degree (pH) 3.25.

ACKNOWLEDGEMENTS

This research was funded by the Doctoral Dissertation Research Program, Directorate of Research, Technology and Community Service Directorate General of Higher Education, Research and Technology with contract number 164/E.5/PG.02.00.PL/2023. The authors would like to express their appreciation to the editor-in-chief and editors of this journal for their help and guidance and to unanimous reviewers for the correction to improve the quality of the article.

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