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Southeast Asian Meliponiculture for Sustainable Livelihood

Atsalek Rattanawanee and Orawan Duangphakdee

Abstract

Stingless bees (Apidae: Meliponini) are one of the most important pollinators of native plants and economic crops in tropical and subtropical parts of the world. They not only establish large perennial colonies with complex social organization but also have a diverse nesting biology. The economic utilization of a total of 60 stingless bee species in Asia has been reported. The current status of meliponiculture in Southeast Asia is mainly focused on pollination utilization and honey and propolis production. This chapter shows that small-scale beekeeping of stingless bees, which is suitable for the flowering pattern in the tropics, is one of the best potential alternative opportunities. The cost-effectiveness analysis based on production yield, investment cost, and profit-return rate is reviewed. Finally, a sustainable utilization of stingless bees is considered to be an enhancer of pollination services both in an agricultural crop and natural ecosystem.

Keywords: stingless bee species diversity, stingless bee beekeeping, products and utilization, marketing and demand, ecological impacts

1. Introduction

Among the 19 tribes of the subfamily Apinae, only Apini (honey bees) and Meliponini (stingless bees) show highly social behavior or eusociality [1]. In contrast to the mono-genus tribe of Apini that consists of 11 valid species [2], the Meliponini demonstrates the most diverse group, not only of the number of species but also of the morphology, nesting habitats, structures, and behavior among species [3, 4]. Meliponini has a wide distribution and is found in the tropical and subtropical regions of the world (**Figure 1**). The highest diversity of stingless bee species is found in the Neotropical with about 391 species and 32 genera, indicating that this area might be the center of origin and dispersal of stingless bees [4, 6, 7]. By contrast, 60, 10, and 50 species have been reported in Asia, Australia, and Africa, respectively [4]. However, the advance of molecular methods has increased the studies on species complexity, and new species of stingless bees are being added [8].

Like eusocial honey bees, stingless bees form colonies with a single female queen, a few hundred to several thousand female workers, and a few hundred males (drones) [1]. The nests of stingless bees show a large variation in the size, substrate used, habitats, and landscapes [9]. In nature, different stingless bee species nest in various cavities, such as hollow tree trunks and stems, under the ground, crevices within rocks, and the nest of other insects [3, 10]. All stingless bees use the same basic material, cerumen, to construct the nest. The worker bees make cerumen by mixing the wax they produce in the wax gland located on the tergites of their

abdomen, with resins that are collected from plants [4]. In spite of high variation in size and ornaments found in the different stingless bee nests, the basic components are remarkably homogeneous across species [4], as shown in **Figure 2**. The nest connects to the outside through the entrance tube made of cerumen. Among the different species of stingless bees, the entrance tube is quite varied in shape and size (**Figure 3**), and it can be used as the characteristic to identify some of the Indo-Malayan stingless bee species.

In contrast to the Asian honey bee (*Apis cerana*), stingless bee colonies are typically long-lived [3, 4] and have low absconding behavior. Some species of stingless bee continuously occupy the original nest, and the nest lives more than

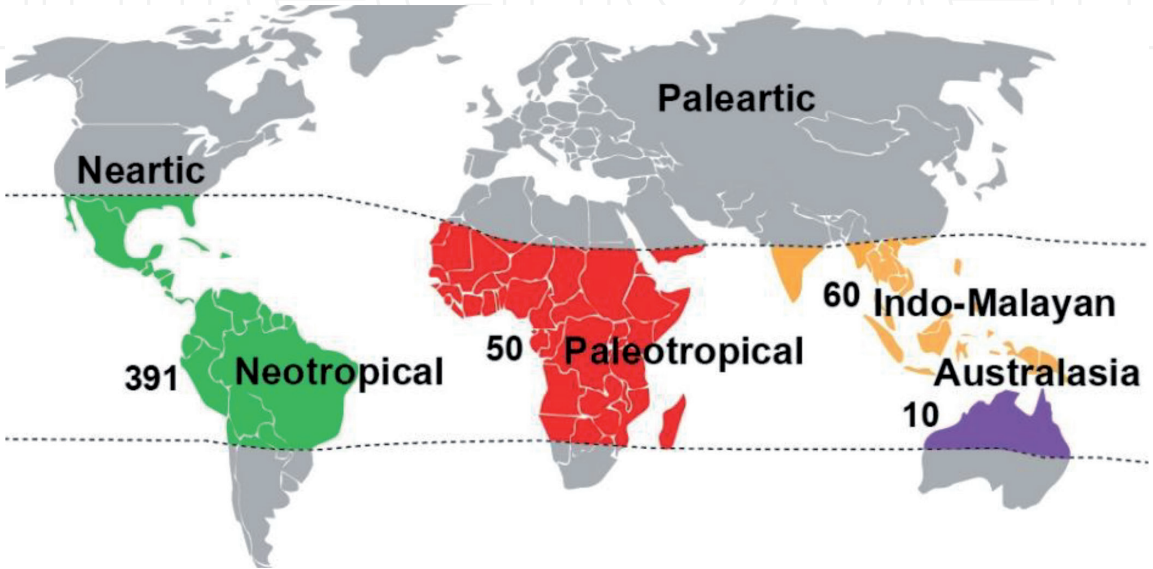


Figure 1.
Geographic distribution of stingless bees (amended in accordance with [4, 5]).



Figure 2.
Basic interior structure of a stingless bee nest: (A) a vertical brood cells, (B) honey and pollen pots, and (C) involucrum.

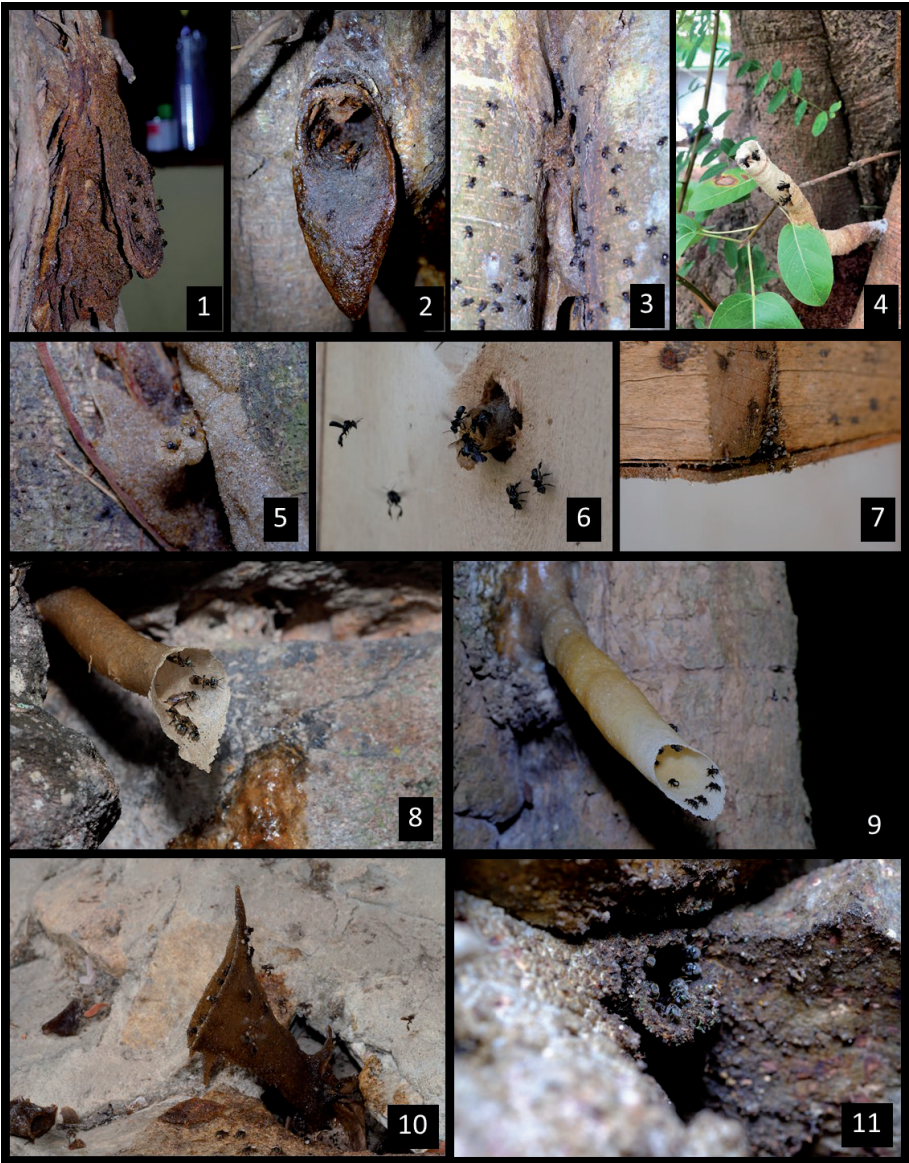


Figure 3.
Variation of entrant tube in some native stingless bee species found in Southeast Asia: (1) Geniotrigona thoracica, (2) Homotrigona fimbriata, (3) Lophotrigona canifrons, (4) Tetragonilla collina, (5) Pariotrigona klossi, (6) Heterotrigona itama, (7) Tetragonula fuscobalteata, (8) Lepidotrigona terminata, (9) Tetrigona melanoleuca, (10) Tetrigona apicalis, and (11) Tetragonula pagdeni.

20 years. These aspects of their biology make stingless bee species successful in meliponiculture in Southeast Asia, including Thailand. At least six of Thailand’s native species have had nests successfully transferred into a wood box to pollinate orchard crops. Two species (*Geniotrigona thoracica* and *Tetragonula pagdeni*) have been used for honey production. Additionally, management costs have been lower than in apiculture. The meliponiculture might be useful to improve household income in the countryside of Southeast Asia, where there is a very high diversity of flora [11, 12].

2. Stingless bees

2.1 General features

Stingless bees are one of the most diverse groups of corbiculate bees. Unlike Apini, Meliponini shows great interspecific variation not only in shape but also size,

color, pattern of wing venation, and size and shape of the corbiculate [4]. However, all stingless bee species have the same basic morphological body patterns as other Hymenopterans (**Figure 4**). Thus, the body of stingless bees can be separated into three main segments: the head, thorax, and abdomen.

On the head or prosoma of a single bee, the main organs are eyes (compound eyes and dorsal ocelli), antennae, and mouth parts. All structures on the prosoma are used to interact with their environment. For stingless bee identification, the size, shape, and number of teeth on the mandibles have been used as the primary key characteristics [4, 13].

On the thorax or mesosoma, two pairs of wings and three pairs of legs are attached and are involved in the locomotion of the bee. These appendages are moved by groups of thorax muscles [14]. Two types of forewing can be observed in Indo-Malayan stingless bee, two-tone (darker at base and clear white at apex) and mono-tone (clear white entire of wing), as shown in **Figure 5A**.

In worker bees, hind legs which are modified for pollen collection are called pollen baskets or corbicula (**Figure 5B**). The tibia is broadly expanded and slightly concave with curved hairs along the edge for keeping the pollen load. Moreover, the inner surface of the hind basitarsus segment is covered with short bristles that are used for grooming the pollen from the body and transferring the pollen to the pollen baskets [4].

The abdomen or metasoma of adult stingless bees consists of nine segments, but only second–seventh segments are externally visible [14]. Unlike honey bees, wax glands located on the tergites (dorsal plates) of the abdomen are active and produce wax in younger adult workers. Most internal organs and systems are found in this body part, including digestive organs, ventral nervous system, circulatory system, and reproductive organs [4, 14].

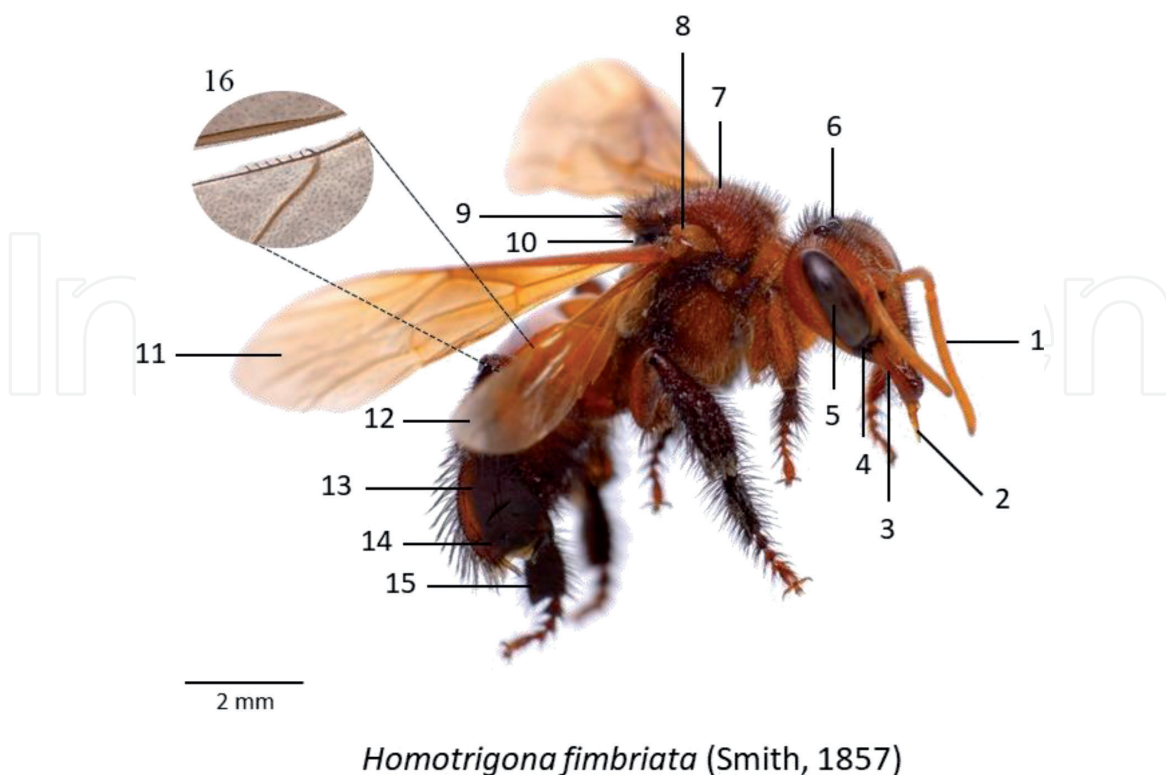


Figure 4.

External morphology of *Homotrigona fimbriata* (Smith, 1857) worker: (1) antennae, (2) proboscis, (3) mandible, (4) malar space, (5) compound eye, (6) ocelli, (7) pronotum, (8) tegula, (9) scutellum, (10) propodium, (11) forewing, (12) hind wing, (13) hind tibia, (14) pollen basket or corbicula, (15) hind basitarsus, and (16) hamuli on hind wing.

2.2 Caste and colony function

In social hymenopteran colonies, there is a division of labor between females of the colony [15]. Two castes (queen and worker) are found in a colony of stingless bees. Like other corbiculate bees, stingless bee colonies consist of two sexes (female and male), which are different in size and shape of external morphology (**Figure 6**). A haplodiploid sex determination system has been described to explain how female and male are produced in all stingless bees [4]. Both the female queen and the worker, called diploid females, develop from fertilized eggs laid by the mother queen, so they have two sets of chromosomes. In contrast, stingless bee males are produced from unfertilized eggs which is known as arrhenotokous parthenogenesis [16], meaning they carry only the mother’s genetic materials [4].

A stingless bee colony consists of a single female queen (fertile female), several hundred to several thousand unfertile female workers, and a few hundred males [17]. Similar to the honey bee of the genus *Apis*, stingless bee workers perform most activities both inside and outside the nest, including cell construction, taking care of the queen and larvae, defending the nest, as well as foraging for food and other

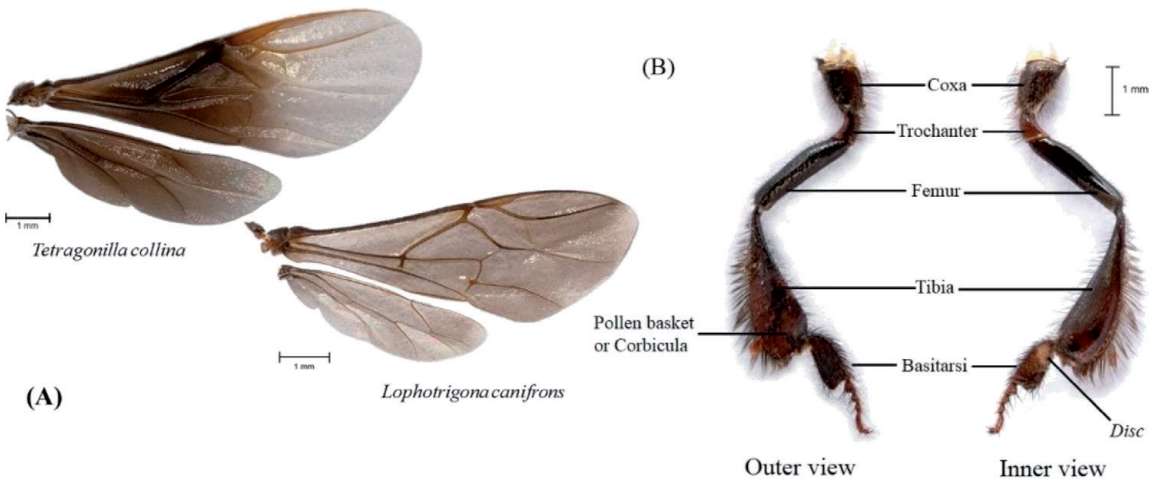


Figure 5.
(A) Fore and hind wings of two Indo-Malayan stingless bee species, *Tetragonilla collina* and *Lophotrigona canifrons*, show the color tone of forewing. (B) Outer and inner views of hind leg of *Tetrigona apicalis* worker showing pollen basket on the tibia.

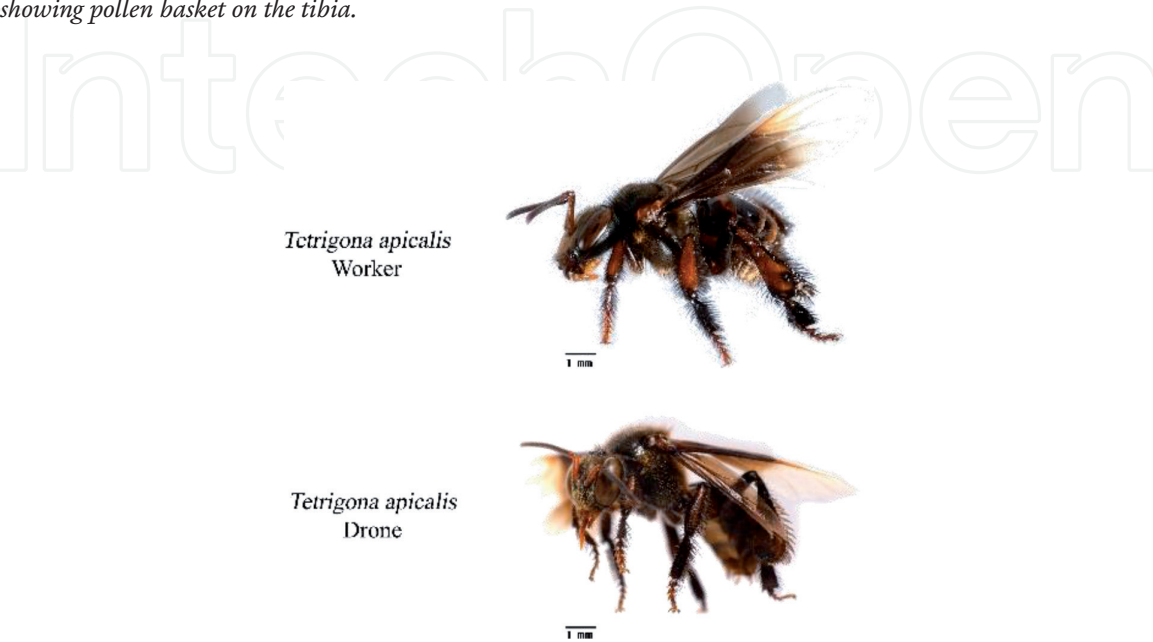


Figure 6.
Sexual dimorphism in *Tetrigona apicalis*.

colony needed materials [17, 18]. Interestingly, the progression of different duties of worker bees corresponds to age after adulthood, known as age polyethism [19]. This phenomenon is also seen in honey bees [19, 20].

Generally, five major stingless bee worker activities are recognized, namely, (1) cleaning brood chambers and feeding larvae, (2) constructing the nest, (3) receiving and processing nectar, (4) guarding in front of the nest entrance, and (5) foraging for food sources and other materials [21, 22]. Similar to *Apis*, young stingless bee workers work inside the nest. They have active wax glands on the tergites, and their main roles are constructing brood cells and cleaning the brood area. After 2 weeks, the ovaries of workers become active, and they produce trophic eggs [4] for feeding the mother queen. They also receive the nectar from foragers and dehydrate it to become honey. Older workers (3–4 weeks old) perform activities related to guarding. At this age, the workers perform short-distance flights for nest orientation [4]. In the final stage (about 1 month old), the worker becomes a forager. However, age polyethism in stingless bees is flexible, meaning that workers can continue or revert across different activities, depending on colony needs [4, 23].

2.3 Nest structure

Although a high variation in size is found in nests of different stingless bee species, the basic materials and patterns are observed [3] as shown in **Figure 2**. Cerumen, the mixture of wax that workers produce, plus resins collected from various plants by workers is the basic material used for nest construction [3]. The outermost part and cover of the interior of the nest are made from bitumen: solid cerumen mixed with propolis. Stingless bees use bitumen to line the cavity and to protect the nest from environment variation. The bitumen also helps to limit the volume of the nesting cavity. It can be removed to permit growth during a blooming period and decrease during a dearth period [4]. Inside the nest of many species, the brood area is separated from the food storage area by using a thin cerumen layer called involucrum [3]. This nest component helps to control the temperature in the brood area. The brood area contains the cells with individual developing larvae. Unlike honey bees, the brood cells of stingless bees are constructed in vertical form and are used only once [3, 4]. The brood cells of stingless bees are connected to each other by small cerumen threads forming brood clusters (**Figure 7A**). In some species, the cells may also be attached wall to wall forming a horizontal comb (**Figure 7B**).

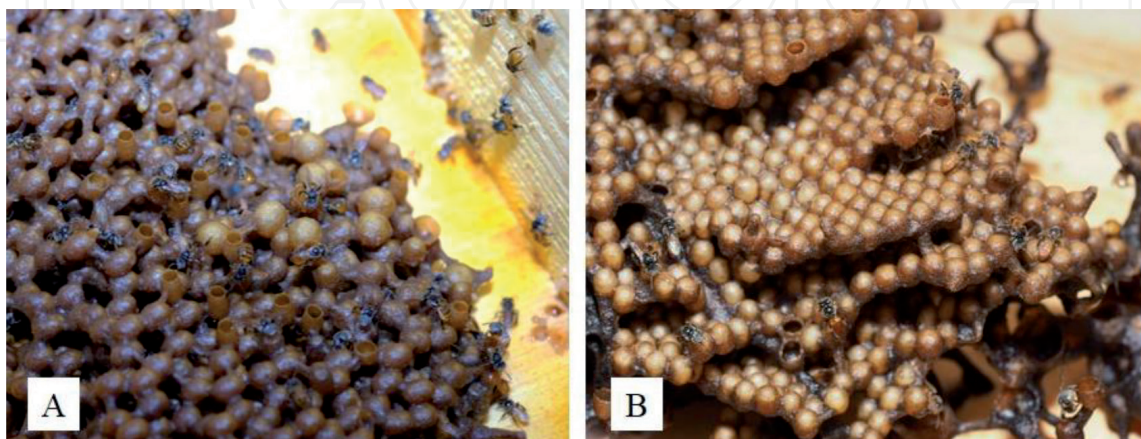


Figure 7.
Two basic type of brood cell arrangement in Southeast Asian stingless bees. (A) Brood cell clusters found in *Tetragonula pagdeni* and (B) cell arrangement as a horizontal comb in *Tetragonula laeviceps*.

Like honey bees of the genus *Apis*, stingless bees collect nectar and pollen and store it as food for the colony for long periods. For storing food, stingless bee workers build special cerumen containers called pots where honey and pollen are stored [3]. Honey and pollen are kept separately, so there are honey and pollen pots [4]. The size and shape of honey and pollen pots are similar in most stingless bees. Usually, both types of food pots are ovoid in shape, but this may also vary across species [3, 4].

3. Transferring a wild colony to an artificial hive box

There are several methods for transferring stingless bee colonies from their natural habitat to artificial hive boxes. This is one of the most important features of meliponiculture. In Southeast Asia, there are several models and sizes of commercial hive boxes available for stingless bees. However, two basic models of boxes, vertical and horizontal, are used depending on the species' arrangement of brood and food pots. For vertical boxes, the brood cluster is usually placed in the bottom section of the boxes, with honey and pollen pots built on the top of the hive. For instance, a vertical commercial hive box has successfully kept a nest of *Geniotrigona thoracica*. This type of hive box is easy to manage and harvest the honey. Horizontal boxes are the more popular for the small stingless bee species. The horizontal model is normally used for species that build the honey and pollen pots next to the brood clusters, such as *Tetragonula pagdeni* and *Tetragonula fuscobalteata*.

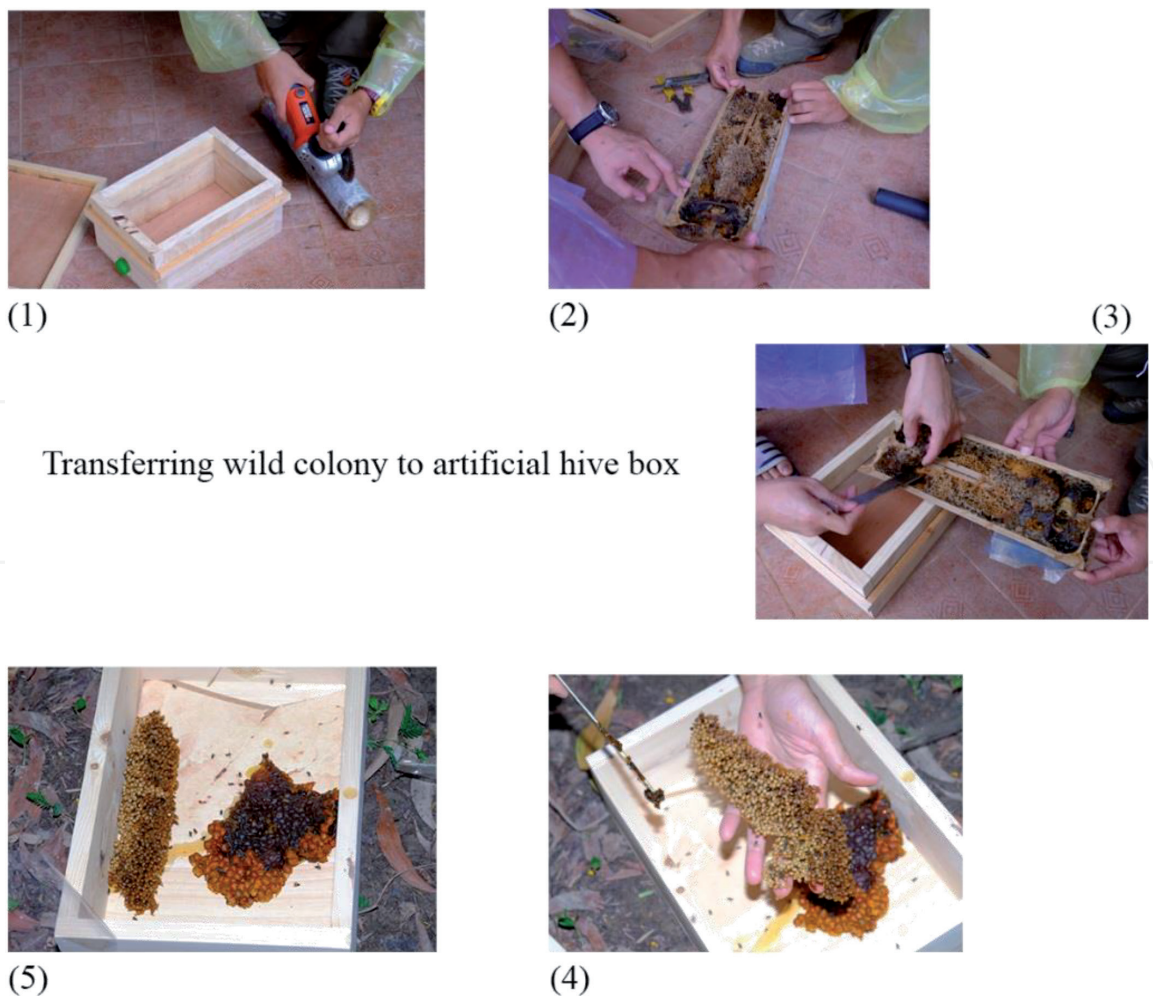


Figure 8.
Step of transferring the natural colony of stingless bee to artificial wood box.



Figure 9.
*A horizontal artificial hive of *Tetragonula pagdeni* is stacked on a four pod stand.*

The steps for transferring a natural stingless bee colony in a log to an artificial hive box are as follows (**Figure 8**):

1. Two opposite longitudinal incisions of the log using a chainsaw are made. This must be done carefully, because the sawing can injure the brood and food pots inside the log.
2. The brood cluster is the first part to remove and transfer, because the mother queen and young workers are found in this area. The brood area is carefully cut and separated from the original nest by using a knife with a sharp, thin blade.
3. The honey and pollen pots are carefully transferred and put on the floor of the new hive box next to the brood area.
4. Finding the mother queen is necessary to increase the success of transferring the colony.
5. The lid of the new hive box should be replaced to inhibit the workers from flying out, and then the new hive box is put near the original log to let the flying workers move to the new hive box. This procedure may take several hours.
6. After all bees are in the new box, the hive is moved to a suitable location. The box should be put on shelves or four pod stands to deter predators (**Figure 9**).

4. Economics of meliponiculture

Traditional uses for stingless bee honey have been documented for a century, but the selling of stingless bee honey has become cost-effective only during the recent

decade in many parts of the world. The price of stingless bee honey, compared to the honey from *Apis*, is relatively high at around US \$40 per liter in Brazil [24], US \$80 in Malaysia [25], and US \$45 in Thailand (Duangphakdee, unpublished data). Recently, meliponiculture has expanded in many parts of Southeast Asia where there are 45 potential stingless bee species [24]. Currently, the primary purpose of stingless bee beekeeping in Southeast Asia (SE Asia) is for pollination services. They are only now beginning to take root for honey production in Southern Asia (in India) and in SE Asia (Malaysia and the Philippines). Commercial meliponiculture has been intensively developed in Malaysia and the Philippines. In Thailand, as in Vietnam, local people still only use stingless bee honey for “medicinal purposes.” Meliponiculture is just at an early state of commercialization. No standard practices have developed for meliponiculture yet. The major difficulty is that of collecting honey from a tree or subterranean nest. The honey harvest technique is still being developed, and it appears still that keeping stingless bees in hives is worth the trouble and difficult to propagate in a large scale [26].

As demand for stingless bee honey is increasing, meliponiculture is getting more interest [25]. The following economic analysis is based on current markets in Malaysia. Two types of stingless bee hives were considered, based on logs (natural) and hives (artificial). Authors examined the investment cost and pricing of a small start-up with 30 colonies. The challenge to new investors was the increasing price of colonies and unpredictable return due to stolen logs, threats from overheating, pests, and parasites. The equivalent annual uniform cost (EAUC) index compares different investments in log and hive system. The study shows that revenue and operational cost are the same in both systems. Because the log type is a 40% cheaper investment, this has 22.7% higher EAUC value than a hive system for the 10 years of life cycle considered. However, both the log and the hive systems offer very good return with a margin exceeding 55%. In addition, the system reached break-even after 8.35 months and 13.56 months with log and hive system, respectively (Figure 10). Meliponiculture is therefore economically viable enough to justify investment in Malaysia [25] and other Southeast Asian countries.

The standard size for stingless bee hives has not yet been determined properly. The number of stingless bee keepers in Thailand has been expanding during the past two decades from 700 in 2014 [27] to 1500 in 2018 [28]. Most meliponikeepers are small-scale farms ranging from 20 to 50 hives. Chanthaburi and Trat provinces

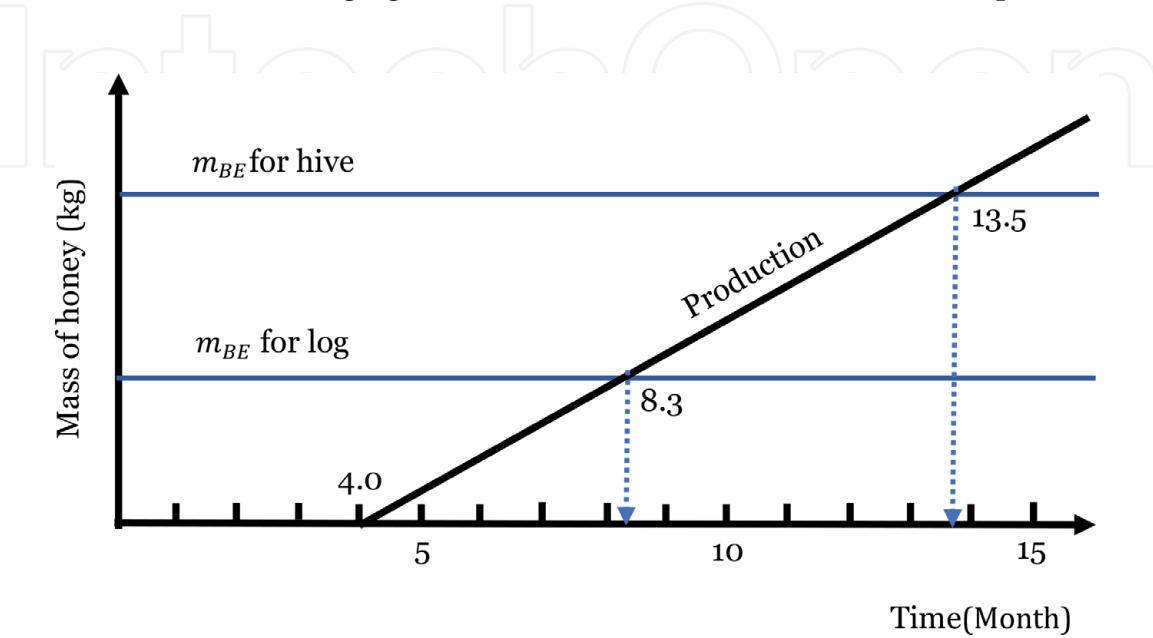


Figure 10.
Breakeven comparison of log and hive system [25].

of eastern Thailand have the most developed commercial meliponiculture for pollination and honey production at approximately 5000 hives [27, 29]. The selling price of Thai stingless bee honey is 1200–1500 THB (\$37–\$47 USD) per kilogram which 10 times and 3 times higher in price of honey from Thai produced *A. mellifera* and wild *Apis* (*A. florea*, *A. dorsata*, and *A. cerana*), respectively. The propolis and wax cerumen are additional active markets in Thailand with per kilogram returns of 1500–2000 THB (\$47–\$62 USD). In total, [29] evaluated that stingless bee hive products added 5.76 million THB (\$177,500 USD) to the regional economy in 2014. Because of the increase in meliponiculture, a number of new stingless bee beekeepers in Thailand are increased gradually to support in-country and international markets in other SE Asian countries.

5. Pollination for agricultural productivity and ecological services

As human population grows, the demand for food is increasing every year. The increase in productivity to improve food security without harming the natural environment, and making the improved productivity sustainable for future generations, is a major challenge [30]. Farmers try to improve the quality of their produce to obtain optimum prices. Pollination is one approach to achieve that goal. Incomplete flowers need pollinators for their fruit sets. Even for self-fertile flowers, cross-pollination is still needed for improved production and better quality of seeds and fruits [31]. Thus, beekeeping not only can improve income but also can increase food security [32].

Stingless bees are candidates for commercial and natural pollination. They are highly diverse and abundant and inhabit the tropical and subtropical parts of the world [33]. In SE Asia there are 68 species from 14 genera [34]. Stingless bees form perennial colonies from which they forage year-round with a variety of body size, nest structure and position, and ecological habitats allowing for selection of the most suitable stingless bee species for a given crop species and crop breeding system [33]. Stingless bees are true generalists that visit a vast array of plants [35]. However, at the individual level, stingless bees tend to specialize in a single flower [23, 36]. Indeed, this combination of traits between generalist and specialist is a characteristic that makes them one of the best contributors to pollination for many crops and wild plants [37].

Native tropical plant crops such as coffee and cacao show a mutually beneficial interaction with stingless bees. The genus *Coffea* (Rubiaceae) is native to tropical and subtropical Africa. The two coffee species, *Coffea arabica* L. and *Coffea robusta*, are grown throughout India and Southeast Asia. Even though *C. arabica* is tetraploid and self-compatible [31], the benefits of cross-pollination are still distinctly shown by producing 30% higher fruit set than autonomous self-pollination [38] and 25% higher fruit weight [39]. During the mass flowering season of coffee, the honeybees and stingless bees are dominant. However, they are often absent in the scattered flowering which occurs frequently in tropical plant blooming behavior. Coffee plantations on the edge of forests are more likely to receive a significant benefit from stingless bees which are more abundant within 600 m of the forest margin than other social bees [40] and other insect pollinators. The study of pollinators in coffee plantations in Sulawesi, Indonesia, found three honey bee species and four stingless bee species as the main pollinating species [40].

For strawberries, it is also reported that the yield is increased using stingless bees. Because the strawberry flower seems not to be attractive to honeybees, stingless bees are the preferred choice for strawberry pollination in greenhouses. Most strawberry cultivars are hermaphrodite and self-fertile, but the anther maturation

and stigma receptivity may vary highly in spatial segregation [31] which makes pollination helpful to increase productivity. In Asia, most of the studies of stingless bee pollination have been conducted in Japan [37, 41]. Strawberry pollination with stingless bees has also been seen in Nan, Thailand (O. Duangphakdee, personal communication). In many instances, the fruit and seed crop orchards at the edges of forests noted that natural pollinators are considered in increasing crop yield. Since 1990, SE Asia has suffered deforestation of 33.2 million hectares or 7.6% of the land area [42], which is the highest relative rate of deforestation of any major tropical region. As a consequence, deforestation and forest fragmentation may contribute to declines in crop pollinator populations. Several studies have been conducted to examine the effect of forest proximity on plant pollination ecology. The evaluation of flower visitor diversity, frequency, and fruit set for three crop species has been conducted in mixed fruit orchards of rambutan (*Nephelium lappaceum* L.), durian (*Durio zibethinus* L.), and mango (*Mangifera indica* L.) [43] in southern Thailand. This study compared 10 pairs of orchards that are located at <1 km and >7 km away from the forest edge. Stingless bees were the main visitors for 70.9% of total flower visits on rambutan (**Figure 11**). The distance from forest edge and location of natural stingless bee colony influenced the fruit set of rambutan significantly [43]. Stingless bees were significantly (two times) more frequent on rambutan flowers nearer to the forest.

In the case of durian and mango, even though stingless bees have been observed as flower visitors, the number of fruit sets was significantly influenced by bats (durian) and flies (mango). The distance to the forest did not affect the fruit yield of these two crops [43, 44]. The evidence suggests that the forest is an insect pollinator reservoir. The conservation of natural habitats surrounding a crop orchard is strongly recommended to maintain a population of forest-insect pollinators in natural habitats [45].

As generalists, stingless bees forage in vast array of plant taxa. A study of pollen foraging and resource partitioning of stingless bees throughout year-round

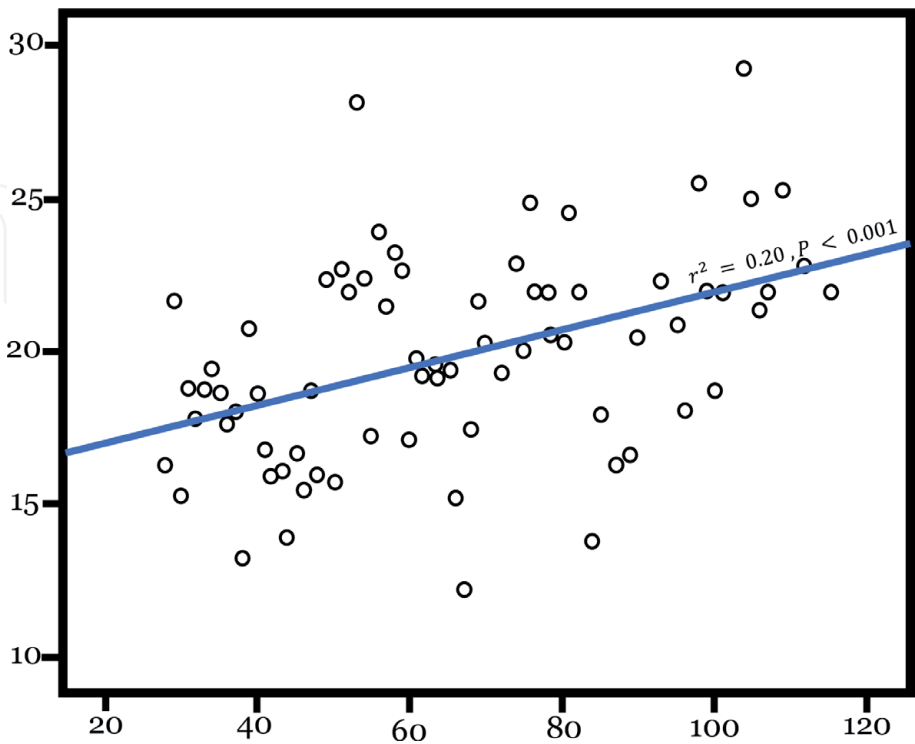


Figure 11.
A linear regression plot for the number of rambutan fruit sets and insect visitation frequency to rambutan flowers in a mixed fruit orchard in Southern Thailand [43].

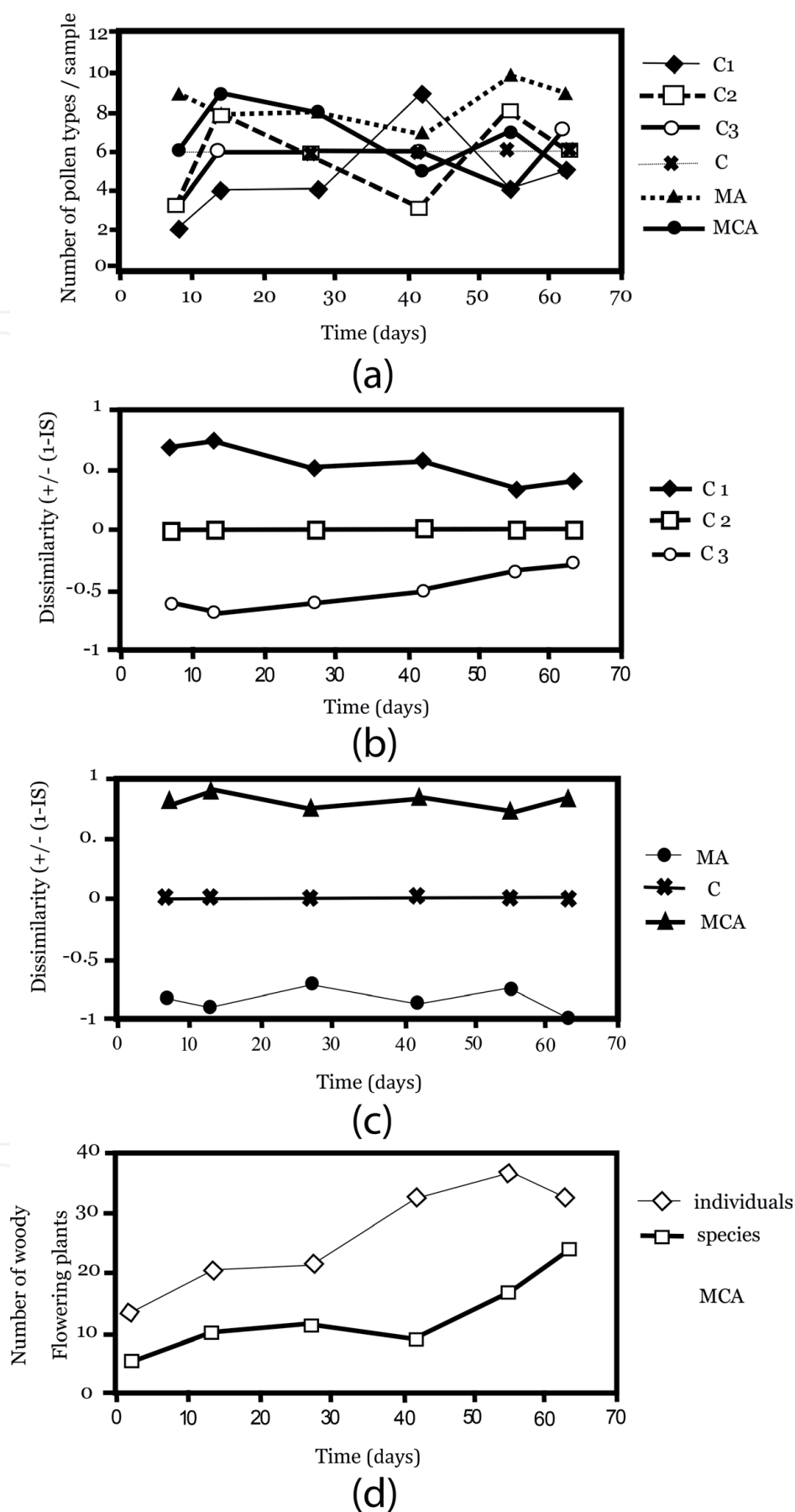


Figure 12. Pollen resource partitioning of stingless bees: (a) pollen-type richness of samples between different colonies of stingless bees (C = *T. collina* (four colonies); MA = *T. melina*; MCA = *T. melanocephala*), (b) dissimilarity of pollen samples within the monospecific collina-aggregation over time, (c) dissimilarity of pollen samples within the mixed aggregation, and (d) flowering activity as a function of time in the habitat [46]. Dissimilarity is calculated as (1-Sørensen-index); Sørensen-index is index of similarity base on the equation of Sorensen [47].

flowering dynamic in northern Borneo rainforest [46] unveils some interesting results. They compared pollen foraging within one monospecific (three colonies of *Trigona collina*) and one mixed nesting aggregation (one colony of *T. collina*, and one colony of each of the close relatives *T. melina* and *T. melanocephala*) in lowland tropical rain forest in Sabah, Malaysia. The results suggest that stingless bees, *Trigona collina*, show specificity of pollen source judged by the pollen similarity among the same species in the same aggregation sites. Within the two aggregations of *T. collina*, the similarity of pollen samples showed a strikingly different pattern over time, and there was no similarity at all between colonies in the mixed nest aggregation (**Figure 12**). Nevertheless, the resource partitioning occurs in their geographic location, with those other species of *T. melanocephala* and *T. melina* showing their highly adaptive trait in pollen foraging.

Stingless bees also show interspecific differences in foraging behavior such as the speed of detecting new food sources. Observations at an artificial feeder revealed that *T. melanocephala* arrived at honey baits quicker than *T. melina*, whereas *T. collina* was reluctant to visit the feeding site [48]. Agriculture in SE Asia is frequently multicultivar system. Multiple plant species are cultivated together. For pollination of several flower phenotypes in a mixed plantation, stingless bees are certainly good choices. The diverse crops in those mixed orchards provide a high-quality foraging habitat for pollinators [40]. Much evidence showed that stingless bees are highly adaptive species that are able to contribute to eco-services in SE Asia.

6. Conclusion

Nowadays, meliponiculture (stingless beekeeping) in SE Asia is significantly increased. The promotion of stingless beekeeping as an additional activity for rural villages, together with high stingless bee species diversity [34], stimulates a revival of this activity. For instance, in Thailand, at least six species (*Tetragonula pagdeni*, *T. laeviceps*, *T. fuscobalteata*, *Lepidotrigona terminate*, *Heterotrigona itama*, and *Geniotrigona thoracica*) are commonly managed for commercial pollination services and honey production. Of these, *T. pagdeni* and *G. thoracica* can be the most easily transferred natural colonies to artificial wooden hive boxes. In addition, there are not only short time to colony recovery after dividing colony (4–8 weeks after dividing) but also show high yield of colony production—honey and pollen [29]. Stingless beekeepers increase colony number of these two stingless bee species for both colonies selling and producing honey in short time periods. Colony of *T. pagdeni* and *G. thoracica* can be sold in price of 800–1500 THB (\$25–\$47 USD) and 4000–5000 THB (\$125–\$157 USD) per colony, respectively. Therefore, *T. pagdeni* and *G. thoracica* are more suitable to promote and develop for meliponiculture in SE Asia. However, the comparisons of honey and propolis yields from common domestic species of stingless bee of SE Asia are highly suggested. The evaluation of status of a potential industry with the stingless bees with regard to honey production and yield, its commercialization, and management should be also taken into account. Unlike *A. mellifera*, meliponiculture in SE Asia is particularly suggested to the small-scale beekeeping with regard to the flora providing source from multi-cultivar systems that are commonly found in this region. The competitive situation of the prices of honey and other products between *Apis* and Meliponini is also a further issue to be determined. The species-based problems and solution that stingless beekeepers faced should be standardized precisely [49–51]. Finally, the management and production scenario should be developed to collectively improve a substantial quantity and quality of stingless bee products as significant competitive items on the international market are suggested.

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