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Sustaining the Stingless Bees: A Comparative Analysis of Commercial and Traditional Harvesting Techniques on Colony Survival and Genetic Diversity: A Review

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Abstract
Stingless bees are vigorous tropical pollinators and producers of premium medicinal honey, driving a growing global industry. However, harvesting techniques may threaten their sustainability. This systematic literature review investigated the impacts of traditional versus commercial harvesting methods on stingless bee colony survival and genetic diversity. The findings revealed that traditional, often destructive harvesting led to high colony mortality, habitat destruction, and unsustainable yields, while also severely reducing wild population sizes and eroding local genetic adaptations. In contrast, commercial harvesting enhanced colony survival through non-invasive techniques, supplemental feeding, and health monitoring. Nevertheless, commercial harvesting introduced significant genetic risks, including genetic bottlenecks and inbreeding depression due to reliance on a limited number of founder colonies for propagation. The study concludes that while commercial practices represent a critical shift towards sustainable management, their long-term success is contingent on integrating active genetic diversity management strategies to safeguard the resilience of these indispensable pollinators.
Keywords: Stingless Bee, Commercial Harvesting, Traditional Harvesting, Colony Survival, Genetic Diversity

Introduction
Stingless honeybees are a captivating species of eusocial insects in which the queen generates the progeny and non-reproductive bees solicit for the young and they are extremely organised. Stingless bees are smaller than honeybees and they are various colours such as black, brown, yellow or metallic green (Rasmussen and Cameron, 2010). As the name implies, their greatest distinguishing feature is a vestigial sting of which their sting is not functional and prevents them from engaging in stinging activity like other honeybees' species. However,

the absence or loss of sting does not render them defenceless. They have an alternative mechanism where they preserve their colonies by biting intruders, raising a commotion by entangling in predators' hair, or secreting tenacious resin at the nest entrances (Michener, 2013).

Stingless Honeybees Nesting

Stingless bees are eusocial insects that reside in tropical and subtropical climates and they are tremendous in creating intricate nests in tree holes, underground, rock crevices, and even termite mounds. Inside these nests, the bees build distinctive spiral-shaped combs to raise their offspring, as well as clusters of miniature pot-like receptacles to store honey and pollen. These storage containers are composed of cerumen, which is a mixture of beeswax and plant resins. Many species have a unique decorative tubular aperture that serves as a protective funnel and controlled entrance for foragers. However, habitat destruction and forest fragmentation will threaten and obliterate the honeybees' colonies because the nests will be destroyed (Kwapong et al., 2010).

Pollinators Stingless Honeybees

In addition to their distinctive structure and nest-building skills, stingless bees are main and effective pollinators of plants (Khalifa et al., 2021). They work as pollinators which transfer pollen from male flower (the anther) to female flower (the stigma) within the same flower (self-pollination) or between plants (cross pollination) (Sukumaran et al., 2020). This is essential to produce quality seeds and fruits (Bartelli and Nogueira-Ferreira, 2014) such as tomatoes, blueberries, and peppers. Stingless bees can increase crop yields by almost 40% (Layek et al., 2021). Therefore, stingless bees are very important to the economy.

Stingless Honeybees Unique Medical Honey

Beyond pollination, stingless bees are renowned for producing exceptional medicinal honey known as Madu Kelulut, which is distinct from European honey (Samsudin et al., 2023) due to its higher moisture content, lower pH, and rich concentration of antioxidants and phenolic compounds, contributing to its anti-inflammatory and antimicrobial properties (Biluca et.al, 2016; Nordin et al., 2018). Stingless bee honey has been reported to have many medicinal properties such as antiseptic, antimicrobial, anticancer, anti-inflammatory and wound-healing properties (Tan et al., 2024; Ahmad et al., 2019). Heterotrigona itama and Geniotrigona thoracica are two main species of stingless honeybees in Malaysia which are prevalently known for highly valued medicinal honey (Ibrahim et al., 2021). Chemical composition of honey may be influenced by species varieties, sources of food collection (nectar and pollen) and different types of climates (Dos Santos et al., 2021).

Stingless Honeybees Harvesting Techniques

The benefits gained from medical honey caused an explosive development of the global pharmaceutical industry and the stingless bee honey has elevated from an ancient medicine to a sought-after superfood. This produces enormous economic benefits to the communities. nevertheless, this will also raise severe concerns about harvesting techniques of stingless honeybees namely traditional (manual) and commercial (mechanical) harvesting practices. The techniques differ significantly in the equipment used to harvest, efficiency and the impact on beehive which consequently influence the honeybees' colony survival and genetic diversity.

Harvesting products from stingless bees vary drastically, from ancient techniques to modern and commercialized practices. However, the impact of harvesting techniques to honeybees' colonies and genetic diversity is missing. This research gap is particularly urgent given the unique pressures of modern meliponiculture. The purpose of this study is to look at how traditional and commercial harvesting affects the colony survival and genetic diversity of stingless bee colonies by reviewing literatures systematically. This will not only provide the theoretical foundation for the research project but will also demonstrate the distinct lack of direct evidence in stingless bees, thereby powerfully justifying the need for the proposed empirical study.

Traditional Harvesting

Traditional harvesting refers to the ancient methods often using minimal and inexpensive equipment by indigenous communities and local beekeepers because they harvest subsistence or small-scale local trade. This approach typically involves locating wild nests in their natural cavities, such as tree hollows, rock crevices, or termite mounds. Harvesters often use axes, machetes, or saws to forcibly open the nest. To access the honey pots, the nest structure, including the brood comb (where the young are raised) and food storage pots, is often severely damaged or destroyed. This process often severely damages or destroys the nest structure to access the honey pots, frequently resulting in the crushing of the brood comb (where larvae and pupae develop) and the death of worker bees and sometimes the queen. These practices are characterized by their opportunistic and often destructive nature which will kill the honeybees' colonies.

Traditional harvesting includes; a) non selective harvesting where high-frequency harvesting may deplete the colonies and inadequate time to replenish food reserves. b) destructive harvesting methods by rough handling, cutting through brood combs to access honey, or using excessive smoke, which can stress or injure bees and damage the nest's integrity; and c) removing all available honey, leaving the colony vulnerable to starvation and resource scarcity. Habitat loss from deforestation and agricultural expansion continues to deplete natural nesting sites and floral resources (Samsudin et al., 2023).

There are several impacts on stingless honeybees' colonies survival if traditional harvesting is used: a) high colony mortality where the queen may be killed, brood is exposed and destroyed, and the structural integrity of the nest is compromised, leaving the bees vulnerable to predators, pests, and weather (Villanueva-G et al., 2023). The immediate loss is not just a single colony but an entire functional unit that may take years to establish.; b) habitat destruction since many nests are in trees, harvesting often involve felling or severely damaging the tree, destroying not only one colony but also a potential nesting site for future swarms (Kiatoko et al., 2021). This represents a double loss: the current inhabitants and a critical resource for population recovery, accelerating habitat degradation.; c) unsustainable yield where a harvester may gain a one-time large yield of honey, propolis, and cerumen, but the colony is not productive afterwards. This makes the practice unsustainable as it reduces the overall population of bees in the ecosystem, creating a negative feedback loop where fewer bees lead to fewer future nests to harvest.

Traditional harvesting also provide impact on genetic diversity; a) reduction in wild population size by directly killing colonies. Traditional harvesting reduces the absolute number of breeding individuals in a population which leads to a smaller effective population size, which is a primary driver of rapid genetic diversity loss through genetic drift (Allendorf et al., 2013).; b) intensive and repeated harvesting in a specific area can wipe out entire local sub-populations. This eliminates unique genetic adaptations that may have developed in that locality (Nocentini et al., 2022). Rationally, traditional harvesting is frequently motivated by a lack of understanding about sustainable practices, an urgent need for food or earnings, and the absence of managed bees. It is a practice of extraction rather than cultivation, indicating a limited capacity or incentive for long-term management.

Commercial Harvesting

Commercial harvesting involves keeping stingless bees in artificial hives. This method focusses on sustainability and long-term production. Commercial harvesting entails raising honeybees in purpose-built hives, which are generally equipped with removable portions and inspection windows to allow for non-invasive harvesting. Beekeepers typically use syringes or small pipettes to properly collect honey from storage pots while avoiding harming the brood. Commercial harvesting only removes extra honey, leaving enough for the colony to subsist. This methodology represents a major transition from destruction to management, necessitating a more thorough grasp of bee biology.

Driven by market forces, commercial harvesting practices are technology driven and often prioritize efficiency and yield which includes: a) selective harvesting where only certain honey pots are opened and a significant portion is left for the bees, especially during non-flowering seasons to avoid more colony losses (Jaffe et al., 2015); b) non-destructive techniques by using specialized equipment such as electric or motorized extractors and use centrifugal force to pitch the honey without destroying the movable frame hives and allow the bees to return and save their time to rebuild their nests ; c) seasonal timing where harvesting is aligned with natural flowering cycles, ensuring bees have ample resources to recover (Jaffe et al., 2015) and d) artificial feeding by using sugar syrup as a substitute for harvested honey, which may lack nutritional quality and impact bee health.

There are several impacts on stingless honeybees' colonies survival if commercial harvesting is used; a) colony splitting where the honeybees' colonies is in the process of dividing a healthy and established hive into two and create a new colony which will be healthy and productive indefinitely. Commercial harvesting will avoid damaging the brood and leaving sufficient food for higher colony survival and produce continuously. Instead of taking the wild nest, commercial harvesting divides a strong heathy hives which propagates the population instead of depleting it and increase the number of productive hives.; b) supplemental feeding by the beekeepers such as providing sugar syrup and pollen substitutes during the times of low nectar flow will prevent starvation to honeybees and will maintain colony strength and ensuring quick recovering after harvest (Mustafa et al., 2023).; c) managed hives are often elevated on stands and protected with barriers to deter ants and other predators which will reduce mortality for wild colonies and ensuring honeybees' colony survival.; d) health monitoring where checking regularly for any signs of diseases and allowing prevention of diseases to escalate colony collapse.; e) selective breeding where commercial beekeepers often propagate colonies from their most productive and docile hives, which can, over time, lead to genetic improvement for managed populations (Nocentini et al., 2022).

Recent studies indicate that commercial harvesting in a large-scale caused overharvesting which can trigger nutritional stress, as the bees must divert resources from brood rearing to rapidly rebuild their food stores, ultimately weakening the colony and increasing its susceptibility to disease and parasites. Intensive harvesting methods aimed at maximizing yield or excessive honey removal can lead to colony stress, increased mortality, and abandonment of the nest (Kamaruddin et al., 2022). The increasing commercial demand for madu kelulut creates a conflict between economic benefit and the preservation of the environment. Anecdotal data suggests that when populations decline locally, aggressive commercial harvesting practices may result in increased colony mortality, absconding, and a loss of genetic diversity.

Commercial harvesting also provide impact on genetic diversity; a) genetic bottlenecks: The practice of colony splitting to expand an apiary often relies on a limited number of parent colonies. This results in a founder effect, where the genetic diversity of the managed population is only a small subset of the wild population's diversity, leading to a genetic bottleneck (Nocentini et al., 2022; Jaffé et al., 2021).; b) inbreeding depression if the number of founder colonies is small and managed populations are closed (no new genetic material introduced), mating between related bees becomes inevitable. This inbreeding can lead to inbreeding depression which is the reduction in fitness, productivity, and survival of offspring due to expression of deleterious genes (Zayed, 2009). Commercial harvesting is rationally motivated by a market-driven approach to selling honey, propolis, and pollination services. Economic pressure for high yields can potentially impact colony survival and genetic diversity.

Conclusion: A Path Forward

In conclusion, traditional stingless bee harvesting is harmful, resulting in high colony mortality, habitat degradation, and a significant decline in colony survival and genetic diversity. Modern commercial harvesting prioritises colony survival through non-invasive procedures, supplemental feeding, and health monitoring, signalling a move towards sustainability. However, commercial harvesting introduces new genetic challenges, such as bottlenecks and inbreeding depression caused by reliance on a small number of parent colonies, highlighting the importance of actively managing genetic diversity even in commercial practices to ensure the long-term health and sustainability of stingless bee populations.

This research is significant because shifting from traditional to commercial harvesting is more complicated because although commercial harvesting solves the problem of mortality in traditional harvesting, it reduces the genetic diversity of honeybees' population over time and cause inbreeding problem. The stingless beekeepers should focus on ensuring the honeybees' sustainability and have a resilient population.

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