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Plantation-Based Apiculture in the Tropics: Beekeeper Perceptions and Institutional Constraints in the *Acacia crassicarpa* Honey Landscape of Sumatra, Indonesia

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plantation-based beekeeping; *Apis mellifera*; honey value chain; institutional collaboration; productivity enhancement

ABSTRACT

Plantation landscapes offer ecological resources for commercial beekeeping, yet the sustainability of *Acacia crassicarpa* honey production in Sumatra faces institutional and market constraints. This study assesses the development potential of plantation-based beekeeping systems by examining productivity performance, honey quality characteristics, stakeholder perceptions, and institutional arrangements. A mixed-methods approach was employed, combining surveys of 60 beekeepers, in-depth interviews with plantation managers and government stakeholders, and laboratory analysis of honey and pollen samples. Quantitative descriptive analysis and qualitative interpretation were used to evaluate production dynamics and value chain constraints. Results indicate an average productivity of approximately 2 kg colony^{-1} month^{-1}, with farm-gate prices averaging around IDR 24,000 kg^{-1} across the study areas. At this price level, acacia honey remains positioned primarily as a bulk commodity, which limits its competitiveness in export markets where quality differentiation and certification are increasingly required. The findings suggest that increasing colony numbers and improving productivity could enable economically viable participation in the global honey supply chain. Alternatively, scaling production may support the development of domestic industrial-based honey utilization. Strengthening technical capacity, certification systems, and institutional coordination is therefore essential to enhance competitiveness and support the sustainable development of Indonesia's plantation-based beekeeping sector.

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INTRODUCTION

Beekeeping has become an increasingly important agricultural activity worldwide, contributing not only to honey production but also to ecosystem services, rural livelihoods, and agricultural productivity through pollination (Feketéné Ferenczi et al., 2023; Gawade et al., n.d.; Gebretsadik & Alemu, 2026; Harianja et al., 2023; Richardson, 2023). Pollinators, particularly honey bees, play a critical role in global food systems, with approximately 75% of the world's major food crops depending to some extent on animal-mediated pollination (Klein et al., 2007). In addition to enhancing crop yields and biodiversity conservation, beekeeping represents a relatively accessible livelihood option for rural communities because it requires limited land, modest initial investment, and can be integrated with existing agricultural and forest-based

production systems (Bradbear, 2009; IPBES, 2016). As a result, beekeeping has increasingly been promoted as a strategy for sustainable rural development in many developing countries.

In parallel with its ecological importance, the global honey market has expanded steadily over the past two decades (Covaci et al., 2023; Liaqat et al., 2025; Phiri et al., 2022; Sapoznik et al., 2023). Rising consumer awareness of natural food products and the growing demand for functional and health-oriented foods have contributed to increasing global honey consumption. Recent statistics indicate that global honey production has reached approximately 1.8–1.9 million tons annually, reflecting the continued expansion of beekeeping activities across both developed and developing regions. Production systems range from smallholder-based traditional practices to highly commercialized operations integrated with modern agricultural value chains (Bradbear, 2009). In many developing countries, beekeeping is increasingly recognized as a strategic agricultural enterprise due to its relatively low barriers to entry and its strong linkages with forest and agricultural landscapes (IPBES, 2016).

Despite this growth, the honey industry faces a range of structural challenges related to market access, product authenticity, value chain governance, and price volatility (Bayissa et al., 2025; Bose & Padmavati, 2024; Kontopanou et al., 2024; Liaqat et al., 2025). Honey adulteration has become a major concern in international markets, undermining consumer trust and creating unfair competition among producers (Biswas et al., 2026; Bose & Padmavati, 2024; Liaqat et al., 2025; Samukelisiwe, 2023). In addition, unequal market power among value chain actors and the limited integration of smallholder beekeepers into high-value markets often constrain the economic benefits captured by producers (Gereffi et al., 2005). Consequently, recent research increasingly examines beekeeping through the lens of agricultural value chains and enterprise upgrading, emphasizing the importance of improving production efficiency, strengthening institutional collaboration, and enhancing market positioning for honey products.

Within this broader context, Indonesia possesses significant potential for the development of commercial beekeeping enterprises due to its high biodiversity and extensive forest landscapes. Among Indonesia's regions, Sumatra has emerged as a key center for the development of *Apis mellifera* beekeeping, particularly for the production of acacia honey derived from *Acacia crassicarpa*. Recent estimates suggest that more than 90% of Indonesia's cultivated honey production originates from acacia honey produced primarily in Riau and Jambi Provinces. This concentration highlights the strategic importance of Sumatra in supporting national honey production and the expansion of Indonesia's commercial beekeeping sector.

The rapid development of beekeeping in these provinces is closely associated with the expansion of industrial plantation forests dominated by *Acacia crassicarpa*. According to the Ministry of Forestry and Environment of the Republic of Indonesia (2022), plantation forests in Riau and Jambi cover approximately 1.2 million hectares, primarily established to supply raw materials for the pulp and paper industry. In addition to their industrial function, these plantation landscapes provide a highly productive foraging environment for honey bees. Unlike many flowering plants that produce nectar during short seasonal periods, *Acacia crassicarpa* secretes extrafloral nectar through glands located at the base of the leaves. Nectar secretion begins when the trees are approximately three months old and continues throughout much of the plant's growth cycle, providing a relatively stable food source for honey bee colonies.

The availability of continuous nectar resources has enabled the development of stationary beekeeping systems in these plantation landscapes. In contrast to migratory beekeeping, stationary systems allow colonies to remain in a single location throughout the year, reducing operational costs associated with colony relocation and supplemental feeding during periods of nectar scarcity. This production model has contributed to the rapid expansion of *Apis mellifera* beekeeping in Sumatra since the mid-2010s. The sector experienced particularly rapid growth during the early phase of the COVID-19 pandemic in 2020, when increased consumer interest in natural products and immune-supporting foods stimulated a surge in domestic honey demand.

During this period, thousands of honey bee colonies were relocated from Java to Sumatra to take advantage of the favorable forage conditions in acacia plantation landscapes.

While this rapid expansion has created new economic opportunities, it has also generated a range of structural challenges affecting the sustainability of beekeeping enterprises. The influx of new investors and small-scale producers has intensified competition within the sector, while many new entrants lack adequate technical knowledge, management capacity, and market experience. As a result, operational challenges such as high colony mortality and inconsistent productivity have been reported in several beekeeping areas in Riau and Jambi. At the same time, declining purchasing power following the COVID-19 pandemic has contributed to a reduction in domestic honey demand, creating additional pressure on producers.

These challenges are further compounded by weaknesses in market organization and supply chain coordination. Marketing channels for cultivated honey remain relatively underdeveloped, and access to export markets is still limited. Many Indonesian beekeeping enterprises lack the institutional support, quality assurance systems, and market information necessary to compete effectively in international honey markets. As a result, producers often rely on fragmented domestic markets characterized by strong price competition and limited value capture at the production level.

These conditions highlight the need to analyze the beekeeping sector not only as a production activity but also as part of a broader value chain system involving multiple stakeholders, including beekeepers, plantation companies, government institutions, traders, and consumers. From a Global Value Chain (GVC) perspective, improving the competitiveness of beekeeping enterprises requires various forms of upgrading, including improvements in production efficiency, product quality, functional roles within the value chain, and diversification of market channels.

Despite its economic potential, research on acacia honey production systems in Sumatra remains scarce, particularly regarding productivity dynamics, stakeholder coordination, and market integration. Existing studies have primarily focused on biological or production aspects of beekeeping, while relatively little attention has been given to the integration of production performance with value chain development and enterprise transformation strategies. In particular, there is a lack of comprehensive analyses that simultaneously address productivity variation among beekeepers, stakeholder coordination within plantation-based production systems, and market structures influencing the sustainability of beekeeping enterprises.

Addressing these gaps is essential for identifying pathways that enable beekeeping enterprises to scale up sustainably and improve their integration into both domestic and international honey markets. Therefore, this study aims to assess the scale-up potential of *Apis mellifera* beekeeping enterprises in Sumatra, focusing on stationary beekeeping systems in Riau and Jambi Provinces. In addition, this research seeks to identify strategic value propositions that can strengthen the market positioning of *acacia* honey within evolving honey value chains.
Specifically, this study addresses the following objectives:

1. To analyze the productivity levels of *Apis mellifera* beekeeping in Riau and Jambi Provinces and identify factors contributing to productivity variation among beekeepers and production locations.
2. To examine stakeholder perceptions, interests, and roles—including beekeepers, industrial plantation forest companies, government institutions, buyers, and local communities—in supporting the transformation of the beekeeping sector and its downstream value chain.
3. To investigate the structure of supply chains and market access conditions influencing the sustainability of beekeeping enterprises and formulate recommendations for improving marketing efficiency and market stability.

4. To develop a comprehensive transformation model for beekeeping enterprises integrating productivity enhancement, product quality improvement, multi-stakeholder collaboration, market development, and the strengthening of product identity and competitiveness.

METHOD

Study Period and Location

This study was conducted from January 2025 to June 2026, encompassing preparation, data collection, analysis, and reporting. Research subjects included *A. mellifera* beekeepers and relevant provincial institutions involved in apiculture in Jambi and Riau Provinces, Indonesia. Beekeepers were selected from regions with active *Apis mellifera* operations: Muaro Jambi, Tanjung Jabung Barat, and Tanjung Jabung Timur in Jambi; Pelalawan, Bengkalis, and Dumai in Riau.

Research Design and Data Collection

A mixed-methods approach combining surveys, field observations, in-depth interviews, and laboratory analyses was employed. The survey targeted key stakeholders: beekeepers, managers of plantations and industrial forests (HTI) hosting beekeeping activities, and provincial government officials overseeing apiculture development and marketing.

Laboratory analyses were conducted to evaluate the physicochemical properties of honey, particularly *Acacia crassicarpa* honey, and other apiculture products, including bee pollen.

Sampling and Respondents

We surveyed 60 *Apis mellifera* beekeepers (30 each in Jambi and Riau), selected purposively from active beekeeping areas. Additional stakeholders included 2 plantation managers and 8 government officials from forestry, livestock, plantation and SME departments.

Data Collection Instruments

Data were collected through: (1) structured questionnaires assessing management practices and perceptions; (2) semi-structured interviews exploring institutional roles; (3) field observations of apiary conditions; and (4) laboratory analyses of honey and bee pollen samples for physicochemical properties.

Data collected from HTI managers and government officials focuses on:

a. Institutional capacity and mandates (roles, regulations, operational capacity)
b. Perceptions of *Apis mellifera* beekeeping (potential, challenges, strategic relevance)
c. Extension services and support programs (availability and effectiveness)
d. Government initiatives (policy and program impacts on sector development)
e. Market systems and financial readiness (price dynamics, value chains, budget support)
f. Environmental integration and social impacts (livelihood and sustainability outcomes)

Data collected from beekeepers focuses on:

a. Beekeeping capacity (knowledge, training, experience)
b. Colony management (propagation, queen rearing, hive maintenance, health)
c. Production and quality control (harvesting, handling, storage practices)
d. Risk management (pests, diseases, pesticides, environmental stressors)
e. Marketing strategies (pricing, market access, value chain participation)

Physicochemical properties evaluated for honey and bee pollen

a. Honey: diastase activity, hydroxymethylfurfural (HMF), and free acidity.

b. Bee pollen: moisture content, carbohydrates, fat, and protein.

Data Analysis

Quantitative data were analyzed using descriptive statistics to summarize productivity and price trends. Qualitative data underwent thematic analysis to identify management constraints and stakeholder perceptions. Triangulation of methods ensured comprehensive understanding of the socio-ecological production system.

The analytical framework integrates three dimensions: (1) production system performance, capturing productivity variations across locations and management practices; (2) stakeholder structure, examining the roles, interactions, and interests of beekeepers, plantation companies, government institutions, traders, and local communities; and (3) value-chain dynamics, focusing on supply chain organization, market access, and price formation.

Four hypotheses guide the analysis: H1 – productivity levels vary across locations and practices; H2 – stakeholder interactions influence sector development and sustainability; H3 – supply-chain structure and market access affect economic performance and market stability; H4 – integrated improvements in productivity, collaboration, and value-chain organization enhance sustainability and competitiveness.

This integrated approach combines productivity analysis, stakeholder mapping, and value-chain evaluation, enabling the identification of strategic pathways for strengthening plantation-based beekeeping systems in Indonesia (Figure 1).

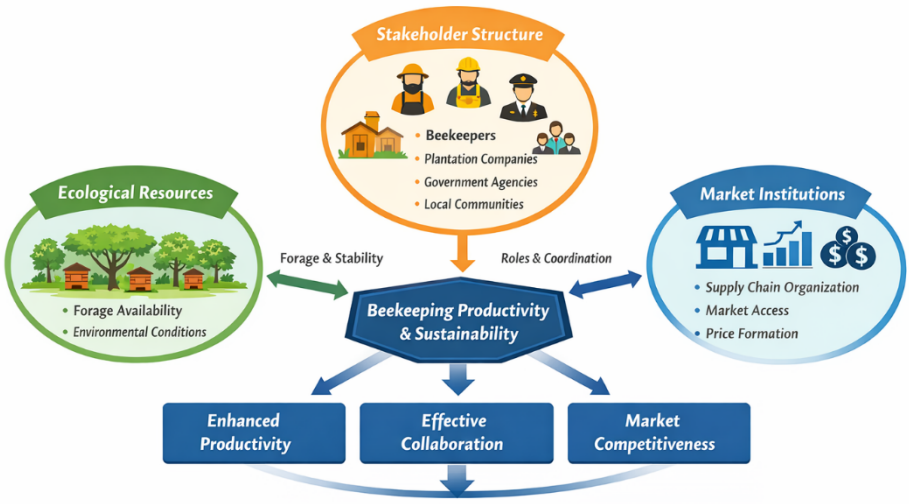


Figure 1. Analytical Framework for Plantation Based Beekeeping System

RESULTS AND DISCUSSION

The Beekeepers Perception of The Beekeeping Management

Beekeeping management in Jambi and Riau shows consistently high scores, indicating favorable perceptions among beekeepers. The overall mean is slightly higher in Jambi (4.61 ± 0.31) than in Riau (4.43 ± 0.36), though both reflect high performance.

Colony Propagation Management shows perfect consensus (5.00 ± 0.00), while Weather and Honey Production remains very high (5.00 ± 0.00; 4.75 ± 0.43). Key operational aspects, including productivity and training, also score highly (4.75 ± 0.43; 4.50 ± 0.50). Value-added products show identical results (4.75 ± 0.43).

Lower scores occur in Threat Management (4.20 ± 0.40; 3.95 ± 0.45) and Forage Competition (4.00 ± 0.00; 3.75 ± 0.43). Forage sustainability differs slightly (4.75 ± 0.50; 4.38 ± 0.48). Overall, low SD (<0.50) indicates strong agreement.

Table 1. The Beekeepers Perception of The Beekeeping Management

No.	Parameter	Jambi (Mean ± SD)	Riau (Mean ± SD)
1	Beekeeper's Skill and Capacity	4.25 ± 0.43	4.25 ± 0.43
2	Honey Productivity Management	4.75 ± 0.43	4.50 ± 0.50
3	Colony Propagation Management	5.00 ± 0.00	5.00 ± 0.00
4	Threat and Disturbance Management*	4.20 ± —	3.95 ± —
5	Bee Forage Resource Competition	4.00 ± 0.00	3.75 ± 0.43
6	Weather and Honey Production	5.00 ± 0.00	4.75 ± 0.43
7	Value Added of Other Bee Products	4.75 ± 0.43	4.75 ± 0.43
8	Training and Upscaling Beekeeping Skills	4.75 ± 0.43	4.50 ± 0.50
9	Sustainability of Bee Forages**	4.75 ± 0.50	4.38 ± 0.48
	Average	**4.61 ± 0.31**	**4.43 ± 0.36**

Data processed by researchers (2026)

a. Threat and Disturbance Management is a composite variable consisting of multiple disturbance factors (Varroa mites, bee-eater birds, macaques, sun bears, and hive theft).
b. Sustainability of Bee Forages combines oil palm plantation and *Acacia crassicarpa* forest as forage sources.

The findings suggest that beekeepers in both regions hold a strongly positive and cohesive perception of beekeeping management systems. The uniformly high mean scores indicate that core management practices—particularly colony propagation, productivity management, and skill development—are well understood and widely accepted as critical components of successful beekeeping.

However, the comparatively lower scores in disturbance management and forage-related aspects highlight structural and ecological challenges that remain less effectively managed. This pattern implies that while technical and operational capacities are relatively well established, external factors such as environmental variability, resource competition, and human–wildlife interactions continue to constrain system performance.

The slightly higher overall scores and lower variability in Jambi further suggest a more stable and consolidated management system, whereas Riau exhibits marginally greater heterogeneity in perceptions, potentially reflecting differences in institutional support, ecological conditions, or experience levels among beekeepers.

Taken together, these results indicate that the transformation of beekeeping systems should move beyond basic capacity building toward strengthening ecological resilience and adaptive management, particularly in relation to forage sustainability and disturbance mitigation.

The Beekeepers Perception of Honey Price and Market Competition

Perceptions of honey price and market competition are generally positive and consistent across regions. Honey Price shows identical means (3.75 ± 0.43), indicating moderate agreement.

Table 2. The Beekeepers Perception of Honey Price and Market Competition

No.	Parameter	Jambi (Mean ± SD)	Riau (Mean ± SD)
1	Honey Price	3.75 ± 0.43	3.75 ± 0.43
2	Market Competition	3.75 ± 0.43	4.00 ± 0.00
3	National Competition	4.00 ± 0.00	4.25 ± 0.43
4	International Competition	4.00 ± 0.00	4.25 ± 0.43
5	Low Price – High Production	4.00 ± 0.00	3.75 ± 0.43
6	Honey Consumer	4.25 ± 0.43	4.25 ± 0.43
7	Fraud and Fake Honey	4.50 ± 0.50	4.50 ± 0.50
8	Honey and Other Bee Products Certification	4.50 ± 0.50	4.50 ± 0.50
	Average	4.09 ± 0.31	4.16 ± 0.33

Data processed by researchers (2026)

Market Competition is slightly higher in Riau (4.00 ± 0.00) than in Jambi (3.75 ± 0.43). Similarly, National and International Competition are higher in Riau (4.25 ± 0.43) than in Jambi (4.00 ± 0.00), suggesting stronger exposure to broader market dynamics.

In contrast, Low Price–High Production is higher in Jambi (4.00 ± 0.00) than in Riau (3.75 ± 0.43), indicating a stronger volume-oriented strategy.

Honey Consumer perceptions are identical (4.25 ± 0.43). Fraud and Certification show the highest scores (4.50 ± 0.50) in both regions, reflecting shared concerns over market integrity.

Overall, low SD (≤ 0.50) indicates strong agreement, with slightly greater variability in Jambi.

Beekeepers perceive market conditions as competitive but manageable, with increasing influence from national and international markets, particularly in Riau. While pricing mechanisms are viewed as moderately stable, they remain influenced by multiple actors, limiting bargaining power.

High scores in fraud awareness and certification reflect a strong concern for market quality and trust, suggesting that institutional mechanisms (e.g., certification, regulation) are critical. Meanwhile, differences in production strategy indicate that Jambi beekeepers are more oriented toward volume-based approaches, whereas Riau beekeepers are relatively more responsive to competitive market structures.

Overall, the findings suggest that strengthening market governance, certification systems, and price transparency is essential to improve value capture and competitiveness in the honey value chain.

Stakeholders Awareness and Perceptions on *Apis mellifera* Beekeeping

Overall, perceptions of government and stakeholders toward beekeeping systems are largely positive, with most dimensions scoring above 4.00, except for extension support.

Institutional Capacity shows a moderate–high score (4.04 ± 0.66), indicating generally strong awareness but some variability in institutional structure and regulatory frameworks.

Perceptions of beekeepers and their activities are highly positive (4.59 ± 0.39), reflecting strong recognition of economic, ecological, and social contributions. Similarly, government expectations for beekeeping development are very high (4.89 ± 0.13), indicating strong strategic alignment with welfare, conservation, and climate objectives.

In contrast, extension and support activities show a very low score (1.42 ± 0.48), highlighting a substantial gap in technical assistance, certification, and operational support. Despite this, the perceived effectiveness of government support remains relatively high (4.00 ± 0.00), suggesting uniform perceptions of existing interventions.

Program outcomes are also rated highly (4.63 ± 0.41), indicating positive impacts on capacity, sustainability, and environmental goals. Indirect institutional benefits show consistent agreement (4.00 ± 0.00), while market systems and budget readiness demonstrate moderately high performance (4.43 ± 0.49).

Environmental integration receives very high scores (4.80 ± 0.40), reflecting strong alignment with biodiversity and climate strategies. Likewise, community empowerment and social impacts are positively perceived (4.40 ± 0.49), particularly in livelihood diversification and inclusion.

Table 3. Stakeholders Awareness and Perceptions on *Apis mellifera* Beekeeping

No.	Assessment Aspect	Mean ± SD
1	Institutional Capacity – Awareness and Mandate	4.04 ± 0.66
2	Provincial Government Perceptions to Beekeepers and Activities	4.59 ± 0.39
3	Government Expectations for *Apis mellifera* Development	4.89 ± 0.13
4	Government Extension and Support Activities	1.42 ± 0.48
5	Perceived Effectiveness of Government Support	4.00 ± 0.00
6	Relevance and Outcomes of Government Programs	4.63 ± 0.41
7	Indirect Institutional Benefits	4.00 ± 0.00
8	Market Systems, Honey Prices, and Budget Readiness	4.43 ± 0.49
9	Environmental and Landscape Integration	4.80 ± 0.40
10	Community Empowerment and Social Impacts	4.40 ± 0.49
	Average	4.12 ± 0.30

Data processed by researchers (2026)

The results indicate a structural imbalance in the beekeeping system. While policy-level commitment, institutional expectations, and perceived outcomes are strong, implementation capacity—particularly extension services—remains critically weak.

High scores in strategic and environmental dimensions suggest that beekeeping is well-positioned within broader development and sustainability agendas. However, the extremely low score in extension support indicates a disconnect between policy intentions and field-level execution.

This gap implies that strengthening technical support systems, training, and institutional facilitation mechanisms is essential to translate high-level commitment into tangible improvements for beekeepers. Without such alignment, the system risks remaining policy-driven but operationally constrained.

Honey Production

The table 4 shows that the *profile of beekeeping enterprises managed by Respondents* illustrates notable differences in the scale of beekeeping operations between respondents in Jambi and Riau, although several operational indicators remain relatively similar.

In terms of colony ownership, beekeepers in Riau manage their enterprises on a considerably larger scale, with an average of 358 ± 8.2 colonies per beekeeper, compared to only 58 ± 4.8 colonies in Jambi. The combined average of both regions is 208 ± 6.5 colonies per beekeeper, indicating a substantial disparity in production capacity between the two areas. This difference suggests that beekeeping enterprises in Riau tend to be more intensive and commercially oriented, while those in Jambi are generally operated on a smaller to medium scale.

Table 4. Profile of Beekeeping Enterprises Managed by Respondents

Variable	Unit	Jambi (n = 30)	Riau (n = 30)	Average (Jambi–Riau)
Colony ownership	Colonies beekeeper^{-1}	58 ± 4.8	358 ± 8.2	208 ± 6.5
Harvest frequency	Harvests month^{-1}	1–2	1–2	1–2
Colony productivity	kg colony^{-1} month^{-1}			
Honey		2.01 ± 0.14	2.06 ± 0.49	2.04 ± 0.32
Royal jelly		–	–	–
Bee pollen		–	–	–
Propolis		–	–	–

Data processed by researchers (2026)

Despite the difference in the number of colonies, the harvest frequency in both regions is relatively similar, ranging from 1–2 harvests per month. This indicates that the harvesting management and production cycles are comparable between the two regions, likely influenced by similar biological characteristics of the bees and environmental conditions.

Regarding colony productivity, honey yield per colony per month is nearly identical between the two regions. In Jambi, honey productivity reaches 2.01 ± 0.14 kg per colony per month, while in Riau it is slightly higher at 2.06 ± 0.49 kg. The overall average of 2.04 ± 0.32 kg suggests that honey production efficiency per colony is relatively consistent, regardless of the scale of operation.

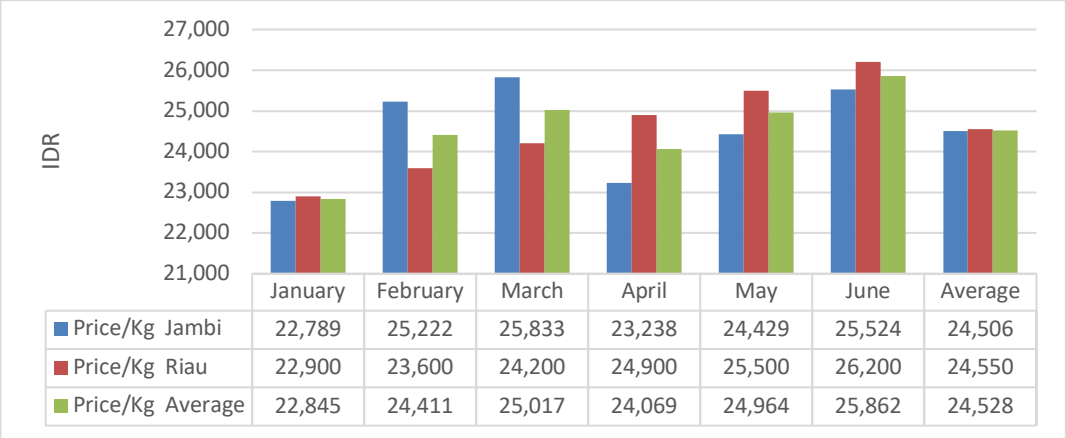
Meanwhile, no production of other bee products such as royal jelly, bee pollen, or propolis was reported in either region. This indicates that the beekeeping enterprises managed by the respondents are primarily focused on honey production, without diversification into other bee-derived products.

Overall, the table 4 highlights that the main difference between Jambi and Riau lies in the scale of beekeeping operations rather than in colony productivity or harvesting practices. This suggests that increasing the number of colonies, particularly in regions like Jambi, could be a potential strategy to enhance total honey production without requiring significant changes in beekeeping management practices.

Honey Price

The graph of Prices of Bulk *Acacia crassicarpa* Honey in Jambi and Riau from January to June 2025 (Figure 2) shows both temporal fluctuations and regional price differences, with a general upward trend toward mid-year.

At the beginning of the period (January), prices in both regions are relatively similar, with Jambi at around IDR 22,789/kg and Riau slightly higher at IDR 22,900/kg. This indicates a relatively stable and comparable market baseline at the start of the year.



	January	February	March	April	May	June	Average
Price/Kg Jambi	22,789	25,222	25,833	23,238	24,429	25,524	24,506
Price/Kg Riau	22,900	23,600	24,200	24,900	25,500	26,200	24,550
Price/Kg Average	22,845	24,411	25,017	24,069	24,964	25,862	24,528

Figure 2. Prices of Bulk *Acacia crassicarpa* Honey Jambi and Riau, During January to June 2025

In February and March, prices in Jambi increase significantly, reaching a peak of approximately IDR 25,833/kg in March. During the same period, Riau experiences a more moderate increase, remaining consistently lower than Jambi. This suggests that Jambi may have experienced tighter supply or stronger demand during this phase.

However, the trend reverses in April. Prices in Jambi drop sharply to around IDR 23,238/kg, while Riau prices rise substantially to about IDR 24,900/kg. This shift marks a transition where Riau becomes the higher-priced market, possibly reflecting differences in harvest timing, supply flow, or market access.

From May to June, both regions show an increasing trend again, but Riau consistently records higher prices than Jambi. The highest price in the entire period occurs in June in Riau (approximately IDR 26,200/kg), while Jambi reaches about IDR 25,524/kg. This indicates stronger price momentum or demand conditions in Riau toward the middle of the year.

Overall, the average prices between the two regions are very close, with Jambi at IDR 24,506/kg and Riau slightly higher at IDR 24,550/kg. The combined average follows a smooth upward trajectory from January to June, reflecting a general strengthening of bulk honey prices over time.

These dynamics likely reflect seasonal production cycles, regional supply variations, and shifting demand across the two provinces.

Physicochemical Properties of Honey and Bee Pollen

Table 5 presents the physicochemical properties of *Acacia crassicarpa* honey samples collected from Jambi and Riau in Sumatra, highlighting variations in quality parameters such as hydroxymethylfurfural (HMF), diastase enzyme activity, and acidity.

The HMF content, which is an important indicator of honey freshness and heat exposure, shows considerable variation among samples. In Jambi, HMF values range from 0 to 21.25 mg/kg, with the highest value recorded in Jambi 2, while several samples (Jambi 4 and Jambi 5) show no detectable HMF. In Riau, HMF levels are generally lower, ranging from 0 to 2.25 mg/kg. The overall mean HMF value of 3.69 mg/kg indicates that the honey samples are relatively fresh and minimally processed, as all values remain well below commonly accepted quality thresholds.

Table 5. Physicochemical Properties of *Acacia crassicarpa* Honey from Sumatra

Physicochemical Properties	Unit	Jambi 1	Jambi 2	Jambi 3	Jambi 4	Jambi 5	Riau 1	Riau 2	Riau 3	Mean
HMF	mg/kg	4.91	21.25	0.75	0	0	2.25	0.39	0	3.69
Diastase Enzyme	DN	9.40	12.63	14.87	12.36	4.65	5.43	8.14	2.55	8.75
Acidity	ml NaOH 1 N/kg	103.2	88.05	91.75	95.11	96.98	63.79	64.22	92.22	86.91

Data processed by researchers (2026)

Diastase enzyme activity, expressed in diastase number (DN), reflects the enzymatic integrity of honey and can be affected by storage and heating. The results show that Jambi samples tend to have higher diastase activity, ranging from 4.65 to 14.87 DN, compared to Riau samples, which range from 2.55 to 8.14 DN. The highest activity is observed in Jambi 3 (14.87 DN), while the lowest is found in Riau 3 (2.55 DN). The overall mean value of 8.75 DN suggests moderate enzymatic activity, indicating that most samples maintain acceptable quality, although some variation may reflect differences in handling or storage conditions.

Acidity levels, measured as ml NaOH 1 N/kg, are relatively high across all samples, indicating the presence of organic acids that contribute to honey flavor and preservation. Jambi samples exhibit higher acidity values (88.05–103.2 ml NaOH/kg) compared to Riau samples (63.79–92.22 ml NaOH/kg). The highest acidity is recorded in Jambi 1 (103.2 ml NaOH/kg), while the lowest is found in Riau 1 (63.79 ml NaOH/kg). The overall mean acidity of 86.91 ml NaOH/kg suggests that *Acacia crassicarpa* honey from these regions is relatively acidic, which may be characteristic of its botanical origin.

In summary, the table indicates that honey from both Jambi and Riau generally meets quality expectations, with low HMF levels and moderate diastase activity. However, Jambi samples tend to show greater variability and higher values in both enzymatic activity and acidity, whereas Riau samples appear more consistent and generally lower in these parameters. These differences may be influenced by environmental conditions, floral sources, and post-harvest handling practices.

The table 6 presents the proximate composition of bee pollen collected from Jambi and Riau, revealing broadly similar nutritional characteristics between the two regions, with only slight variations in component proportions.

Moisture content is slightly higher in Riau (18.94%) compared to Jambi (18.33%), suggesting that bee pollen from Riau may retain more water. This difference, although small, could influence storage stability and susceptibility to microbial growth if not properly dried.

Ash content, which represents the total mineral content, is marginally higher in Riau (3.42%) than in Jambi (3.35%). This indicates that bee pollen from Riau may contain slightly more mineral elements, potentially reflecting differences in soil composition and plant sources.

Table 6. Proximate Composition of Bee Pollen from Jambi and Riau

Component	Jambi (%)	Riau (%)
Moisture	18.33	18.94
Ash	3.35	3.42
Carbohydrate	52.79	51.78
Fat	5.12	5.53
Protein	20.41	20.33

Data processed by researchers (2026)

Carbohydrates form the largest proportion of bee pollen in both regions, accounting for 52.79% in Jambi and 51.78% in Riau. This confirms that bee pollen serves as a significant energy source, with Jambi showing a slightly higher carbohydrate level.

Fat content is relatively low but shows a noticeable difference, with Riau (5.53%) exceeding Jambi (5.12%). This variation may be linked to differences in botanical origin, as lipid composition in bee pollen is influenced by plant species.

Protein content is nearly identical between the two regions, with values of 20.41% in Jambi and 20.33% in Riau. This consistency highlights that bee pollen from both areas is a rich and reliable source of protein, including essential amino acids and enzymes.

Overall, bee pollen from Jambi and Riau exhibits a comparable nutritional profile, characterized by high carbohydrate and protein content, moderate moisture levels, and minor differences in mineral and fat composition. These variations are likely driven by environmental conditions and floral diversity in each region.

Integrated Governance Model

1. Bridging Top-Down and Bottom-Up Transformation in Plantation Beekeeping Systems

   The development of plantation-based beekeeping industries requires a governance framework that integrates both grassroots initiatives and institutional interventions. In complex agro-industrial landscapes, sectoral transformation rarely emerges solely from either community-driven innovation or centralized institutional control. Instead, sustainable development is often achieved through governance arrangements that combine bottom-up participation with top-down policy coordination within a multi-level governance system (Ostrom, 2009; Termeer et al., 2010).

   In the context of plantation apiculture, bottom-up approaches emphasize the empowerment, experiential knowledge, and adaptive capacities of beekeepers, while top-down strategies focus on regulatory frameworks, institutional coordination, and policy-

driven sector development. These two approaches should therefore be understood as complementary mechanisms that collectively support the transformation of the beekeeping sector rather than as competing paradigms.

The comparative characteristics of these two development pathways are summarized, which highlights the different drivers, strategic orientations, and transformation mechanisms associated with bottom-up and top-down approaches in the beekeeping sector. As shown in the table, bottom-up pathways are primarily driven by beekeeper initiatives and focus on capacity building and adaptive production practices, whereas top-down approaches emphasize institutional governance, regulatory frameworks, and market coordination.

The findings of this study indicate that relying solely on beekeeper-driven initiatives may not be sufficient to overcome structural constraints related to market access, regulatory standards, and landscape governance. Similar challenges have been observed in agricultural value-chain development, where smallholder innovation often requires institutional support to overcome structural market barriers (Kaplinsky & Morris, 2001; FAO, 2018). Conversely, development strategies that depend exclusively on centralized institutional control frequently fail to address the operational realities and ecological knowledge embedded in local production systems. Consequently, a hybrid governance model that integrates bottom-up and top-down transformation pathways becomes necessary to ensure the long-term sustainability and competitiveness of plantation-based apiculture systems.

Within this integrated governance framework, beekeepers remain the central actors in production and local resource management, while institutional stakeholders—including government agencies, plantation companies, and research institutions—provide structural support that enhances system performance. Such multi-actor governance arrangements reflect the broader concept of polycentric governance, where multiple actors operating at different institutional levels collaboratively manage shared ecological resources (Ostrom, 2009).

At the grassroots level, bottom-up processes strengthen the technical and organizational capacity of beekeepers. These processes include improvements in colony management practices, diversification of hive products, collective marketing initiatives, and local innovation in apiary management. Local ecological knowledge accumulated by beekeepers plays a particularly important role in adapting colony management strategies to seasonal nectar flows and plantation landscape dynamics. Previous studies have shown that beekeeper knowledge and adaptive management practices significantly influence colony productivity and resilience (Bradbear, 2009; VanEngelsdorp & Meixner, 2010).

At the institutional level, top-down interventions create an enabling environment that supports industry development. Government agencies play a central role in establishing regulatory frameworks for honey quality standards, certification systems, and food safety regulations that ensure product authenticity and market credibility. Plantation companies also contribute to landscape governance by coordinating pesticide management schedules, allocating safe apiary zones, and maintaining nectar-producing vegetation within plantation ecosystems. Such landscape-level governance mechanisms are particularly important in large-scale agricultural environments, where pollinator populations are highly sensitive to land-use practices and agrochemical exposure (Klein et al., 2007; Potts et al., 2016).

The interaction between these governance levels creates a multi-level governance system that strengthens the entire beekeeping value chain. Through collaborative partnerships among beekeepers, plantation managers, government institutions, and market actors, plantation landscapes can be transformed into multifunctional agroecosystems that support both honey production and ecosystem services such as pollination. Pollinator-dependent agricultural systems increasingly rely on such collaborative governance frameworks to balance ecological sustainability with economic productivity (Garibaldi et al., 2013).

2. Bridging Top-Down and Bottom-Up Transformation in Plantation Beekeeping Systems

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The integrated relationships among these governance components are synthesized in Table 7, which presents the Integrated Governance Model for Transforming Plantation-Based Beekeeping Systems. The tabble illustrates how bottom-up beekeeper initiatives interact with top-down institutional interventions across three interconnected transformation dimensions: productivity improvement, stakeholder collaboration, and value-chain governance.

Table 7. Comparative Perspective: Bottom-Up vs Top-Down Development Pathways

Dimension	Bottom-Up Approach	Top-Down Approach
Main driver	Beekeepers	Institutions and policy
Key focus	Capacity building and production practices	Governance and regulation
Market strategy	Cooperative marketing	Market certification and regulation
Landscape management	Local adaptive practices	Corporate and policy coordination
Transformation pathway	Grassroots empowerment	Institutional structuring

Data processed by researchers (2026)

From a systems perspective, this integrated governance model aligns three critical transformation dimensions. The first dimension involves improving productivity through enhanced beekeeper capacity and improved colony management practices. The second dimension focuses on strengthening institutional collaboration between beekeepers and other stakeholders to ensure sustainable landscape management and regulatory compliance. The third-dimension addresses value-chain organization and market governance, which are essential for improving economic returns and ensuring product authenticity in honey markets. Strengthening these interconnected dimensions is widely recognized as a key strategy for developing resilient agricultural value chains (Kaplinsky & Morris, 2001; FAO, 2018).

This integrated transformation pathway directly supports the hypotheses tested in this study. Improvements in beekeeper capacity and management practices contribute to addressing variations in productivity across locations and management systems, as proposed in Hypothesis 1. Institutional collaboration between beekeepers, plantation companies, and government agencies strengthens stakeholder relationships, supporting Hypothesis 2. Meanwhile, reforms in supply-chain governance and market regulation enhance economic performance and market stability, as outlined in Hypothesis 3. Finally, the combined effects of productivity improvements, stakeholder collaboration, and value-chain restructuring provide empirical support for Hypothesis 4, which emphasizes the importance of integrated interventions in transforming the acacia honey industry toward greater sustainability and competitiveness.

Ultimately, the integrated governance model demonstrates that the transformation of plantation-based beekeeping industries depends on coordinated actions across multiple levels of governance. By linking beekeeper-driven innovation with institutional policy support and market governance, the model provides a strategic framework for developing a resilient and sustainable honey industry within plantation landscapes.

Figure 3. Intergrated Governance Model for Transforming-bases Beekeeping System

Transformation of the Acacia Honey Industry within the Global Value Chain (GVC) Framework

transformation of plantation-based beekeeping industries in Sumatra—particularly in the provinces of Jambi and Riau—can be more comprehensively understood through the lens of the Global Value Chain (GVC) framework. These regions represent highly potential landscapes for honey production due to the extensive presence of industrial acacia plantations that provide abundant nectar resources for *Apis mellifera colonies*. However, despite this ecological potential, the economic performance of the beekeeping sector remains constrained by structural limitations in production capacity, market organization, and value-chain coordination.

The transformation process discussed in this study builds upon the analytical framework developed in the previous sections. Highlighted the role of beekeeper-driven innovation through a bottom-up transformation model, while emphasized institutional interventions through top-down governance mechanisms. These two development pathways were subsequently integrated, which presented an integrated governance model illustrating how beekeeper initiatives, institutional support, and stakeholder collaboration interact within a multi-level governance system. The comparative characteristics of these governance approaches were also summarized, which highlighted the complementary roles of grassroots innovation and institutional coordination in shaping sectoral transformation.

Building on these governance perspectives, the transformation of the acacia honey industry can be further analyzed through the Global Value Chain framework, which focuses on how value creation, coordination, and upgrading occur along interconnected networks linking producers, processors, traders, and final markets (Kaplinsky & Morris, 2001; Gereffi et al., 2005). Agricultural commodities such as honey are therefore embedded within complex governance structures that determine how economic value is distributed among actors along the chain.

In the context of plantation-based beekeeping systems in Sumatra, the acacia honey sector can be conceptualized as an emerging value chain, where multiple actors—including beekeepers, plantation companies, honey processors, traders, and consumers—participate in different stages of production, processing, and commercialization. However, similar to many emerging agricultural industries in developing economies, this value chain often exhibits fragmented production systems, limited technological adoption, weak market coordination, and restricted access to premium market segments (Gereffi et al., 2005; Ponte & Sturgeon, 2014).

To address these structural limitations, the transformation model proposes a pathway for strengthening the acacia honey industry through value chain upgrading, a central concept within the GVC literature. Value chain upgrading refers to the process through which producers and firms move toward higher-value activities, improve operational efficiency, and enhance their competitive position within global and domestic markets (Kaplinsky & Morris, 2001; Gereffi et al., 2005).

Integrated Transformation Pathway

Presents the integrated transformation pathway for strengthening the acacia honey industry within plantation landscapes in Sumatra. The model synthesizes the governance perspectives developed throughout this study, beginning with the bottom-up transformation dynamics and the top-down institutional transformation framework. These two governance approaches were

subsequently integrated within a multi-level governance perspective and conceptually compared in Table 7, highlighting the complementary roles of grassroots innovation and institutional coordination in supporting sectoral development.

Building upon this governance foundation, extends the analysis by incorporating a value-chain upgrading perspective to illustrate how institutional and production dynamics interact to enhance industry performance. The model demonstrates that transformation in plantation-based apiculture is driven not only by governance reforms but also by strategic improvements along the value chain. Specifically, four upgrading pathways—process upgrading, product upgrading, functional upgrading, and chain upgrading—play a central role in improving productivity, product quality, market participation, and sector diversification.

Process upgrading focuses on improving beekeeping management practices, colony productivity, and honey harvesting techniques within plantation ecosystems. Product upgrading emphasizes quality improvement, traceability, and differentiation of acacia honey to access higher-value markets. Functional upgrading involves the increased participation of beekeeper organizations in value-chain activities such as processing, branding, and marketing, thereby strengthening their bargaining power and economic resilience. Chain upgrading refers to the expansion of market opportunities through diversification into new distribution channels, including premium honey markets, apitherapy products, and value-added bee products.

Taken together, the transformation pathway demonstrates that the sustainable development of plantation-based beekeeping systems requires coordinated improvements across three interrelated dimensions: production systems, value-chain organization, and institutional governance. Beekeeper innovation enhances local adaptive capacity and production efficiency, while institutional support from plantation companies and government agencies provides regulatory frameworks, landscape management coordination, and market facilitation mechanisms. At the same time, value-chain upgrading enables the sector to capture higher economic value and strengthen market competitiveness.

Through the interaction of these elements, the model provides a strategic framework for enhancing the competitiveness, resilience, and sustainability of the acacia honey industry within plantation ecosystems. More broadly, the integrated framework offers a novel analytical perspective for understanding how plantation landscapes can support the development of competitive honey value chains in emerging apicultural regions.

CONCLUSION

This study shows that plantation landscapes in Sumatra particularly those dominated by *Acacia crassicarpa* possess strong ecological capacity to support plantation-based beekeeping. The abundant extrafloral nectar produced by young acacia stands can sustain colonies of *Apis mellifera*, while positive perceptions and adaptive attitudes among beekeepers in Jambi and Riau indicate substantial social readiness for expanding apiculture within plantation ecosystems. Despite this potential, current productivity and market performance remain constrained by inconsistent colony management, limited access to training and financing, and weak institutional coordination, including insufficient market regulation and honey quality control. Nevertheless, the ecological resource base suggests a significant untapped bioeconomic opportunity, as even a small proportion of available plantation area could generate substantial honey production and economic value. Conceptually, this study contributes to the literature by linking plantation-based apiculture with the Global Value Chain, highlighting how production innovation, institutional governance, and value-chain upgrading jointly shape the competitiveness of emerging honey industries. Overall, integrating apiculture into plantation landscape management represents a strategic pathway to accelerate the development of Indonesia's beekeeping industry, while simultaneously enhancing rural livelihoods, supporting pollinator conservation, and increasing the multifunctional value of industrial forestry systems.

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