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From Traditional *Kawe Lengkuran* to Modern Grafting: A Socio-Historical Analysis of Besemah Coffee Cultivation, Indonesia

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Abstract: The transformation of coffee cultivation in the Besemah highlands demonstrates a negotiation between traditional practices and modern propagation technologies. This study traces changes from *kawe lengkuran*, an age-old technique of regenerating old stems, to grafting systems that utilize local rootstocks and superior scion varieties. Using mixed methods integrating ethnographic documentation, documentation of locally recognized grafted coffee clones and their farmer-reported traits, and a quantitative survey based on five dimensions of farmer rationality, this study reveals that innovation adoption proceeds through interconnected rationalities influenced by socio-ecological contexts. The analysis shows that *kawe lengkuran* continues to shape how farmers evaluate cultivation effectiveness, while grafting increasingly trusted for improving productivity and enhancing disease resistance. Variations cross three hamlets illustrate that local history, elevation differences, and social networks influence farmers' technical decisions, whereas knowledge dimensions, intention to adopt technology, and social norms show relatively uniform patterns, reflecting a shared readiness for vegetative innovation. This study demonstrates that the transition from *kawe lengkuran* to grafting reflects a socio-ecological reconfiguration in which traditions, farmer roles, and modern agronomy practices interact to drive changes in the Besemah coffee plantation system, thereby broadening our understanding of smallholder innovation dynamics and the co-evolution of traditional and modern agricultural knowledge.

Keywords: coffee cultivation, traditional knowledge, grafting, kawe lengkuran, Mount Dempo

Introduction

Coffee plays an important economic and cultural role in Indonesia, contributing to rural livelihoods, exports, and shaping producing regions' socio-ecological landscape (Jha et al. 2011). The Besemah community near Mount Dempo, South Sumatra, has a longstanding coffee cultivation tradition that underpins its cultural identity and ecological adaptation (Turčinović et al. 2025). The community has refined coffee propagation techniques that reflect accumulated local knowledge and responding to socio-economic pressures such as fluctuating coffee prices, the need to improve household income, pest and disease challenges, and increasing exposure to external agricultural knowledge and technologies (Cahyono et al. 2020). Traditionally farmers used *kawe lengkuran*, a natural seedling regeneration method, before adopting *kawe pungpungan* for improved plant vigor. Recently, *kawe sambung pucuk*, a grafting method, has become increasingly dominant due to its advantages in yield stability and disease resistance (Wright et al. 2024).

Coffee cultivation in the Besemah highlands around Mount Dempo plays multiple roles that extend beyond agricultural production. Economically, coffee represents the primary livelihood source for most smallholder households and forms the backbone of the rural economy in the region. Socially, coffee farming practices are embedded in intergenerational knowledge systems, local identity, and community cooperation, where cultivation techniques and planting materials are often exchanged through kinship and neighborhood networks. Ecologically, coffee cultivation in Besemah is typically integrated with shade trees and diverse agroforestry components, contributing to landscape stability and biodiversity in the mountainous environment of South Sumatra. These intertwined economic, social, and ecological functions make coffee cultivation a central element of the Besemah socio-ecological system and provide an important context for understanding the transformation of propagation techniques examined in this study (Poncet et al., 2024).

Understanding changes in coffee cultivation is increasingly important as global coffee production faces multiple structural challenges, including climate variability, soil degradation, market volatility, and declining farmer income (Bracken et al. 2023). These pressures highlight the need for locally adapted cultivation strategies that can sustain productivity while maintaining ecological resilience in smallholder farming systems. In many coffee-producing regions, farmers rely not only on scientific recommendations but also on accumulated ecological knowledge developed through long-term interaction with their environment (Yanou et al. 2023). Such knowledge systems often guide decisions related to crop management, plant regeneration, and adaptation to environmental variability (Nguyen et al. 2020). The Besemah region in the highlands surrounding Mount Dempo, South Sumatra, provides a particularly relevant case for examining these dynamics. Coffee cultivation in this area reflects a dynamic interplay between inherited agronomic practices such as *kawe lengkuran*, a traditional stem regeneration technique and newer innovations like *kawe sambung pucuk* (grafting). Situated within broader socio-historical and ecological contexts, the Besemah coffee system offers valuable insights into the co-evolution of local knowledge and technological innovation in addressing ongoing challenges in global coffee production.

Previous studies on Robusta coffee cultivation have primarily focused on agronomic practices, agroforestry management, and technological innovations aimed at improving productivity and sustainability. For example, research on coffee agroforestry systems highlighted the role of diversified cropping systems and farmer-led innovations in enhancing ecological resilience and farmers' livelihoods (Cahyono et al., 2020; Kuyah et al., 2021). Other studies examine the technological and governance dimensions of sustainable coffee production within global supply chains (Wright et al., 2024). While these studies provide important insights into agronomic improvement and sustainability strategies, they rarely address how local cultivation practices evolve historically within specific cultural landscapes.

In particular, limited researches and attention have been given to integrating socio-historical perspectives with farmer' decision-making processes in Robusta coffee systems. This gap is evident in Mount Dempo, a major Robusta coffee region, where a comprehensive research on the evolution of coffee propagation techniques in the Besemah community, from *kawe lengkuran* to *kawe pungpungan* and *kawe sambung pucuk* remains scare. The limited integration of historical ethnography and farmers' perspectives on local wisdom constrains a comprehensive understanding of how knowledge systems evolve and influence agricultural practices and sustainability. This study analyzes Besemah coffee propagation systems and farmers' persepectives on local wisdom, aiming to support sustainable agricultural strategies and contribute to discussions on local knowledge in resilient agroecosystems (Nguyen et al. 2020).

Material and Methods

Study Area

This study was conducted in three coffee-producing hamlets located on the slopes of Mount Dempo, South Sumatra, Indonesia, within the traditional Besemah cultural area (Figure 1). These hamlets include Dusun Talang Camai (3.992308° S; 103.192065° E), Dusun Talang Belumai (4.012470° S; 103.285918° E), and Dusun Cawang Lama (4.084578° S; 103.224197° E). The area is characterized by mountainous topography at elevation of approximately (700–1,500 meters above sea level), a humid tropical climate, and volcanic soil that are highly suitable for Robusta coffee cultivation.

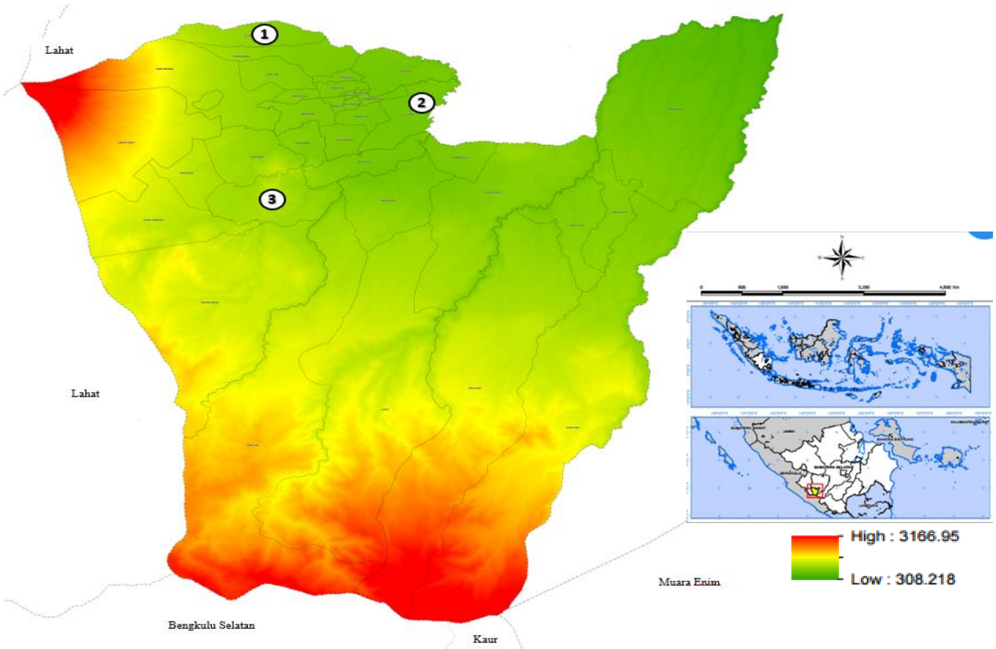

Figure 1. Research location map (1. Talang Camay, Selibar; 2. Talang Belumai, Ulu Rurah; 3. Cawang Lama, Muara Siban)

Research design

This study used a mixed-methods design to explore the socio-historical development of coffee cultivation practices and farmers' perspectives on local wisdom. Using a convergent parallel design, qualitative and quantitative data were collected simultaneously and analyzed separately. The qualitative component includes literature review, interviews, and observation highlighting *kawe lengkuran*, *kawe pungpungan*, and *kawe sambung pucuk* techniques. The quantitative component used structured questionnaires to evaluate farmers' perceptions of local wisdom in coffee cultivation.

Data Collection

Data were collected in August 2025 through in-depth semi-structured interviews and participatory observations. Interviews with key informants explored the emergence and transformation of *kawe lengkuran*, *kawe pungpungan*, and *kawe sambung pucuk*; as well as perceptions of propagation methods; socio-economic conditions; and intergenerational knowledge transfer. A total of 12 key informants were interviewed using purposive sampling to capture diverse perspectives related to the transformation of coffee cultivation practices in the Besemah region. The key informants consisted of senior coffee farmers with more than 25 years of farming experience (n = 5), farmer innovators who actively developed and disseminated grafting techniques (n = 3), community elders with knowledge of traditional cultivation practices such as *kawe lengkuran* (n = 2), and local agricultural facilitators involved in extension and farmer training (n = 2). Participatory observation during agricultural activities documented cultivation practices and actor interactions. Interviews were conducted in Besemah and Indonesian languages, audio-recorded with consent, and documented with notes.

Quantitative data were collected through questionnaire surveys of coffee farmers. The questionnaire captured three dimensions: socio-demographic characteristics (age, gender, education, land size, farming experience, residence time, and income); cultivation practices and adoption of propagation techniques, focusing on *kawe lengkuran*, *kawe pungpungan*, and *kawe sambung pucuk* usage, adoption reasons, and their perceived impact on yields and pest resistance; and perceptions of local wisdom, economic aspects, social norms, and innovation adoption. Perception items used a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree). Face-to-face interviews were conducted with assistance from local language-proficient residents.

Data Analysis

Data were analyzed using a mixed-methods approach that combined qualitative and quantitative analysis techniques in a complementary manner, following the general guidelines for mixed-methods research. Quantitative data were analyzed using descriptive statistics and inferential statistical tests. One-way analysis of variance (ANOVA) was applied to examine differences in mean scores among the three hamlets for the five dimensions of farmer rationality. The analyzed variables included: (1) perception of *kawe lengkuran*, (2) perception of grafting (*sambung pucuk*), (3) economic considerations and risk perception, (4) social norms and environmental influence, and (5) knowledge and intention to adopt technology. When significant differences were detected, Tukey’s Honestly Significant Difference (HSD) post-hoc test was used to identify pairwise differences between villages. Qualitative data from interviews and observations were analyzed using thematic analysis, focusing on patterns of knowledge transmission, historical changes in propagation techniques, and farmers’ perceptions of technological innovation. The integration of qualitative insights with quantitative statistical patterns allowed for a more comprehensive interpretation of the transformation of coffee cultivation practices in the Besemah region.

Results

Transformation of the Besemah Coffee Plantation System

The transformation of the Besemah coffee plantation system (Figure 2) illustrates the trajectory of socio-historical changes that are interconnected, from the pre-colonial communal agrarian regime to digital technology and modern cultivation in the contemporary era. This representation shows that changes in coffee production in the Besemah region are determined by colonial intervention, postcolonial institutional reconstruction, and the local community's ability to adapt technically, including shifting from *kawe lengkuran* to grafting technique, in response to regional economic dynamics and global market demands.

In the postcolonial period, transferring ownership from colonial authorities to local farmers and regional governments restructured land tenure and decentralized decision-making, expanding farmers' autonomy in production strategies and strengthening family-based farming. Within this flexible framework, technological innovations, especially grafting (*kawe sambung pucuk*) spread through informal knowledge networks, social learning, and local experimentation, with pioneering farmers demonstrating increased productivity and plant resilience. The technology's adoption was reinforced by market pressures for stable yields and disease resistance, linking local practices to economic incentives. Simultaneously, farmers' rationalities shifted from tradition-based to integrating local ecological knowledge such as *kawe lengkuran* practices with modern technical considerations for input efficiency, risk management, and yield optimization. Instead of replacing traditional practices, grafting was adapted within the local agroecological system, resulting in hybrid cultivation configurations reflecting a gradual, adaptive transformation within the Besemah coffee plantation system.

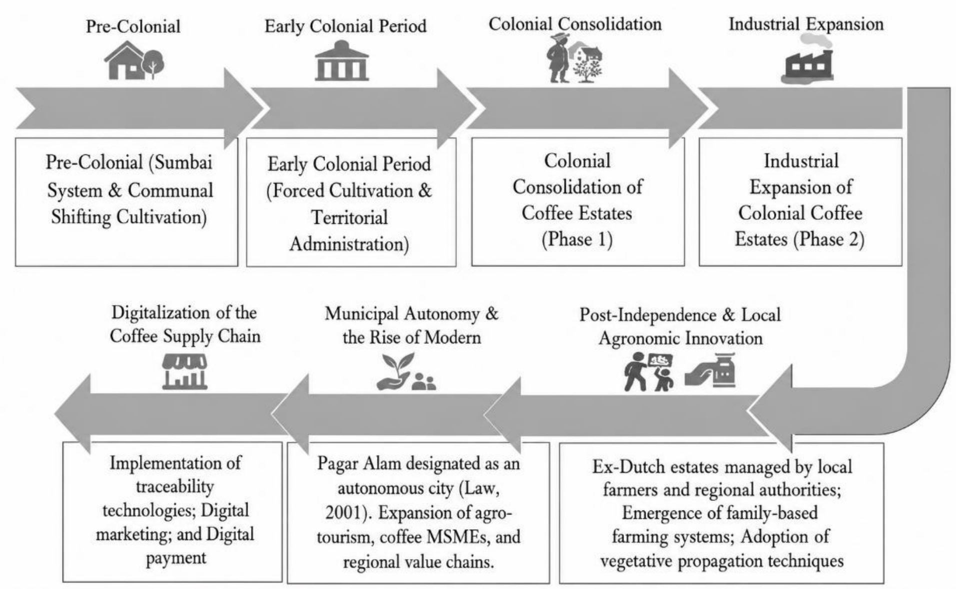

Figure 2. Socio-historical transformation of the Besemah coffee plantation system around Mount Dempo

Figure 2 illustrates a path-dependent transformation process, in which traditional practices such as *kawe lengkuran*, are not replaced but rather reconfigured to form the foundation for the adoption of grafting techniques. This process demonstrates the coexistence of two agronomic regimes, namely traditional ecological knowledge and modern technological systems that operate simultaneously. It also highlights farmers's rolenot merely as users of technology, but as active agents who integrate innovation with local knowledge systems; and the interconnection between institutional change and technical transformation.

The results show that the Besemah coffee plantation system has undergone structural transformation. As illustrated in Figure 2, cultural, economic, and technological changes have shaped agricultural systems and coffee production in the Besemah region. In the pre-colonial phase, the sumbai system and shifting cultivation regulated access rights, planting patterns, and spatial rotation according to ecological conditions. This system faced disruption during the early colonial period through cultural changes and territorial reorganization, which shifted production toward a more extractive regime. The expansion of colonial plantations strengthened coffee monoculture, intensified agricultural dualism between colonial estates and people's land, and integrated Besemah coffee into global trade through colonial infrastructure.

In the postcolonial period after Dutch plantations transferred to local farmers, data show that resource control shifts encouraged family farming systems, cultivation diversification, and coffee stand rejuvenation. Pagar Alam's designation as an autonomous city in 2001 accelerated agro-tourism development, coffee micro-enterprises, and regional value chain integration. Recent adoption of modern technology and digital systems correlates with improved supply chain transparency and stronger positions for smallholder farmers in market segments. These transformations show evolution from external-dominated production toward an inclusive agricultural system, enabling Besemah's strategic participation in the global coffee economy.

Plant Propagation Techniques: From Traditional Kawe Lengkuran to the New Paradigm of Grafting

The transformation of coffee plant propagation techniques in Besemah is clearly reflected in the visual representations of *kawe lengkuran*, *kawe pungpungan*, and *kawe sambung pucuk* (Figure 3). These three techniques illustrate the long journey of agricultural innovation within the Besemah community, ranging from traditional practices that emphasize natural regeneration and canopy architecture control to modern vegetative approaches that enable the acceleration of plantation rejuvenation and the strengthening of productivity through the selection of superior clones.

Figure 3. Documentation of Besemah Kawe practices around Mount Dempo, Pagar Alam City, South Sumatra (Kawe Lengkuran; Kawe Pungpungan; and Kawe Sambung Pucuk)

The results show that the propagation system for Besemah coffee plants has undergone significant technical shifts, moving from traditional practices such as *kawe lengkuran* and *kawe pungpungan* to more standardized and agronomically controlled grafting techniques. Field documentation (Figure 3) illustrates how *kawe lengkuran*, which has long been a long-standing hereditary practice around Mount Dempo, is carried out by manipulating the relatively tall coffee stems (4-7 m), where farmers utilize the morphology of secondary branches that are allowed to grow naturally and lengthwise from the main stem.

A distinctive feature of the "*kawe lengkuran*" method is that the main stem grows tall to maintain photosynthetic capacity and productivity, while unproductive parts are periodically cleaned. "Pencetikan" involves light cutting at the stem tip to stimulate new shoot growth. The cut stem is then bent downward for easier maintenance and harvesting. Farmers select one or two healthy shoots as candidates for productive stems in the next cycle. The Besemah community identifies successful *lengkuran* through physiological changes: softer leaf texture, lighter green color, and increased branches. This selection serves as an ecological adaptation strategy that ensures continued production without replacing the entire plant.

In addition to the *lengkuran* technique, the Besemah community uses the *kawe pungpungan* method by pruning shoots at around four years of age, which is considered a critical phase for managing plant growth. At this stage, the coffee plant has exited its juvenile phase and entered a stable reproductive phase, with sufficiently developed vascular tissue to support efficient nutrient transport to the fruit. Pruning at this age is believed to stimulate the formation of more productive lateral shoots and enhance the photosynthetic efficiency of plants. This understanding is integrated into the local classification system of coffee fruit growth, starting from early fruiting stage, followed by the basal fruiting stage (approximately three years old), and culminating in the peak productive stage (around four years of age). This final stage is considered the most optimal phase for pruning interventions (*kawe pungpungan*), as it maximizes both yield quantity and fruit quality.

The Besemah community's top-grafting practices show a shift from traditional kawe systems to standardized forms of vegetative propagation, as shown in Figure 3. Farmers manage four key components: scion, graft union, interstock, and rootstock. Scions are selected from high-yielding local clones and grafted onto mature rootstocks. Interstocks demonstrate farmers' understanding of physiological compatibility between scion and rootstock, which is critical for successful grafting. Moreever, the uniformity of graft wrapping practices indicates collective learning towards sustainable practices, increasing successful tissue union and graft survival rates.

Grafting System: Evaluation Based on Empirical Evidence

The evaluation of Besemah coffee grafting requires understanding clone diversity at the farmer level, including scion origin and field performance. Table 1 presents 24 grafted clones from various villages illustrates that clone selection is based on farmer’s experience and ecological adaptation. Data on location, elevation, morphology, and farmer-reported performance further demonstrates how grafting technology is implemented and adapted within local contexts.

Table 1. Grafted Coffee Clones of Besemah Highlands

No.	Clone Name	Location (Hamlet – Sub-village)	Elevation (m asl)	Morphological Agronomic Traits	Farmer-Based Performance (Perception-Based Evidence)
1	Kawe Buntut Liling	Talang Belumai – Ulu Rurah	719.5	Young fruit resembles a snail shell (liling = snail)	A local clone with highly distinctive fruit morphology, facilitating visual identification in the field.
2	Kawe Arsad (Kawe Curup)	Talang Belumai – Ulu Rurah	729.7	Also known as Kawe Curup (scion originated from Curup)	An introduced clone that has adapted well in Besemah; reflects interregional planting-material exchange.
3	Kawe Tugu Sari	Talang Belumai – Ulu Rurah	723.2	Result of grafting using scion from Tugu Sari	Example of integrating external planting materials into the local grafting system; indicates strong genetic adaptability.
4	Kawe Yoyo	Talang Belumai – Ulu Rurah	732.8	A grafted clone developed by farmer Yoyo	Widely adopted by local farmers; suggests strong perceived field performance and adaptability.
5	Kawe Cipit Hijau	Cawang Lama – Mersiban	976.2	Bright green young leaves (non-reddish); relatively small but dense and firm fruit	Perceived to have superior bean quality and good tolerance to high-elevation conditions; a candidate for premium-quality clones.
6	Kawe Nangka	Cawang Lama – Mersiban	968.6	Leaves resemble jackfruit leaves	Distinctive leaf morphology enables easy field identification; indicates phenotypic diversity within grafted clones.
7	Kawe Muli	Cawang Lama – Mersiban	957.4	Originated from successful grafting by farmer Muli	Its scions are widely used; reflects high farmer confidence in its vigor and yield potential.
8	Kawe Mawar	Cawang Lama – Mersiban	958.2	Flower resembles a rose with elongated pedicel	Unique floral traits may influence flowering synchrony and aesthetic value; commonly used as a clone identifier.
9	Kawe Lampung	Cawang Lama – Mersiban	955.8	Scion originated from Lampung; reported to bear heavy fruit	A highly productive introduced clone widely used by farmers; demonstrates successful interprovincial adaptation of planting materials.
10	Kawe Jupri	Talang Belumai – Ulu Rurah	719.5	Plants appear sturdier and are perceived as more disease-tolerant	Considered relatively resistant to biotic stress; potential as a rootstock or disease-tolerant scion source.
11	Kawe Don Clone	Talang Camay – Selibar	961.3	Grafted scion producing higher fruit yields	Widely used due to high productivity; an example of farmer-led selection based on harvest performance.
12	Kawe Didit Clone	Talang Cawang Lama – Muara Siban	946.5	Grafted clone developed by farmer Didit	Has spread widely across Pagar Alam City; illustrates diffusion of grafting innovation from an individual to the wider community.
13	Kawe Surani Clone	Talang Cawang Lama – Muara Siban	944.2	Grafted seedlings reported to bear heavy fruit	Widely used; perceived as a high-yielding clone in Talang Cawang Lama.
14	Kawe Gunung Agung Clone	Talang Cawang Lama – Muara Siban	943.0	Scion originated from Gunung Agung area	Represents a clone adapted to a new locality; shows flexibility of the grafting system to external scion sources.
15	Kawe Jagung Clone	Talang Camay – Selibar	973.4	Long leaves resembling young corn leaves	Leaf morphology indicates high vegetative vigor; useful as a visual indicator for farmers when selecting clones.
16	Kawe Cipit Abang Clone	Talang Camay – Selibar	974.1	Red-colored young leaves	A commonly found clone; reddish young leaves aid visual identification and may indicate tolerance to radiation/environmental stress.

No.	Clone Name	Location (Hamlet – Sub-village)	Elevation (m asl)	Morphological Agronomic Traits	Farmer-Based Performance (Perception-Based Evidence)
17	Kawe Pandi Clone	Talang Camay – Selibar	978.6	Recognized as the first grafted clone in Besemah; produces heavy fruit	Holds high historical value and serves as a performance benchmark for other clones; a symbol of early grafting success in the community.
18	Kawe Ci Anca Clone	Talang Cawang Lama – Muara Siban	957.1	Grafted cutting discovered by Ibu Anca; widely used	The most widespread clone in the hamlet; indicates strong ecological adaptability and socio-economic acceptance.
19	Kawe Putih Clone	Talang Camay – Selibar	977.3	Grafted scion successfully developed by farmer Putih	Widely adopted; represents individual innovation becoming a collective asset.
20	Kawe Madi Clone	Talang Cawang Lama – Muara Siban	943.1	Grafted scion developed by farmer Mardi	Extensively used in Besemah; demonstrates how agronomic success drives diffusion through social networks.
21	Kawe Pran Clone	Talang Cawang Lama – Muara Siban	968.0	Developed by a successful farmer (Pran); produces heavy fruit	Adopted widely due to Pran's strong reputation; exemplifies how social status of farmer-innovators influences clone adoption.
22	Kawe Ardi Clone	Talang Cawang Lama – Muara Siban	943.3	Grafted scion widely used by other farmers	Reflects trust-based diffusion networks; considered stable and economically beneficial.
23	Kawe Cik Ari Clone	Talang Camay – Selibar	1009.2	A popular clone; named after the landowner (Cik Ari)	Grows at >1,000 m elevation, showing strong adaptation to cooler agroecological zones; serves as a highland reference clone.
24	Kawe Percy Clone	Talang Camay – Selibar	1001.8	One of the earliest-generation clones; originated from farmer Percy's successful cutting graft	Holds historical importance as a pioneering clone; valuable for documenting the evolution of grafting technology and local genetic resource conservation.

Notes: 1) Elevation is expressed in meters above sea level (m asl). 2) Performance descriptions are based on farmers' perceptions and field experience (perception-based evidence), not controlled experimental measurements. 3) Quantitative data, such as productivity and grafting success rates, were not uniformly available across all clones and study locations.

The grafting system in Besemah coffee has produced a wide diversity of local clones with varying agronomic performances across the agroecological zones of Mount Dempo's. Study of 24 clones show that grafting success is influenced by scion-rootstock compatibility, plant-elevation interaction, and farmer selection practices. At 719–733 meters above sea level, clones such as Kawe Buntut Liling, Kawe Arsad, Kawe Tugu Sari, and Kawe Yoyo show stable production with distinctive morphological traits. Kawe Buntut Liling has a snail house-shaped fruit primordium, whereas the wide spread adoption of Kawe Yoyo by farmer's indicates consistent yields. External clones like Kawe Arsad and Kawe Tugu Sari demonstrate successful adaptation to local Besemah's conditions.

In higher elevations ranging from 943–1,009 m above sea level, local clones including Kawe Cipit Hijau and Kawe Lampung showed better environmental tolerance than lowland clones. Kawe Cipit Hijau shows promise for highland bean quality, while Kawe Lampung and Kawe Don are recognized for their high-yield potential. Through grafting, coffee varieties have diffused across provinces. Overall, farmer-developed local clones demonstrate community innovation's contribution to the Besemah coffee gene bank. Historical clones Kawe Pandi and Kawe Percy indicate how grafting success has stimulated technological innovation and supported, the establishment of a clonal system for plantation regeneration. These findings underscore grafting as a key mechanism for enhancing genetic diversity and sustaining Besemah coffee production in the Mount Dempo region.

Dynamics of Farmers' Rationality: Between the Tradition of Kawe Lengkuran and the Modernization of Sambung Pucuk

The demographic characteristics of respondents from the three research locations, Talang Camai, Talang Belumai, and Cawang Lama-are summarized in Table 2. A total of 120 farmers participated in this study, with an equal number of respondents (n = 40) from each village. The respondents represent a farming community predominantly composed of men with relatively low levels of formal education and long-term involvement in coffee cultivation. This demographic profile provides an important contextual foundation for understanding the dynamics of farmer rationality, particularly in examining how traditional *kawe lengkuran* practices coexist and interact with the increasing adoption of modern agricultural techniques, including *sambung pucuk*. Variations in age structure, education level, ethnic composition, and livelihood strategies across the three villages highlight both shared socio-cultural characteristics and local differences that shape farmers' decision-making processes.

Table 2. Demographic Profile of Coffee Farmers in Talang Camai, Talang Belumai, and Cawang Lama

Characteristics	Category	Number (n)			Percentage (%)		
		TC	TB	CW	TC	TB	CW
Age (years)	Mean ± SD	42.8 ± 15.2	49.8 ± 10.8	48.2 ± 12.1	–	–	–
	Range	19 – 77	28 – 74	23 – 67	–	–	–
Gender	Male	27	26	36	67.5	65.0	90.0
	Female	13	14	4	32.5	35.0	10.0
Educational attainment	Elementary school (including grade 5)	16	20	16	40.0	50.0	40.0
	Junior high school	9	8	8	22.5	20.0	20.0
	Senior high school	9	10	10	22.5	25.0	25.0
	Vocational high school	4	1	3	10.0	2.5	7.5
	Bachelor's degree	2	1	3	5.0	2.5	7.5
Primary occupation	Farmer/Coffee farmer	37	38	33	92.5	95.0	82.5
	Farmer with other occupations*	3	2	7	7.5	5.0	17.5
Ethnicity	Besemah	40	24	36	100.0	60.0	90.0
	Javanese	-	14	3		35.0	7,5
	Sundanese	-	2	-		5.0	–
	Batak	-	-	1		–	2,5
Years of coffee farming	Mean	27.1	24.3	24.6	–	–	–
	Range	1 – 60	1 – 55	4 – 50	–	–	–
Length of residence (years)	Mean	21.1	23.6	32.1	–	–	
	Range	1 – 40	1 – 55	5 – 67	–		
Coffee farming as main income source	Yes	40	39	39	100.0	97.5	97.5
	No	-	1	1	-	2.5	2.5

TC: Talang Camai, TB: Talang Belumai, CW: Cawang Lama

The demographic profile in Table 2 reveals important structural patterns characterizing the coffee farming communities in the three studied villages. In general, farmers are predominantly male, especially in Cawang Lama (90%), although women continue to make significant contributions in Talang Camai and Talang Belumai. The age variation shows that farmers in Talang Belumai are relatively older compared to those in Talang Camai, indicating generational differences in experience and decision-making, while the broad age range across all locations reflects intergenerational coexistence. The relatively low level of educational attainment highlights the dominance of experience-based knowledge, although the presence of a small number of highly educated farmers indicates the introduction of new perspectives. More than 90% of respondents consider coffee their primary occupation, underscoring its role as the main source of livelihood, with indications of greater livelihood diversification in Cawang Lama. The ethnically homogeneous composition in Talang Camai and the more heterogeneous makeup in Talang Belumai point to variations in the potential for social networking and knowledge exchange. Additionally, the long farming experience (more than two decades) and lengthy residence reflect the strong foundations of local, environment-based knowledge. Overall, these demographic characteristics affirm that farmers' decisions are heavily influenced by experience, social context, and economic dependence on coffee, which are key factors in understanding adoption patterns of innovations such as grafting techniques.

A deeper understanding of how Besemah farmers weigh agricultural heritage against cultivation innovation can be gleaned from the statistical summary in the following table, which presents the mean values, 95% confidence intervals, and ANOVA test results for the five main dimensions of rationality. This presentation not only enables the identification of structural differences in perceptions and technical considerations between villages but also reflects how each community constructs meaning, manages risk, and responds to technological changes in their daily agricultural practices.

Table 3. Comprehensive Summary of Besemah Farmers' Rationality

DIMENSION	HAMLET	MEAN	F-VALUE	P-VALUE
Perception of *Kawe Lengkuran*	Belumai	4.009 ± 0.267	6.945	0.0014**
	Cawang Lama	3.868 ± 0.415		
	Talang Camai	4.193 ± 0.452		
Perception of Grafting	Belumai	4.094 ± 0.270	1.767	0.1756
	Cawang Lama	4.060 ± 0.382		
	Talang Camai	4.213 ± 0.451		
Economic Considerations & Risk	Belumai	4.011 ± 0.368	4.193	0.0175*
	Cawang Lama	4.198 ± 0.402		
	Talang Camai	4.260 ± 0.375		
Social Norms & Environmental Influence	Belumai	3.880 ± 0.322	0.954	0.3883
	Cawang Lama	3.870 ± 0.411		
	Talang Camai	4.035 ± 0.868		
Knowledge & Intention to Adopt	Belumai	3.880 ± 0.370	0.254	0.7756
	Cawang Lama	3.903 ± 0.430		
	Talang Camai	3.985 ± 0.461		

*Notes: Values are presented as mean ± standard deviation; N Belumai = 40; N Talang Camai = 40; N Cawang Lama = 40; *p < 0.05; ** p < 0.01 (ANOVA).*

Table 3 presents a comprehensive overview of the five dimensions of farmer rationality in the three research areas, revealing a combination of local contextual variation and uniformity in knowledge structures within the Besemah community. Significant differences were found in perceptions of kawe lengkuran ($F = 6.945$; $p = 0.0014$), with the highest value in Talang Camai (4.193), followed by Belumai (4.009) and Cawang Lama (3.868), indicating that traditional practices remain strong and serve as a cognitive framework for assessing innovation. In addition, the dimensions of economic considerations and risk perception also differed significantly ($F = 4.193$; $p = 0.0175$), with Talang Camai exhibiting a greater economic orientation and higher risk tolerance compared to the other areas. Conversely, no significant differences were found in perceptions of grafting technology ($p = 0.1756$), social norms and environmental influences ($p = 0.3883$), as well as knowledge and intent to adopt technology ($p = 0.7756$), suggesting that technology acceptance, knowledge diffusion, and social influence have occurred widely and evenly throughout the community. These findings affirm that Besemah farmers' rationality is shaped through the interaction between the strength of locally rooted traditions and a collective awareness of innovation.

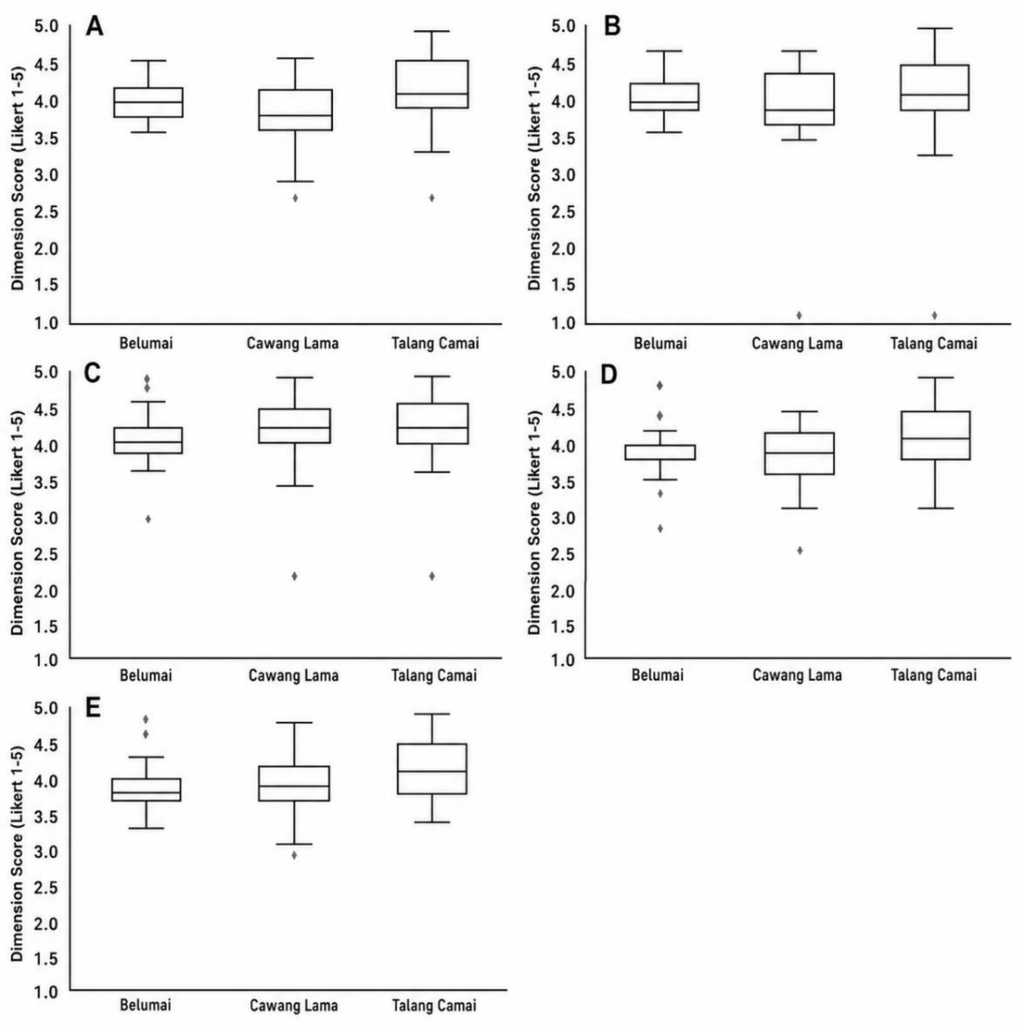

Figure 4. Boxplots of five farmer rationality dimensions across three Besemah hamlets (Belumai, Cawang Lama, Talang Camai). Each panel shows the distribution of mean Likert scores (1–5) for (A) perception of kawe lengkuran, (B) perception of top grafting (sambung pucuk), (C) economic considerations and risk perception, (D) social norms and environmental influence, and (E) knowledge and intention to adopt technology.

Figure 4 shows all hamlets have positive perceptions of *kawe lengkuran* with varying intensity. Talang Camai displays the highest median, showing strong preservation of agricultural traditions despite adopting grafting techniques. Cawang Lama shows a lower median and wider spread, reflecting varied perceptions based on agricultural experience and generational differences. The pattern from Belumai to Talang Camai indicates widespread embrace of grafting as an economically valuable technique, with Talang Camai's high median suggesting farmer consensus on grafting's benefits.

The economic consideration and risk dimension (Figure 4) shows differences between villages, with Talang Camai ranking highest due to economic calculations and risk tolerance. Belumai and Cawang Lama show conservative patterns with lower medians. The Social Norms & Environmental Influence dimension (Figure 4) shows consistent distribution from Belumai to Talang Camai, indicating social influence in innovation preferences. The Knowledge & Intention to Adopt Technology dimension (Figure 4) reveals high median values across villages, highest in Talang Camai, showing modern coffee technology adoption stems from agronomic knowledge. Belumai's narrow distribution indicates homogeneous technical knowledge, with adoption varying by economic context.

The higher Economic Consideration & Risk scores observed in Talang Camai (Figure 4c) are consistent with the interview findings, in which several farmers emphasized that *kawe sambung pucuk* (grafting) enables faster rejuvenation of aging coffee trees and allows earlier harvest cycles compared with the traditional *kawe lengkuran* method. One farmer explained that grafting allows them to restore plantation productivity without having to wait for new seedlings to mature, thereby reducing the economic risk associated with maintaining stable yields. Similarly, the relatively high scores in the Knowledge and Intention to Adopt Technology dimension reflect the strong exchange of practical experience among farmers. Interview data indicate that many grafting techniques spread through informal farmer networks, where successful grafted clones and cultivation practices are shared and demonstrated within the farming community.

Discussion

This study shows that the transformation of the Besemah coffee plantation system cannot be understood merely as a technical shift from traditional to modern practices, but rather as a gradual, historical, and interconnected socio-ecological transition process. The transformation that occurs is more accurately understood as a process of reconfiguration rather than substitution, where local knowledge systems remain foundational in comprehending and adopting new innovations (Tilley 2020). These findings strengthen the arguments in the agrarian transition literature, which emphasize that changes in smallholder agricultural systems are often path-dependent, meaning they are heavily influenced by previous history and social structures. However, in contrast to some studies that portray modernization as a disruptive process for local practices, this research demonstrates that traditional knowledge actually functions as an adaptive mechanism that allows for the more contextual integration of new technologies (Martinez et al. 2024).

The practices of *kawe lengkuran* and *kawe pungpungan* form the foundation of agronomic knowledge for Besemah farmers' understanding of plant growth and production cycles. These practices reflect an ecological knowledge system developed through observing coffee plants' responses to the mountainous environment (Córdova et al. 2018). Understanding leaf texture, color, branches, and fruit development stages demonstrates agronomic literacy, despite lacking modern scientific terminology. When grafting was introduced, it integrated with existing practices, being accepted for its ability to accelerate rejuvenation and increase productivity while aligning with farmers' ecological understanding (Kuyah et al. 2021). Technology adoption in Besemah thus occurs as innovations gain legitimacy through proven agronomic experience.

Clone-based evaluation shows that grafting in Besemah operates as a farmer-led, socially diffused innovation system, where individual farmer innovations gradually spread through informal community networks. The presence of 24 grafted clones with diverse characteristics indicates selection tailored to environmental conditions and production goals. Clones developed in medium-to highland areas show grafting success depends on physiological compatibility and farmers' scion selection (Razi et al. 2024). Clone naming after individuals reflects innovation legitimized through field success and social networks. Farmers act as primary agents in producing and validating agronomic knowledge. Grafting enriches Besemah coffee's genetic diversity while strengthening the productive resilience of smallholder systems and their potential for broader market integration, demonstrating how locally grounded innovation can support the sustainability of smallholder coffee cultivation (Nguyen & Drakou 2021).

Analyzing farmers' rationality reveals how technology adoption decisions form locally. Differences in perceptions of *kawe lengkuran* and economic considerations show that modernization varies across villages. Talang Camai exhibits high openness to grafting while maintaining traditional practices, indicating that tradition serves as a framework for assessing new technologies (Zhao et al. 2022). The generally high, yet varied levels of knowledge and adoption intentions indicate that information about grafting practices has been widely disseminated among farmers, although the degree of familiarity and readiness to adopt the technology differs slightly between hamlets. Community differences stem from how farmers weigh economic implications, risks, and technology suitability. These findings show farmers' rationality is contextual, shaped by traditional values, economic conditions, and field experiences (Vanclay, 2004).

The demographic characteristics of farmers including age, educational level, and length of farming experience play an important role in shaping the process of adoption and internalization of grafting as a transformative practice. Age influences the level of openness to innovation, with younger farmers generally being more adaptive and willing to experiment, while older farmers tend to be more selective and cautious. However, senior farmers also act as social validators who determine the legitimacy of technology based on empirical experience in the field. Additionally, the level of formal education does not directly determine the adoption of grafting, as experiential learning and social interaction serve as the main mechanisms for knowledge transmission. This indicates that agronomic literacy in this context is practical and contextual, making technologies more readily accepted when they can be explained within existing frameworks of local knowledge (Faronny et al., 2024). Meanwhile, years of farming experience affect the depth of technology internalization: experienced farmers tend to integrate grafting into their existing knowledge systems, while less experienced farmers are more oriented toward practical benefits such as increased yields.

The relationship between demographic characteristics, perceptions, and farmers' rationality shows that the decision to adopt grafting is not solely based on economic calculations, but is also influenced by experience, local values, and social standing within the community. The process of social learning plays an important role in bridging these demographic differences, where innovations are often initiated by more open-minded farmers, but are only widely adopted after receiving legitimacy from more experienced farmers. This demonstrates that technology adoption is a collective process involving social negotiation and knowledge exchange.

This study also identifies various challenges in the process of adopting grafting, such as uncertainty of successful unions, compatibility between rootstock and scion, as well as economic risks. However, these challenges do not completely hinder adoption; rather, they become part of the collective learning process through experimentation and observation. This affirms that the adoption of technology in smallholder farming systems is a dynamic, experience-based social process. This study not only confirms the importance of local knowledge, farmer participation, and agroecological adaptation in sustainable agriculture, but also contributes conceptually by demonstrating that innovation can emerge through the integration of traditional practices, not by replacing them. The grafting technique in Besemah is expected to continue developing dynamically. The increasing diversity of clones, active social learning mechanisms, and external pressures such as climate change and market demands are all driving forces in the evolution of this technology.

Conclusion

The transformation of coffee cultivation in Besemah demonstrates that agricultural modernization does not occur through the replacement of tradition, but rather through a process of socio-ecological reconstruction rooted in local knowledge systems. Traditional practices such as *kawe lengkuran* continue to serve as cognitive and practical frameworks that farmers use to evaluate and internalize new technologies, while grafting techniques have emerged as a key innovation that boosts productivity, resilience, and market integration. This study affirms that sociocultural transformation is internalized through adaptive processes, where farmers actively reinterpret innovations within the context of existing knowledge systems. Based on these findings, several strategic and policy implications can be formulated. First, agricultural interventions need to adopt an integrative approach by embedding modern techniques into traditional practices, rather than replacing them, thereby ensuring cultural compatibility and increasing adoption rates. Second, strengthening farmer-based knowledge systems becomes crucial, particularly through the promotion of farmer-to-farmer learning, support for local innovators, and the strengthening of social networks that facilitate the diffusion of grafting technology. Third, innovation strategies must be contextual, taking into account economic aspects, risk perceptions, and the agroecological conditions of farmers, while also improving access to planting materials suited to local conditions, markets, and digital technologies.

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