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ARTICLE

Adoption of Good Agricultural Practices (GAP) among Arabica Coffee Farmers in Simalungun, Indonesia

R. Hamdani Harahap [1], Abdul Rauf [2], Rahmawaty [3], Isfenti Sadalia [4], Farid Aulia [5], Abdullah Akhyar Nasution [6]*

[1] *Postgraduate Development Studies Study Program, FISIP USU Medan, Kota Medan 20222, Indonesia*
[2] *Animal Husbandry Study Program, Faculty of Agriculture, USU Medan, Kota Medan 20222, Indonesia*
[3] *Faculty of Forestry, USU Medan, Kota Medan 20222, Indonesia*
[4] *Faculty of Economics and Business, USU Medan, Kota Medan 20222, Indonesia*
[5] *Social Anthropology Study Program, FISIP USU Medan, Kota Medan 20222, Indonesia*
[6] *Anthropology Study Program, Universitas Malikussaleh, Aceh Utara 24351, Indonesia*

ABSTRACT

The implementation of Good Agricultural Practices (GAP) in Arabica coffee cultivation in Simalungun, Indonesia still faces various challenges even though this practice is known to increase productivity and sustainability. Farmers still tend to use traditional methods and have limited understanding of modern agricultural techniques. This is a major problem in optimizing the implementation of GAP among local farmers, so it is necessary to study the factors that influence the level of GAP implementation. This study involved 117 coffee farmers in various sub-districts through in-depth interviews and questionnaires. The results showed that many farmers had not met GAP standards, especially in terms of seed selection, fertilization, and pest control. Correlation analysis revealed that the level of farmer education had a strong relationship with the understanding and implementation of sustainable agricultural practices. Based on these findings, a coordinated approach is needed involving various stakeholders, including government agencies, educational institutions, and the private sector. Comprehensive training programs and

*CORRESPONDING AUTHOR:
Abdullah Akhyar Nasution, Anthropology Study Program, Universitas Malikussaleh, Aceh Utara 24351, Indonesia;
Email: abdullah.akhyar@unimal.ac.id

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improved support systems are highly recommended to ensure farmers have the resources and knowledge needed to optimize coffee production sustainably. Collaboration between the government, educational institutions, and farmers is key to creating a coffee cultivation environment that is beneficial for both producers and the ecosystem.
Keywords: Coffee Farmer Knowledge; Coffee Cultivation; GAP (Good Agriculture Practices); Coffee Farmers; Coffee Productivity

1. Introduction

Indonesia is the fourth largest coffee producing country in the world after Brazil, Vietnam, and Colombia. However, in recent years, the global coffee industry has faced challenges of imbalance between supply and demand. In 2021/22, global coffee production fell by 2.1% to 167.2 million bags, while consumption increased by 3.3% to 170.3 million bags, creating a supply deficit of 3.1 million bags [1]. At the national level, although Indonesian coffee production increased from 752.51 thousand tons (2019) to 762.38 thousand tons (2020), coffee productivity is still relatively low due to various factors, such as the use of traditional cultivation methods, low seed quality, and limited knowledge of farmers regarding modern cultivation techniques. Climate change and the high percentage of old coffee plants also exacerbate this condition [2]. Most of Indonesia's coffee production comes from Community Plantations (99.33%) (BPS, 2020), including in Simalungun Regency, the fourth largest Arabica coffee producing area in North Sumatra.

In this study, the implementation of Good Agricultural Practices (GAP) is assessed through a comprehensive evaluation of key cultivation components that align with nationally and internationally recognized GAP standards for Arabica coffee. These components include land selection and preparation, the use of shade plants, seed selection and propagation, planting techniques, fertilization practices, pruning and rejuvenation strategies, pest and disease control, weeding and plantation sanitation, plant spacing and layout, as well as harvesting methods and post-harvest handling. By structuring the analysis around these specific aspects, the research aims to identify the extent to which each practice is applied or neglected by coffee farmers in Simalungun Regency. This approach not only allows for a detailed mapping of GAP adoption levels but also helps to uncover the underlying socio-economic, institutional, and cultural factors that influence the selective implementation of these practices.

The application of GAP in coffee cultivation includes practices from the nursery stage, land preparation, planting shade plants, fertilization, pruning, to harvesting and post-harvest. Previous research has shown that farmers' knowledge and confidence in GAP have a positive effect on the level of its implementation [3]. However, the level of GAP implementation is still low, especially in the cultivation aspect [4]. Limitations in extension, the complexity of GAP guidelines, and lack of institutional support are obstacles to the comprehensive adoption of GAP among coffee farmers. Although various studies have highlighted the importance of GAP in increasing coffee productivity, there are still few studies that examine in depth the knowledge and practice of GAP cultivation at the community coffee farmer level, especially in Simalungun Regency. Therefore, this study aims to:

1. Find out how the knowledge and application of GAP are by coffee farmers in Simalungun Regency in various aspects of cultivation.
2. Measure the level of relationship between farmers' knowledge through education and the level of implementation of GAP application in komi farming that is carried out.
3. Identify the reasons behind the coffee cultivation practices applied by farmers in the region.

This study focuses on Arabica coffee farmers in Simalungun Regency. The GAP aspects studied include land selection and preparation, use of shade plants, seed selection, plant propagation, planting, fertilization, pruning, shade management, rorak making, harvesting, and pest and disease control. This study does not cover aspects of coffee distribution or marketing.

2. Literature Review

The gap in coffee cultivation studies mostly lies in the implementation of Good Agricultural Practices (GAP) which is still uneven, especially in areas with unique geographic and socio- economic characteristics such as Simalungun Regency. GAP, which is a technical framework for sustainable cultivation, has developed rapidly as a primary approach to increasing coffee productivity, cultivation efficiency, and environmental sustainability. However, its implementation at the farmer level, especially smallholder farmers in remote areas, has not been optimal. This shows a real gap between technical knowledge and actual practices in the field, which has an impact on the productivity and quality of coffee yields. Research shows that GAP covers various technical aspects of cultivation ranging from land selection, fertilization, pruning, shading strategies, to integrated pest control (IPM). The implementation of GAP as a whole can increase yields and coffee bean quality, including resistance to coffee berry borer pests [5–7]. The implementation of agroforestry and shade strategies has also been shown to contribute to improving the sensory quality of coffee through improvements in bean size and flavor profiles [8–10].

However, research results also show that the level of GAP adoption is still low. Ridwan et al. noted that the highest level of GAP implementation was only in the post-harvest aspect (77%), while the cultivation aspect was at the lowest point (24%) [4]. Research by Pongvinyoo et al. emphasized the importance of farmer trust in GAP in encouraging consistent implementation. Unfortunately, the lack of continuity of extension services and the complexity of technical guidelines are major obstacles to the adoption of this practice [3].

Furthermore, a contextual approach shows variations in perceptions and practices of sustainable cultivation. The study by Brenes-Peralta et al. highlights how coffee farmers in Central America face the complexity of decision-making in the context of sustainable production [11]. Meanwhile, Millard E. highlighted the structural constraints faced by farmers in a supply chain system that does not support sustainability [12]. On the other hand, Kharel K.R and Adhikari D.B. emphasized that sustainable strategies must also consider aspects of market competitiveness so that farmers gain economic benefits [13]. Le Q.V. et al. even showed that dependence on monoculture systems and the use of chemicals causes ecological and social vulnerability, encouraging farmers to return to more sustainable traditional practices [14]. In Indonesia, the focus of coffee GAP research is still largely partial limited to certain segments such as superior varieties [15], soil management [8], fertilization [16], pest control [5], and shading and pruning strategies [9,17–19]. Although this approach makes important contributions, there are not many studies that holistically link GAP to local contexts such as Simalungun.

This is reinforced by the absence of terms such as "Simalungun" in the mapping of coffee research topics, which indicates a gap in the exploration of specific areas producing superior coffee. In fact, Simalungun Regency is known as one of the producers of quality Arabica coffee with a distinctive taste and has received Geographical Indication certification since 2015. However, existing scientific studies only focus on aspects of ecology, fertilization, pest control, seeds, and coffee shop business [20–22]. The absence of in-depth studies related to the implementation of GAP locally strengthens the urgency of this research. In terms of benefits, GAP not only promises increased productivity, but also farmer welfare and consumer satisfaction. GAP helps improve farmers' working conditions and ensures product safety and quality [23–25]. Compliance with GAP also contributes to the preservation of ecosystems and biodiversity, which is in line with market demand for environmentally friendly products [26,27].

2.1. Conceptual Framework of the Study

The implementation of Good Agricultural Practices (GAP) among smallholder coffee farmers is influenced by a range of socio-economic, institutional, and perceptual factors. Drawing on Rogers' Diffusion of Innovations Theory (2003), this study views GAP adoption as a form of agricultural innovation that diffuses through a farming community based on farmer characteristics, external support mechanisms, and perceived attributes of the practices. In the context of this study, education level is a key independent variable hypothesized to affect the level of GAP implementation, with the assumption that more educated farmers are more likely to understand, trust, and apply recommended practices. However, education alone is not sufficient to explain adoption behaviour. Other factors such as farm size, access to extension services, farmers' knowledge and perceptions of GAP, labor availability, and whether coffee is treated as a primary or secondary crop also influence the degree of GAP adoption.

This conceptual framework (**Figure 1**) posits that these factors can interact where, for example, higher education may lead to greater awareness but may require institutional support to translate into practice. Similarly, landholding size may affect the economic feasibility of applying labor- or input-intensive GAP components. The model thus integrates both individual-level characteristics (e.g., age, education, knowledge) and contextual variables (e.g., support services, crop prioritization) in explaining variance in GAP implementation.

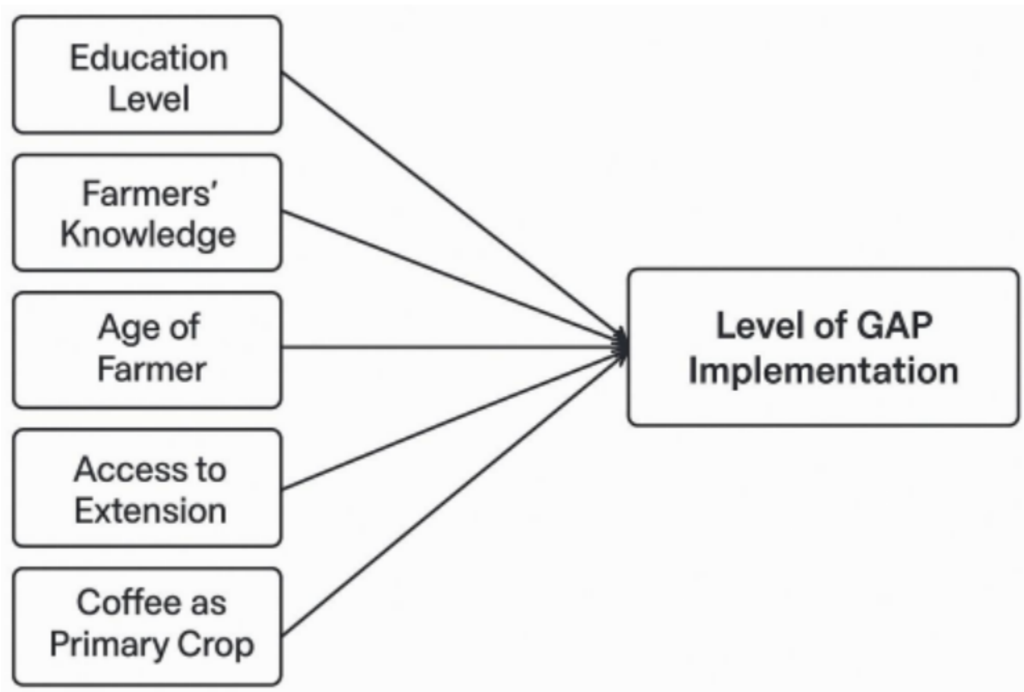

Figure 1. Conceptual framework of the study.

Source: Author.

3. Research Methods

This study employs a mixed methods approach combining both quantitative and qualitative techniques to provide a comprehensive understanding of Arabica coffee farmers' knowledge, practices, and influencing factors in the implementation of Good Agricultural Practices (GAP) in Simalungun Regency, Indonesia. The use of mixed methods is justified by the dual need to quantitatively measure GAP implementation levels and qualitatively explore the underlying behavioural and contextual drivers of adoption.

The research followed an exploratory field study design. Primary data were collected through structured questionnaires, direct field observations, and in-depth interviews with selected key informants including experienced coffee farmers, farmer group leaders, and agricultural extension officers. Purposive sampling was used to select 117 respondents (**Table 1**) from various sub-districts, ensuring representation across age groups, land sizes, and cooperative affiliations. The sample was stratified based on farm activity concentration and accessibility.

Table 1. Distribution of farmer respondents.

No.	Regency	Sub-District	Village	Number of Respondents	%
1	Simalungun	Dolok Pardamean	Gunung Purba	4	3.4
			Parik Sabungan	7	6
			Sirube-nube	2	1.7
		Jumlah		13	11.2
2		Pematang Purba	Manik Saribu	3	2.6
			Jumlah	3	2.6
		Pematang Raya	Mangadei	2	1.7
			Pemasyarakat	3	2.6
			Pematang Raya	1	0.8
		Sub total		6	5.2
3		Pematang Sidamanik	Sait Buttu	39	33.6
			Manik Saribu	1	0.8
			Nagori Paimahan	2	1.7
			Manik Haluan	2	1.7
			Manik Saribu	4	3.4
			Manik Silau	2	1.7
			Parmahan	11	9.5
			Bandar Manik	1	0.8
		Sub total		62	53.4
		Purba	Manik Huluan	1	0.8
			Pematang Purba	2	1.7
			Purba Dolok	12	10.3
		Sub Total		15	12.9
		Silima Kuta	Seribu Dolok	19	15.5
		Total		19	15.5
		Total		117	100

Source: Questionnaire, 2024.

The quantitative component was based on a structured questionnaire covering core GAP dimensions, including land preparation, use of shade plants, fertilization, pruning, pest and disease control, and seed selection. Socio-demographic variables (e.g., age, education, farm size, extension access, and primary crop type) were also included. The questionnaire was pre-tested to ensure content validity and reliability. Data were analysed using SPSS 26, applying ANNOVA, correlation and multiple linear regression to evaluate the effect of five explanatory variables (education level, age, farm size, access to extension services, and whether coffee is the primary crop) on the GAP implementation score. This approach enabled us to control for confounding influences and assess each variable's independent contribution to GAP adoption.

The qualitative component utilized an ethnographic approach, focusing on capturing the cultural and behavioural factors shaping farmer decisions. Interview transcripts were coded and analysed thematically to identify recurring patterns, such as resistance to shade planting, traditional reliance on non-certified seeds, and institutional limitations post-COVID. Qualitative findings were used to triangulate and contextualize quantitative results. This integrated design provides both empirical rigor and contextual depth, enabling a nuanced understanding of GAP implementation patterns among Arabica coffee farmers and offering actionable insights for targeted policy and extension interventions.

4. Results and Discussion

4.1. Respondent Characteristics

According to the tabulation conducted, from the education aspect, 117 respondents are in the low to medium category. Details of the education level variable can be seen in the following **Table 2**:

Table 2. Respondents' education level.

No	Education Level	Category	Total	Percentage
1	Did not graduate from elementary school	Very low	16	13.7
2	Graduated from elementary school	Low	30	25.6
3	Graduated from junior high school	Average	33	28.2
4	Graduated from high school	High	28	23.9
5	Graduated from college	Very high	10	8.5
Total			117	100.0
Average			**2.88**	

Source: Questionnaire, 2024.

The data in **Table 3** shows that the area of farmers' land is dominated by land between 0.10–1.20 ha. This data at least explains that not all land owned by farmers is planted with coffee.

Table 3. Total area of agricultural land (m^2/ha).

Total Area of Agricultural Land		Frequency	%
m^2	ha		
500–1000	0.05–0.10	5	4.28
1001–3000	0.10–0.30	19	16.24
3001–6000	0.30–0.60	36	30.76
6001–9000	0.60–0.90	17	14.53
9001–12000	0.90–1.20	18	15.38
12001–18000	1.20–1.80	5	4.28
18001–25000	1.80–2.50	10	8.55
> 25000	> 2.50	7	5.98
Total		117	100

Source: Researcher's processing (2024).

Table 4 summarizes key soil-and-site, planting, management, and seed-related characteristics reported by Arabica coffee farmers in Simalungun Regency. Nearly 90% of farms are on flat topography and 93% lie on plains, indicating minimal erosion risk and ease of access. Planting spacing is overwhelmingly uniform (97%), reflecting adherence to recommended layouts. Most farmers actively manage their coffee plots (85%), though many also interplant other crops. The Katimor Sigararutang variety accounts for roughly 79% of plantings, with Ateng Super making up the remainder. Seed sourcing is dominated by on-farm seed collection (48.7%) and grafting (43.6%), while certified or external sources (Plantation Service, kiosks, fellow farmers) collectively constitute less than 7% highlighting potential quality gaps. Finally, knowledge about seed procurement is primarily transferred peer-to-peer (73.5%), with minimal direct input from extension agents or experts.

Table 4. Agronomic and seed-sourcing characteristics of Arabica coffee farmers in Simalungun Regency.

Indicator	Category	Percentage (%)
Topography	Flat	89.75
	Moderate	10.25
Plantation Location	Plains	93.16
	Slope facing East	4.27
	Slope facing West	1.71
	Valley	0.86
Planting Spacing	Regular	97.43
	Irregular	2.57
Crop Management	Managed	84.61
	Naturally Left	15.39
Coffee Variety	Katimor Sigararutang	78.63
	Ateng Super	21.37

Table 4. *Cont.*

Indicator	Category	Percentage (%)
Seed Source	Own seed from existing plants	48.65
	Own grafts	43.58
	Plantation Service	3.42
	Other	2.56
	Kiosks	0.85
	Fellow farmers	0.85
Information Source for Seed	Other farmers	73.51
	Input suppliers	17.94
	Other	6.84
	Village traders	1.71
	PPL/Experts	0

Source: Questionnaire, 2024.

4.2. Coffee Plant Care and Maintenance

Most farmers report carrying out manual weeding 72.6% of respondents typically twice a year, using simple tools such as machetes and hoes. However, on-site observations reveal that labor shortages and the cost of hiring help often lead to neglected plots, despite 67.2% claiming exclusive hand-weeding and a further 3.2% combining manual and chemical methods (only 2.3% rely solely on herbicides). Although knowledge of fertilization protocols is widespread with farmers aware that urea (0–100 g per tree), SP-36 (100–200 g per tree), and KCl (100–200 g per tree) should be applied twice yearly most producers seldom practice it. Those who do generally apply around 0.5 kg of organic manure per tree biannually, but chemical fertilizers remain rare due to perceived high costs and low priority for coffee compared to other crops.

Pruning and rejuvenation are adopted by a minority of growers only 33.4% perform formative or maintenance pruning to remove old, diseased, or overcrowded branches, and 44.8% engage in rejuvenation by cutting back stems and replanting unproductive shoots. Non-adopters often cite a reluctance to remove seemingly productive wood or simply lack sufficient knowledge of the benefits of systematic branch management. Shade management practices are similarly limited. Just one-third of respondents (33.4%) plant permanent shade trees mainly lamtoro and some use temporary shade crops like banana or eggplant until the main shade canopy establishes. Many believe that Simalungun's cooler, cloud-prone climate reduces the need for shade, and they view the establishment and upkeep of shade trees as an unnecessary expense.

Harvest timing is much more consistent: 97.8% of farmers report their primary harvest occurs in the rainy season (September–November), though the equatorial environment permits "track" harvesting year-round when maintenance is sufficient. Coffee berry borer remains the chief pest, causing 35–60% damage, and is managed through attractant traps, strict sanitation (destroying fallen fruit), Beauveria bassiana fungal sprays, and targeted pruning. Other pests and diseases stem borers, various lice, leaf rust, and root nematodes are addressed sporadically through pruning, sanitation, and occasional pesticide applications. While awareness of GAP plant-care practices is high among Simalungun's Arabica farmers, actual implementation is uneven: critical operations such as fertilization, pruning, and shade management are under-utilized, constrained by labor availability, financial considerations, and local perceptions of necessity.

Most respondents stated that their hope in overcoming coffee plant pests and diseases is technical assistance/mentoring from PPL (52.8%). Technical assistance includes how farmers overcome pests and plant diseases naturally. Other assistance expected by farmers is pesticide assistance, and assistance in replacing old plants with new plants. Regarding the implementation of GAP in coffee farming applied by respondents, it is known that the majority are in the fairly appropriate category. More detailed distribution of this can be seen in the following **Table 5**:

Table 5. Scale of GAP Implementation by Coffee Farmers in Simalungun.

No	Achievement	Nilai	Total	Percentage
1	Not Appropriate	1	1	0.9
2	Less Appropriate	2	43	36.8
3	Quite Appropriate	3	62	53.0
4	Appropriate	4	11	9.4
5	Very Appropriate	5	-	-
Total			117	100.0
Average			**2.71**	

Source: Questionnaire, 2024.

4.3. The Influence of Education on GAP Practices by Coffee Farmers in Simalungun

Referring to the achievement of the education level variable (**Table 2**) which is at an average of 2.8 and the GAP implementation variable (**Table 5**) at 2.71, based on the correlation analysis carried out, the following results were obtained (**Table 6**).

The correlation analysis yielded an R value of 0.694, signifying a fairly strong positive relationship between farmers' education level and their degree of GAP implementation. Furthermore, the R^2 of 0.481 indicates that approximately 48.1% of the variability in GAP implementation can be attributed to differences in education level, with the remaining 51.9% of the variation explained by other factors. The results of the Anova test show the following results in **Table 7**.

Table 6. Model summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.694[a]	0.481	0.477	0.466

Note: [a]. Predictors: (Constant), Level of education.

Table 7. ANOVA test result.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	23.157	1	23.157	106.683	0.000[b]
	Residual	24.963	115	0.217		
	Total	48.120	116			

Note: [b]. Predictors: (Constant), Level of education.

An analysis of variance (ANOVA) conducted to assess the overall feasibility of the regression model produced an F-statistic of 106.683 with a corresponding p-value of 0.000, which is well below the 0.05 significance threshold. This result confirms that the model significantly explains the relationship between farmers' education level and their degree of GAP implementation, demonstrating the regression's overall predictive validity. The coefficient analysis of the two variables shows the following results in **Table 8**.

The estimated regression equation includes an intercept of 1.615, which represents the baseline GAP implementation score when a farmer's education level is zero. The education coefficient of 0.380 ($p < 0.001$) indicates that for each additional unit increase in education level, the expected GAP implementation score rises by 0.380 units, an effect that is both positive and statistically significant. The results of the simple regression analysis above indicate that the appropriateness of GAP implementation by Arabica coffee farmers in Simalungun is influenced by the level of education. Based on the analysis of the data findings, it shows that the higher the level of education, the more appropriate the GAP implementation carried out by farmers on the coffee plantation land they own.

Table 8. Coefficients regression result.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.615	0.114		14.114	0.000
	Education level	0.380	0.037	0.694	10.329	0.000

4.4. Multiple Regression Analysis

A multiple linear regression analysis was conducted to evaluate the influence of several variables on the level of GAP implementation among Arabica coffee farmers in Simalungun (**Table 9**). The model included education level, age of farmer, farm size, access to extension services, and whether coffee was the farmer's primary crop.

GAP Implementation

$$= \beta 0 + \beta 1(\text{Education}) + \beta 2(\text{Age}) + \beta 3(\text{Farm size}) + \beta 4(\text{Extension Access}) + \beta 5(\text{Coffee Primary crop}) + \varepsilon$$

Table 9. Multiple regression analysis results.

Predictor	Coefficient (B)	Std. Error	t-Statistic	p-Value
(Constant)	1.421	0.251	5.66	0
Education Level	0.31	0.059	5.25	0
Age	−0.045	0.037	−1.22	0.225
Farm Size	0.123	0.043	2.86	0.005
Extension Access	0.387	0.101	3.83	0
Coffee as Primary Crop	0.291	0.089	3.27	0.001

Source: Author.

The results indicate that the overall model was statistically significant [$F(5,111) = 28.97$, $p < 0.001$], explaining approximately 56.6% of the variance in GAP implementation (Adjusted $R^2 = 0.552$). Among the predictors, education level ($\beta = 0.310$, $p < 0.001$), access to extension services ($\beta = 0.387$, $p < 0.001$), farm size ($\beta = 0.123$, $p = 0.005$), and coffee as a primary crop ($\beta = 0.291$, $p = 0.001$) were all significant positive predictors. Age was not a significant predictor ($p = 0.225$). These findings confirm that while education plays a crucial role in promoting GAP adoption, other contextual factors such as institutional support and economic prioritization of coffee farming also have strong explanatory power.

4.5. Reasons for Limited Implementation of Good Agricultural Practices (GAP)

1. Traditional Cultivation Practices: Coffee farming in Simalungun is largely shaped by hereditary and traditional methods. Many farmers believe their knowledge is sufficient and resist adopting modern techniques. Time constraints, divided attention between farming and other income sources (e.g., running coffee shops), and the predominantly elderly farmer demographic contribute to slow adaptation to GAP, compounded by low engagement in training and group meetings.
2. Limited Practical Knowledge and Institutional Support: While farmers are familiar with basic GAP principles such as fertilizer dosages or pest control techniques, actual application remains low due to labor shortages, aging workforces, and financial limitations. Field observations reveal inconsistencies between stated practices and field conditions, particularly in weeding, pruning, and pest control. The decline in extension services and institutional support post-COVID-19 has exacerbated this gap. Misconceptions, such as believing shade trees are unsuitable for local climates, further hinder proper adoption. Inadequate cooperative governance, weak financial management, and lack of technical training continue to obstruct consistent implementation.
3. Coffee as a Secondary Crop: For many farmers, Arabica coffee is not the primary income source but a supplementary crop. This deprioritization leads to minimal investment in certified seeds, fertilization, and structured GAP practices. Farmers focus

more on other commercial crops like corn or vegetables. The variability in group commitment and limited follow-through on training recommendations weaken institutional effectiveness. Although landholdings are substantial, coffee cultivation often takes a backseat, with limited maintenance except during harvest periods.

4.6. Level of GAP Application by Practice

Based on the field survey and interviews, the application of individual GAP components varies widely among farmers. Land preparation and spacing were generally consistent with GAP standards (applied by over 90% of respondents). In contrast, only 33.4% of farmers practiced pruning, and 25% applied appropriate fertilization despite knowing the correct methods. Shade tree use was limited (33.4%), often due to misconceptions about local climate suitability. Certified seed usage was very low (<15%), with most farmers relying on home-grown seeds. Pest and disease control was largely traditional, with little use of integrated pest management (IPM) techniques. This suggests that while awareness of GAP exists, practical adoption remains selective and inconsistent.

5. Discussion

This study revealed that the implementation of GAP (Good Agricultural Practices) by Arabica coffee farmers in Simalungun Regency is still relatively low, with 62 respondents (53%) only in the "quite appropriate" category, and only 9.4% meeting the "appropriate" category. This finding confirms the gap between knowledge and practice which is also reflected in the study of Ridwan I. et al., which shows the low implementation of GAP in the cultivation aspect [4]. More specifically, the implementation of GAP in terms of fertilization, pruning, use of shade plants, and pest control shows inconsistency. Although farmers have knowledge about the type and dosage of the right fertilizer [16], its implementation is not carried out optimally. Obstacles such as limited funds, labor, and the perception that coffee is not a main crop also affect minimal cultivation practices [12].

The level of education has been shown to have a significant effect on the implementation of GAP. The results of the regression analysis showed a strong relationship ($R = 0.694$; $R^2 = 0.481$), indicating that almost half of the variation in GAP implementation was explained by the level of farmer education. This is in line with the findings of Pongvinyoo et al., which emphasized the importance of trust and understanding as the main drivers of GAP adoption [3]. Although the majority of farmers stated that they carried out maintenance activities such as weeding and pruning, field observations showed that coffee gardens were still poorly maintained. This indicates a difference between farmers' perceptions and the reality on the ground. According to Brenes-Peralta et al., this is common in smallholder farming communities that face structural pressures and limited access to information and resources [11].

In addition, most farmers still plant coffee from their own propagated seeds, not from certified seeds. In fact, the use of superior seeds has been shown to increase productivity [15]. On the other hand, the rejection of shade plants also shows a lack of understanding of their ecological benefits, which have been shown to affect plant health and soil quality [17]. The results of this study indicate that the challenges in implementing GAP lie not only in technical aspects, but also in social, economic, and cultural aspects. Therefore, a local-based extension approach that considers traditional values and strengthening the institutional capacity of farmers is important to encourage wider and more sustainable adoption of GAP in Simalungun.

6. Conclusion

This study highlights the importance of implementing Good Agriculture Practices (GAP) in Arabica coffee cultivation in Simalungun, Indonesia, as a strategy to improve productivity and quality of harvests. The results show that although GAP has great potential in improving agricultural efficiency and sustainability, its implementation still faces various challenges. One of the main challenges in implementing GAP is the lack of knowledge and skills of farmers regarding good agricultural practices. Many farmers still use traditional methods that pay little attention to sustainability and efficiency standards. Other influential factors are limited access to agricultural technology, infrastructure, and ongoing technical assistance.

The results of the correlation analysis in this study indicate that the level of farmer education has a positive relationship with GAP implementation. Farmers with higher levels of education tend to be quicker in understanding and implementing more efficient and sustainable agricultural practices compared to those with lower levels of education. Therefore, increasing access to agricultural education and training is a key factor in the successful adoption of GAP. In addition, government policies and the role of related institutions are important factors in supporting the successful implementation of GAP. Clearer regulations, training programs, and incentives for farmers who implement sustainable agricultural practices can increase GAP adoption among coffee farmers in Simalungun.

Despite its contributions, this study is subject to several limitations that must be acknowledged. First, the analysis heavily relies on self-reported data gathered from coffee farmers through questionnaires and interviews. While efforts were made to ensure confidentiality and minimize social desirability bias, there remains a risk that responses may not fully align with actual on field practices. Discrepancies between perceived versus practiced GAP components such as weeding, fertilization, or pruning could introduce response bias, potentially overestimating the degree of implementation. Second, the geographic scope of the study is limited to the Simalungun District of North Sumatra, which, although a prominent Arabica coffee-producing region, may not be representative of other coffee-growing areas in Indonesia or globally. The specific socio-economic conditions, cultural attitudes, and institutional support structures in Simalungun may differ significantly from those in other regions, thereby limiting the external validity and generalizability of the findings.

Third, while a mixed methods approach was adopted to enhance analytical richness, the qualitative component was constrained by time and resource limitations. The ethnographic engagement, though valuable, was relatively short-term and focused primarily on farmers. This excludes critical insights from other stakeholders such as agricultural extension agents, local government officers, private sector actors (e.g., processors and exporters), and cooperative managers. Inclusion of these perspectives could have provided a more holistic understanding of the institutional, market, and policy-level barriers to GAP adoption.

Additionally, the econometric model, including multiple explanatory variables, may still omit latent variables such as risk aversion, trust in institutions, or historical exposure to agricultural innovations. The absence of these unobserved variables might limit the explanatory power of the model, suggesting a potential avenue for further research using structural equation modelling or path analysis. Future studies should consider employing longitudinal designs, expanding the geographic coverage, and incorporating triangulated data from multiple actors along the coffee value chain. This would deepen understanding of dynamic behavioural patterns, track changes in GAP adoption over time, and improve policy relevance for diverse production contexts.

7. Recommendations

This study highlights that effective GAP adoption among smallholder coffee farmers in Simalungun depends as much on socio-cultural contexts traditions, group dynamics, and economic perceptions as on technical knowledge [3,11]. Future innovation models should integrate participatory and anthropological methods to align recommendations with local practices. An adaptive extension program co-designed by local government, cooperatives, and private partners (e.g., Indocafco, Bank Indonesia) must offer hands-on training, certified inputs, and field support tailored to farmers' age, education, and socioeconomic status. Emphasizing locally relevant practices such as pruning, fertilization, and shade management can boost productivity and sustainability, while engaging younger farmers ensures long-term resilience [16,17].

To address these challenges, future agricultural innovation models should go beyond linear technology transfer and adopt participatory, socio-anthropological approaches that engage farmers in the co-design of solutions. This includes recognizing indigenous knowledge systems, respecting community rhythms, and aligning GAP recommendations with the lived realities and cultural norms of local farmers. Participatory Rural Appraisal (PRA), farmer field schools, and peer-led demonstration plots are examples of tools that can bridge the gap between prescribed practices and ground-level adoption. An adaptive and inclusive extension program is essential. Such a program should be jointly developed by local government bodies, coffee cooperatives, and strategic private sector partners such as Indocafco, Starbucks, or Bank Indonesia—who already have a presence in the region. These actors must work collaboratively to provide not only hands-on technical training and capacity-building, but also ensure access to certified planting materials, production inputs, microfinance, and ongoing mentorship. Extension interventions should be tailored to the diverse socio-economic profiles of farmers, taking into account factors such as age, educational background, landholding size, and household labour capacity.

Moreover, emphasis must be placed on promoting the adoption of locally relevant and high-impact practices such as targeted pruning, timely fertilization, shade management, and integrated pest control which directly influence both productivity and crop resilience. Demonstrating the economic benefits of such practices through yield trials, success stories, and local champions can accelerate behavioural change. Special attention should also be given to engaging younger generations of farmers, who are often more open to innovation but face barriers to entry due to lack of land ownership or capital. Providing them with entrepreneurial pathways, digital tools, and leadership roles within farmer organizations can help secure the future of sustainable coffee production in the region.

Author Contributions

Conceptualization, R.H.H. and A.A.N.; methodology, R.H.H.; software, F.A.; validation, R.H.H., A.R. and R.R.; formal analysis, A.R.; investigation, R.R.; resources, I.S.; data curation, F.A.; writing—original draft preparation, R.H.H.; writing—review and editing, A.A.N.; visualization, F.A.; supervision, I.S.; project administration, A.A.N.; funding acquisition, A.A.N. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

This research was conducted in accordance with applicable ethical guidelines for social and agricultural research involving human participants. The research design, including the interview and survey instruments, was reviewed and approved by the Research Institute of the Universitas Sumatera Utara (USU) as part of the internal research protocol licensing process for the graduate program.

Prior to fieldwork, the research team coordinated with local government agencies in Simalungun Regency and obtained administrative approval for data collection. All procedures were designed to minimize risks and ensure the confidentiality of respondent information, in accordance with research ethics standards for informed participation.

Informed Consent Statement

Informed consent was obtained in writing and verbally from all respondents prior to data collection. Farmers were given a comprehensive explanation of the research objectives, participation methods, right of withdrawal, and confidentiality. Respondents indicated their consent by signing a form or making an audio recording after understanding the implications of participation.

Data Availability Statement

The raw data supporting the findings of this study are not publicly available as they contain sensitive respondent information and are subject to confidentiality agreements. Aggregated data summaries are available through the corresponding author (abdullah.akhyar@unimal.ac.id) upon reasonable request and for academic purposes, in accordance with institutional data protection regulations.

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Conflicts of Interest

The authors declare no financial or non-financial conflicts of interest in this research. No financial relationships or affiliations with commercial entities were identified that could have influenced the study design, data analysis, or interpretation of the results. The research was solely aimed at the development of sustainable agricultural science.

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