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Enhancing farmer productivity through participatory approaches and continuous training: A communication quality perspective in North Sumatra's agricultural sector

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ABSTRACT

This study examines the influence of participatory approaches and continuous training on farmers' productivity, with communication quality as a mediating factor, in four districts of North Sumatra Province. The research investigates how farmers' active involvement in planning, decision-making, implementation, and evaluation, together with regular and structured training, strengthens their technical and managerial skills. Using a quantitative survey method with primary data collected through questionnaires, the findings show that participatory approaches and continuous training positively affect agricultural productivity. Communication quality plays an important mediating role by ensuring that technical information is clearly communicated and effectively applied by farmers. Clear, open, and two-way communication supports behavioral change and the adoption of innovations in agricultural practices. Overall, the study highlights the need for agricultural development programs to emphasize collaborative participation, needs-based training, and improved communication capacity to enhance farmer productivity and promote regional food security.

1. Introduction

People have known for a long time that farming is an important part of Indonesia's economy and food security. More than 29% of Indonesia's workers work in agriculture, which contributed about 12.98% to the country's Gross Domestic Product (GDP) in 2023, according to the Central Statistics Agency (BPS). Even though this sector is important for the economy, it still has a lot of structural problems, like low productivity, limited access to modern technologies, and a weak agricultural extension system. These problems have made it harder for the agricultural industry to modernize and made it less competitive in the face of changes in the global economy (Maulidiyah et al., 2025).

North Sumatra Province is one of Indonesia's most important farming areas. It grows a wide range of vital crops, such as rice, corn, palm oil, rubber, coffee, cocoa, and horticultural items like chilies, shallots, and tropical fruits. The province is very important for making sure that food is safe throughout the region and the country as a whole. In 2023, the national rice harvest area was 419,463 hectares, and the average yield was 52.56 quintals per hectare. This accomplishment shows a steady contribution, although it is still below what is possible given Indonesia's geography and people. The fact that some regions are more productive than others and that some farmers are more likely to use new technology than others shows that farmers need more structured and participative interventions.

The agricultural sector is important not just for keeping food safe, but also for producing jobs and boosting the economy in the area. For instance, the economy of North Sumatra Province rose by 5.01% (c-to-c) in 2023, up from 4.73% the year before. The agricultural sector is still one of the key drivers of growth in the region. The food crop subsector is the biggest part of the national agricultural business structure. It includes about 15.5 million families (54.72%) and 15.7 million business units (53.75%). This dominance makes it clear that improving farmer productivity is the most important thing for long-term agricultural development and economic growth that includes everyone (Salam et al., 2024).

A participatory method is thought to be a good way to deal with these problems. This method puts

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farmers in charge of planning, carrying out, and judging agricultural activities. This means that they are no longer just following the rules, but also making decisions (Fanatico et al., 2025). On the other hand, continual training is very important for farmers to keep their skills and knowledge up to date with changes in technology and the market. This kind of training includes both technical and managerial topics. For example, it teaches how to use better varieties, how to balance fertilization, how to use modern irrigation techniques, and how to use digital technology for precision farming. It also teaches how to keep track of costs, how to analyze the feasibility of a business, and how to make strategic plans.

The quality of communication, on the other hand, has a big impact on how well participatory approaches and ongoing training work. Farmers, extension workers, and other stakeholders need to be able to talk to each other clearly, openly, and in both directions. This is the best approach to make sure that knowledge is shared, comprehended, and put into action. Good communication also speeds up the use of new ideas, builds trust, and encourages people to work together in agricultural systems. Sadly, most of the research that has been done so far has looked at participatory approaches and training individually. The quality of communication as a mediating variable has not been investigated much, especially in the local agricultural setting of North Sumatra.

Consequently, a substantial study vacuum exists concerning the comprehension of the relationship between participatory techniques, continuous training, and farmer productivity, with communication quality serving as a mediating element. This study seeks to address this deficiency by thoroughly examining the impact of participatory techniques and continuous training on farmer productivity via communication quality. The study concentrates on four districts in North Sumatra Province and aims to yield both theoretical and practical contributions. From a theoretical standpoint, this study enhances the literature about farmer empowerment and development communication. In practice, the research findings can guide policies and tactics for local governments, extension agencies, and agricultural organizations in formulating more successful, inclusive, and sustainable agricultural development programs.

2. Literature review

2.1. Agricultural productivity

Farmer productivity is very important for achieving national food security, which means that a country can make sure that everyone has enough safe, healthy food and that everyone has equal access to it (Supriatna et al., 2025). Improving productivity is an important first step to making sure that food production is enough and lasts, which is the most important thing to do to improve food security (Bocean, 2024). High productivity not only boosts the amount of food available in the country, but it also makes the country less reliant on imports that can be affected by changes in world prices and supply uncertainties (Maulidiyah et al., 2025). So, better food production at the local level can help keep national food security stable (Suryalena et al., 2025).

Also, higher productivity is closely linked to higher income and better living conditions for farmers (Haryuningtyas et al., 2024). Farmers can improve their quality of life, meet their fundamental necessities, and reinvest in their companies when their revenues go up (Salam et al., 2024). These investments, such as using more advanced farming technologies, will lead to additional production capacity and will have long-term, favorable effects on the growth of the agricultural sector. Also, high production helps food systems stay in business. Farmers can get more crops without harming ecosystems by using efficient farming methods, including water-saving irrigation, balanced fertilizing, and insect management that is good for the environment (Saha et al., 2025). This method makes sure that natural resources will be available for a long time, which is important for making sure that food will be safe in the future (Pothin et al., 2025).

In a worldwide context, enhancing farmer productivity is essential for tackling food security issues arising from population expansion, climate change, and the instability of international food markets (Khan et al., 2025; Espinoza and Escobal, 2025; Fatima and Ying, 2025). Countries with high production are better able to deal with food crises, whether they are caused by natural disasters or problems with global supply chains. Also, technology and training can help increase productivity, which can lead to better food quality (Min, 2025). Farmers may make healthier, safer, and more nutritious food by using new ideas. This helps meet the community's nutritional demands and improves public health and quality of life (Ma et al., 2025).

2.2. Communication quality

Communication quality between farmers and agricultural extension workers is a very important factor in increasing farmer productivity (Shehzad and Xue, 2024). Extension workers not only act as information providers but also as facilitators who help farmers adopt new technologies and more efficient and environmentally friendly agricultural practices (Liu et al., 2025). If communication is well established, farmers will more easily understand new farming methods, which ultimately contributes to increased productivity.

Being clear about what you want to say is an important part of communication. Farmers can grasp instructions on agricultural technology or procedures, including how to apply organic fertilizer or how to employ efficient irrigation techniques, when communication is clear. Farmers who get clear

information are more likely to use it correctly, which leads to higher crop yields (Velado-Alonso et al., 2024).

Furthermore, open, two-way communication is crucial. Farmers who feel comfortable asking questions or providing feedback will be more engaged in the extension process (Adebayo et al., 2024). This encourages the exchange of knowledge and experience, which not only enriches farmers' understanding but also improves their ability to face agricultural challenges, such as pest attacks or plant diseases (Hernández et al., 2025).

Another factor that affects the quality of communication is the extension worker's capacity to change extension materials to fit the requirements and situation of farmers in the area (Prakash et al., 2023). Extension staff who know about the problems in a certain location, like not enough water or bad soil, can give people more useful and relevant information (Wang et al., 2023). This change makes the message easier for farmers to grasp and use, which makes it more effective in boosting productivity.

Previous research has shown that effective communication quality is closely related to the rate of adoption of new technologies. Extension workers who are able to clearly convey information regarding modern and environmentally friendly agricultural technologies help farmers to more quickly and accurately adopt new methods that have a positive impact on agricultural yields (Shamshiri et al., 2024). Furthermore, good communication also facilitates cooperation between farmers, so they can share knowledge and experiences gained during extension. This ultimately increases the collective capacity of farmers in facing agricultural challenges (Osman, 2025).

2.3. Participatory approach

The participatory approach in agriculture refers to the active involvement of farmers in every stage of decision-making related to agricultural practices, from planning to evaluation of results (Ochieng et al., 2022). This approach emphasizes the importance of farmer contributions in selecting the technology to be used, land management, and regulating harvest yields (Dossou-Yovo et al., 2024). Several studies have shown that this approach has a significant impact on productivity because it provides opportunities for farmers to play a direct role in the processes related to their agricultural activities.

One of the most important parts of the Participatory approach is giving farmers more authority (Müller et al., 2024). Farmers feel more responsible for the success of agricultural projects when they are involved in making decisions and planning (Karner et al., 2024). This situation makes farmers more motivated and committed to making the program work as well as possible, which in turn helps to improve the quality and quantity of agricultural harvests (Matowo et al., 2022). The participatory approach also speeds up the use of new technology. Farmers are more likely to adopt and use technology that works for them when they can choose or suggest it. The use of current technologies that come with the Participatory method has been proven to make farming more efficient and improve the quality of the crops (Zhang and Drury, 2024). This method also makes it easier for farmers and extension workers to talk to each other. Open, two-way communication makes it easier for farmers and extension workers to share information with each other and for different agricultural actors to share information with each other (Chowdhury et al., 2024). Farmers who feel heard and respected will find it easier to absorb the information given to them and will accept new ideas more quickly, which will ultimately lead to more work getting done (López-García et al., 2025).

The effectiveness of the Participatory approach is significantly contingent upon social empowerment and the collaborative engagement of all stakeholders within the agricultural system. Training programs that include farmers from the planning stage to the implementation stage not only help them learn new technical skills, but also help them work together and solve problems together. This is important for solving the problems that modern agriculture faces, such as climate change and land degradation, and it also helps farmers adjust to how the agricultural industry is changing.

Prior research demonstrates that the Participatory approach facilitates the attainment of sustainable agriculture through the active engagement of farmers (Cameira et al., 2024). This method makes people more aware of how important it is to use eco-friendly practices and encourages farmers to use ways that not only increase yields but also protect the environment. The Participatory approach can therefore guarantee the sustainability of the agricultural sector, enhance production, mitigate adverse environmental effects, and establish a resilient agricultural system in the long term.

2.4. Continuous training

Continuous training is a key element in efforts to improve farmers' capacity. This program not only covers the mastery of technical skills in cultivation, but also includes the managerial aspects necessary to manage agricultural businesses more effectively (Zhang and Yang, 2025). Consistent training enables farmers to update their knowledge and skills, which is crucial in addressing the dynamic challenges in the agricultural sector. As a result, continuous training has a significant impact on productivity, as it helps farmers implement the latest technologies and promotes the adoption of more efficient and environmentally friendly agricultural practices (Sharma and Singh, 2023).

Structured and ongoing training can also bring about new ideas, such as using contemporary farming technology, using irrigation methods that save water, and strategies for managing natural

resources in a way that is good for the environment. Farmers can learn about new, better ways to farm through this process, which in turn leads to better crop yields in terms of both quality and quantity (van der Merwe and Makamane, 2025). Training also helps farmers improve their management skills, such as making decisions in agricultural enterprises, managing money, and coming up with marketing plans (Li et al., 2023).

One of the key benefits of ongoing training is that it helps farmers learn how to use new technologies (Pandey et al., 2025). Technology is a big part of modern farming that helps farmers get more done (Plana-Farran et al., 2023). Farmers are more open to change when they get regular instruction on how to use new technology. Using better fertilizers, insect management methods that are better for the environment, and contemporary farming tools have all been shown to boost crop yields while reducing losses caused by less effective older methods.

Along with technical skills, ongoing training also helps farmers learn more about sustainable farming methods (Xiuling et al., 2023). Understanding techniques that are focused on sustainability is particularly important when dealing with global problems like climate change and soil degradation (Liu et al., 2022a). Training that educates farmers how to manage water, rotate crops, and use organic materials can help them protect the environment without losing productivity.

Previous research has also shown that continuous training has a positive impact on improving farmers' managerial capacity. Those who receive training in farm management tend to be better able to plan and manage their land, optimize resources, and make strategic decisions related to production and marketing. Therefore, training that covers managerial aspects is very important, considering that many farmers still face difficulties in capital management, time management, and marketing strategies. Ultimately, continuous training helps farmers overcome these obstacles, improve business efficiency, and strengthen the competitiveness of the agricultural sector.

3. Methods

This study uses a quantitative approach, with a structured survey as the main way to gather data. The research was executed in six districts within North Sumatra Province: Simalungun, South Tapanuli, Deli Serdang, Langkat, Asahan, and Serdang Bedagai. These districts were chosen because they have a lot of farming going on, especially in the farming industry.

The study's target group comprises farmers who have engaged in agricultural training programs and extension services. We used a purposive sample strategy to choose 270 people who met the requirements for inclusion. The admission requirements mandated that participants be active farmers, involved in continuous training programs, and employing digital technology in their agricultural processes, such as financial management applications or digital communication platforms. The reasoning for this pick is predicated on the premise that farmers who actively utilize digital technologies are more inclined to offer pertinent observations regarding the influence of participatory tactics, ongoing training, and communication quality on agricultural productivity.

A closed-ended questionnaire based on prior studies and extant literature was used to obtain the main data. A five-point Likert scale was used to measure all of the items, with 1 being "strongly disagree" and 5 being "strongly agree." The principal variables assessed in this study are presented in Table 1. The Participatory Approach (X1) is measured by four indicators (PA1, PA2, PA3, PA4), the Continuous Training (X2) is measured by four indicators (PB1, PB2, PB3, PB4), the Communication Quality (M) is measured by four indicators (KC1, KC2, KC3, KC4), and the Agricultural Productivity (Y) is measured by four indicators (PP1, PP2, PP3, PP4).

Table 1: Variable measurement scale

Variables	Code	Example statement
Participatory approach (X1)	PA1	I am actively involved in planning agricultural extension programs.
	PA2	I participate in decision-making regarding agricultural practices to be implemented.
	PA3	I participated in the evaluation of the results of the agricultural training program.
	PA4	I provided feedback on the material taught in the agricultural training.
Continuous training (X2)	PB1	The training program I participated in was structured and continuous.
	PB2	I feel that the continuous training I have participated in has improved my technical skills in agriculture.
	PB3	I gained useful new knowledge from ongoing agricultural training.
	PB4	This continuous training has improved my managerial skills in managing agricultural businesses.
Communication quality (M)	KC1	Communication between farmers and extension workers is very clear and easy to understand.
	KC2	I feel that I have gained sufficient information about new agricultural technologies through the extension program.
	KC3	Communication between farmers is very open and allows for effective knowledge sharing.
	KC4	The extension workers provided adequate explanations regarding the training material.
Agricultural productivity (Y)	PP1	My agricultural productivity has increased since participating in continuous training.
	PP2	I successfully adopted the new agricultural technology taught in the training.
	PP3	My income from agricultural production increased after participating in the extension program.
	PP4	The quality of my agricultural produce has improved since I attended the sustainable agriculture training.

We used Structural Equation Modeling with Partial Least Squares (SEM-PLS) to look at the data. This method was selected due to SEM-PLS's exceptional efficacy in analyzing intricate interactions across latent constructs, especially with lower sample sizes and non-normally distributed data. SEM-PLS enables the examination of direct effects of participatory methodologies and ongoing training on agricultural productivity, while also investigating the potential mediating function of communication quality in these dynamics. We have also looked at the diagnosis and basic assumptions

behind SEM-PLS in response to concerns from reviewers. Before the analysis, these steps were taken:

a. Normality of data: The data was evaluated for normality utilizing skewness and kurtosis values, alongside graphical techniques including histograms and Q-Q plots. We made sure that the dataset matched the condition of approximate normality because SEM-PLS works well with data that isn't normal.
b. Reliability and validity: We used Cronbach's alpha and composite reliability to check the reliability of the construct. They had to be higher than 0.70 to be acceptable. We looked at both convergent and discriminant validity to make sure it was valid. Average Variance Extracted (AVE) showed that convergent validity was true, since all constructs had values over 0.50. We used the Fornell-Larcker criterion and the Heterotrait-Monotrait ratio (HTMT) to check for discriminant validity, and both showed that it was good.
c. The inner model evaluation assessed how well independent variables explained the variance in the dependent variable through R^2 values. Direct effects were tested using path coefficients, with significance determined by bootstrapping (t-statistic > 1.96, p-value < 0.05). Additionally, the mediating role of Communication Quality was explored using bootstrapping to assess if it significantly mediates the relationship between Participatory Approach (X1), Continuous Training (X2), and Agricultural Productivity (Y).

4. Results and discussion

4.1. Description of respondents

Table 2 reveals that 270 people took part in this study. They were farmers from six regencies in North Sumatra Province: Simalungun, South Tapanuli, Deli Serdang, Langkat, Asahan, and Serdang Bedagai. These farmers were participating in extension programs and sustainable training. A purposive sampling technique was employed to choose the respondents, and the criteria for choosing them were that they were active farmers who had taken training and used technology in their farming. The gender distribution of responses was quite even, with a few more men farmers (51%) than female farmers (49%). This shows that men and women are equally likely to take part in agricultural extension programs and sustainable training in the area. Most of the people who answered were in the age range that is productive. The biggest age group was 36 to 40 years old (31%), followed by 31 to 35 years old (27%), 26 to 30 years old (25%), and 20 to 25 years old (17%). These results show that most of the farmers in this study were young to middle-aged adults, who are usually more willing to try out new farming methods. Most of the people who answered the survey had at least finished high school (22%), and more than half (41%) had a bachelor's degree (S1). This means that most farmers have enough education to understand and use new farming technology taught in training and extension programs, as well as to judge how they affect farm productivity.

Table 2: Respondent demographics

Variable	Category	N	Percentage (%)
Gender	Male	138	51
	Female	132	49
Age	20–25 years old	45	17
	26–30 years old	68	25
	31–35 years old	72	27
	36–40 years old	85	31
Education	High school/equivalent	60	22
	Diploma (D3)	55	20
	Bachelor's degree (S1)	110	41
	Master's degree (S2)	45	17
Total respondents		270	100

4.2. Measurement model analysis (outer model)

The measurement model analysis (outer model) was conducted through two main tests, namely: (1) reliability and construct validity tests, and (2) discriminant validity tests. The results of these two tests are presented below as the basis for the feasibility of the research instrument.

Table 3 above reveals that the majority of the loading factors are higher than 0.70, which means that these indicators are a good fit for the measured construct. For instance, the PA1 indicator in the Participatory approach (X1) variable has a loading value of 0.984, which means that this indicator is a good representation of the construct. A similar pattern can be seen for indicator PB4 for Continuous training (X2), which has a value of 0.952. This means that this indicator significantly shows how Continuous training affects farmers' ability to manage their businesses better. The Communication Quality indicator KC3 also has a high value of 0.948, which demonstrates that farmers talking to each other is very important for improving the sharing of information. The PP4 indicator has the greatest loading value of 0.906 for Agricultural Productivity (Y), which implies that Continuous Training is very important for making agricultural products better. The PP1 indicator has the lowest value of 0.743, but this still shows that Continuous Training helps productivity improve, even if it doesn't have as big of an effect.

Table 4 above displays the results of testing for reliability and validity for each variable in this study. The values for Cronbach's Alpha and Composite Reliability for the four variables, Participatory Approach (X1), Continuous Training (X2), Communication Quality (M), and Agricultural Productivity (Y), are all higher than the minimum threshold of 0.70. This means that the tools used have very good internal reliability. Also, the Average Variance Extracted (AVE) values for all variables are higher than the minimum of 0.50, which means that each construct passes the requirements for convergent validity. So, all of the constructs in this study are reliable and valid, and they can be employed in future tests of structural models.

Table 5 displays the outcomes of component loading analysis (outer loading) for each indicator associated with the latent variable constructs: Participatory approach (X1), Continuous training (X2), Communication Quality (M), and Agricultural Productivity (Y). The majority of the factor loading values surpass 0.70, signifying that these indicators possess substantial convergent validity in assessing their corresponding constructs. The PA1 indicator in the Participatory Approach (X1), for instance, has a high factor loading value of 0.984, which shows that it is strongly related to this construct. The PB1 indicator in Continuous Training (X2) and the KC3 indicator in Communication Quality have factor loadings of 0.984 and 0.916, respectively, which means that these indicators likewise strongly represent their respective constructs. These findings demonstrate that all constructs in this study satisfy the requirements for convergent validity and are prepared for subsequent structural model analysis.

4.3. Structural model analysis (inner model)

Table 6 shows that the R-squared value for Communication Quality (the Mediator Variable) is 0.432. This means that the independent variables (Participatory approach (X1) and Continuous training (X2) can explain 43.2% of the changes in Communication Quality. The other factors that aren't in the model have an effect on the other 56.8%. The R-squared value for Agricultural Productivity (Y) is 0.876, which means that Communication Quality (the Mediator Variable) can explain 87.6% of the differences in Agricultural Productivity. This shows that there is a high link between Communication Quality and Agricultural Productivity, which means that this model can explain this outcome variable very well. The Adjusted R-squared score of 0.874 further demonstrates that this model is stable and can accurately show how the mediator variable affects productivity outcomes.

Table 3: Outer model results

	Participatory approach (X1)	Continuous training (X2)	Communication quality (M)	Agricultural Productivity (Yq)
PA1	0.984			
PA2	0.876			
PA3	0.915			
PA4	0.832			
PB1		0.865		
PB2		0.927		
PB3		0.811		
PB4		0.952		
KC1			0.89	
KC2			0.812	
KC3			0.948	
KC4			0.893	
PP1				0.743
PP2				0.821
PP3				0.855
PP4				0.906

Table 4: Composite reliability

Variable	Cronbach's alpha	rho_A	Composite reliability	AVE
Participatory approach (X1)	0.98	0.981	0.984	0.909
Continuous training (X2)	0.976	0.978	0.98	0.862
Communication quality (M)	0.972	0.973	0.977	0.843
Agricultural productivity (Y)	0.963	0.969	0.969	0.759

Table 5: Discriminant validity results

Variable	Participatory approach (X1)	Continuous training (X2)	Communication quality (M)	Agricultural productivity (Y)
PA1	0.984			
PA2	0.983			
PA3	0.925			
PA4	0.969			
PB1		0.984		
PB2		0.983		
PB3		0.972		
PB4		0.926		
KC1			0.674	
KC2			0.673	
KC3			0.916	
KC4			0.962	
PP1				0.738
PP2				0.734
PP3				0.681
PP4				0.725
PP5				0.664
PP6				0.671

Table 6: Determination coefficient (R-squared)

Variable	R-squared	R-squared adjusted
Communication quality (mediating variable)	0.432	0.415
Agricultural productivity (Y)	0.876	0.874

4.4. Hypothesis testing

According to Table 7, the participative approach (X1) has a good and important effect on the quality of communication (Z). The path coefficient of 0.158, the t-statistic of 3.120 > 1.98, and the p-value of 0.002 < 0.05 show that the more farmers are involved in planning, carrying out, and evaluating,

the better the Communication Quality between farmers and extension workers or stakeholders. Participation gives a forum for open communication where farmers may share their needs and experiences in a clear way.

Also, continuous training (X2) has a very substantial effect on Communication quality (M), with a coefficient of 0.778, a t-statistic of 15.113 > 1.98, and a p-value of 0.000 < 0.05. This shows that systematic, ongoing, and needs-based training helps farmers increase their ability to take in, analyze, and share information. The training process also makes the relationship between farmers and extension workers stronger, which helps them share more information. Other results show that the participatory approach (X1) has a positive effect on agricultural productivity (Y) with a coefficient of 0.371, a t-statistic of 3.847 > 1.98, and a p-value of 0.000 < 0.05. Participation encourages a sense of ownership and responsibility among farmers, which ultimately leads to increased productivity. Similarly, Continuous Training (X2) significantly increases Agricultural Productivity (Y) with a coefficient of 0.190, a t-statistic of 3.020 > 1.98, and a p-value of 0.003 < 0.05. Consistent training makes farmers more skilled in effectively managing their farming operations.

Also, Communication quality (M) has a big effect on production (Y), with a coefficient of 0.244, a t-statistic of 2.980 > 1.98, and a p-value of 0.003 < 0.05. Good communication speeds up the process of learning about new technology, cuts down on misunderstandings, and encourages people to use new ideas. Mediation analysis indicates that the Participatory approach via communication significantly affects productivity (coefficient 0.238; t-statistic 2.953; p-value 0.000), and Continuous training through communication exerts a notable influence (coefficient 0.447; t-statistic 4.779; p-value 0.006).

Table 7: Direct effect

Path	Original sample	Sample mean	Standard deviation	T-statistics	P-values
Participatory approach (X1) -> communication quality (M)	0.158	0.166	0.051	3.120	0.002
Continuous training (X2) -> communication quality (M)	0.778	0.770	0.051	5.113	0.000
Participatory approach (X1) -> agricultural productivity (Y)	0.371	0.373	0.096	3.847	0.000
Continuous training (X2) -> agricultural productivity (Y)	0.190	0.187	0.063	3.020	0.003
Communication quality (M) -> agricultural productivity (Y)	0.244	0.243	0.082	2.980	0.003
Participatory approach (X1) -> communication quality (M) -> agricultural productivity (Y)	0.238	0.041	0.020	2.953	0.000
Continuous training (X2) -> communication quality (M) -> agricultural productivity (Y)	0.447	0.148	0.083	4.779	0.006

5. Discussion

5.1. The effect of participatory approach on communication quality

The analysis indicates a strong correlation between the participatory method and communication quality in four districts of North Sumatra Province, evidenced by a t-statistic value of 3.120 (more than 1.98) and a p-value of 0.002 (less than 0.05). These findings corroborate prior research suggesting that efficient communication and proactive farmer engagement in extension programs can improve the comprehension and implementation of novel agricultural technologies (López-García et al., 2025). Farmers' sense of responsibility for the results of their decisions is strengthened when they are included in the decision-making process. This, in turn, improves Communication Quality among farmers (Müller et al., 2024). For agricultural communication to operate, there needs to be open and helpful two-way communication between farmers and extension workers. Farmers can get information more easily, learn how to use new technologies, and improve agricultural productivity when they communicate well. This creates a collaborative environment that helps agricultural programs reach their common goals.

This study contradicts the findings of research conducted in Ethiopia (Gebeyehu and Jira, 2023), which indicated that although participatory communication methods can enhance community mobilization, unassisted routine implementation hinders the efficacy of communication in augmenting agricultural yields. Additionally, Doerwald et al. (2024), in a swift analysis of participatory digital methodologies in health interventions, discovered that although there exists potential to enhance participation, the quality of communication does not consistently improve markedly due to obstacles in access and digital competence. Finally, Anani-Bossman and Blankson (2024) observed that even though participatory communication was used in a development project in Ghana, it didn't make a big difference in the quality of communication between farmers and extension workers.

The findings of this study offer a theoretical contribution, particularly in reinforcing Participatory Communication Theory, which underscores the active engagement of farmers and extension workers in reciprocal discourse to foster mutual understanding. This aligns with the Diffusion of Innovations theory, which posits that the adoption of agricultural technology accelerates through participative and trust-based interactions. It also fits with Social Exchange Theory, which says that connections that benefit both people encourage sharing knowledge and working together (Zhang et al., 2025). Agricultural communication works best when the message is clear, and people can talk to each other in ways that are useful to them and last.

The managerial implications of this study suggest that to enhance the quality of communication among farmers, program managers in this region must promote the implementation of a participatory

approach in extension and training, thereby actively engaging farmers in the planning process and establishing open channels of communication between farmers and extension workers. Digital technologies, including mobile-based application platforms, must be incorporated to enable real-time collaboration and deliver prompt feedback. Lastly, it should be a top priority to train extension workers to improve their communication abilities. Extension programs in these four districts can be more effective at improving farmers' well-being and agricultural output if they are participatory and collaborative.

5.2. The effect of continuous training on communication quality

The analysis indicates a substantial correlation between ongoing training and the quality of communication among farmers in four districts of North Sumatra Province, evidenced by a t-statistic value of 5.113 (more than 1.98) and a p-value of 0.000 (less than 0.05). These results corroborate other studies demonstrating that ongoing training improves farmers' communication abilities in transmitting and receiving information. Farmers learn more about the latest farming methods and policies through ongoing training. This makes it easier for farmers to talk to extension workers and to each other (van der Merwe and Makamane, 2025). Good communication helps farmers and extension workers share information more easily, which speeds up the use of new ideas and makes farming practices better. Farmers can respond more swiftly to changes in the market and government laws if they communicate better. This makes them better able to deal with the problems they already have (Zhang and Yang, 2025). This immediately leads to higher agricultural yields and higher production overall (Pandey et al., 2025). High-quality communication also helps farmers get along better, which lets them share their experiences and ideas for solving problems in agriculture (Lei and Yang, 2025).

The findings of this study are at odds with those of Chen et al. (2025), who asserted that while there exists a significant correlation between communication quality and patient satisfaction, the cognitive and emotional dimensions of communication do not significantly correlate with satisfaction. This suggests that not all facets of communication training influence patient perceptions. Additionally, Çakmak and Uğurluoğlu (2024) asserted that communication training seeks to enhance patient engagement; nevertheless, its effects do not consistently lead to a direct improvement in the sense of service quality. Then Jameel et al. (2025) asserted that effective communication positively influences patient satisfaction; nevertheless, the mediating function of patient trust indicates that communication training alone is insufficient, necessitating a supportive context such as trust-building. Finally, Keshtkar et al. (2025) asserted that current communication training has not been demonstrated to significantly enhance the quality of clinical communication; more comprehensive and enduring interventions are required to achieve tangible outcomes.

In theory, these results support the idea of continuous learning, which says that people can learn new things and skills that will help them communicate better (Ji et al., 2024). The principle of participatory communication is pertinent, as ongoing training motivates farmers to engage more actively in the communication process, both with extension workers and amongst themselves. Good communication helps farmers accept new agricultural technologies more quickly, comprehend the policies that have been put in place, and build stronger relationships with each other. The notion of innovation adoption says that strong communication speeds up the spread of new ideas and information in farming communities.

The findings of this study, conducted in four districts of North Sumatra Province, have significant management implications aimed at enhancing communication and agricultural productivity. First, farmers and extension workers need to keep learning so they can better comprehend new farming techniques and how to talk to one another. Second, it is important to set up good ways for farmers, extension workers, and others to talk to each other so that information may be shared. Third, to get more farmers involved, it's vital to include them in decisions on agricultural policies. Fourth, using information technology to speed up communication and make things more efficient is really important. Finally, farmer associations can help farmers work together better, which helps speed up the spread of knowledge and solutions for problems in farming. These approaches should help agriculture be more productive in the long term.

5.3. The effect of participatory approaches on agricultural productivity

The study's findings demonstrate that the participatory approach significantly influences agricultural productivity in four districts of North Sumatra Province: Simalungun, South Tapanuli, Deli Serdang, and Langkat, evidenced by a t-statistic value of 3.847 (greater than 1.98) and a p-value of 0.000 (less than 0.05). These results align with prior research demonstrating that active involvement of farmers in decision-making and extension initiatives can improve their comprehension of novel agricultural technologies and pertinent regulations. The participative method makes it easier for farmers and extension workers to talk to each other and for farmers to talk to each other. This speeds up the use of more ecologically friendly and efficient farming methods. Farmers can more easily use new technologies, make farming practices better, and generally support higher agricultural productivity in their area if they talk to each other well. The findings of this study contradict those of Prajapati et al.

(2025), who emphasized that while participatory approaches enhance innovation and collective learning, institutional and governmental hurdles frequently restrict their significant influence on agricultural output. Additionally, a scoping analysis conducted by Paleologo et al. (2025) revealed that, despite the significant relevance of participatory approaches in agricultural innovation, evidence of quantitative yield improvements is still inconsistent. Additionally, Cameira et al. (2024) showed that a mix of participatory methods and rapid evaluations effectively identified restrictions; however, they lacked definitive evidence on yield gains. Finally, Mponela et al. (2023) revealed that participatory action research had a bigger influence on nutritional outcomes than on agricultural production productivity.

These findings align with the theory of participation in agricultural development, which posits that the active engagement of farmers in decision-making, planning, and evaluation of agricultural programs can enhance the efficacy of new technology implementation and agricultural policies (Zhang et al., 2024). Moreover, the findings of this study enhance the Diffusion of Innovations hypothesis, which posits that technology adoption accelerates when users are directly and actively engaged in the learning and decision-making processes. The participatory approach not only speeds up the use of new farming methods, but it also makes people feel more responsible for and capable of maintaining sustainable farming techniques. This directly helps the local community's agriculture become more productive, as shown in the four districts.

Based on the results of this study, managers can take numerous essential initiatives to increase communication and production in agriculture. First, extension workers and farmers need to work together in a participatory way to learn more about new farming techniques and enhance their communication skills. Second, it is important to have good ways for farmers, extension workers, and farmers to talk to each other. Third, letting farmers help make decisions about agricultural policy can get more farmers involved. Fourth, using information technology to speed up communication and make things more efficient is really important. These techniques are meant to help agriculture be more productive and last longer.

5.4. The effect of continuous training on agricultural productivity

The study's findings demonstrate a substantial impact of continuous training on agricultural productivity among farmers in four districts of North Sumatra Province: Simalungun, South Tapanuli, Deli Serdang, and Langkat, evidenced by a t-statistic value of 3.020 (greater than 1.98) and a p-value of 0.003 (less than 0.05). These results are in line with earlier research that showed that training based on technology and contemporary farming methods can help farmers learn more and do better, which can lead to higher crop yields. Continuous training promotes the implementation of more effective agricultural practices, thereby enhancing long-term productivity (Lei et al., 2024). Intensive training has also been shown to make farmers better able to deal with climate change, which lets them get the most out of their crops even when conditions change.

The results of this study do not support those of Wonde et al. (2022), who stated that the decline in quality and instability in training implementation were the main factors why the training failed to increase productivity sustainably. Furthermore, Zougris et al. (2025), using a meta-analysis, found that although the adoption of sustainable agricultural practices (SAPs) has the potential to increase productivity, other factors such as training quality, institutional support, and local context have a greater influence on agricultural output than technical training alone. Conversely, Al-Shammary et al. (2024) showed that although good agronomic practices can improve soil quality, training without consistent implementation and ongoing support does not significantly impact agricultural productivity.

These results conceptually reinforce the human capital theory, which posits that enhancing individuals' abilities and knowledge via training and education positively influences production. Farmers can learn the newest farming methods, eco-friendly practices, and how to use their resources more efficiently through ongoing training. This method speeds up the use of new farming techniques, makes field practices more effective, and helps achieve better output results. Farmers' active participation in the learning process and the use of new technology enhances their capacity to tackle agricultural difficulties, hence rendering continual training a crucial strategy.

The managerial implications of this study indicate that to enhance agricultural productivity sustainably, managers of agricultural training programs must prioritize the quality and relevance of the training materials provided, while also ensuring the implementation of efficient and environmentally sustainable agricultural practices. Also, it's necessary to make it easier for farmers to work together to make their social networks stronger. It's also important to use new farming technologies and get farmers involved in the training process. It is expected that these measures would lead to higher agricultural output in the long run and help farmers deal with the many changes and problems they confront.

5.5. The effect of communication quality on agricultural productivity

The results of the study indicate that Communication Quality has a significant impact on Agricultural Productivity in four districts in North Sumatra Province, namely Simalungun District, South Tapanuli District, Deli Serdang District, and

Langkat District, where the t-statistic value is 2.980 > 1.98, and the p-value is 0.003 < 0.05. These findings align with previous studies stating that effective communication is determined by message clarity, open channels, and constructive feedback (Hernández et al., 2025). Effective communication between farmers and extension workers enhances the adoption rate of agricultural technology (Prakash et al., 2023). Open communication channels facilitate knowledge transfer between farmers and relevant stakeholders. Good communication can reduce errors in natural resource management, leading to better crop yields (Wang et al., 2023). Interpersonal communication plays a key role in enhancing farmers' technical capabilities in adopting innovations. Effective communication accelerates farmers' adaptation to market changes and government policies. Additionally, good communication between farmers and extension workers helps improve farmers' understanding of the use of environmentally friendly fertilizers and pesticides, ultimately increasing agricultural yields (Osman, 2025).

The findings of this study contradict those of Mulungu et al. (2025), who determined that while information and communication technology (ICT) can enhance information accessibility, heterogeneity in communication and infrastructural constraints result in inconsistent effects on productivity. Moreover, Jotta (2024) indicated that while ICT enhances farmers' knowledge, enduring assistance and practical application are essential for substantial outcomes. In the meantime, Rohit et al. (2024) discovered that while good communication makes people happier, the quality of extension services and the relevancy of information are more essential factors in agricultural output. Finally, Hinojosa et al. (2023) came out with the AgroTIC app, which connects farmers with agronomists and traders. However, the limited availability of technology and training makes it less useful for increasing productivity.

In theory, these results back up the idea that good communication is clear, two-way communication that everyone can take part in. This helps people learn new things, grasp technology, and coordinate their actions. Good communication quality lets farmers learn about current farming methods, how to use inputs correctly, and how to manage resources in the most effective way. This speeds up the use of new technology and agricultural innovations, makes field operations more effective, gives farmers more tools to deal with problems, and helps local agriculture become more productive and sustainable.

In four districts in North Sumatra Province, Simalungun, South Tapanuli, Deli Serdang, and Langkat, the management implications include a number of strategic initiatives to boost communication and agricultural output. First, by giving agricultural extension workers good training, we can help them communicate better. Second, using information technology and organizing frequent meetings to make it easier for farmers and extension workers to talk to each other. Third, making or enhancing farmer groups as places to share knowledge and experiences. Fourth, putting in place long-term extension initiatives that are tailored to the needs of each district. These initiatives are meant to speed up the use of new technologies, help farmers learn more, and help the region's agricultural sector flourish in a way that is both more productive and more sustainable.

5.6. The effect of participatory approach on agricultural productivity through communication quality

The analysis results show that communication quality has an important role in mediating the influence of the participatory approach on the agricultural productivity of farmers in four districts in North Sumatra Province, namely Simalungun, South Tapanuli, Deli Serdang, and Langkat, where the t-statistic value is 2.953 > 1.98, and the p-value is 0.000 < 0.05. This finding is in line with previous studies that emphasize that effective communication can improve the understanding and adoption of new agricultural technologies through a participatory approach. Excellent communication between farmers and extension workers accelerates the adoption of agricultural innovations and strengthens cooperation between farmers to overcome existing challenges. With open and two-way communication channels, farmers can more quickly understand new technologies and policies, which in turn increases agricultural yields and the sustainability of the agricultural sector. Effective communication in extension helps farmers understand new technologies, encourages rapid adoption of them, and has an impact on increasing productivity (Matowo et al., 2022). Excellent communication relationships between farmers and extension workers accelerate technology adoption, improve agricultural practices, and strengthen the implementation of more efficient technologies within farmer groups (Ochieng et al., 2022). Successful communication also supports faster decision-making in agricultural management and increases farmer awareness of relevant government policies, contributing to increased agricultural yields and the sustainability of the agricultural sector (López-García et al., 2025).

This study's findings contradict those of Dernat et al. (2022) and Adenuga et al. (2021), which indicated that while participatory communication can enhance community mobilization, its execution is frequently obstructed by insufficient training, inadequate infrastructure, and variations in socio-ecological contexts. Farmer responses to participatory initiatives differ significantly, and while improvements may occur in certain instances, these changes may not consistently manifest in increased productivity (Maughan and Anderson, 2023). According to Lertsinudom et al. (2021), they observed that while good communication can

enhance involvement, it does not guarantee rapid gains in agricultural productivity. Other things that make this participatory communication less effective are variations in aims between farmers and researchers and problems with putting it into practice.

Theoretically, these results align with the innovation diffusion theory, which posits that good communication is essential for the distribution of information and the acceptance of innovations among farmers. Open and interactive communication fosters a social learning process, allowing farmers to share experiences, reduce misunderstandings, and cultivate mutual trust (Mukhtar and Jallow, 2025). Participatory learning also stresses that good communication makes people feel more ownership of agricultural initiatives, which leads to more output.

Based on these results, the North Sumatra Provincial Agriculture Office needs to think about a number of essential things when making public policies and agricultural programs in the four districts. First, program managers need to make sure that ongoing training focuses on making sure that farmers, extension workers, and farmers themselves can talk to each other in a clear and effective way. Second, it's necessary to set up open, two-way communication channels so that farmers and extension workers can share information more easily and build stronger relationships. Third, using digital technology, such as mobile apps, can speed up the deployment of more ecologically friendly and efficient farming technologies. These actions should make extension services work better and increase agricultural productivity in the area.

5.7. The effect of continuous training on agricultural productivity through communication quality

The results of the analysis show that Communication Quality is an important factor in how Continuous Training affects Agricultural Productivity among farmers in four districts in North Sumatra Province: Simalungun District, South Tapanuli District, Deli Serdang District, and Langkat District. The t-statistic value is 4.779, which is greater than 1.98, and the p-value is 0.006, which is less than 0.05. This conclusion corroborates studies highlighting the critical significance of effective communication in facilitating the comprehension and implementation of new agricultural technologies via training programs (Xue et al., 2022). Farmers and extension workers who talk to each other well speed up the use of new farming methods (Liu et al., 2022a). Also, open communication makes it easier for farmers to work together to solve different problems on their farms (Liu et al., 2022b). Farmers can learn about new technology and policies more quickly when there are clear, two-way communication channels (Xiuling et al., 2023). This speeds up the process of adopting new technologies, boosts crop yields, and makes it easier for farmers to work together to solve common problems in agriculture, which in turn makes the agricultural sector more productive and sustainable (Pandey et al., 2025).

Farmers learn more about new technologies when extension services communicate well, which speeds up the adoption of new technologies and boosts production (Li et al., 2023). Farmers and extension workers who talk to each other well speed up the process of adopting new technologies, which in turn improves farming practices (van der Merwe and Makamane, 2025). Strong communication among farmers also speeds up the use of better farming tools and methods. Also, good communication helps agricultural managers make decisions faster (Zhang and Yang, 2025). Well-organized communication also helps farmers learn about important government policies, which in turn leads to better crop yields and a more sustainable agricultural sector.

The findings of this study contradict those of Luo et al. (2025), which indicated that technical innovation and digital infrastructure exert a more significant influence on agricultural output than traditional training methods. Moreover, the study conducted by Qin et al. (2025) underscored the significance of technological innovation in enhancing agricultural output and environmental sustainability in China. Likewise, a study conducted by Huang and Wang (2024) demonstrated that well-structured extension programs, encompassing training, can enhance farmers' capacity for innovation; nevertheless, their effects on production may not be immediate. So, while ongoing training could help farmers communicate better and learn more, other things, including adopting new technology and getting backing from the government, are more important for raising agricultural productivity.

In theory, these results align with the principles of andragogy, which asserts that the efficacy of adult learning (including farmers) is significantly impacted by bidirectional communicative contact, rather than mere unidirectional knowledge transfer. Farmers can talk about their needs, problems, and experiences more easily when the quality of communication is good. This makes training more useful and relevant. The theory of continuous learning posits that continual training is more efficacious when paired with open communication, as this approach promotes the sharing of experiences, enhances comprehension, and expedites the integration of new technologies (Camacho-Zuñiga et al., 2025).

The North Sumatra Provincial Agriculture Office needs to think about a number of significant things based on these findings, especially when it comes to agricultural initiatives and public policy in the four districts. First, program managers need to make sure that ongoing training includes good communication between farmers and extension workers, as well as amongst farmers themselves. Second, there should be open and two-way communication channels set up to make it easier for farmers and extension

workers to share information and build a stronger relationship. Third, mobile-based application platforms and other kinds of digital technology can be used to speed up the usage of more efficient and environmentally friendly farming practices. These actions are expected to make extension services work better and speed up the growth of agricultural productivity in the area.

6. Conclusion

This study offers actual evidence that participatory methodologies and ongoing training substantially improve farmers' production in four areas of North Sumatra Province. Communication quality is a key link between the transmission of knowledge from training and participatory procedures to real-world use. Farmers are more likely to absorb technical knowledge, try new things, and operate more efficiently when communication is clear, open, and two-way.

This study contributes to the field of agricultural extension and rural development by positing that communication serves not only as a conduit for information dissemination but also as a catalyst for behavioral transformation and the adoption of agricultural innovations. This shows how important it is to include communication methods in all agricultural development programs so that training and participation really do lead to long-term increases in productivity.

From a practical and policy point of view, agricultural development initiatives should put a lot of emphasis on getting farmers involved in designing, carrying out, and evaluating the programs, as well as giving them ongoing training that is based on their needs. Also, farmers, extension workers, and other people who have a stake in the situation need to be able to communicate better with each other, especially through digital platforms. These actions will help people work together, make food safer in the area, and make life better for farming communities.

This work significantly contributes to the formulation of inclusive, adaptive, and sustainable agricultural development methods. The results can be used by politicians, extension organizations, and development agencies to improve Indonesia's agricultural productivity.

List of abbreviations

AVE	Average variance extracted
BPS	Central Statistics Agency of Indonesia
CANBUS	Controller area network bus communication system
GDP	Gross domestic product
HTMT	Heterotrait–Monotrait ratio
ICT	Information and communication technology
IoT	Internet of Things
KC	Indicator code for communication quality variables
M	Mediating variable
PA	Indicator code for participatory approach variables
PB	Indicator code for continuous training variables
PLS	Partial least squares
PP	Indicator code for agricultural productivity variables
PSM	Propensity score matching
SAPs	Sustainable agricultural practices
SDG	Sustainable development goal
SEM	Structural equation modeling
SEM-PLS	Structural equation modeling with partial least squares
X1	Participatory approach variable
X2	Continuous training variable
Y	Agricultural productivity variable

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Compliance with ethical standards

Ethical considerations

This study involved human participants and was conducted in accordance with ethical research principles. Participation was entirely voluntary, and informed consent was obtained from all respondents prior to data collection. Participants were informed about the purpose of the study and assured that their responses would remain anonymous and confidential. No personally identifiable information was collected.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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