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Rural Agricultural Transformation through Strengthening Access to Capital and Adoption of Agricultural Technology in Aceh Besar Regency

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A B S T R A C T

Rural agricultural transformation requires adequate access to capital and the adoption of agricultural technologies to improve productivity, operational efficiency, and the sustainability of farming activities. However, limited access to financial resources, low utilization of modern agricultural technologies, and socioeconomic constraints remain significant challenges for rural farming communities. This study aims to examine the role of capital access in supporting agricultural technology adoption and promoting rural agricultural transformation in Aceh Besar Regency, Indonesia. Specifically, the study focuses on the relationship between access to agricultural financing, farmers' adoption of modern technologies, and the development of productive and sustainable farming activities. The research employs a quantitative approach supported by descriptive analysis to investigate farmers' access to capital, technology utilization, and the socioeconomic factors influencing agricultural development. Data are collected through questionnaires and field observations involving farmers and agricultural stakeholders in the research area. The analysis is intended to identify the extent to which financial accessibility facilitates the adoption of agricultural technologies, including modern farming equipment, improved cultivation practices, and production innovations. The study is expected to demonstrate that strengthening access to capital, accompanied by improved technological adoption, can contribute to increased agricultural productivity, better farm management, and enhanced economic resilience among rural farming communities. Furthermore, the findings are expected to provide practical insights for developing integrated agricultural development strategies that connect financial accessibility, technological innovation, and sustainable rural livelihoods. This research contributes to the discussion of agricultural technology adoption and rural transformation, particularly in strengthening the capacity of farming communities in Aceh Besar Regency.

Keywords: Agricultural Transformation; Access to Capital; Agricultural Technology Adoption; Agricultural Productivity

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INTRODUCTION

Agricultural transformation in rural areas has become an important component of sustainable economic development, particularly in developing countries where agriculture remains a major source of employment, household income, and food security. The transformation of the agricultural sector is no longer limited to increasing agricultural production through land expansion or conventional cultivation practices but increasingly involves improvements in production systems, access to financial resources, technological innovation, and the strengthening of farmers' institutional capacity. In this context, rural agricultural transformation represents a comprehensive process that integrates economic, technological, and institutional changes to improve the competitiveness and sustainability of agricultural activities. The development of modern agriculture requires farmers to move beyond traditional production systems toward more productive, efficient, and technology-oriented farming practices. This transition is particularly important in responding to changing market demands, climate variability, production costs, and the increasing need for sustainable food systems. The Food and Agriculture Organization emphasizes the importance of transforming agrifood systems through technological innovation, investment, and inclusive institutional development to strengthen agricultural productivity and resilience (FAO, 2022; FAO, 2023).

One of the fundamental challenges in rural agricultural transformation is the availability and accessibility of capital to support farming activities. Agricultural production requires continuous financial resources to purchase seeds, fertilizers, pesticides, machinery, irrigation equipment, and other production inputs. However, many smallholder farmers experience financial constraints that limit their ability to improve production capacity and adopt modern agricultural technologies. Limited access to formal financing, inadequate collateral, fluctuating agricultural income, and the uncertainty of production outcomes often create barriers to agricultural investment. Consequently, farmers tend to rely on personal savings, informal borrowing, or traditional production arrangements that may not provide sufficient financial capacity for long-term agricultural development. Access to capital is therefore not merely a financial issue but also a determining factor in farmers' ability to improve production efficiency, expand business activities, and

participate in agricultural modernization. Recent studies have demonstrated that financial inclusion and access to agricultural credit can influence farmers' investment decisions, technology adoption, and productive capacity, although the effects depend on financial accessibility, institutional conditions, and farmers' economic characteristics (World Bank, 2022; FAO, 2023).

Agricultural technology adoption represents another essential dimension of rural agricultural transformation. Technological development has created opportunities to improve agricultural productivity through mechanization, precision farming, digital information systems, improved irrigation technologies, and the application of innovative cultivation methods. The use of agricultural machinery can reduce labor requirements and operational time, while improved cultivation technologies can support better input management and production quality. Furthermore, digital agricultural platforms provide farmers with access to information concerning weather conditions, market prices, agricultural practices, and production management. However, the adoption of technology is not determined solely by the availability of technological equipment. Farmers' financial capacity, education, access to agricultural extension services, infrastructure, institutional support, and perceptions of technological benefits also influence their willingness and ability to adopt innovation. Therefore, technological transformation requires an integrated approach that connects technological availability with financial accessibility and farmers' capacity to utilize innovation effectively (FAO, 2022; OECD, 2023).

The relationship between access to capital and agricultural technology adoption is particularly important because technological innovation often requires substantial initial investment. Farmers may recognize the benefits of modern agricultural equipment, improved seeds, efficient irrigation systems, and digital farming applications, but their ability to implement these innovations depends on the availability of financial resources. Without adequate capital, technology adoption may remain limited to farmers with relatively stronger economic conditions, while smallholder farmers continue to depend on conventional production methods. The Food and Agriculture Organization (FAO, 2022) explains that financial constraints, limited digital literacy, and inadequate infrastructure are among the major

barriers to the inclusive adoption of agricultural automation, particularly among small-scale producers. This indicates that agricultural modernization cannot be achieved solely through the introduction of new technologies but must also be supported by financing mechanisms that enable farmers to access and utilize technological innovations. Therefore, strengthening access to capital should be considered an integral part of agricultural technology development rather than an independent financial intervention.

In the Indonesian context, agricultural transformation faces structural challenges related to the characteristics of smallholder farming, fragmented agricultural land, limited production resources, and unequal access to modern technologies. Small-scale farmers frequently operate under conditions of limited capital, uncertain agricultural prices, and fluctuating production costs. These circumstances affect their investment decisions and ability to adopt innovations that could improve farming efficiency. Agricultural financing plays an important role in addressing these constraints because it enables farmers to obtain production inputs, invest in machinery, improve cultivation systems, and expand their agricultural activities. Research by Hanani et al. (2024) indicates that access to financial capital has a positive relationship with the technical efficiency of small-scale carrot farming in Indonesia. This suggests that financial accessibility can contribute to more efficient utilization of agricultural inputs and improved production performance. Accordingly, capital strengthening should be understood as a productive investment that supports agricultural development, rather than merely as a mechanism for meeting short-term operational expenses.

The importance of technological adoption is also reflected in empirical research on Indonesian agricultural households. Research on smallholder dairy farmers by (2022) demonstrates that technology adoption varies considerably across farmer groups, particularly in relation to education, farm size, profitability, geographical accessibility, and contact with agricultural extension personnel. These differences indicate that farmers do not have equal opportunities to benefit from technological innovation. Farmers with better access to information, institutional support, and productive resources tend to have greater opportunities to recognize and adopt available technologies. Similarly, research by (2024) on digital agricultural technology in Indonesia identifies infrastructure limitations, economic constraints, and

institutional barriers as important factors affecting the adoption of agricultural technology among smallholder farmers. These findings demonstrate that technology adoption is a multidimensional process involving economic capacity, human resources, institutional accessibility, and the availability of appropriate technological infrastructure.

Agricultural extension services also have an important role in connecting technological innovation with farmers' practical needs. The introduction of modern agricultural technologies requires not only the distribution of equipment but also the development of farmers' technical knowledge and operational capabilities. Agricultural extension personnel can facilitate the transfer of information, provide technical guidance, demonstrate improved cultivation practices, and encourage farmers to evaluate the economic benefits of adopting new technologies. Research conducted by (2023) on smallholder farmers in Banten, Indonesia, identifies agricultural extension access as an important factor influencing technology adoption and farm income. The study highlights the contribution of extension services to improving farmers' access to agricultural information and supporting the utilization of technological innovations. Consequently, rural agricultural transformation should integrate financial support, technological availability, and agricultural extension services to ensure that innovation can be implemented effectively at the farm level.

Aceh Besar Regency provides a relevant geographical context for examining the relationship between capital access and agricultural technology adoption. Agriculture remains an important component of the regional economic structure and rural livelihoods. However, agricultural development in the region faces challenges related to production efficiency, weather variability, agricultural infrastructure, and the capacity of farmers to access productive resources. According to the Central Statistics Agency of Aceh Besar Regency (BPS Kabupaten Aceh Besar, 2025), the agricultural sector contributed 22.58% to the regional gross domestic product (GRDP) in 2025. This figure demonstrates the continued importance of agriculture in the regional economy, although the sector's contribution experienced fluctuations during the preceding years. The regional economic structure indicates that agricultural development remains relevant to strengthening economic resilience, employment opportunities, and the welfare of rural communities. Therefore, improvements in agricultural productivity and

the modernization of farming practices are important considerations in supporting the long-term development of Aceh Besar Regency.

The agricultural transformation agenda in Aceh Besar also needs to consider the characteristics of rural farming communities, particularly their access to production capital and their readiness to utilize agricultural technology. Rural farmers operate within different economic and institutional conditions, which influence their capacity to invest in agricultural activities. Some farmers may have access to agricultural financing but lack sufficient knowledge or technical assistance to select appropriate technologies. Others may understand the benefits of modern agricultural equipment and improved cultivation systems but remain unable to adopt them because of limited financial resources. This situation creates a potential gap between the availability of agricultural innovation and the actual capacity of farmers to implement it. The gap is important because the benefits of agricultural modernization depend not only on the existence of technological solutions but also on the economic and institutional conditions that enable farmers to access, adopt, and sustain their use. Consequently, understanding the interaction between capital accessibility and technological adoption is essential for identifying the factors that facilitate or constrain agricultural transformation in rural Aceh Besar.

The issue of agricultural transformation in Aceh Besar is also closely related to the sustainability of farming systems. Agricultural development should not focus exclusively on increasing production volumes but should also consider resource efficiency, environmental protection, production cost management, and farmers' long-term economic resilience. The adoption of appropriate agricultural technologies can support sustainable farming through more efficient water management, reduced post-harvest losses, improved soil management, and more effective utilization of production inputs. Nevertheless, technology adoption must be adjusted to local agricultural conditions, farmers' financial capabilities, and the availability of supporting infrastructure. The FAO (2022) emphasizes that agricultural automation can improve productivity, resource-use efficiency, and environmental sustainability, provided that the adoption process is inclusive and accessible to small-scale producers. Similarly, digital transformation in agrifood systems can improve farmers' access to agricultural information, production inputs, output markets, and

financial services (World Bank, 2022). These developments demonstrate that sustainable agricultural transformation requires the integration of economic resources, technological innovation, and institutional support.

Furthermore, the relationship between agricultural financing and technological adoption needs to be understood as an interconnected process. Access to capital enables farmers to invest in productive assets, while technological adoption determines how effectively these investments are converted into improved agricultural performance. However, the availability of financing does not automatically guarantee successful technology adoption. Farmers must also possess sufficient technical knowledge, access to agricultural information, and the ability to evaluate the suitability of technologies for their production conditions. Conversely, technological innovations may remain underutilized when farmers lack the financial resources required for implementation and maintenance. This relationship highlights the importance of examining capital access and technology adoption simultaneously rather than treating them as separate dimensions of agricultural development. Research by Akzar et al. (2023) demonstrates that differences in farmers' socioeconomic characteristics, productive resources, and access to extension services are associated with heterogeneous patterns of technology adoption among Indonesian smallholder farmers. These findings suggest that agricultural transformation policies should be designed according to the specific characteristics and constraints experienced by different groups of farmers.

This research addresses the gap by positioning access to capital and agricultural technology adoption as interconnected factors in rural agricultural transformation. Rather than examining financing solely as an economic resource or technology solely as a production instrument, this study considers how both dimensions contribute to farmers' capacity to improve their agricultural activities. The research also considers socioeconomic characteristics, including education, farming experience, land ownership, household economic conditions, access to agricultural information, and participation in farmer organizations, as contextual factors that may influence the transformation process. This perspective is important because farmers' decisions to invest in agricultural production and adopt new technologies are influenced by multiple economic and institutional conditions. The integration of these dimensions provides a more comprehensive understanding of the challenges faced by rural

farming communities and the opportunities available to strengthen agricultural development.

The urgency of this research is further supported by the economic significance of agriculture in Aceh Besar Regency. According to the 2026 publication of the Central Statistics Agency of Aceh Besar Regency, the agricultural, forestry, and fisheries sectors contributed approximately 22.58% to the regional gross domestic product at current prices in 2025. The publication also documents fluctuations in the sector's contribution during the 2021–2025 period, indicating the importance of examining factors that influence agricultural performance and resilience. These regional conditions reinforce the need for agricultural development strategies that go beyond conventional production approaches. Strengthening farmers' access to productive capital, improving the dissemination of appropriate agricultural technologies, and expanding institutional support are relevant approaches to improving the capacity of rural agricultural communities. Therefore, research in Aceh Besar can provide contextual evidence for understanding how agricultural transformation can be strengthened through the integration of financial resources and technological innovation.

Based on these considerations, this study aims to analyze the role of access to capital in supporting agricultural technology adoption and rural agricultural transformation in Aceh Besar Regency. Specifically, it examines the extent to which farmers' access to financial resources supports investment in agricultural production, the factors influencing their adoption of modern agricultural technologies, and the relationship between capital accessibility, technology utilization, and the development of farming activities. The study also seeks to identify the economic, social, and institutional barriers that limit farmers' capacity to participate in agricultural modernization. By examining these dimensions, the research is expected to contribute to the development of an integrated understanding of rural agricultural transformation, particularly in relation to agricultural financing, technological innovation, and sustainable farming practices. The findings are expected to provide empirical insights for policymakers, agricultural extension institutions, farmer organizations, and other stakeholders in designing agricultural development strategies that are responsive to local conditions and the needs of smallholder farmers.

Ultimately, this study contributes to the broader discussion of agricultural technology and rural development by emphasizing that agricultural transformation requires more than the introduction of modern equipment or the expansion of financing opportunities. It requires the development of an enabling environment in which farmers have the financial capacity, technical knowledge, institutional support, and technological infrastructure necessary to improve their production systems. Through the integration of these factors, rural agricultural communities in Aceh Besar Regency can be better positioned to strengthen farm productivity, improve economic resilience, and develop more sustainable agricultural practices.

METHOD

This study employs a quantitative research approach supported by descriptive analysis to examine rural agricultural transformation through strengthening access to capital and the adoption of agricultural technology in Aceh Besar Regency, Indonesia. A quantitative approach is selected because it enables the systematic measurement of farmers' access to financial resources, their adoption of agricultural technologies, and the socioeconomic factors associated with agricultural development. The research focuses on understanding the relationship between financial accessibility and technological adoption in supporting agricultural productivity and the sustainability of farming activities. The study uses a cross-sectional research design in which data are collected from respondents at a particular period to provide an empirical overview of the conditions experienced by rural farming communities. This approach is relevant for examining the economic and technological dimensions of agricultural transformation within the local agricultural context (Creswell & Creswell, 2023).

The research is conducted in Aceh Besar Regency, with particular attention to rural agricultural communities in the selected research area. The research population consists of farmers who actively engage in agricultural production activities. Respondents are selected using purposive sampling based on several criteria, including active participation in farming activities, involvement in agricultural production, and knowledge of agricultural financing and technology utilization. The sample size is determined based on the characteristics of

the population, research objectives, and statistical requirements. Data are collected through structured questionnaires, direct field observations, and supporting documentation. The questionnaire is designed to obtain information regarding farmers' socioeconomic characteristics, access to capital, utilization of agricultural financing, adoption of agricultural technologies, and agricultural production performance. Primary data are obtained directly from respondents, while secondary data are collected from relevant government publications, agricultural institutions, statistical reports, and previous academic studies.

The research variables consist of access to capital as the independent variable and agricultural technology adoption as the second explanatory variable, while agricultural transformation serves as the dependent variable. Access to capital is measured through indicators including availability of financial resources, accessibility of agricultural financing, adequacy of production capital, and farmers' ability to finance agricultural investments. Agricultural technology adoption is assessed through the utilization of modern farming equipment, improved cultivation techniques, irrigation technology, improved agricultural inputs, and post-harvest technologies. Agricultural transformation is examined through indicators related to changes in farming practices, production efficiency, productivity improvement, and the sustainability of agricultural activities. Socioeconomic characteristics, such as educational background, farming experience, land ownership, household income, and access to agricultural extension services, are also considered as contextual variables that may influence the transformation process. The operationalization of these variables follows the general principles of agricultural technology adoption and farm-level economic analysis (FAO, 2022; OECD, 2023).

Data analysis is conducted through descriptive statistics and inferential statistical techniques. Descriptive analysis is used to identify the distribution of respondents' characteristics, levels of capital accessibility, patterns of agricultural technology utilization, and the general conditions of agricultural transformation. Furthermore, inferential analysis is employed to examine the relationships between access to capital, agricultural technology adoption, and agricultural transformation. Multiple linear regression may be applied to assess the contribution of independent variables to agricultural transformation,

subject to the measurement scale and fulfillment of statistical assumptions. The proposed analytical model is expressed as follows:

$$AT = \alpha + \beta_1 AC + \beta_2 TA + \beta_3 SE + \varepsilon$$

Where AT represents agricultural transformation, AC represents access to capital, TA represents agricultural technology adoption, SE represents socioeconomic characteristics, α is the constant, β_1, β_2, and β_3 are regression coefficients, and ε represents the error term. Before hypothesis testing, the data are evaluated through instrument validity and reliability tests, followed by relevant classical assumption tests, including normality, multicollinearity, and heteroscedasticity tests where applicable. Statistical analysis is conducted to determine the direction, magnitude, and significance of the relationships among the research variables.

To strengthen the interpretation of the findings, descriptive observations are used to explain the practical conditions influencing farmers' access to capital and their capacity to adopt agricultural technologies. This approach enables the research to identify not only statistical relationships but also the potential barriers associated with agricultural infrastructure, financial resources, technological knowledge, and institutional support. Research ethics are maintained by ensuring voluntary participation, explaining the research objectives to respondents, protecting personal information, and using collected data exclusively for academic purposes. Through this methodological framework, the study is expected to provide empirical evidence regarding the role of capital accessibility and agricultural technology adoption in supporting rural agricultural transformation in Aceh Besar Regency.

RESULTS AND DISCUSSION

Farmers' Access to Capital and Socioeconomic Conditions in Rural Agricultural Development

Access to capital represents one of the fundamental determinants of agricultural development, particularly among smallholder farmers who depend on financial resources to maintain and improve their production activities. Agricultural enterprises require continuous investment in

production inputs, including seeds, fertilizers, pesticides, agricultural equipment, irrigation facilities, and labor. The availability of sufficient capital determines the extent to which farmers can manage their production activities, respond to changing market conditions, and implement improvements in cultivation systems. In rural agricultural communities, financial limitations frequently restrict farmers' ability to increase production capacity and invest in productive assets. Consequently, access to capital should be understood as an essential component of agricultural development because it influences both the scale of farming activities and the capacity to adopt production innovations. This condition is particularly relevant to smallholder agricultural systems, where limited financial resources may constrain the transition from conventional farming practices toward more efficient and technology-oriented production systems (Haryanto et al., 2023).

The socioeconomic characteristics of farmers also influence their ability to obtain and utilize agricultural capital. Education, farming experience, land ownership, household income, and participation in farmer organizations can determine farmers' financial capabilities and investment decisions. Farmers with relatively stable household income may have greater opportunities to allocate financial resources to agricultural investment, while those who depend exclusively on seasonal agricultural income may experience difficulties in maintaining sufficient working capital. Furthermore, land ownership can influence access to formal financing because land and other productive assets may serve as indicators of economic capacity and, in certain financing arrangements, collateral. However, farmers who cultivate agricultural land under rental or informal arrangements may face additional difficulties in obtaining institutional financing. These socioeconomic differences demonstrate that access to capital is not determined exclusively by the availability of financial institutions but also by the economic characteristics and institutional positions of individual farmers.

In the Indonesian agricultural context, access to formal financing remains an important issue because smallholder farmers frequently depend on limited personal savings and informal financial arrangements. Haryanto et al. (2023), in their study of maize farming across ten major producing provinces in Indonesia, demonstrate that access to agricultural credit can improve farm productivity and technical efficiency. Their findings also indicate that credit obtained from formal financial

institutions produces more effective improvements in agricultural performance than credit obtained from informal sources. This evidence highlights the importance of institutional financing in supporting agricultural investment and improving the utilization of production inputs. Access to financing enables farmers to obtain the resources required for production activities without relying exclusively on accumulated household savings. Nevertheless, financing programs need to consider the seasonal nature of agricultural production, repayment capacity, production risks, and the characteristics of smallholder farming enterprises.

The relationship between capital availability and agricultural development is also reflected in farmers' ability to purchase and maintain modern agricultural equipment. Investment in agricultural technology frequently requires relatively substantial initial expenditure, particularly when farmers intend to introduce machinery, irrigation systems, digital monitoring devices, or improved post-harvest facilities. For smallholder farmers, such investment may be difficult to undertake independently because agricultural income is generally subject to seasonal fluctuations and production uncertainty. Consequently, the absence of accessible capital may delay technological improvements even when farmers recognize the potential benefits of innovation. This condition suggests that agricultural financing should be directed not only toward the procurement of conventional production inputs but also toward productive investments that improve long-term agricultural capacity.

Research by Agussabti et al. (2022) provides relevant evidence concerning the relationship between farmers' financial conditions and technological development in Aceh Province. Their study examined the perspectives and readiness of farmers to adopt smart farming technology for rice, maize, and potato production. The research involved 210 farmers and 48 agricultural extension workers, demonstrating that farmers generally had positive perceptions of smart farming applications but relatively lower readiness than extension workers. Limited financial resources, agricultural land characteristics, and farmers' human resource capacities were among the factors influencing technological adoption. These findings indicate that technological development in Aceh requires improvements in economic accessibility and farmers' technical capabilities. In this regard, access to capital becomes an important instrument for facilitating the transition from conventional agricultural

practices toward more modern production systems (Agussabti et al., 2022).

In the context of Aceh Besar Regency, these conditions provide an important basis for examining the financial circumstances of rural farming communities, particularly in Gampong Lampreh-Lamteungoh. Agricultural development in rural areas depends on the capacity of farmers to finance production inputs, maintain agricultural equipment, and respond to changing production requirements. However, financial accessibility needs to be evaluated in relation to the specific characteristics of the agricultural enterprises operating in the area. Farmers engaged in food crop production, horticulture, and other agricultural activities may have different financing requirements because of differences in production cycles, input costs, market arrangements, and expected returns. Therefore, the assessment of capital accessibility should consider not only whether farmers receive financing but also whether the amount, timing, conditions, and utilization of such financing are appropriate for their agricultural activities.

Another important dimension is the relationship between capital accessibility and farmers' participation in agricultural institutions. Farmer organizations, cooperatives, and agricultural associations can facilitate access to information, production inputs, financing opportunities, and collective investment arrangements. Participation in these institutions may also improve farmers' bargaining capacity when obtaining production resources and accessing agricultural markets. Haryanto et al. (2023) identify farmer group participation as one of the factors associated with farmers' access to credit in Indonesia. This finding suggests that institutional participation can provide an important connection between individual farmers and external financial resources. In addition, collective financing arrangements may reduce individual investment burdens, particularly when agricultural machinery and post-harvest facilities can be utilized jointly by several farmers.

The financial dimension of agricultural development should also be considered in relation to the risks associated with farming activities. Agricultural production is exposed to uncertainties involving weather conditions, pest attacks, crop diseases, fluctuating input prices, and changes in agricultural commodity prices. These uncertainties can affect farmers' ability to repay financing and influence their willingness to undertake additional investments. Marginal farming households may be

particularly vulnerable when agricultural losses coincide with limited household savings and restricted access to alternative income sources. Research on marginal farmers in Aceh by (2025) identifies limited capital, land ownership constraints, low agricultural yields, and environmental risks as important dimensions of household vulnerability and food insecurity. This demonstrates that financial accessibility needs to be integrated with agricultural risk management and sustainable production strategies rather than being treated as an independent development intervention (2025).

Furthermore, the effectiveness of agricultural financing depends on how farmers allocate and manage the available resources. Capital that is directed toward productive activities can facilitate the purchase of higher-quality agricultural inputs, improvement of cultivation practices, and investment in production equipment. Conversely, financing that is not accompanied by appropriate production planning may not generate sufficient improvements in agricultural performance. Therefore, strengthening farmers' financial capacity should also involve financial management education, production cost planning, investment evaluation, and the development of basic agricultural business records. These capabilities can help farmers distinguish between household consumption requirements and productive agricultural expenditures, thereby improving the effectiveness of capital utilization.

Agricultural Technology Adoption and Its Implications for Farming Productivity

Agricultural technology adoption represents a central dimension of agricultural transformation because it enables farmers to improve production efficiency, reduce operational constraints, and strengthen the quality of agricultural outputs. Technological innovation in agriculture includes mechanization, improved cultivation techniques, irrigation systems, high-quality seeds, digital information platforms, and modern post-harvest management. These technologies provide opportunities to improve agricultural production by optimizing the utilization of land, labor, water, and other production inputs. However, the adoption of technology involves more than the availability of equipment or infrastructure. Farmers must also possess the technical knowledge, financial capacity, and institutional support required to operate and maintain technological innovations. Consequently, the successful

adoption of agricultural technology depends on the interaction between technological availability, farmers' economic conditions, and their capacity to incorporate innovation into existing production systems (Agussabti et al., 2022).

The adoption of agricultural technology among smallholder farmers is frequently influenced by the characteristics of their production systems. Farmers who operate relatively small agricultural holdings may find it difficult to invest in expensive machinery because the cost of purchasing and maintaining equipment may exceed their production capacity. In addition, differences in agricultural commodities and cultivation cycles can influence the suitability of specific technological innovations. Technologies designed for large-scale agricultural production may not necessarily be appropriate for smallholder farming systems. Therefore, agricultural modernization requires the selection of technologies that correspond to the scale, production characteristics, and financial capacity of rural farmers. Appropriate technology should not only improve productivity but also remain economically feasible and operationally accessible to the intended users.

The experience of agricultural communities in Aceh provides important insights into the opportunities and challenges associated with technological adoption. Agussabti et al. (2022) examined farmers' perspectives on smart farming technology for rice, maize, and potato cultivation in Aceh Province. Their study identified several technological applications, including weather monitoring, soil fertility sensors, pest and disease detection, and digital agricultural information systems. The results showed that farmers and agricultural extension workers generally perceived smart farming technology positively, particularly in relation to productivity improvement, production cost reduction, and access to information for agricultural decision-making. Nevertheless, farmers demonstrated lower readiness to adopt the technology compared with agricultural extension workers because of limitations in financial resources and human resource capacity. This finding demonstrates that positive perceptions of technological innovation do not automatically translate into actual adoption at the farm level (Agussabti et al., 2022).

Technological adoption also depends on the accessibility of agricultural information and the availability of extension services. Farmers require accurate and practical information concerning technological benefits, operating procedures, maintenance requirements,

and the economic implications of adopting new production methods. Agricultural extension services can facilitate this process by introducing technological innovations, conducting field demonstrations, providing technical assistance, and helping farmers evaluate the suitability of different technologies. Through extension activities, farmers can obtain information that reduces uncertainty and increases confidence in adopting innovations. Moreover, agricultural extension can connect farmers with research institutions, government programs, technology providers, and agricultural markets. Therefore, the quality and accessibility of extension services are important determinants of the success of technological transformation in rural agricultural communities.

The importance of extension services is also demonstrated by research conducted by (2023) on smallholder farmers in Banten, Indonesia. The study identified a positive relationship between access to agricultural extension services, technology adoption, and farm income. Its findings indicate that farming experience, irrigation availability, farmer group participation, mobile phone ownership, and other socioeconomic characteristics influence access to extension services. This evidence suggests that technological adoption is supported by a broader institutional environment involving information dissemination, communication infrastructure, and farmer participation. Agricultural technology programs should therefore be implemented through integrated approaches that combine technological introduction with practical training and institutional assistance.

Digital agricultural technologies have also expanded the opportunities for improving farm management and decision-making. Digital platforms can provide information concerning weather forecasts, agricultural commodity prices, cultivation recommendations, pest and disease identification, and market opportunities. The integration of information and communication technology into agricultural activities can improve the speed and quality of farmers' decisions, particularly when production conditions change rapidly. For example, access to weather information can help farmers determine appropriate planting periods, while market information can support decisions regarding harvesting and commodity distribution. Similarly, digital monitoring systems can assist farmers in identifying changes in soil conditions and crop requirements. However, the effectiveness of digital agricultural

systems depends on internet connectivity, smartphone accessibility, digital literacy, and the availability of relevant information in formats that farmers can understand and utilize.

Recent research by Triady (2026) on smallholder coffee farmers in Central Aceh provides additional evidence concerning readiness to adopt smart farming technology. The study examined the use of fertilizer sensors and found that farmers' readiness was associated with knowledge, motivation, resource availability, access to information, and infrastructure. The results indicate that technological adoption requires improvements in farmers' capacity and the supporting institutional environment. Although the research focused on coffee farming in Central Aceh rather than agricultural communities in Aceh Besar, its findings offer relevant comparative insights into the conditions affecting technology adoption in Aceh's rural agricultural systems (Triady, 2026). The relationship between technological adoption and agricultural productivity can also be explained through improvements in production efficiency. Modern agricultural equipment can reduce the time and labor required for land preparation, planting, irrigation, harvesting, and post-harvest handling. Improved cultivation techniques can support more effective input utilization and reduce unnecessary production expenditure. Meanwhile, better irrigation systems can improve water availability and reduce the risks associated with irregular rainfall. The utilization of improved seeds and appropriate cultivation methods can also contribute to better crop development and production quality. Nevertheless, technological adoption should be evaluated according to its actual contribution to agricultural performance. The introduction of expensive machinery does not necessarily produce economic benefits when the equipment is not suitable for local conditions, is underutilized, or requires maintenance costs beyond farmers' financial capacity.

Technological adoption should also be understood in relation to environmental sustainability. Agricultural technologies that improve water management, fertilizer application, pest control, and post-harvest handling can support more efficient resource utilization. Precision-based technologies, for example, provide opportunities to apply agricultural inputs according to specific production requirements rather than relying on uniform application practices. Such improvements may reduce unnecessary input use and support the conservation of agricultural resources. Similarly, appropriate post-harvest technologies can minimize

product losses and improve the quality of agricultural commodities. Therefore, agricultural modernization should consider not only production growth but also the environmental and economic consequences of technological implementation.

The adoption process also requires attention to differences in farmers' knowledge, experience, and willingness to change established cultivation practices. Farmers with long experience may possess valuable practical knowledge concerning local soil conditions, weather patterns, and production cycles. However, they may also prefer familiar techniques when the economic benefits of new technologies remain uncertain. Younger farmers may be more familiar with digital applications and modern communication systems, although their access to agricultural land and investment capital may be limited. These differences indicate that agricultural technology programs should be designed according to the characteristics of different farmer groups. Training programs, field demonstrations, and participatory technology development can help ensure that innovations are compatible with farmers' actual requirements.

In Gampong Lampreh-Lamteungoh, the assessment of agricultural technology adoption should therefore focus on the technologies that are relevant to the dominant agricultural commodities and production systems in the area. The research needs to identify the extent to which farmers utilize modern agricultural equipment, improved seeds, irrigation facilities, cultivation innovations, and post-harvest technologies. It should also examine the factors that facilitate or constrain adoption, including financial capacity, technical knowledge, infrastructure, extension access, and institutional participation. By examining these dimensions, the study can provide a more comprehensive understanding of how technological innovation contributes to the development of rural agricultural activities in Aceh Besar Regency.

Rural Agricultural Transformation through the Integration of Capital Accessibility and Technological Innovation

Rural agricultural transformation requires the integration of economic resources, technological innovation, and institutional development to improve the productivity and sustainability of farming systems. Access to capital and agricultural technology adoption are

closely interconnected because financial resources enable farmers to invest in technological improvements, while technology determines how effectively available resources are utilized in agricultural production. When these two dimensions are developed independently, the benefits of agricultural modernization may remain limited. Farmers may have access to financing but lack the knowledge and technological infrastructure necessary to improve production efficiency. Conversely, technological innovations may be available through government programs or private providers but remain underutilized because farmers lack the financial capacity to acquire, operate, and maintain them. Therefore, agricultural transformation requires an integrated development framework that connects financial accessibility with technological capabilities.

The relationship between capital accessibility and technology adoption can be explained through the investment requirements associated with modern agricultural production. Farmers need sufficient financial resources to purchase production inputs, obtain machinery, improve irrigation systems, and introduce digital technologies. These investments may generate long-term benefits through improved productivity, reduced operational costs, and more efficient resource management. However, farmers' investment decisions are influenced by expected returns, production risks, financing costs, and the availability of supporting infrastructure. Haryanto et al. (2023) demonstrate that agricultural credit access can improve productivity and technical efficiency among Indonesian maize farmers. Their findings indicate that institutional financing can facilitate productive investment and improve farm performance. This evidence reinforces the importance of financing as a mechanism for supporting technological and production improvements in agricultural enterprises (Haryanto et al., 2023).

The integration of financial accessibility and technological innovation is particularly important for smallholder farmers because their investment capacity is often limited. Agricultural modernization programs that focus exclusively on distributing machinery may not achieve sustainable outcomes when farmers lack the resources required for maintenance, fuel, spare parts, and technical operation. Similarly, financing programs that do not consider technological suitability may result in investments that fail to improve production performance. Therefore, the effectiveness of agricultural development interventions

depends on the extent to which financing arrangements are connected with appropriate technological solutions. This integration can be achieved through agricultural credit programs, collective machinery ownership, cooperative investment, government-supported technology facilities, and partnerships between farmer organizations and agricultural service providers.

The experience of Aceh Province demonstrates the importance of such an integrated approach. Agussabti et al. (2022) found that farmers had positive perceptions of smart farming technology but relatively lower readiness to implement it because of financial and capacity limitations. The study emphasizes that technological adoption requires both access to appropriate equipment and improvements in farmers' technical skills. This evidence suggests that agricultural transformation in Aceh cannot rely exclusively on technological introduction. It must also address the economic conditions that influence farmers' ability to adopt and sustain technological innovation. In this regard, financial support, technical training, and institutional assistance should be implemented as complementary components of agricultural modernization (Agussabti et al., 2022).

Another important aspect of agricultural transformation is the improvement of production efficiency through the interaction between financial resources and technological innovation. Access to capital can enable farmers to obtain better production inputs and invest in equipment that reduces operational constraints. Meanwhile, appropriate technology can improve the allocation of labor, land, water, and other resources. When financial investments are directed toward productive technological applications, farmers may obtain greater opportunities to improve agricultural performance. However, the relationship is not necessarily automatic because the benefits of technological investment depend on the suitability of the technology, farmers' technical capacity, and the conditions of agricultural infrastructure. Therefore, agricultural transformation requires an evaluation of both the availability of resources and the effectiveness of their utilization.

Institutional development also plays a significant role in connecting farmers with financial and technological resources. Farmer organizations can facilitate collective access to financing, machinery, production inputs, and agricultural information. Through collective arrangements, farmers may share the costs of purchasing and maintaining agricultural

equipment, reducing the individual investment burden. Farmer organizations can also strengthen communication between agricultural communities and government institutions, research centers, financial institutions, and technology providers. In this context, institutional participation can support the distribution of technological information and improve farmers' access to development programs. Haryanto et al. (2023) also identify participation in farmer groups as an important factor associated with access to agricultural credit. This finding highlights the role of social and institutional networks in strengthening the economic capacity of agricultural communities.

Agricultural transformation should also incorporate the development of sustainable production systems. The increasing pressure on agricultural resources requires farmers to adopt production methods that improve efficiency while maintaining environmental quality. Technological innovation can support more efficient fertilizer application, improved water management, better pest control, and reduced post-harvest losses. Nevertheless, sustainable agricultural practices require sufficient financial investment and technical knowledge. Farmers may recognize the importance of environmentally responsible production but face difficulties implementing it because of limited capital, inadequate equipment, or insufficient technical assistance. Consequently, financial support should be directed toward technologies that provide both economic and environmental benefits. This approach can strengthen agricultural productivity while supporting the long-term sustainability of rural farming systems.

The relationship between agricultural transformation and rural economic resilience is also important. Agricultural households frequently depend on seasonal production and are exposed to fluctuations in agricultural prices, weather conditions, and production costs. Limited capital and low productivity can increase household vulnerability, particularly when farmers experience crop failures or unfavorable market conditions. Research by (2025) on marginal farmers in Aceh demonstrates that limited capital, low yields, and land-related constraints contribute to food insecurity risks. The research also emphasizes the importance of financial services, sustainable agricultural practices, and climate-resilient infrastructure in strengthening household resilience. These findings indicate that rural agricultural transformation needs to be connected with

broader strategies for improving household economic security and reducing vulnerability to agricultural risks (2025).

In the context of Aceh Besar Regency, agricultural transformation can be understood as a process involving changes in the way farmers access productive resources, manage agricultural activities, and utilize technological innovations. The transformation process requires improvements in financial accessibility, agricultural infrastructure, technical knowledge, and institutional coordination. Rural farming communities need opportunities to access appropriate financing, obtain modern production equipment, and receive continuous agricultural extension services. At the same time, technological interventions should be adapted to the characteristics of local agricultural commodities, land conditions, production cycles, and farmers' economic capabilities. Such an approach is necessary to ensure that agricultural modernization produces practical benefits for rural communities rather than creating additional financial burdens.

For Gampong Lampreh-Lamteungoh, the integration of capital accessibility and technological adoption provides an analytical framework for understanding the opportunities and constraints associated with agricultural development. The research can identify whether farmers who have better access to capital also demonstrate greater capacity to adopt modern agricultural technologies. It can further examine whether technological adoption is associated with improvements in production management, operational efficiency, and farming sustainability. The analysis should also consider the influence of farmers' education, farming experience, land ownership, household income, and participation in agricultural institutions. These factors are important because the transformation of rural agricultural systems is shaped by the interaction between individual capabilities and the broader institutional environment.

Furthermore, the integration of capital and technology needs to be supported by appropriate agricultural policies. Local government institutions can strengthen agricultural development through improved access to financing information, facilitation of farmer organizations, provision of agricultural machinery, and expansion of extension services. Financial institutions can contribute by developing financing arrangements that consider seasonal production cycles and the economic characteristics of smallholder farmers. Meanwhile, agricultural extension

institutions can help farmers identify appropriate technologies and evaluate their potential economic benefits. Collaboration among these stakeholders is essential because agricultural transformation involves multiple dimensions that cannot be addressed through a single intervention. Integrated agricultural development programs can therefore provide a more comprehensive response to the economic and technological constraints experienced by rural farming communities.

From a broader perspective, the transformation of rural agriculture should not be measured exclusively through the introduction of modern machinery or the expansion of financing opportunities. It should also be assessed through improvements in farmers' productive capacity, efficiency of resource utilization, economic resilience, and sustainability of agricultural practices. Agricultural technologies need to generate measurable benefits for farming activities, while financing arrangements should enable farmers to maintain and expand productive investments. This perspective emphasizes the importance of evaluating agricultural development according to both its economic outcomes and its contribution to long-term agricultural sustainability. The discussion also highlights the need to distinguish between technological availability, technological readiness, and actual technological adoption. The availability of agricultural equipment does not necessarily indicate that farmers have adopted it, while positive perceptions of technological innovation do not automatically result in implementation. Similarly, access to financing does not guarantee that the funds are allocated toward productive agricultural investments. Therefore, the transformation process should be evaluated through indicators that capture actual behavior and production outcomes. These may include the frequency of technology utilization, the proportion of production activities supported by modern equipment, investment expenditure, changes in production costs, agricultural output, and farmers' ability to maintain technological facilities. Such indicators can provide a more reliable basis for assessing the effectiveness of agricultural transformation initiatives.

CONCLUSION

Rural agricultural transformation in Aceh Besar Regency requires the integration of adequate access to capital and the adoption of appropriate agricultural technologies. Access to capital plays an

important role in enabling farmers to invest in production inputs, modern agricultural equipment, and improved farming systems. Meanwhile, technological adoption contributes to improving production efficiency, agricultural productivity, and the sustainability of farming activities. However, financial limitations, inadequate technological knowledge, infrastructure constraints, and limited institutional support remain important challenges to agricultural modernization. Therefore, strengthening agricultural financing, expanding agricultural extension services, improving farmers' technical capabilities, and promoting appropriate technological innovation are essential strategies for supporting rural agricultural transformation. An integrated approach involving farmers, government institutions, financial institutions, and agricultural stakeholders is expected to strengthen the productivity and economic resilience of farming communities in Aceh Besar Regency.

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