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ABSTRACT

This study examines the first-level impacts of a Tissue Culture Laboratory (TCL) and a Cavendish banana demonstration farm on smallholder farming communities. It aims to assess the success of the TCL in producing disease-free, high-quality planting materials and to analyze its economic, social, and institutional contributions, including improvements in productivity, livelihoods, market access, community participation, gender and youth engagement, employment generation, and stakeholder collaboration. Employing a beneficiary-centered, embedded mixed-methods design, the study integrates quantitative and qualitative approaches to capture both measurable outcomes and lived experiences. A participatory methodology was employed, involving smallholder farmers, cooperative members, women and youth participants, as well as key stakeholders such as cooperative leaders, project implementers, and local government officials. Key stakeholders such as cooperative leaders, project implementers, and local government officials also provided contextual insights. Quantitative data from structured surveys (n = 40) were analyzed using descriptive and comparative statistics to evaluate changes in key indicators. Qualitative data from focus group discussions and key informant interviews enriched the analysis, while document reviews of cooperative records and project reports supported triangulation to ensure validity and reliability. The findings indicate that tissue-cultured plantlets substantially improved banana yield, quality, and marketability, resulting in increased income and employment opportunities. The intervention also strengthened cooperative engagement and enhanced the participation of women and youth. However, operational challenges, including laboratory contamination, logistical constraints, and membership inactivity, persist. Overall, the study underscores the potential of localized biotechnology interventions in advancing climate-resilient agriculture and sustainable rural development.

Keywords: tissue culture, banana farming, smallholder agriculture, impact evaluation, Philippines, rural livelihoods

INTRODUCTION

Banana cultivation remains a vital agricultural sector in Mindanao, with the Philippines consistently ranking among the world's leading exporters, second only to Ecuador (Tulod et al., 2025). Despite this global competitiveness, smallholder banana farmers continue to face persistent structural and environmental challenges, including poverty, limited access to modern agricultural technologies, and low productivity. These constraints are further exacerbated by climate change, rising production costs, land limitations, and insufficient knowledge of innovative farming practices necessary to enhance the sector's viability and profitability (Gebregiorgis et al., 2024).

At the local level, banana farming in Davao Region is a major livelihood activity, particularly for smallholder farmers cultivating Lakatan varieties. However, the municipality is highly vulnerable to environmental hazards such as flooding and landslides, which significantly affect agricultural productivity. Prolonged soil saturation can lead to root rot, nutrient deficiencies, and eventual plant mortality, while excessive moisture creates favorable conditions for the spread of diseases such as Panama disease and bacterial wilt. In landslide-prone areas, heavy rainfall contributes to soil erosion and physical damage to crops, particularly during fruit-bearing stages. These environmental risks not only reduce yield and product quality but also disrupt farm operations and market access. These conditions underscore the urgent need for technological and institutional interventions that can enhance resilience and sustainability in smallholder farming systems (Mata et al., 2020).

In this context, access to innovative technologies such as tissue culture propagation becomes critical. Tissue culture laboratories produce disease-free, genetically uniform, and climate-resilient planting materials, which can significantly improve crop performance and reduce vulnerability to environmental stressors.

To address these gaps, a National Government Organization (NGO), in partnership with the Local Government Unit (LGU), implemented a project in 2023 aimed at revitalizing the tissue culture laboratory and establishing a Cavendish banana demonstration farm. The intervention sought not only to restore the production of disease-free plantlets but also to introduce improved cultivation practices through a research-based demonstration farm. The project tested various input combinations and identified the integrated use of organic and synthetic inputs as the most effective approach in enhancing yield and fruit quality. Over time, the demonstration farm evolved from a research initiative into a sustainable income-generating enterprise for cooperative members.

Despite these developments, there remains a need for a systematic evaluation of the proj-

ect's impacts on smallholder farmers. In particular, it is important to assess whether the intervention has improved productivity, income, market access, and social outcomes, as well as its potential for scalability and replication. Furthermore, understanding how improvements in banana quality influence market perception and pricing is essential for linking smallholder production to higher-value markets (Sarmiento et al., 2024).

Accordingly, this study conducts a comprehensive impact assessment of the tissue culture laboratory and Cavendish demonstration farm. The assessment examines multiple dimensions of impact, including agricultural productivity, product quality, economic benefits, employment generation, social inclusion, institutional strengthening, and environmental sustainability. By providing evidence-based insights, the study aims to inform policy and program design, support the scaling of similar interventions, and contribute to broader efforts in promoting rural development, climate resilience, and poverty reduction in smallholder agricultural systems.

Theoretical Framework

The Sustainable Livelihood Framework (Natarajan et al., 2022) provides a comprehensive lens for examining how access to livelihood assets influences outcomes among smallholder farmers. In this study, the Tissue Culture Laboratory (TCL) and Cavendish demonstration farm are viewed as interventions that enhance key assets, particularly human capital through skills development, social capital through cooperative strengthening, and financial capital through increased income and employment opportunities. These improvements contribute to greater livelihood resilience and adaptive capacity, especially in contexts characterized by environmental risks and limited access to modern agricultural technologies.

Complementing this, the Diffusion of Innovation theory (Yu, 2022) explains the adoption of tissue-cultured plantlets as driven by their perceived relative advantage, compatibility with existing farming practices, and observable benefits such as higher yield and improved quality. The presence of demonstration farms and institutional support further facilitates trialability and knowledge transfer, accelerating adoption among farmers. However, variations in participation, particularly among youth, suggest that diffusion remains uneven and highlights the need for sustained capacity-building and stakeholder support to ensure broader and long-term adoption.

MATERIALS AND METHODS

Research Design

This study employed a concurrent embedded mixed-methods design, wherein quantitative and qualitative data were collected simultaneously, with one strand providing supportive insight to the other (Dawadi et al., 2021). Quantitative

data were derived from structured surveys and document records to capture measurable changes in productivity, income, and operational performance (Kotronoulas et al., 2023) while qualitative data from focus group discussions and key informant interviews were embedded to provide contextual understanding of farmer experiences, perceptions, and implementation dynamics (Gundumogula & Gundumogula, 2020). This design enabled the integration of numerical trends with in-depth narratives, allowing for triangulation and a more comprehensive assessment of the intervention's impacts on smallholder banana farming systems.

Participants

40 smallholder farmers and stakeholders using purposive sampling. To ensure the accuracy and relevance of the data collected, the assessment applied specific inclusion and exclusion criteria for selecting participants: Inclusion Criteria:

- Smallholder banana farmers actively cultivating Cavendish or Lakatan varieties who directly received or used tissue-cultured plantlets provided through the project.
- Members of farmer cooperatives who were involved in the project, either through implementation or coordination roles.
- Women and youth who took part in any stage of the planting, propagation, or maintenance processes associated with the tissue culture initiative.
- Key stakeholders such as cooperative leaders, agricultural technicians, project implementers, and local government officials who were involved in planning, managing, or supporting the project.

Exclusion Criteria:

- Farmers growing banana varieties unrelated to the tissue culture laboratory intervention.
- Those who did not participate in any part of the project.
- Cooperative members who joined only after the project's implementation and have no relevant experience or knowledge of the intervention.
- Local officials or personnel who had no involvement in the design, implementation, or evaluation of the project.

Data Analysis

The study employed a combination of quantitative and qualitative data analysis techniques to provide a comprehensive assessment of the intervention. Descriptive statistics, including frequency counts and percentages, were used to summarize the socio-economic characteristics of participants and key indicators such as productivity, income, and employment. Comparative analysis was conducted to examine changes before and after the implementation of the Tissue Culture Laboratory (TCL) and Cavendish demonstration farm, allowing for the identification of trends and measurable improvements in yield, quality, and economic outcomes. Complementing these,

thematic analysis was applied to qualitative data from focus group discussions and key informant interviews, following a systematic process of coding, categorization, and theme development. This approach enabled the identification of recurring patterns related to farmer experiences, technology adoption, livelihood changes, and institutional dynamics. The integration of these methods facilitated data triangulation, thereby enhancing the validity, depth, and reliability of the study's findings.

Ethical Consideration

Prior to the conduct of the impact assessment, a research proposal was submitted to a PHREB Level II–accredited research ethics committee. The proposal received formal ethical clearance under Protocol Code 1167-06-2025, confirming that the study meets national ethical standards for research involving human participants. As such, the implementation of the assessment was conducted with full adherence to ethical principles, including voluntary participation, confidentiality, and non-maleficence, ensuring that no harm or undue risk was posed to any participant.

Furthermore, this report has been developed with the assistance of generative artificial intelligence (AI) tools, specifically OpenAI's ChatGPT, for purposes such as language enhancement, synthesis of technical content, and formatting assistance. However, the content, interpretation, insights, and conclusions presented herein are grounded on original field data, personal analysis, and engagement with project stakeholders. The use of AI was limited to supporting the writing process and did not involve data fabrication, plagiarism, or misrepresentation of facts

RESULTS

Productivity & Quality

The comparative data between Lakatan/Cardava and Cavendish varieties reveal substantial differences in productivity, disease incidence, and planting material quality, all of which highlight the advantages brought by the use of tissue-cultured plantlets. The farmer-participants consistently reported that the adoption of tissue-cultures Cavendish plantlets resulted in notable improvements in both yield and fruit quality.

Table 1 presents the comparative indicators.

Table 1

Comparative Banana Productivity in terms of Quality and Yield per Hectare

Indicator	Lakatan / Cardava	Cavendish
Average number of banana plants (Mother plant) per hectare	1,500-1,800	1,800-2,000
average harvest per bunch (in kilos)	15-30	35-50
number of hands per bunch	7-9 hands	8-12 hands
total yield (in metric tons/ hectare/year)*	15.000-19.992	38.543-51.391
number of harvest cycles per plant	1 in a year	3 in 2 years

first harvest (Months)	10-14	9-12
Ratoon interval (months)	12-14	9-12
type of planting material used	Suckers or Corms	Tissue-Cultured
Reported Incidence of Plant Diseases		
Panama Disease	Frequent	No Reported Case
Black Sigatoka	Frequent	Minimal
Banana Buncy Top	Frequent	Minimal
Moko	Frequent	Minimal
Diamond Spot (Insect Activity)	Minimal	Minimal
Banana Freckle	Frequent	No Reported case

**computed based on the actual yield recorded 1-21 weeks*

Plant Density and Yield Performance. Cavendish banana farm exhibited a higher planting density, averaging 1,800 to 2,000 mother plants per hectare, compared to 1,500 to 1,800 for Lakatan or Cardava. In terms of yield, Cavendish bananas produced 35–50 kilograms per bunch, with 8–12 hands, whereas Lakatan/ Cardava yielded only 15–30 kilograms per bunch with 7–9 hands.

These differences translated into significantly higher annual productivity, with Cavendish farm producing 38.543 to 51.391 metric tons per hectare per year, compared to 15.000-19.992 metric tons for Lakatan/Cardava.

Harvest Frequency and Growth Cycle. Cavendish bananas first harvest within 9–12 months compared to 10–14 months for Lakatan/Cardava. Morever, Cavendish allowed for three harvest cycles within two years, while Lakatan/Cardava produced only one harvest annually. The ratoon interval was also shorter (9-12 months vs. 12-14 months), enabling faster crop turnover.

Planting Material and Quality Control. Lakatan and Cardava varieties were propagated using suckers or corms, which were often inconsistent and susceptible to diseases transmission. In contrast, Cavendish bananas were cultivated using tissue-cultured plantlets, resulting in improved genetic uniformity, plant, vigor, and yield consistency.

Disease Incidence. Lakatan/Cardava varieties frequently exhibited diseases such as Panama Disease, Black Sigatoka, Banana Bunchy Top, Moko, and Banana Freckle. In contrast, Cavendish farm reported:

- No cases of Panama Disease and Banana Freckle
- Minimal incidence of other diseases
- Only 5-10 affected plants per hectare per harvest cycle

Production Monitoring and Harvest Scheduling. Table 2 indicates that a total 819 bunches were bagged, with 705 bunches harvested between January and June 2925. The use of a color-coded bagging system enabled systematic monitoring of fruit maturity and scheduling of staggered harvests.

Table 2

Banana Bagging and Harvest Report as of June 2025

Actual bagging report				Month Harvested					
Year	**week bagged**	**color**	**Number of Bunches**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
2024	41	WH	10	oc*					
	42	GN	46	46					
	43	YL	67	67					
	44	BR	79	79					
	45	BK	87		87				
	46	OR	102		102				
	47	LB	100			100			
	48	RD	84				84		
	49	GY	61					61	
	50	LG	79						79
	51	BL	45						
	52	MR	31						
2025	1	WH	15	**FOR HARVEST**					
	2	GN	13						
Total			**819**	**705**					

**oc stands for overripe cut, not acceptable to market*

Economic Impact

The findings on economic impact demonstrate that the Cavendish banana demonstration farm and the Tissue Culture Laboratory (TCL) have generated measurable financial and employment benefits across multiple levels –cooperative, individual, household, and community. By examining income generation, profit distribution, labor compensation, and job creation, the results provide a comprehensive picture of how the intervention contributes to improving livelihoods and strengthening the local rural economy.

Economic Impact to the Cooperative. Table 3 reveals the income statement of the cooperative from January to June 2025 reflects a growing yet fluctuating income stream derived from the Cavendish banana demonstration farm.

Table 3

Income in the Cavendish Farm

Date of Harvest	Sales	Expenses	Net Income
January 22, 2025	₱ 94,204.42	₱36,634.00	₱57,570.42
February 10, 2025	₱69,613.00	₱29,613.00	₱40,000.00
February 19, 2025	₱60,414.45	₱23,418.00	₱36,996.45
March 10, 2025	₱41,000.00	₱28,857.00	₱12,143.00
April 8, 2025	₱45,000.00	₱30,024.00	₱14,976.00
May 6, 2025	₱25,224.00	₱19,738.00	₱5,486.00
June 2, 2025	₱28,000.00	₱15,290.00	₱12,710.00
Total	**₱363,455.87**	**₱183,474.00**	**₱179,981.87**
60% Net Income (Farm Owner)			**₱107,989.12**
40% Net Income (Cooperative)			**₱71,992.75**

**second peak of harvest season will be projected on month of September or October 2025*

Over seven harvest cycles conducted from January to June 2025, the cooperative generated a total gross sales revenue of ₱ 363,455.87 and incurred total operational expenses amounting to ₱183,474.00, resulting in a cumulative net income of ₱179,981.87. Based on the agreed income-sharing arrangement, 60% of the net income equivalent to ₱107,989.12, was allocated to the farm owner, while the remaining 40%, or ₱71,992.75, accrued to the cooperative.

These figures indicate that the Cavendish demonstration farm was able to generate positive returns within a relatively short operating period, demonstrating the income-generating potential of the enterprise at the cooperative level.

Economic Impact to the Individual (Farm Worker). At the individual level, Table 4 shows that each of the 25 participating members received an estimated total income of ₱7,338.96 over the six-months harvest period. Per harvest cycle, individual earnings ranged from approximately ₱611.60 to ₱1,465.36, depending on the scale of harvest operations and the corresponding labor requirements. These earning were derived from member's participation, and reflect the project's contribution in providing supplemental income to cooperative members.

Table 4

Work Compensation shared by Individual Farm Worker

Date of Harvest	Total Pay-out	Individual Income*
January 22, 2025	₱36,634.00	~ ₱1,465.36
February 10, 2025	₱29,613.00	~ ₱1,184.52
February 19, 2025	₱23,418.00	~ ₱936.72
March 10, 2025	₱28,857.00	~ ₱1,154.28
April 8, 2025	₱30,024.00	~ ₱1,200.96
May 6, 2025	₱19,738.00	~ ₱789.52
June 2, 2025	₱15,290.00	~ ₱611.60
Total	**₱183,474.00**	~ ₱7,338.96

**Pay-out divided by 25 active members, these includes meals and snacks*

Economic Impact to the Household. In terms of household economic outcomes, the project generated an additional monthly income ranging from ₱600 to ₱1,500 for participating farmer-households. Relative to the self-reported monthly income from Lakatan and Cardava farming, this represented an increase of approximately 8.16% to 15%. Although modest in absolute terms, this increment suggests that the cooperative-based Cavendish enterprise contributed meaningfully to household income diversification and offered an additional buffer against the income instability commonly experienced in smallholder banana farming.

Economic Impact to Employment Generation. The project also contributed to employment generation within the community. The establishment and operation of the Tissue Culture Laboratory directly created seven employment positions, while the Cavendish farm generated 25 direct farm-based jobs. Beyond these direct roles, the project also stimulated indirect employment opportunities, particularly in transport services, food vending, and specialized labor such as dehanding. These findings suggest that the intervention produced broader local economic effects by creating both regular and seasonal work opportunities linked to banana production and post-harvest activities.

Social Impact

The implementation of the Tissue Culture Laboratory (TCL) and Cavendish Demonstration Farm generated multidimensional social impacts across economic, educational, health, institutional, and environmental domains.

Economic Development and Livelihood Opportunities. In terms of economic development, the projects created both direct and indirect employment opportunities. The Cavendish demonstration farm provided paid work in land preparation, planting, maintenance, harvesting, and post-harvest operations, while the TCL employed seven technical personnel. Additional indirect employment was observed in transport services, food vending, and agro-input supply chain. These income-generating activities contributed to improved household financial capacity, enabling expenditures on housing, education, healthcare, and savings.

Education and Youth Empowerment. Educational outcomes also improved, as farmer-participants reported increased capacity to support their children's schooling, including tertiary education. The intervention further complemented this through education assistance programs provided by implementing partners.

Health and Well-being. Health and well-being indicators showed positive changes with respondents reporting improved food security and access to healthcare services. Increased income enabled households to purchases more nutritious food and access medical support.

Strengthening of Community Institutions. At the institutional level, the project strengthened the cooperative, as evidence by increased participation in farm operations, profit-sharing, and decision-making processes. Previously inactive member became re-engaged due to the economic benefits of the project. Addition-

ally, the LGU enhanced its technical capacity through the operation of the TCL, enabling localized production of planting materials.

Environmental Stewardship. From an environmental perspective, the TCL promoted the use of disease-free and climate-resilient planting materials, reducing dependency on chemical inputs and improving farmland sustainability.

Role of women and youth. The project demonstrated a significant in gender roles and leardership dynamics within the community. Women played central roles in both the TCL and the Cavendish demonstration farm, serving not only as laborers but also as managers and decision-makers. All TCL personnel were women, and a woman served as the lead coordinator of the Cavendish farm. Women actively participated in cooperative governance, including financial planning, farm management, and operational decision-making. Their involvement extended to training programs on agricultural practices, quality control, and post-harvest handling. In contrast, youth participation remained relatively limited. Many young individuals expressed low interest in agriculture, often preferring non-agricultural career paths. However, scholarship programs and exposure to modern agricultural technologies introduced by the project created opportunities for increased youth engagement.

Partnership and Stakeholder Engagements. The implementation of the TCL and Cavendish demonstration farm was supported by a multi-stakeholder partnership involving the LGU, NGO, academe, farmers' cooperative, and market actors. These stakeholders contributed to various aspects of the project, including technical support, funding, capacity-building, market linkage, and institutional development. The cooperative facilitated farmer participation, while the LGU provided operational support for the TCL. External partners contributed to training, monitoring, funding, and market integration. Overall, the findings demonstrate that multi-stakeholder partnerships are critical in scaling agricultural innovations and achieving inclusive rural development outcomes. The synergy among stakeholders ensures not only project success but also sustainability and replicability.

DISCUSSION

The findings demonstrate that the adoption of tissue-cultured Cavendish plantlets significantly improves productivity and quality compared to traditional Lakatan/ Cardava varieties. Higher planting density, increased yield per bunch, and shorter harvest cycles contribute to more efficient land use and greater annual output, reinforcing evidence that tissue culture enhances plant uniformity and productivity. Moreover, the reduced disease incidence highlights the effectiveness of clean planting materials in minimizing crop losses and input costs (Suresh Kumar & Mohan, 2023). Improved farm management practices, including structured harvesting and color-coded bagging systems, further support quality control and reduce post-harvest losses, aligning with export-oriented production standards (Walsh, 2022). These results indicate a transition from subsistence-based farming toward more market-oriented and commercially viable production systems.

Economically, the integration of tissue culture technology within a cooperative framework generated both direct and indirect income benefits. Although individual earnings per cycle were modest, cumulative gains significantly improved cooperative profitability and household income, consistent with findings that productivity gains combined with market access drive smallholder income growth (Uma et al., 2022). Employment generation—both skilled and unskilled—also reflects the expansion of rural labor markets within agricultural value chains (Horton et al., 2023). These outcomes affirm that integrated agricultural interventions contribute to inclusive economic development (Mokgomo et al., 2022), while also enhancing human capital through improved access to education and well-being (Nalani et al., 2021; Assari, 2025).

At the social and institutional levels, the strengthening of the cooperative underscores the importance of collective action in building resilient rural communities. The prominent leadership of women further demonstrates the role of gender inclusivity in enhancing productivity and governance (Chebet, 2023), with positive implications for household welfare (Anderson et al., 2021). However, limited youth participation remains a concern, reflecting broader trends of disengagement from agriculture (Giwu et al., 2024). Addressing this gap through innovation exposure and education will be essential for long-term sustainability.

Furthermore, the success of the intervention highlights the critical role of multi-stakeholder partnerships in agricultural development. Collaborative engagement among government, private sector, academe, and farmer organizations supports collective action (Holahan & Lubell, 2022) and enables smallholders to integrate into higher-value markets through inclusive value chains (Krysovatyy et al., 2024). This

aligns with the concept of shared value, where economic and social benefits are jointly created (Uddin et al., 2023), and underscores the role of academic institutions in sustaining innovation and capacity-building (Serafina et al., 2022).

Despite these contributions, the study is limited by its small sample size, absence of a control group, and reliance on self-reported data, which may affect generalizability and causal attribution. Nevertheless, when interpreted through the Sustainable Livelihood Framework and Diffusion of Innovation theory, the findings demonstrate that the intervention enhanced key livelihood assets and achieved high adoption due to its perceived advantages and observable benefits. Future research should adopt longitudinal and comparative designs and further examine value chain integration, particularly export linkages, to better understand pathways for scaling smallholder participation in high-value agriculture.

CONCLUSIONS

This study demonstrates that the integration of tissue culture technology within smallholder banana farming systems can generate substantial improvements in productivity, product quality, income, and social outcomes. The findings confirm that the use of tissue-cultured Cavendish plantlets significantly enhances yield performance, reduces disease incidence, and enables more efficient production cycles compared to traditional planting methods. These technical gains translate into measurable economic benefits at the cooperative, individual, and household levels, while also stimulating employment and strengthening local value chains.

Beyond economic outcomes, the study highlights the broader social transformations associated with the intervention. The empowerment of women in leadership and technical roles, increased community participation through cooperative structures, and improvements in education and well-being collectively demonstrate the multidimensional impact of agricultural innovation. These outcomes reinforce the argument that technology-driven interventions, when embedded within community-based and institutional support systems, can serve as effective instruments for inclusive rural development.

Importantly, the findings underscore that the viability of smallholder banana farming is significantly enhanced when farmers are integrated into value chains through strategic partnerships with large-scale agribusiness firms that have access to export markets. Such linkages enable smallholders to overcome the limitations of local markets—where prices remain low regardless of product quality—and instead access higher-value, quality-driven markets that offer more stable demand and improved income potential. This transition from local to export-oriented systems represents a critical pathway for scaling smallholder partici-

pation in high-value agriculture.

From a theoretical perspective, the results affirm the relevance of the Sustainable Livelihood Framework and Diffusion of Innovation theory in understanding how technological interventions influence livelihood outcomes and adoption dynamics. The enhancement of livelihood assets and the rapid uptake of tissue culture technology illustrate how innovations can be successfully diffused when they are accessible, beneficial, and supported by enabling institutions.

Overall, the study contributes to the growing body of evidence that localized agricultural biotechnology, combined with cooperative organization and multi-stakeholder partnerships, can drive sustainable and inclusive development in rural communities. To sustain and scale these gains, continued investment in technical capacity, institutional strengthening, and market integration will be essential. Such efforts will not only improve the resilience and competitiveness of smallholder farmers but also position them as active participants in global agricultural value chains.

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