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Bioscience and economic and multi-dimensional approaches to sustainable cacao production: A model for livelihood, environmental stewardship, and technology adoption in Lasam, Cagayan, Philippines

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ABSTRACT

This extension-driven research project examines how bioscience innovations and community-based economic strategies advance sustainable cacao production in Lasam, Cagayan, Philippines. The program integrates plant biosciences, agroecology, capacity building, and technology adoption to strengthen local livelihoods and promote climate-resilient agroecosystems. Using descriptive, developmental, and qualitative approaches, the study assessed outcomes of nursery establishment, training interventions, technology dissemination, and livelihood adoption among cacao farmers. Results show that bioscience-based propagation techniques generated more than 5,000 high-quality cacao seedlings, significantly improving field survival, growth vigor, and overall farm productivity. Training programs enhanced the competencies of over 600 farmers in cacao agronomy, plant physiology, integrated pest management, postharvest bioconversion, and value-adding technologies that support small-scale processing. Economic outcomes included a 25–30% increase in household income, diversification of livelihood streams through cacao by-products, and strengthened local enterprise development driven by improved market access and community partnerships. Ecologically, the adoption of cacao agroforestry systems enhanced on-farm biodiversity, soil fertility, and microclimatic stability, contributing to long-term environmental sustainability. Social impacts included stronger community engagement, increased participation of women in processing and marketing, and enhanced local leadership in agricultural initiatives. Overall, the project demonstrates that integrating bioscience research, economic empowerment, and extension services provides a scalable model for rural development, sustainable agriculture, and climate-adaptive farming communities.

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INTRODUCTION

Cacao (*Theobroma cacao* L.) is one of the most economically significant high-value crops in the Philippines, with increasing demand driven by the expanding local chocolate industry and international market opportunities. As a climate-resilient perennial crop suited to agroforestry systems, cacao has become an attractive commodity for upland and lowland communities seeking sustainable livelihood options. In northern Luzon, particularly in Lasam, Cagayan, the crop presents a promising avenue for diversifying income and promoting ecological stability (Magallon *et al.*, 2022; Lirag, 2021). Despite this potential, many cacao-producing communities continue to struggle with production inefficiencies stemming from limited access to high-quality planting materials, insufficient technical knowledge on modern cacao agronomy, and weak linkages to value-adding technologies and enterprise development.

Traditional farming practices in these localities often lack the integration of bioscience innovations-such as improved propagation protocols, pest-resistant varieties, and physiological management techniques-that could significantly enhance crop performance (Magallon *et al.*, 2022; Paguntalan *et al.*, 2020). Furthermore, the absence of structured capacity-building initiatives reduces farmers' ability to adopt technologies that increase productivity and profitability. As global agriculture increasingly shifts toward science-driven and climate-adaptive approaches, rural communities must be equipped with the knowledge and tools necessary to remain competitive and resilient (Malinao, 2024; Placencia *et al.*, 2025).

Recognizing these gaps, this extension-driven research project was established to integrate plant biosciences, agroecology, and economic development strategies into a holistic support system for cacao farmers in Lasam. The project aimed to enhance the entire cacao value chain-from nursery establishment and seedling propagation to field management, pest control, postharvest bioconversion, and product innovation. Through comprehensive training programs, technology dissemination, and enterprise-oriented livelihood interventions, the initiative sought to elevate the technical capacities of local farmers, strengthen community-based production systems, and improve overall farm sustainability (Malinao, 2024; Lirag, 2021).

The importance of this project extends beyond agricultural productivity. Cacao is widely recognized for its role in promoting agroforestry, biodiversity conservation, and soil health restoration. When integrated into diversified farming systems, cacao contributes to carbon sequestration and microclimatic regulation-crucial components in addressing the impacts of climate change (Paguntalan *et al.*, 2023; Paguntalan *et al.*, 2020). Thus, fostering cacao-based livelihoods not only enhances income but also strengthens ecological resilience.

By employing descriptive, developmental, and qualitative research approaches, the project generated comprehensive insights into the biological, economic, and social outcomes of science-based interventions. These outcomes underscore the transformative potential of combining bioscience innovations, community capacity building, and extension services. Ultimately, this introduction frames the project as a scalable and context-sensitive model for agricultural modernization, sustainable rural development, and climate-adaptive farming in the Cagayan Valley and beyond.

MATERAIS AND METHODS

This study employed a descriptive, developmental, and qualitative research design to evaluate the outcomes of bioscience-driven interventions and economic strategies for sustainable cacao production in Lasam, Cagayan. The descriptive component documented the status of cacao production practices, farmer competencies, and livelihood conditions before and after the project, while the developmental aspect focused on designing, implementing, and refining cacao propagation protocols, training modules, and technology dissemination strategies. The qualitative approach captured farmers' experiences, perceptions, and community-level changes resulting from the interventions.

The study was conducted in selected barangays of Lasam, Cagayan, involving local cacao farmers, community leaders, women's groups, and extension partners. A total of 600 farmers participated in trainings, and additional stakeholders contributed to nursery management, agroforestry establishment, and cacao product development. Participants were selected through purposive sampling based on their involvement in cacao farming and willingness to adopt new technologies.

Data were collected using multiple methods, including field observations to assess nursery conditions, seedling growth, farm management, and agroforestry layouts; key informant interviews (KIIs) with farmer leaders, agricultural technicians, and project implementers to understand local practices and constraints; and focus group discussions (FGDs) to gather insights on training effectiveness, livelihood impacts, technology adoption, and gender participation. In addition, project documents and output records, such as nursery production logs, training attendance, and economic reports, were reviewed for quantitative assessment.

The project interventions included the establishment of cacao nurseries using enhanced propagation techniques, training programs on cacao agronomy, plant physiology, integrated pest management, postharvest processing, and value-adding technologies. Technology dissemination was achieved through demonstration farms, agroforestry models, bioconversion processes, and small-scale product innovations. Livelihood integration focused on enterprise development, product packaging, and market linkages.

Data were analyzed thematically for qualitative information and using descriptive statistics for quantitative indicators, including seedling production, income changes, and farmer participation levels. Triangulation across data sources ensured the reliability and validity of the findings. Ethical considerations were observed, with participants providing informed consent and maintaining confidentiality throughout the study.

RESULTS AND DISCUSSION

The extension-driven project yielded significant outcomes in cacao production, farmer capacity, economic gains, ecological sustainability, and social engagement.

Nursery establishment and seedling production

The project's bioscience-based propagation methods successfully produced 5,120 high-quality cacao seedlings, exceeding the target of 4,500. Techniques such as controlled germination, grafting, and seedling hardening contributed to enhanced survival and vigor, addressing a critical bottleneck in smallholder cacao production (Table 1).

Table 1. Nursery establishment and seedling production outcomes

Parameter	Target	Achieved	Remarks
Number of seedlings produced	4,500	5,120	Exceeded target by 13.7%
Seedling survival rate (%)	80%	87%	Improved survival due to enhanced propagation
Farmer participation in nursery management	50	62	Higher engagement observed

The results indicate that integrating plant bioscience innovations into nursery management can substantially improve both the quantity and quality of planting materials. The higher-than-expected survival rate demonstrates the effectiveness of controlled propagation techniques in promoting resilient seedlings (Aggangan *et al.*, 2021; Paguntalan *et al.*, 2023). Increased farmer participation suggests that hands-on nursery activities foster knowledge transfer and ownership, which are essential for sustainable adoption of improved farming practices.

Farmer training and capacity building

Training programs enhanced the technical competencies of over 600 farmers, focusing on cacao agronomy, plant physiology, integrated pest management, postharvest bioconversion, and value-adding technologies (Table 2).

Table 2. Farmer training and capacity-building outcomes

Training topic	Number of participants	Knowledge improvement (Self-reported %)	Practical adoption rate (%)
Cacao agronomy	600	85%	72%
Integrated pest management	600	80%	68%
Postharvest bioconversion	620	88%	75%
Value-adding technologies	580	83%	70%

Table 3. Household income and livelihood impact

Indicator	Before intervention (PHP/month)	After intervention (PHP/month)	% increase
Average household income	12,000	15,000	25%
Revenue from cacao by-products	2,500	4,000	60%
Number of households with diversified income	50	80	60%

Table 4. Ecological and social outcomes

Aspect	Indicator	Result
Biodiversity	Number of companion species planted	120 species across 5 farms
Soil health	Observed soil organic matter improvement	Moderate to high (qualitative)
Community participation	Active participants in processing/marketing	300+ individuals
Women's involvement	% of women in project activities	45%

The high knowledge improvement and adoption rates indicate that participatory and hands-on training approaches effectively translate scientific knowledge into practical farming applications. Farmers reported increased confidence in managing their farms, implementing pest and disease control measures, and exploring processing innovations. These findings align with studies highlighting the importance of extension programs in improving smallholder competencies and promoting technology adoption (Magallon *et al.*, 2022; Placencia *et al.*, 2025).

Economic outcomes

Households adopting project interventions reported a 25–30% increase in monthly income, primarily from higher cacao yields and diversified by-products. Value-adding activities, such as tablea and cacao delicacies, strengthened local enterprises.

The results demonstrate that combining improved agricultural practices with livelihood-oriented interventions can substantially enhance household income and resilience. Increased revenue from cacao by-products highlights the potential for small-scale value addition to improve economic sustainability (Lirag, 2021; Malinao, 2024). Diversification also reduces dependence on a single income source, contributing to more stable rural livelihoods (Table 3).

Ecological and social impacts

The adoption of cacao agroforestry systems improved biodiversity, soil fertility, and microclimatic conditions, while social outcomes included enhanced community participation and women's engagement in processing and marketing (Table 4).

The ecological outcomes confirm that integrating cacao into agroforestry systems contributes to environmental sustainability and climate resilience. Planting companion species and improving soil organic matter enhances biodiversity and soil fertility, supporting long-term farm productivity. Socially, increased participation—especially of women—fosters inclusive development, strengthens community cohesion, and ensures equitable distribution of benefits. These findings underscore the holistic value of coupling bioscience-based interventions with community engagement (Paguntalan *et al.*, 2023; Paguntalan *et al.*, 2020).

CONCLUSION

The extension-driven project in Lasam, Cagayan demonstrates that integrating bioscience innovations, agroecology, technology adoption, and economic

strategies significantly enhances sustainable cacao production. The use of improved propagation techniques successfully produced over 5,000 high-quality seedlings, leading to higher survival rates and more resilient agroforestry systems. Training programs effectively strengthened the technical competencies of over 600 farmers, enabling them to implement modern practices in cacao agronomy, pest management, postharvest bioconversion, and value-added processing.

Economically, the project contributed to a 25–30% increase in household income, largely due to higher yields and diversified revenue streams from cacao by-products. Ecologically, the introduction of cacao agroforestry improved biodiversity, soil health, and microclimatic conditions, reinforcing climate-resilient farming practices. Socially, the initiative fostered greater community participation and women's engagement, promoting equitable distribution of benefits and enhancing local leadership in agricultural development.

Overall, the project demonstrates that a holistic, science-based, and community-centered approach can create a scalable model for sustainable agriculture, rural development, and climate-adaptive livelihood systems.

RECOMMENDATIONS

To further strengthen sustainable cacao production in Lasam, Cagayan, it is recommended that local government units (LGUs) and agricultural agencies support the expansion of cacao nurseries and propagation training, ensuring a wider availability of high-quality seedlings for smallholder farmers. In addition, continuous capacity-building programs should be implemented, including regular training workshops and knowledge-sharing sessions, to enhance farmers' technical skills in areas such as pest management, postharvest processing, and value-adding technologies. Strengthening market linkages and enterprise development is also crucial; farmers should be assisted in accessing broader markets for their cacao products and in establishing small-scale enterprises to maximize income from value-added products. The promotion of agroforestry systems is highly encouraged, integrating cacao with companion species to improve biodiversity, soil fertility, and overall ecological sustainability. Furthermore, future interventions should maintain a gender-inclusive approach, actively supporting women's participation in production, processing, and marketing to ensure equitable distribution of benefits within the community. Finally, monitoring and evaluation mechanisms should be established to continuously assess farm productivity, income generation, and ecological impacts, ensuring long-term sustainability and providing a replicable model for other cacao-producing regions.

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