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Optimizing Cardava Banana Propagation: A Comparative Study of Macroclonal and Traditional Methods for Agricultural Sustainability and Educational Innovation

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ABSTRACT

Background: Cardava banana (*Musa spp.*) production in the Philippines is constrained by slow multiplication rates and disease transmission associated with traditional sucker propagation, as well as the high cost and limited accessibility of tissue culture. Macropropagation offers a low-cost alternative, particularly when combined with locally available farm waste substrates. This study evaluated the effects of five farm waste-based media on shoot emergence and early growth of macropropagated and traditionally propagated Cardava bananas under greenhouse conditions, assessed field growth and yield performance and examined the educational outcomes of integrating macropropagation activities into science instruction.

Method: A factorial experiment in a Completely Randomized Design compared soil (control), soil amended with coconut husk, compost, mung bean pod hull and rice hull. Field trials compared the growth and yield of macropropagated and traditionally propagated plants. Educational outcomes were evaluated using a quasi-experimental pretest–posttest design involving hands-on propagation activities.

Results: Macropropagated plants exhibited significantly faster shoot emergence and greater early growth than traditionally propagated plants across all media ($p<0.001$). Among substrates, soil amended with mung bean pod hulls produced the fastest emergence and greatest plant height, followed by compost- and coconut husk–amended soils, while rice hull–amended soil performed the poorest. Field evaluation showed significantly higher yields in macropropagated plants, with an average increase of 7.10 kg per plant ($p<0.001$). Educational results indicated substantial improvements in posttest scores, student engagement, interest in agriculture and knowledge retention compared with theory-based instruction. The findings demonstrate that macropropagation supported by farm waste-based substrates provides a flexible and sustainable approach to improving Cardava banana production while enhancing experiential learning in agricultural education.

Key words: Cardava banana, Experiential learning, Farm waste substrates, Macropropagation, *Musa spp.*, Yield performance.

INTRODUCTION

Banana (*Musa spp.*) is a major staple and cash crop cultivated widely in tropical regions. In the Philippines, the cooking-type Cardava banana (locally known as saba) plays a critical role in household food security and rural livelihoods, particularly among smallholder farmers. Recent assessments have shown that Cardava banana production contributes significantly to rural incomes; however, productivity remains constrained by limited access to high-quality planting materials and inefficiencies in the value chain (Orejudos *et al*., 2022; Samanhudi *et al*., 2021). At the farm level, most growers continue to rely on sword and water suckers as planting materials, a conventional vegetative propagation method characterized by low multiplication rates and a high risk of pest and disease transmission (Tumuhimbise and Talengera, 2018).

Although tissue culture has been promoted as a means of producing disease-free and genetically uniform banana planting materials, its adoption among smallholder farmers remains limited. High production costs, technical requirements and restricted access to specialized laboratories, particularly in geographically isolated and disadvantaged areas, have constrained widespread use of this technology. These limitations underscore the need for alternative propagation systems that are affordable, technically simple and based on locally available resources (Tumuhimbise and Talengera, 2018).

Macropropagation using whole corms or large corm sections has emerged as a viable alternative for rapid multiplication of banana planting materials. Studies have demonstrated that *in vivo* macropropagation can substantially increase sucker production and improve early

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plant growth when appropriate management practices are applied (Husna and Miah, 2023). Reviews further indicate that macropropagation reduces disease risks associated with farmer-sourced suckers while avoiding much of the cost and infrastructure required for tissue culture (Tumuhimbise and Talengera, 2018). However, the effectiveness of macropropagation systems is strongly influenced by the physical and nutritional characteristics of the propagation medium.

In Philippine smallholder farming systems, large quantities of agricultural residues, such as compost, coconut husks, mung bean pod hulls, rice hulls and banana pseudostems, are generated but often underutilized (Dela Cruz *et al*., 2008). Previous studies have shown that selected farm waste–based substrates can improve shoot emergence and early vigor of Cardava banana under macroclonal propagation (Paderes *et al*., 2022). Similar benefits of organic amendments on banana growth and physiological performance have been reported in similar studies, including the use of organic manure and biological amendments in tissue culture-derived banana (Samanhudi *et al*., 2021). Identifying effective alternative substrates is particularly important when specific residues are seasonally unavailable (Kumar *et al.,* 2021).

Beyond agronomic relevance, banana macropropagation provides a practical context for experiential learning in agricultural and biological science education. Experiential learning theory emphasizes learning through direct experience, reflection and application (Kolb, 1984). Empirical studies have shown that hands-on agricultural activities significantly enhance students' engagement, understanding and achievement compared with lecture-based approaches (Bala, 2024). Integrating banana macropropagation experiments into biology instruction, therefore, offers an opportunity to simultaneously generate locally relevant research evidence and strengthen student learning.

Against this background, the present study aimed to (i) compare the effects of different farm waste-based substrates on shoot emergence and early growth of macropropagated and traditionally propagated Cardava banana plantlets under *ex situ* greenhouse conditions, (ii) evaluate the subsequent growth and yield performance of macropropagated and conventionally propagated plants under field conditions and (iii) assess the educational outcomes of integrating macropropagation activities into biology instruction.

MATERIALS AND METHODS

Experimental site and research period

The study was conducted at the Tissue Culture Laboratory and Greenhouse of the Abra State Institute of Sciences and Technology (ASIST), Poblacion, Lagangilang, Abra, Philippines, from March 2024 to September 2025. Greenhouse experiments were carried out under semi-controlled conditions, followed by field evaluation in an adjacent ASIST experimental area under uniform agronomic management.

Experimental design

The greenhouse experiment was laid out as a factorial experiment in a Completely Randomized Design (CRD) with two factors.

- **Propagation media (five levels):** Soil only (control), soil + coconut husk, soil + compost, soil + mung bean pod hull and soil + rice hull
- **Propagation method (two levels):** Macropropagation and traditional sucker propagation.

A total of ten treatment combinations were randomly assigned to experimental units.

For field evaluation, macropropagated and traditionally propagated plants were compared using a completely randomized design, with planting positions randomly assigned to minimize field variability.

Propagation procedures

Traditional propagation used sword suckers approximately 20 cm in height obtained from healthy mother plants. Suckers were cleaned and planted directly into assigned media. Macropropagation involved decortication and decapitation of corms using sterilized knives to expose latent buds. Corms were disinfected with alcohol and fungicide prior to planting. Regular irrigation was applied to maintain adequate moisture.

Data collection

Greenhouse data collected one month after planting included days to shoot emergence and plant height (cm). Field data included plant height measured at 6, 12 and 18 months after transplanting and yield expressed as fruit or bunch weight per plant (kg). Educational data were gathered using pretest-posttest assessments, observation checklists and student feedback surveys.

Statistical analysis

Greenhouse data were analyzed using two-way analysis of Variance (ANOVA) to determine the effects of propagation media, propagation method and their interaction. Mean separation was performed using Tukey's Honest Significant Difference (HSD) test at a 5% level of significance. Field data were analyzed using independent t-tests, while educational outcomes were evaluated using paired t-tests.

RESULTS AND DISCUSSION

Effectiveness of farm waste media on shoot emergence and early growth

Shoot emergence

The mean number of days required for primary bud emergence across the five farm waste media is presented in Table 1. Across all treatments, macropropagated plants consistently exhibited faster shoot emergence than traditionally propagated plants. Based on Tukey's honest significant difference (HSD) test, the overall ranking of

media performance for shoot emergence was as follows: T4-Soil + Mung Bean Pod Hull (a) > T3-Soil + Compost (ab) ≈ T2 -Soil + Coconut Husk (ab) > T1-Soil only (bc) > T5-Soil + Rice Hull (c).

T4 (a) produced the fastest shoot emergence, with macropropagated plants emerging at 10 days and traditionally propagated plants at 14 days. T3 and T2 (ab) were statistically comparable to T4, indicating that compost- and coconut husk-amended soils provided similarly favorable conditions for early bud activation. The control treatment, T1 (bc), showed moderate emergence, whereas T5 (c) showed the slowest emergence across both propagation methods.

The superior performance of T4 can be attributed to the nutrient-rich nature of mung bean pod hulls, which enhance nitrogen availability and microbial activity, thereby supporting early metabolic processes required for bud initiation (Algan *et al*., 2011; Geng *et al*., 2021). Compost and coconut husk similarly improved emergence relative to the control due to improved moisture retention and gradual nutrient release. In contrast, the poor performance of rice hull-amended soil (c) reflects its slow decomposition rate and limited short-term nutrient availability (Jasey, 2018; Nguyen *et al*., 2022).

One-way ANOVA, as shown in Table 2, confirmed significant differences among media for both macropropagated ($F = 27.35$, $p<0.001$) and traditionally propagated plants ($F = 35.47$, $p <0.001$). The Tukey grouping clearly demonstrates that, although mung bean pod hulls remain the most effective substrate, compost and coconut husk represent statistically comparable and practical alternatives when legume residues are unavailable.

Table 1: Average days for primary bud emergence.

Farm waste media	Macropropagated (Days)	Traditionally propagated (Days)
T1: Soil only	15	21
T2: Soil + Coconut husk	13	19
T3: Soil + Compost	12	18
T4: Soil + Mung bean pod hull	10	14
T5: Soil + Rice hull	18	25

Plant growth performance

Mean plant height at 2 and 4 months after planting is presented in Table 3. Across all treatments, macropropagated plants attained significantly greater height than traditionally propagated plants.

Tukey's HSD test revealed the following general ranking of propagation media for early plant height: T4-soil + mung bean pod hull (a) > T3-soil + compost (ab) ≈ T2-soil + coconut husk (ab) > T1-soil only (bc) > T5-soil + rice hull (c).

T4 (a) consistently produced the tallest plants, reaching 55 cm at 2 months and 90 cm at 4 months under macropropagation. However, T3 and T2 (ab) did not differ significantly from T4, indicating that these substrates also supported strong early growth. The control treatment (bc) showed intermediate performance, while T5 (c) produced the shortest plants, reflecting limited nutrient contribution during early growth.

Two-way ANOVA in Table 4 indicated significant main effects of media ($F = 20.17$, $p<0.001$) and propagation method ($F = 25.59$, $p < 0.001$), as well as a significant interaction effect ($F = 3.94$, $p = 0.010$), suggesting that the magnitude of media effects varied with propagation method. Overall, nutrient-dense organic substrates promoted superior early growth (Singh *et al*., 2020), supporting the use of compost and coconut husk as alternative propagation media alongside mung bean pod hulls (Geng *et al*., 2021; Nguyen *et al*., 2022; Goyal *et al.,* 2020).

Comparative performance of macropropagation and traditional propagation in the field

Growth rates

Macropropagated plants, as shown in Plate 1, consistently exhibited greater height at all field evaluation stages (6, 12

Table 2: One-way ANOVA on the average number of days for shoot emergence across farm waste media for both propagation methods.

Source	SS	df	MS	f	p-value
Between groups	210.76	4	52.69	27.35	< 0.001
Within groups (Error)	57.71	50	1.15		
Total	268.47	54			

Table 3: Average plant height (cm) at 2 and 4 months.

Farm waste media	Macropropagated (2 months)	Traditionally propagated (2 months)	Macropropagated (4 months)	Traditionally propagated (4 months)
T1: Soil only	40	35	75	65
T2: Soil + Coconut husk	45	37	80	70
T3: Soil + Compost	50	40	85	75
T4: Soil + Mung bean pod hull	55	45	90	80
T5: Soil + Rice hull	30	25	60	50

Table 4: One-way ANOVA on plant height.

Source	SS	df	MS	f	p-value
Farm waste media	2650.44	4	662.61	20.17	< 0.001
Propagation method	840.18	1	840.18	25.59	< 0.001
Farm waste media × propagation	517.22	4	129.31	3.94	
Error	2603.56	50	52.07		
Total	6611.40	59			

Table 5: Average plant height (cm) at different growth stages.

Growth stage (Months)	Traditional propagation	Macropropagation
6	85	92
12	130	155
18	190	210

Table 6: Average yield (kg) per plant.

Propagation method	Average yield (kg)
Traditional propagation	18
Macropropagation	25

Table 7: Paired t-test analysis.

Statistic	Value
Mean difference (kg)	7.10
Standard deviation (kg)	1.84
Number of pairs (n)	30
t-statistic	21.09
p-value	3.88×10^{-19}

Table 8: Pre-and post-lecture assessment scores.

Assessment type	Average score (%)
Pre-lecture	55
Post-lecture	85

and 18 months). At 18 months, macropropagated plants reached an average height of 210 cm compared with 190 cm for traditionally propagated plants (Table 5).

These results are consistent with earlier studies reporting that macropropagation produces more uniform and vigorous banana planting materials due to improved sanitation and reduced pathogen exposure during propagation (Wairegi *et al*., 2022; Astorga-Quirós *et al*., 2023). Enhanced early vigor likely contributed to faster canopy establishment, a critical determinant of banana productivity.

Yield performance

Yield data in Table 6 showed that macropropagated plants produced an average of 25 kg per plant, significantly higher than the 18 kg obtained from traditionally propagated plants (Plate 2). The paired t-test in Table 7 confirmed this difference to be highly significant ($t = 21.09$, $p<0.001$), corresponding to a mean yield advantage of 7.10 kg per plant.

This yield improvement underscores the economic advantage of macropropagation. At a planting density of 100 plants, the additional yield of approximately 710 kg per harvest represents a substantial gain in income and food supply. Similar yield advantages associated with macropropagation have been reported across banana cultivars, highlighting the robustness of this method (Ravi *et al*., 2021; Wairegi *et al*., 2022).

Impact on students' understanding of plant propagation methods

Pre-and post-instruction assessment

Student assessment results indicated a substantial improvement in understanding of plant propagation concepts following participation in hands-on macropropagation activities. Mean scores increased from 55% in the pretest to 85% in the posttest, representing a 30% gain (Table 8). Paired t-test analysis confirmed the significance of this improvement ($t = 9.21$, $p<0.001$).

Student feedback and perceived learning outcomes

Qualitative analysis of student reflections further supported the quantitative learning gains. Common themes emerging from student feedback included enhanced understanding of propagation techniques, increased engagement and interest in agriculture, improved confidence in practical skills and greater appreciation for sustainable agricultural practices (Table 9).

These findings are consistent with experiential learning theory, which emphasizes the role of concrete experience in reinforcing conceptual understanding (Kolb, 1984). Similar gains in learning outcomes have been reported in agricultural education studies employing experiential approaches (Adekunle *et al*., 2022; Bala, 2024).

Student engagement, interest and knowledge retention

Engagement and interest

Survey results (Table 10) showed that 90% of students reported increased engagement during lessons, while 80% expressed heightened interest in agricultural sciences following the practical activities. These outcomes align with evidence that hands-on instruction enhances motivation and relevance in science education (Freeman *et al*., 2014).

Table 9: Common themes from student feedback.

Theme	Insight	Example responses
Enhanced understanding of techniques	Hands-on experience significantly improved my understanding of propagation methods.	Seeing and performing the propagation techniques helped me understand the concepts much better. Seeing and performing the propagation techniques helped me understand the concepts much better.
Increased engagement and interest	Practical experiments increased student interest and engagement in agricultural sciences.	I found the experiments engaging and they made the lessons more interesting.
Confidence in practical skills	Practical sessions boosted confidence in performing propagation techniques independently.	I now feel confident I can perform these propagation techniques independently.
Appreciation for sustainability	Improved appreciation for sustainable agricultural practices	Learning about sustainable agriculture through practical experiments was eye-opening.
Suggestions for improvement	Constructive feedback on enhancing practical sessions	More time should be allocated for the practical sessions to allow for a deeper understanding.
Challenges faced	Highlighted areas for improvement in equipment and instructions	There was confusion during the experiments due to a lack of clear instructions.



Plate 1: Comparative growth stages of traditionally propagated (Right) and macropropagated banana plants (Left) at six months.



Plate 2: Yield comparison between traditional (left) and macropropagated (Right) banana plants at 18th months.

Knowledge retention

Follow-up assessment conducted three months after instruction revealed a knowledge retention rate of 75% among students exposed to both theoretical and practical learning, compared with 50% among students receiving theory-only instruction (Table 11). This 25% difference highlights the long-term cognitive benefits of experiential learning, consistent with recent educational research (Adekunle *et al.*, 2022).

Table 10: Survey on the impact of practical agricultural experiments on student engagement and interest.

Theme	Frequency
Increased engagement	90%
Better understanding of concepts	85%
Heightened interest in agriculture	80%

Table 11: Knowledge retention rates.

Instruction type	Retention rate (%)
Theoretical only	50
Practical + theoretical	75

CONCLUSION

The study confirms that macropropagation combined with farm waste-based substrates significantly enhances the growth, propagation efficiency, and yield of Cardava banana. Soil amended with mung bean pod hulls produced the best early growth performance, while macropropagated plants consistently outperformed traditionally propagated materials under greenhouse and field conditions. The method resulted in higher plant vigor and an average yield increase of 7.10 kg per plant, demonstrating strong potential for improving smallholder productivity. Integrating macropropagation into biology instruction also improved student learning, engagement, and knowledge retention through experiential learning. Overall, the approach offers a sustainable, low-cost strategy that simultaneously supports agricultural productivity and innovation in agricultural education.

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Disclaimers

The views and conclusions presented in this paper are solely those of the authors and do not necessarily reflect the official policies, positions, or endorsements of Abra State Institute of Sciences and Technology or any affiliated institutions. Any errors or omissions remain the responsibility of the authors.

Informed consent

All student participants involved in the educational component of this study provided prior written informed consent after being fully briefed on the study's purpose, procedures, potential risks and voluntary nature of participation. No identifying information was collected and all responses were kept strictly confidential. Participation or non-participation did not affect students' academic standing. The study was reviewed and approved by the ASIST Research Ethics Committee, ensuring compliance with ethical standards for research involving human participants.

Conflict of interest

The authors declare that there are no conflicts of interest, financial or otherwise, that could have influenced the conduct or outcomes of this research. The study was conducted independently, without any commercial or external funding that might create bias.

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