Table of Contents

Journal of Biodiversity, Climate Change and Sustainable Development
Volume 11 No. 1 (2026)

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

J Biod Clim Chg & Sust Dev 11(1):1-10 (2026)

From ocean waste to poultry plate: Yellowfin tuna (*Thunnus albacares*) by-product meal as a sustainable protein feed supplement for broiler chickens

Jan Bernard M. Victorio & Ruben P. Tablizo

College of Agriculture & Fisheries, Catanduanes State University, Calatagan, Virac 4800, Catanduanes, Philippines

Correspondence: E-mail jtmasagca27@gmail.com

Abstract

Fish processing generates large quantities of organic by-products such as viscera, bones, fins, scales, and skin that represent both an environmental management challenge and an underexploited protein-rich resource for sustainable animal feed formulation. This study evaluated the effects of four yellowfin tuna (*Thunnus albacares*) by-product meal (TBM) inclusion levels: T1 (3%), T2 (5%), T3 (8%), and T4 (0%, control) on the growth performance and feed conversion ratio (FCR) of broiler chickens over a 43-day experimental period. A Completely Randomized Design (CRD) with three replications per treatment was used (n = 108 birds; 27 per treatment). Growth parameters assessed included initial body weight, weekly weight gains (weeks 1–3), final body weight, total weight gain, and FCR. One-way ANOVA tested treatment differences at $\alpha = 0.05$. Results showed that T3 (8% TBM) achieved the highest final mean body weight (1,685.37 g), greatest total weight gain (1,386.46 g), and best FCR (4.46), significantly outperforming the control group (T4: 995.55 g; FCR = 8.22; $p < 0.001$). The 8% TBM inclusion improved growth performance by 56.4% and feed efficiency by 45.7% relative to controls. These findings support TBM at 8% inclusion as a cost-effective, nutritionally appropriate, and environmentally sustainable partial protein supplement for broiler diets, contributing to circular food systems innovation in island agricultural economies such as Catanduanes, Philippines.

Keywords: *yellowfin tuna*; *tuna by-product meal; fish waste valorization; broiler growth performance; feed conversion ratio; circular bioeconomy; sustainable poultry production; Catanduanes; Philippines*

Introduction

Global aquatic food systems generate an estimated 35 million metric tons of fish processing by-products annually, comprising viscera, heads, bones, fins, scales, gills, skin, and trim from commercial fish processing operations, representing approximately 50-70% of total fish wet weight that does not enter the human food chain (Olsen et al., 2020; FAO, 2022). The yellowfin tuna (*Thunnus albacares*) processing industry alone generates by-products constituting approximately 64% of raw fish weight through filleting, canning, and loining operations (Tacon et al., 2026; Tacon & Metian, 2022), making it one of the highest-volume fish by-product streams in the global seafood industry. Traditionally, these organic by-products have been either discarded as solid waste with coastal pollution, greenhouse gas emissions from decomposition, and public health risks or processed into low-value fish meal for aquafeed, with minimal economic or nutritional optimization (Olsen et al., 2020; Mohan et al., 2021). The valorization of fish processing by-products as high-value, nutritionally characterized ingredient streams for terrestrial animal feed represents a paradigmatic circular bioeconomy solution that simultaneously addresses three interconnected challenges: the environmental management of fish processing waste streams; the growing global protein deficit in conventional livestock and poultry feed; and the production cost pressures confronting smallholder poultry producers in island developing economies (Tacon et al., 2026; Tacon & Metian, 2022; Barroso et al., 2020; FAO, 2022).

Fishmeal, which is the conventional processed form of fish by-products is widely recognized as one of the highest-quality protein supplements available for poultry nutrition, characterized by its complete amino acid profile (particularly lysine, methionine, and threonine), high digestibility (85-92%), elevated levels of long-chain omega-3 polyunsaturated fatty acids (EPA and DHA), and rich complement of bioavailable minerals (calcium, phosphorus, selenium) and fat-soluble vitamins (A, D, E, K) (Barroso et al., 2020; Chowdhury et al., 2021). These nutritional properties make fish-derived protein sources theoretically superior to many plant-based alternatives commonly used in commercial broiler diets. However, the economic cost of full-specification fishmeal determined primarily by reduction fishery commodity markets and fluctuating global supply has historically limited its inclusion in smallholder poultry diets, particularly in remote island provinces such as Catanduanes, Philippines, where feed transportation costs add substantially to already elevated fishmeal prices (Tacon & Metian, 2022). The direct valorization of locally generated tuna processing waste into on-farm or locally produced tuna by-product meal (TBM) bypassing commercial fishmeal supply chains offers a cost-effective alternative for island poultry producers that simultaneously leverages locally abundant fish waste resources and reduces dependence on imported or commercially supplied protein supplements (Mohan et al., 2021; Olsen et al., 2020).

Modern commercial broiler strains have been selectively bred for rapid growth, feed efficiency, and lean muscle deposition under nutritionally optimal conditions, with dietary protein requirements of 23-24% for starter (0-14 days), 20-21% for grower (15-28 days), and 18-19% for finisher (29-42 days) phases (NRC, 1994 as applied by Chowdhury et al., 2021; Singh et al., 2022). Meeting these protein requirements with high-quality, bioavailable amino acids is a primary determinant of broiler growth rate and feed conversion efficiency, making protein ingredient selection the most economically and nutritionally consequential formulation decision in commercial broiler diet design. In the Philippines, broiler production constitutes one of the most important components of the domestic livestock sector, with total broiler production of approximately 1.2 billion kg liveweight annually (PSA, 2023), yet profitability of smallholder broiler enterprises is chronically constrained by feed costs representing 60-70% of total production cost and the limited availability of locally sourced, cost-competitive protein supplements (Torres et al., 2021). Tuna processing by-products that are available in substantial quantities from the yellowfin tuna canning and processing industries concentrated along Bicol Region and eastern Philippine coastlines represent a geographically proximate, biologically appropriate, and potentially cost-effective partial protein supplement for broiler diets that has been insufficiently characterized in the peer-reviewed literature for Philippine island production contexts (Tacon et al., 2026; Tacon & Metian, 2022; Mohan et al., 2021).

The available literature on fish by-product meal inclusion in broiler diets consistently documents positive effects on growth rate, FCR, and carcass quality at inclusion levels of 5-10% of diet dry matter, with the most pronounced benefits attributed to improved amino acid balance, enhanced calcium and phosphorus bioavailability from fish bone collagen hydrolysate, and the growth-promoting effects of unidentified fish growth factors (UGFs) present in whole fish by-product preparations (Barroso et al., 2020; Chowdhury et al., 2021; Torres et al., 2021). Inclusion levels above 10-12% are generally associated with diminishing growth benefits and the emergence of fishy off-flavors in broiler meat attributable to muscle accumulation of trimethylamine oxide (TMAO) metabolites from fish-derived omega-3 fatty acids (Singh et al., 2022), defining a practical optimal inclusion range of 5-10% that the present study directly investigates. The current study was designed to fill the specific evidence gap in Philippine island context by evaluating locally prepared yellowfin tuna by-product meal at graded inclusion levels (3%, 5%, 8%, and 0% control) in broiler diets under small-scale, farmgate-relevant production conditions in Catanduanes, generating data directly applicable to island smallholder poultry producers.

The circular bioeconomy framework which is operationalized in the European Green Deal, the Global Biodiversity Framework, and the UN SDG 12 (Responsible Consumption and Production) and SDG 14 (Life Below Water) agendas provides the overarching policy rationale for fish waste valorization that extends the significance of this study beyond its immediate agronomic findings (Olsen et al., 2020; FAO, 2022; CBD, 2022). In island agri-fisheries systems, where fishing and fish processing are primary economic activities, the valorization of fish by-products into on-farm poultry feed supplements creates circular material flows that reduce organic waste disposal costs, lower poultry feed expenditure, and contribute to the food security and income diversification of coastal fishing households with outcome that directly advances the UN Decade of Ocean Science for Sustainable

Development priorities articulated in the national ocean action agenda (NEDA, 2023). Furthermore, the reduction of fish processing waste volumes through valorization reduces the organic loading of coastal waters and estuaries, contributing to the preservation of the mangrove and coastal fisheries habitats that are central to the blue economy of Catanduanes, consistent with the integrated coastal resource management principles promoted by SURMABIOCON and ACE-HEMS programs funded by the Philippine Commission on Higher Education (CHED) (Masagca et al., 2018; Masagca & Trinidad, 2020).

This study aimed to: (1) characterize the proximate nutritional composition of locally prepared yellowfin tuna (*T. albacares*) by-product meal (TBM) and compare it against commercial fishmeal and soybean meal nutritional standards; (2) evaluate the effects of graded TBM inclusion levels (0%, 3%, 5%, and 8%) on broiler body weight gain across initial, weekly, and final measurement periods; (3) determine which TBM inclusion level produces the highest overall growth performance (total weight gain) and best feed conversion efficiency (lowest FCR); (4) analyze significant differences in growth performance and FCR among the four treatment groups using one-way ANOVA; and (5) assess the potential economic and environmental benefits of locally produced TBM as a circular bioeconomy feed ingredient for island smallholder broiler producers in Catanduanes, Philippines.

Methodology

Experimental design and animals

The study was conducted at the College of Agriculture and Fisheries, Catanduanes State University (CatSU), Virac, Catanduanes, Philippines, over a 43-day experimental period. A Completely Randomized Design (CRD) with four treatments and three replications per treatment was employed (n = 108 one-day-old commercial broiler chicks [Cobb 500 strain] in total; 27 birds per treatment; 9 birds per replicate unit). The four dietary treatments were: T1 = 3% yellowfin tuna by-product meal (TBM) in diet dry matter; T2 = 5% TBM; T3 = 8% TBM; and T4 = 0% TBM (commercial diet only, control). CRD was selected as the experimental design because of the homogeneous environmental conditions within the poultry facility, which satisfied the equal variance assumption of CRD, consistent with standard poultry nutrition experimental design practice (Chowdhury et al., 2021; Torres et al., 2021). Birds were randomly assigned to treatment groups through lottery sampling to ensure unbiased allocation.

Preparation of yellowfin tuna by-product meal (TBM)

Fresh yellowfin tuna (*T. albacares*) processing by-products that compre entrails (viscera), fins, bones, scales, and gills were sourced from local fish processing operations in Virac, Catanduanes and processed into tuna by-product meal (TBM) using a standardized protocol adapted from Olsen et al. (2020) and Mohan et al. (2021). Processing steps: (1) by-products were thoroughly washed with clean water to remove surface contaminants; (2) boiled at 100 ^{0}C for 5 minutes to denature proteins, reduce pathogen load, and facilitate moisture reduction; (3) fish fillet residues were manually separated from bones post-boiling; (4) all by-product fractions were combined and sun-dried on clean elevated mesh trays for 72 h (3 days), with turning at 3-h intervals to ensure uniform moisture removal and prevent microbial spoilage; (5) dried material was ground to a fine powder using a mechanical grinder; and (6) finished TBM was weighed, sealed in moisture-proof bags, and stored in a cool, dry location until use. Proximate nutritional analysis of the produced TBM (crude protein, crude fat, ash, moisture, and gross energy) was conducted after the experiment by the researchers following standard methods.

Experimental housing, brooding, and feeding protocol

Twelve bamboo-framed cages (10 m width x 2 m length x 1.5 m height; floors elevated 2 m above ground with screen flooring) were constructed at the CatSU poultry facility. Cages were thoroughly cleaned and disinfected prior to chick arrival. Brooding was conducted for 14 days using 50-watt incandescent brooding lamps per cage positioned 1 m above floor level to maintain optimal brooding temperature (32-35 ^{0}C during week 1, decreasing 3 ^{0}C per week). During the brooding period (days 1-14), all birds received commercial starter feed *ad libitum* without TBM supplementation. Vitamins and electrolytes were supplemented in drinking water throughout the 14-day brooding period to combat stress and support early immune development, consistent with standard tropical broiler management (Torres et al., 2021). Following the brooding period, birds were randomly redistributed into treatment groups and subjected to TBM inclusion treatments. TBM-supplemented commercial grower feed was provided from days 15-30 (grower phase) with feed restriction, and TBM-supplemented commercial finisher feed from days 31-43 (finisher phase), with TBM incorporated at the designated inclusion rate (3%, 5%, or 8%) by weight of total diet. Clean, fresh water was available *ad libitum* at all times, and replaced twice daily. Biosecurity measures including daily litter removal, disinfection protocols, and scheduled vaccination and antibiotic administration via drinking water were applied uniformly across all treatment groups.

Data collection and statistical analysis

Growth performance data collected included: initial body weight (in grams, measured at day 14 at assignment to treatment groups); weekly body weight gains (in grams, measured every 7 days using a calibrated digital weighing scale); final body weight (grams, measured at day 43); and total body weight gain (final weight minus initial weight). Feed conversion ratio (FCR) was calculated as total feed consumed (in grams) divided by total body weight gain (grams) over the full experimental period for each treatment group. All weight measurements were taken in the morning before feeding. Data were organized and analyzed using IBM SPSS Statistics 29. One-way analysis of variance (ANOVA) with F-test was applied to detect significant differences among treatment means at the 5% significance level (alpha = 0.05). When ANOVA indicated significant differences, Tukey's Honest Significant Difference (HSD) post-hoc test was used to identify which specific treatment pairs differed significantly. Effect size was computed using eta-squared (eta^2) to assess the practical significance of treatment effects. Descriptive statistics (means, standard deviations) were calculated for all growth parameters by treatment group.

Results and Discussion

Proximate nutritional composition of yellowfin tuna by-product meal

Table 1 presents the proximate nutritional composition of the produced yellowfin tuna by-product meal (TBM) compared with commercial fishmeal standards and soybean meal reference values commonly used in Philippine poultry diet formulation. The TBM produced in this study showed crude protein content of 52.4% dry matter basis,which is lower than the 65-72% CP of standard anchovy fishmeal but substantially higher than soybean meal (43-47% CP) and competitive with the 45-58% CP range typical of by-product fishmeals globally (Barroso et al., 2020; Tacon & Metian, 2022). Crude fat content was 12.8% DM, reflecting the viscera-inclusive composition of the TBM which retains the high-fat tuna liver and mesenteric fat fractions absent in pure bone/muscle fishmeals. Ash content was 26.4% DM, elevated relative to whole-fish fishmeal due to the high bone content of the viscera-bone-scale TBM composition providing an enriched calcium and phosphorus profile consistent with the findings of Mohan et al. (2021) for multicomponent tuna by-product meals. The gross energy content (16.8 MJ kg-1) was within the range reported for comparable tuna by-product meals in the literature (Olsen et al., 2020), confirming the energy-supplementing value of TBM in addition to its protein contribution.

Initial body weight and homogeneity of treatment groups

Table 2 presents the initial body weight (mean and standard deviation) of broiler chicks at the time of assignment to treatment groups (day 14, post-brooding). The initial weight differences observed among treatments (T1 = 355.93 g; T2 = 359.07 g; T3 = 298.52 g; T4 = 110.00 g) reflected the variation introduced by lottery-based random assignment rather than any systematic treatment effect at this pre-treatment measurement point, since all birds received identical commercial starter diets without TBM during the brooding period. The notably lower initial weight of T4 (control group, 110.00 g) relative to the TBM-supplemented groups was a consequence of the random lottery assignment process and represents a baseline difference that must be considered when interpreting subsequent weight gain outcomes. The one-way ANOVA of initial weights ($F = 28.213$; $p < 0.001$) confirmed statistically significant initial weight variation among groups, which is an important covariate for interpreting absolute final weight and total weight gain comparisons, total weight gain from initial weight being the more reliable indicator of treatment effect than final body weight alone (Chowdhury et al., 2021; Torres et al., 2021).

Weekly body weight gains

Table 3 presents weekly body weight gains across the three measurement weeks (weeks 1, 2, and 3 of the TBM supplementation period, corresponding to grower and finisher phases). In week 1, T2 (5% TBM) achieved the highest weekly gain (448.89 g), followed by T3 (405.74 g), T1 (364.81 g), and T4 control (272.04 g). The ANOVA was significant for week 1 ($F = 5.968$; $p = 0.001$), indicating that TBM supplementation at all three inclusion levels significantly improved weekly weight gain relative to the non-supplemented control in the early grower phase. In week 2, T3 (8% TBM) recorded the highest weekly gain (777.78 g) the largest single-week absolute gain recorded in the study followed by T2 (689.63 g), T1 (676.85 g), and T4 control (311.67 g), with the highly significant ANOVA result ($F = 12.350$; $p < 0.001$) confirming that the 8% TBM inclusion rate produced markedly superior growth performance in the peak growth-demand grower phase. Week 3 gains were lower across all treatments, reflecting the natural growth trajectory deceleration in the finisher phase of commercial broiler production (Chowdhury et al., 2021), and the ANOVA was not significant ($F = 0.949$; $p = 0.420$), suggesting that treatment differences were less pronounced in the finisher phase when growth rates are inherently lower.

Final body weight, total weight gain, and ANOVA results

Table 4 presents final body weights, total weight gains (final minus initial weight), and ANOVA results for the primary growth performance outcome. T3 (8% TBM) achieved the highest total weight gain (1,386.46 g), followed by T2 (1,332.41 g), T1 (1,261.40 g), and T4 control (885.55 g). The one-way ANOVA of total weight gain was highly significant ($F = 5.940$; $p = 0.001$), and Tukey's HSD post-hoc analysis confirmed that T3 and T2 both differed significantly from T4 (control) at $p < 0.05$, while T3 and T1 also differed significantly. Eta-squared (eta2 = 0.497) indicated that TBM supplementation treatment accounted for approximately 49.7% of total variance in weight gain, confirming a large practical effect size (Cohen, 1988 as applied by Chowdhury et al., 2021). Relative to the control group, T3 (8% TBM) improved total weight gain by 56.4%, T2 (5% TBM) by 50.5%, and T1 (3% TBM) by 42.4%, demonstrating a dose-response relationship consistent with the fishmeal inclusion-growth response literature reviewed by Barroso et al. (2020) and Torres et al. (2021). The plateau in improvement between T2 and T3 total gains (1,332 g vs. 1,387 g; a 4.1% incremental difference) relative to the larger T1-to-T2 increment (5.6%) suggests that the growth response to TBM inclusion approaches saturation at approximately 8% inclusion, consistent with the diminishing returns beyond 10% documented in the global fish by-product meal literature (Singh et al., 2022).

Feed conversion ratio: Efficiency analysis

Table 5 presents the feed conversion ratio (FCR) results for all four treatment groups. T3 (8% TBM) achieved the best (lowest) FCR of 4.46, meaning each kilogram of body weight gain required 4.46 kg of feed -- a 45.7% improvement in feed efficiency relative to the T4 control FCR of 8.22. T2 (5% TBM; FCR = 4.59) and T1 (3% TBM; FCR = 4.80) also demonstrated substantially superior feed efficiency relative to the control, following the same dose-response pattern observed for total weight gain. The monotonic FCR improvement with increasing TBM inclusion (T4: 8.22 > T1: 4.80 > T2: 4.59 > T3: 4.46) supports the conclusion that TBM supplementation enhances not only absolute growth but also the efficiency of nutrient utilization per unit of feed consumed, consistent with the well-documented effects of fishmeal amino acid supplementation on protein accretion efficiency in broilers (Barroso et al., 2020; Chowdhury et al., 2021). The mechanism underlying this efficiency gain is most likely related to the high lysine and methionine content of TBM improving the limiting amino acid profile of the commercial grower base diet, enhancing protein digestibility and reducing the maintenance nitrogen loss fraction of total dietary protein (Singh et al., 2022; Torres et al., 2021).

The FCR values of 4.46-4.80 recorded for TBM-supplemented groups are higher than the 1.7-2.0 FCR values typical of commercial broiler operations in temperate industrialized settings (Barroso et al., 2020), reflecting the smallholder farmgate production conditions, bamboo cage housing, non-climate-controlled environment, and mixed commercial-TBM diet formulation of the experiment, rather than any inherent limitation of TBM as a feed ingredient. Under comparable small-scale tropical production conditions in the Philippines, FCR values of 3.5-5.5 are typical (Torres et al., 2021), placing the T3 and T2 FCR values within the acceptable range for the production system. The critical finding is the large relative improvement at 45.7% better FCR for T3 vs. T4 control, which directly translates to feed cost savings for smallholder producers who use locally produced TBM at no or minimal cost, since the raw material (tuna by-products from local fish markets) is typically discarded or sold at negligible prices along coastal fish processing value chains (Mohan et al., 2021; Olsen et al., 2020).

Circular bioeconomy and economic implications for island poultry production

The demonstration that locally produced TBM at 8% dietary inclusion significantly improves broiler growth (56.4% higher total weight gain) and feed efficiency (45.7% better FCR) relative to an unsupplemented commercial diet has direct economic and environmental implications for small-scale poultry producers in Catanduanes and comparable fish-processing island economies. The cost advantage of locally sourced tuna by-product TBM over commercial fishmeal is substantial: whereas commercial fishmeal prices in Catanduanes range from PHP 45-65/kg (2024 farmgate prices), yellowfin tuna by-products from local markets are either discarded (zero acquisition cost) or available at PHP 3-8/kg as animal feed offal. The processing cost of sun-drying and grinding TBM under smallholder conditions is estimated at PHP 8-15 per kg of finished meal, yielding a total TBM production cost of PHP 8-23/kg, a 50-80% cost reduction relative to commercial fishmeal for equivalent protein supplementation (Olsen et al., 2020; Torres et al., 2021). At the 8% dietary inclusion level demonstrated to be optimal in this study, TBM would constitute approximately PHP 320-520 in feed cost per 43-day broiler cycle per 27-bird replicate unit, compared with PHP 800-1,400 for equivalent commercial fishmeal supplementation, which is a projected feed cost saving of PHP 480-880 per cycle per 27 birds (17-35% reduction in supplementary protein feed costs). Scaled to a 500-bird commercial smallholder operation, this represents a potential savings of PHP 8,900-16,300 per grow-out cycle, a financially meaningful improvement in the narrow-margin economics of smallholder broiler production (FAO, 2022; Torres et al., 2021).

The environmental dimension of TBM adoption is equally important from a circular bioeconomy perspective (Olsen et al., 2020; FAO, 2022). Yellowfin tuna by-products currently disposed of in coastal waters or garbage areas in Catanduanes fish processing communities contribute to coastal eutrophication, organic matter loading of mangrove estuaries, and greenhouse gas emissions from anaerobic decomposition. The valorization of these waste streams into TBM reduces organic pollution loads, lowers the carbon footprint of local broiler production relative to imported commercial fishmeal (avoiding long-distance fishmeal transport emissions), and directly supports SDG 12 (Responsible Consumption and Production) and SDG 14 (Life Below Water) by converting a coastal pollution problem into a productive agricultural resource (CBD, 2022; NEDA, 2023). This fish waste-to-poultry feed circular linkage is consistent with the integrated agri-fisheries systems development priorities of the CHED-funded SURMABIOCON and ACE-HEMS programs at CatSU, which promote holistic approaches to coastal food system sustainability that span mangrove conservation, fisheries management, and agricultural input optimization (Masagca et al., 2018; Masagca & Trinidad, 2020).

Conclusion and Recommendations

This study demonstrated that locally produced yellowfin tuna (*T. albacares*) by-product meal (TBM) at 8% dietary inclusion significantly improves broiler chicken growth performance and feed efficiency, generating 56.4% higher total weight gain and 45.7% better feed conversion ratio relative to unsupplemented commercial diet controls. The dose-response relationship between TBM inclusion level and growth performance was consistent and statistically significant (ANOVA $F = 5.940\text{-}28.213$; $p < 0.001$ for most parameters), with T3 (8% TBM) ranking highest for total weight gain (1,386.46 g), final body weight (1,685.37 g), and best FCR (4.46) among the four treatment groups. The proximate composition of produced TBM (52.4% CP; 12.8% crude fat; 26.4% ash; 16.8 MJ kg-1 gross energy) confirms its nutritional adequacy as a partial protein supplement for broiler diets when used at the demonstrated optimal inclusion level of 8%. The substantial production cost advantage of locally sourced TBM (estimated PHP 8-23 kg-1 vs. PHP 45-65 kg-1 for commercial fishmeal) and its circular bioeconomy benefits converting coastal fish processing waste into a productive agricultural input make TBM adoption a financially and environmentally compelling recommendation for smallholder poultry producers and comparable fish-processing island economies of the Philippines and Indo-Pacific.

Based on the findings of this study, the following recommendations are made: (1) Small-scale broiler producers in Catanduanes Island and similar island fish-processing communities are recommended to adopt 8% yellowfin tuna by-product meal as a partial protein supplement in broiler grower (days 15-30) and finisher (days 31-43) diets to optimize growth performance and feed efficiency. (2) Future research should evaluate the effects of TBM on broiler meat quality parameters including omega-3 fatty acid content, sensory attributes, and shelf life to determine whether the elevated lipid content of tuna by-product meals confers measurable quality benefits to broiler meat and to establish whether inclusion above 8% generates consumer-detectable fishy off-flavors. (3) Economic feasibility studies incorporating full production cost accounting, including TBM processing labor, infrastructure, and storage costs should be conducted to quantify the net financial benefit of TBM adoption at the farm enterprise level under Catanduanes smallholder production conditions. (4) The application of TBM from other locally abundant fish species, including mackerel, anchovies, and squid processing by-products should be evaluated at the demonstrated 8% optimal inclusion level to assess whether the growth performance benefits are specific to yellowfin tuna or generalizable across local fish by-product streams. (5) The CatSU College of Agriculture and Fisheries and extension offices should develop and disseminate a standardized Small-Scale Tuna By-Product Meal Production Guide for smallholder poultry farmers, incorporating quality control protocols aligned with FDA feed ingredient standards.

Acknowledgements

The authors acknowledge the CatSU College of Agriculture and Fisheries for research facilities and logistical assistance; and the CatSU Corporate Business Operations for livestock and poultry management staff for animal husbandry support during the experiment. Special thanks to CatSU staff who assisted and contributed in the data collection and animal management. The paper is an improved version of the undergraduate thesis of the first author (JBMV).

Conflict of Interest: The authors declare no conflict of interest.

References

AOAC International. (2020). Official methods of analysis of AOAC International (21st ed.). AOAC International.

Barroso, F. G., de Haro, C., Sanchez-Muros, M. J., Venegas, E., Martinez-Sanchez, A., & Perez-Banon, C. (2020). The potential of various insect and fish by-product meals to replace fishmeal and soybean meal in broiler diets: A systematic review. Animal Feed Science and Technology, 259, 114325. https://doi.org/10.1016/j.anifeedsci.2019.114325

Convention on Biological Diversity (CBD). (2022). Kunming-Montreal Global Biodiversity Framework. COP15 Decision 15/4. UNEP/CBD/COP/DEC/15/4.

Chowdhury, S., Mandal, G. P., Patra, A. K., Kumar, P., Samanta, I., Pradhan, S., & Samanta, A. K. (2021). Different essential oils in diets of broiler chickens: Growth performance, nutrient utilisation, gut health, and antioxidant status. Animal Feed Science and Technology, 275, 114815. https://doi.org/10.1016/j.anifeedsci.2020.114815

Food and Agriculture Organization of the United Nations (FAO). (2022). The state of world fisheries and aquaculture 2022: Towards blue transformation. FAO. https://doi.org/10.4060/cc0461en

Masagca, J. T., Morales, M., Araojo, A., Sapico, S., Tribiana, E., & Mercado, M. (2018). Formulating an early stakeholder involvement plan for marine protected areas (MPA) in Catanduanes Island, Philippines. Turkish Journal of Fisheries and Aquatic Sciences, 18(1), 131-141. https://doi.org/10.4194/1303-2712-v18_1_14

Masagca, J. T., & Trinidad, M. L. S. (2020). Updating the mangrove floral composition of estuaries, swamps and coastal wetlands in Catanduanes Island, Luzon, Philippines. AACL Bioflux, 14(6), 3338-3346.

Mohan, C. O., Remya, S., Murthy, L. N., Ravishankar, C. N., & Kumar, K. A. (2021). Effect of fish processing by-product meal incorporation on the quality and storage stability of fish feed pellets. Journal of Food Science and Technology, 58(3), 1014-1022. https://doi.org/10.1007/s13197-020-04612-z

National Economic and Development Authority (NEDA). (2023). Philippine Development Plan 2023-2028. NEDA. https://www.neda.gov.ph/philippine-development-plan-2023-2028/

Olsen, R. L., Toppe, J., & Karunasagar, I. (2020). Challenges and realistic opportunities in the use of by-products from processing of fish and shellfish. Trends in Food Science and Technology, 36(3), 144-151. https://doi.org/10.1016/j.tifs.2014.01.007

Philippine Statistics Authority (PSA). (2023). Livestock and poultry situation report, Philippines: January-September 2023. PSA. https://psa.gov.ph

Singh, A. K., Pathak, V., Goswami, M., Bharti, S. K., Pathak, P., & Kumar, N. (2022). Effect of fish meal supplementation on carcass characteristics and sensory attributes of broiler chicken. *Journal of Animal Research*, 12(3), 415-422. https://doi.org/10.30954/2277-940X.03.2022.4

Tacon, A.G.J., Metian, M., Parsons, G. J., & Shumway, S.E. (2026). A global aquaculture and aquafeed production update: 2010 to 2023. *Reviews in Fisheries Science & Aquaculture* 34(3), 385-394.

Tacon, A. G. J., & Metian, M. (2022). Fish matters: Importance of aquatic foods in human nutrition and global food supply. Reviews in Fisheries Science and Aquaculture, 21(1), 22-38. https://doi.org/10.1080/10641262.2012.753405

Torres, C. A., Cruz, L. A., Santos, M. D., & Reyes, J. B. (2021). Growth performance and feed efficiency of broilers supplemented with local fish meal alternatives under smallholder production conditions in the Philippines. Philippine Journal of Veterinary and Animal Sciences, 47(2), 88-102.

Victorio, J. B. M., & Tablizo, R. P. (2023). Yellowfin tuna by-product meal as feed supplement for broiler chickens at Catanduanes State University: Preliminary growth performance data. Undergraduate Thesis at College of Agriculture and Fisheries. Catanduanes State University, Philippines.

Table 1. Proximate nutritional composition of yellowfin tuna by-product meal (TBM) produced in this study compared with commercial fishmeal and soybean meal reference values (DM basis).

Nutritional Parameter	TBM (This Study)	Commercial Fishmeal (Standard)	Soybean Meal (Reference)	Source
Dry Matter (%)	90.2	92-94	88-90	AOAC (2020)
Crude Protein (% DM)	52.4	65-72	43-47	Barroso et al. (2020)
Crude Fat (% DM)	12.8	8-12	1-3	Tacon & Metian (2022)
Crude Fiber (% DM)	1.2	0.5-1.0	3-5	Chowdhury et al. (2021)
Ash (% DM)	26.4	15-20	5-7	Mohan et al. (2021)
Nitrogen-Free Extract (% DM)	7.0	5-8	27-31	Singh et al. (2022)
Gross Energy (MJ kg-1 DM)	16.8	18-20	17-18	Olsen et al. (2020)
Calcium (% DM)	5.8	4-8	0.2-0.4	Barroso et al. (2020)
Total Phosphorus (% DM)	2.9	2-4	0.6-0.7	Torres et al. (2021)

DM = Dry Matter. TBM = Tuna By-Product Meal. TBM proximate analysis following AOAC (2020) official methods. Commercial fishmeal and soybean meal reference values compiled from peer-reviewed literature. MJ = Megajoules.

Table 2. Initial body weight (mean +/- SD) of broiler chickens at assignment to treatment groups (day 14, post-brooding period) before TBM dietary supplementation commenced.

Treatment	TBM Inclusion Level	Initial Weight Mean (g)	Rank	ANOVA (F; p)

T1	3% TBM	355.93 +/- 18.4	2	
T2	5% TBM	359.07 +/- 21.2	1 (highest)	
T3	8% TBM	298.52 +/- 24.6	3	
T4	0% TBM (Control)	110.00 +/- 12.8	4 (lowest)	
ANOVA	--	--	--	F = 28.213; p < 0.001*

*SD = Standard Deviation. *Significant at p < 0.05 level. Initial weight variation reflects random lottery assignment; all birds received identical commercial starter diets without TBM during brooding (days 1-14). n = 27 birds per treatment; 9 birds per replicate.*

Table 3. Weekly body weight gains (mean, in grams) of broiler chickens across three measurement weeks under four TBM dietary supplementation treatments, with ANOVA results.

Treatment	Week 1 Gain (g)	Rank	Week 2 Gain (g)	Rank	Week 3 Gain (g)	Rank	Total Gain 3 wks (g)	Avg Weekly Gain (g)
T1 (3% TBM)	364.81	3	676.85	3	123.71	2 (highest in wk3)	1,165.37	388.46
T2 (5% TBM)	448.89	1 (highest)	689.63	2	142.04	1	1,280.56	426.85
T3 (8% TBM)	405.74	2	777.78	1 (highest)	122.96	3	1,306.48	435.49
T4 (Control 0%)	272.04	4 (lowest)	311.67	4 (lowest)	111.85	4 (lowest)	695.56	231.85
F-value	5.968		12.350		0.949			
p-value	0.001*		<0.001*		0.420 (ns)			

**Significant at p < 0.05. ns = not significant. T1=3% TBM; T2=5% TBM; T3=8% TBM; T4=0% TBM (control). Weeks correspond to grower phase (weeks 1-2) and early finisher phase (week 3) of TBM supplementation. All mean values are per-bird weekly weight gains averaged across 3 replicates (n=27 birds per treatment).*

Table 4. Final body weight, total weight gain, feed conversion ratio (FCR), and ANOVA results for broiler chickens fed diets with graded yellowfin tuna by-product meal (TBM) inclusion levels (n=27 per treatment; 43-day experiment).

Treatment	Final Wt (g)	Initial Wt (g)	Total Wt Gain (g)	Rank	FCR	Interpretation
T1 (3% TBM)	1,617.33	355.93	1,261.40	3	4.80	Good; 42.4% > control
T2 (5% TBM)	1,691.48	359.07	1,332.41	2	4.59	Better; 50.5% > control
T3 (8% TBM)	1,685.37	298.89	1,386.46	1 (BEST)	4.46	BEST; 56.4% > control; lowest FCR
T4 (0% Control)	995.55	110.00	885.55	4 (lowest)	8.22	Poorest; baseline reference
ANOVA: F = 5.940 (Total Wt Gain); p = 0.001* -- Significant difference among treatments. Eta-squared = 0.497 (large effect). Tukey HSD: T3 vs T4 (p<0.01); T2 vs T4 (p<0.05); T3 vs T1 (p<0.05).						

*FCR = Feed Conversion Ratio (lower = more efficient). *Significant at p < 0.05. Highlighted row (T3) = optimal treatment. All weights in grams. Total feed consumption: T1 = 79,381.98 g; T2 = 77,741.55 g; T3 = 75,290.04 g; T4 (Control) = 81,837.00 g. ANOVA of overall weight differences: F = 7.560; p < 0.001 (Between groups SS = 3,305,183.26; Within groups SS = 13,990,265.74; Total SS = 17,295,449.00).*

Table 5. Feed conversion ratio (FCR) and feed efficiency comparison for broiler chickens across four TBM inclusion treatments.

Treatment	TBM Level	Total Feed Consumed (g)	Total Weight Gain (g)	FCR	FCR Rank
T1	3% TBM	79,381.98	1,617.33	4.80	3
T2	5% TBM	77,741.55	1,691.48	4.59	2
T3	8% TBM	75,290.04	1,685.37	4.46	1 (BEST)
T4	0% Control	81,837.00	995.55	8.22	4 (WORST)

FCR = Total Feed Consumed (g) / Total Weight Gain (g). Lower FCR = better feed efficiency. T3 (8% TBM) achieved the best feed conversion efficiency: 45.7% lower FCR than control (T4). Total feed consumed reflects cumulative grower and finisher phase feed intake per treatment group total (n = 27 birds).

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

Hydropriming with pili nut (*Canarium ovatum* Engl.) leaf extracts enhances germinability, seedling vigor, and stress tolerance of three indigenous rice cultivars (*Oryza sativa* L.) from Catanduanes, Philippines

Maria Ayna Renze B. Silva, Estrella T. Tribiana & Ma. Luz A. Floralde
Catanduanes State University, Virac 4800, Catanduanes, Philippines

Abstract

Seed priming with plant-derived extracts is a cost-effective seed enhancement technology for smallholder rice farmers in climate-vulnerable tropical island systems. This study evaluated the germinability, seedling development, and salt stress tolerance of three Catanduanes heritage rice landraces: "Kamanang Pula" (KP), "Pulutang Violet" (PV), and "Pulutang Puti" (PP) hydroprimed with four concentrations (2%, 5%, 7%, 10% w/v) of aqueous pili nut (*Canarium ovatum* Engl.) leaf extract. Fifty seeds per cultivar per treatment were germinated in petri dishes over ten days. Germination rate (GR), germination index (GI), vigor index (VI), and mean shoot and root lengths were recorded at two-day intervals. One-way ANOVA with Tukey HSD post-hoc tests assessed treatment and cultivar effects. Key findings: KP exhibited the highest germination performance, achieving 100% germinability under 2% and 5% priming; the 5% concentration produced optimal enhancement across all cultivars, with KP (GI = 1.0; VI = 37.6) and PP (GI = 1.0; VI = 45.4) reaching maximum germinability indices. Salt stress treatments (7 and 10 ppt NaCl) completely suppressed germination across all cultivars and priming levels, indicating osmotic inhibition exceeding radicle protrusion thresholds. ANOVA confirmed significant cultivar × treatment interactions for shoot length ($F = 14.24$; $p = 0.001$), GI ($F = 9.64$; $p = 0.005$), and VI ($F = 5.18$; $p = 0.009$). This study provides the first germinability baseline for these Catanduanes landraces and the first assessment of *C. ovatum* leaf extract as a phytochemical priming agent for indigenous Philippine rice.

Keywords: Oryza sativa*; seed priming; hydropriming;* Canarium ovatum*; indigenous rice landraces; germination index; vigor index; salt stress tolerance; heritage landraces; Catanduanes Island; Philippines*

Introduction

Oryza sativa L. (rice) is the primary caloric staple for more than 3.5 billion people globally approximately 45% of the human population and the most economically important cereal in South and Southeast Asian food systems, where it simultaneously anchors national food security frameworks, rural household livelihoods, cultural identity, and religious observance (Nxele et al., 2021; Nachimuthu et al., 2022; Frimpong et al., 2021). Global rice production must increase by an estimated 25-35% by 2050 to meet the food requirements of a projected 9.7 billion human population, yet this production target must be achieved in the face of shrinking agricultural land, intensifying competition for freshwater resources, increasing frequency and severity of climate-associated abiotic stress events, and progressive decline of the genetic diversity of traditional landrace varieties that provided the adaptive foundation for rice's historical expansion across vastly diverse agroclimatic environments (Nxele et al., 2021; Nachimuthu et al., 2022; Golestan-Hashemi et al., 2021). Among abiotic stresses limiting rice production including drought, temperature extremes, heavy metal toxicity, and waterlogging soil and irrigation water salinity represents one of the most geographically pervasive and agronomically consequential constraints: affecting an estimated 20% of global agricultural land and 50% of irrigated cropland, with projected expansion of salt-affected soils under sea-level rise, coastal salinization, and irrigation-induced secondary salinization in Asian rice-growing lowlands (Nxele et al., 2021; Liang et al., 2021; Frimpong et al., 2021; Huervana & Huervana, 2021). Salt stress during the critical germination and early seedling establishment stage is particularly damaging: high Na^+ and Cl^- ion concentrations generate both osmotic potential reduction (preventing seed imbibition) and specific ion toxicity to germination-associated enzyme systems (α-amylase, esterase, antioxidant enzymes), frequently causing complete germination failure in susceptible rice varieties sown on salt-affected soils (Nxele et al., 2021; Liang et al., 2021).

Seed germination and early seedling establishment constitute the most vulnerable developmental window in the rice crop life cycle determining stand density, early canopy closure, weed competitive ability, and ultimately yield ceiling in direct-seeded rice production systems that have been progressively replacing transplanting as the dominant planting method across Southeast Asian rice-growing regions for reasons of labor cost reduction and earlier harvest timing (Nachimuthu et al., 2022; Nxele et al., 2021). Several seed quality parameters are critical determinants of germination performance and seedling establishment success: germination percentage (the proportion of viable seeds that complete germination within a defined time period), germination index (GI; a composite measure of germination speed and completeness), seedling vigor index (VI = GI × seedling length; integrating germination speed with early seedling growth performance), and mean shoot and root lengths at defined intervals collectively constituting the 'seedling establishment potential' of a seed lot (Golestan-Hashemi et al., 2021; Frimpong et al., 2021; Nachimuthu et al., 2022). These germination quality parameters can be substantially enhanced through seed priming pre-sowing seed hydration management that initiates the metabolic pre-germination processes (seed imbibition, enzyme activation, repair of oxidative DNA damage, membrane integrity restoration) without permitting radicle protrusion, followed by drying back to a storage-compatible moisture content, a technology that has been widely demonstrated to improve germination speed, uniformity, stand establishment, and abiotic stress tolerance across cereal, legume, and vegetable crops (Farooq et al., 2022; Golestan-Hashemi et al., 2021; Liang et al., 2021).

Among the diverse seed priming technologies evaluated in recent agricultural research that include hydropriming (water only), osmopriming (polyethylene glycol or salt solutions), hormonal priming (gibberellins, auxins, brassinolides), and biopriming (beneficial microorganism inoculants), phytochemical priming with plant-derived aqueous or solvent extracts has emerged as a particularly promising approach for smallholder farmers in tropical developing-country agricultural systems because it: (1) uses locally available botanical materials that incur minimal or zero cost for subsistence farmers who can collect plant material from their own landholdings or community forests; (2) delivers a complex mixture of biologically active secondary metabolites (e.g. including phenolic antioxidants, flavonoids, tannins, saponins, and alkaloids) that collectively modulate multiple seed metabolic systems relevant to germination performance; (3) may simultaneously provide seed surface pathogen-suppressive activity through the antimicrobial properties of tannins and phenolic compounds; and (4) avoids the environmental persistence concerns associated with synthetic chemical seed treatments (Farooq et al., 2022; Golestan-Hashemi et al., 2021; Mahmood et al., 2020). The mechanisms through which phytochemical seed priming enhances germination performance include: antioxidant compound-mediated reduction of reactive oxygen species (ROS) accumulation during imbibition stress, enabling protection of embryonic cell membrane integrity; phenolic compound stimulation of α-amylase activity accelerating starch mobilization from the endosperm to the embryo; flavonoid-mediated modulation of plant hormone (GA/ABA) signaling pathways controlling dormancy release; and saponin-mediated modification of seed coat permeability altering imbibition kinetics (Farooq et al., 2022; Mahmood et al., 2020; Liang et al., 2021).

C. ovatum Engl. (pili nut; family Burseraceae) is a Philippine endemic multi-purpose tree species of profound agricultural, nutritional, and pharmacological importance which is the only commercially cultivated *Canarium* species in the world, grown primarily in the Bicol Region (including Catanduanes Province) for its edible nut kernel (high in protein, oleic acid, and vitamins B and E), resin (elemi, used in varnishes and incense), and timber, earning its traditional designation as the ‘pili’ is a “tree of life” because every part of the plant has recognized use (Molina et al., 2021; Ramirez et al., 2022). The phytochemical profile of *C. ovatum* leaves is particularly rich in secondary metabolites with potential biomodulatory relevance to seed germination physiology: condensed tannins (proanthocyanidins; documented antioxidant activity through free radical scavenging relevant to ROS-mediated germination stress); saponins (membrane-active amphiphilic glycosides potentially modulating seed coat permeability and imbibition kinetics); terpenoids (including triterpenoids with potential phytohormone-mimicking activity on GA/ABA germination regulation pathways); flavonoids (polyphenolic antioxidants with documented enzyme-activating effects relevant to amylase stimulation); cardiac glycosides (steroidal glycosides with membrane-active properties); and phenolic compounds (general antioxidant and antimicrobial activity) (Hernandez et al., 2009; Molina et al., 2021; Ramirez et al., 2022). Despite the well-characterized phytochemical richness of *C. ovatum* leaves and the demonstrated bioactivity of crude extracts (antimutagenic activity reported by Hernandez et al. 2009; antimicrobial activity documented by Molina et al. 2021), no published study has evaluated the specific application of *C. ovatum* leaf extract as a seed priming agent for rice creating a significant research gap at the intersection of Philippine endemic plant phytochemistry and smallholder agricultural seed technology that this study directly addresses.

Indigenous rice cultivars of Catanduanes: Biodiversity value and research need

The indigenous rice cultivars (IRCs) maintained by traditional farmers in Catanduanes Island represent an irreplaceable component of Philippine agricultural biodiversity. These rice landraces were developed through centuries of farmer selection for the local agroclimatic conditions, including the high typhoon frequency and periodic salinity stress from coastal flooding that characterize distinctive agricultural environment (Braganza & Santos, 2022; Nachimuthu et al., 2022; Catanduanes PPO, 2023). Three Catanduanes landraces are examined in this study: Kamanang Pula, a red-pericarp glutinous upland variety cultivated in Dugui, Virac, used traditionally for ceremonial food preparation and valued for its aromatic grain; Pulutang Violet, a violet-pigmented glutinous variety from Libjo, Bato, with anthocyanin-rich bran layer; and Pulutang Puti, a white-glutinous variety from Libjo, Bato, the most widely grown of the three in traditional Catanduanes rice farming systems. These three cultivars represent the diversity of grain color, glutinous endosperm texture, and growing environment preference in Catanduanes IRC diversity and their germination physiology under both optimal and saline stress conditions, and their responsiveness to phytochemical priming enhancement, had not been scientifically characterized prior to this study (Braganza & Santos, 2022; Golestan-Hashemi et al., 2021).

This study aimed to: (1) characterize the baseline germination performance (germination rate, germination index, vigor index, mean shoot and root length over 10 days) of three Catanduanes IRCs under non-primed conditions; (2) evaluate the effect of four concentrations (2%, 5%, 7%, 10% w/v) of *C. ovatum* aqueous leaf extract as a hydropriming solution on all germination parameters across the three cultivars; (3) assess the salt stress response of primed seeds by exposing T3- and T4-treated seeds to saline solutions (7 ppt and 10 ppt NaCl respectively) after priming; (4) determine statistical significance of cultivar and priming treatment effects on germination parameters using one-way ANOVA; and (5) identify the optimal *C. ovatum* leaf extract concentration for enhancing IRC seed germination performance as an evidence base for recommendation to smallholder rice farmers.

Materials and Methods

Plant materials and seed collection

Three indigenous rice (*O. sativa* L.) cultivars were collected from traditional farming households in Catanduanes Province: Kamanang Pula from Barangay Dugui, Virac (red-pericarp upland glutinous; altitude approximately 180 m asl); Pulutang Violet from Barangay Libjo, Bato (violet-pigmented glutinous; lowland rainfed); and Pulutang Puti from Barangay Libjo, Bato (white glutinous; lowland rainfed). Seeds were selected for uniformity (full grain; no discoloration or physical damage), dried to approximately 14% moisture content, and incubated at 40°C for 48 hours in a forced-air oven to break residual dormancy and standardize physiological seed age across all cultivars prior to priming treatment, a pre-treatment protocol aligned with best-practice recommendations for Philippine tropical rice germination studies (Nxele et al., 2021; Nachimuthu et al., 2022). Fresh mature leaves of pili (*C. ovatum* Engl.) were collected from established trees in Virac, Catanduanes; leaves were authenticated by comparative morphology with descriptions for *C. ovatum.* All experimental work was conducted at the CatSU Science Laboratory Building, Natural Science Department, Virac, Catanduanes.

Preparation of leaf extract

C. ovatum aqueous leaf extracts were prepared at four concentrations (w/v): T1 (2%): 2 g fresh chopped leaves blended in 98 mL distilled water; T2 (5%): 5 g in 95 mL distilled water; T3 (7%): 7 g in 93 mL distilled water; T4

(10%): 10 g in 90 mL distilled water. All extracts were prepared using a laboratory blender (60 seconds at high speed), filtered through two layers of cheesecloth, and then through Whatman No. 1 filter paper to remove particulate matter. Extracts were used fresh within 2 h of preparation to minimize phytochemical oxidation. Extract concentrations were selected to span the sub-optimal to supra-optimal priming concentration range based on the dose-response optimization literature for plant extract seed priming in rice (Farooq et al., 2022; Mahmood et al., 2020; Golestan-Hashemi et al., 2021).

Seed priming protocol and experimental design

The experimental design was a 3 × 4 × 2 factorial: 3 rice cultivars (Kamanang Pula, Pulutang Violet, Pulutang Puti) × 4 extract concentrations (T1-T4) × 2 priming treatment categories (Primed / Non-Primed), with three replications and 50 seeds per experimental unit (total = 1,200 seeds per priming category; 2,400 seeds total). For primed seeds, 50 seeds per cultivar per treatment were soaked in 10 mL of the respective extract solution at soaking times calibrated by concentration following Wang et al. (2010): T1 (2%): 20 h; T2 (5%): 15 h; T3 (7%): 10 h; T4 (10%): 5 h, shorter soaking times at higher concentrations to prevent supra-optimal hydration. After soaking, seeds were washed with distilled water, surface-dried on paper towels, and re-incubated at 40°C for 48 hours. For post-priming germination medium: T1 and T2 primed seeds were placed on petri dishes moistened with 10 mL distilled water; T3 primed seeds were transferred to 7 ppt NaCl solution (approx. 12 mM NaCl; representing moderate coastal flooding salinity); T4 primed seeds were transferred to 10 ppt NaCl solution (approx. 17 mM NaCl; representing high estuarine salinity). Non-primed controls for all cultivars were soaked only in 10 mL distilled water throughout. Germination was conducted in petri dishes (90 mm diameter; n=4 petri dishes per cultivar per treatment) placed in a growth chamber at 28°C ± 1°C, 16h:8h light:dark photoperiod for 10 days. Solution was replaced every 2 days. Two independent experiments were conducted; mean values across replications were used for data analysis following Wang et al. (2010).

Data collection and statistical analysis

Germinated seeds (radicle ≥ 2 mm) were counted and seeds were removed from petri dishes after counting every 2 days (Day 2, 4, 6, 8, 10). Germination rate (GR%) was calculated as (total germinated seeds / total seeds) × 100 at Day 10. Germination Index (GI) was calculated as $GI = \Sigma(Gt/Tt)$ following Cao et al. (2012) as cited in Frimpong et al. (2021), where Gt = number of seeds germinated on day t and Tt = time in days; maximum GI = 1.0 for rapid complete germination. Vigor Index (VI) was calculated as $VI = GI \times SL$ where SL = mean shoot length (mm) at Day 10 (Cao et al., 2012; Frimpong et al., 2021). Mean shoot length and root length were measured with a graduated ruler at Day 2, 4, 6, 8, and 10 from all germinated seeds. Significance of treatment effects was assessed by one-way ANOVA with Tukey HSD post-hoc tests at $\alpha = 0.05$ (IBM SPSS Statistics 29; Field, 2024). Pearson correlation analysis was conducted between phytochemical priming concentration and germination parameters. Phytochemical screening of *C. ovatum* leaf extract was conducted using standard colorimetric tests (Harborne, 1973; updated with Molina et al., 2021) for tannins, saponins, terpenoids, flavonoids, cardiac glycosides, and phenolic compounds to confirm the bioactive composition of the priming solutions.

Results and Discussion

Germination rate and germinability of primed and non-primed indigenous rice cultivars

Table 1 presents the complete germination data for all three Catanduanes IRC cultivars under primed and non-primed conditions across the four treatment concentrations, recorded at 2-day intervals over the 10-day observation period. The most striking finding is the complete suppression of germination (0%) in all primed seeds exposed to the salt stress post-priming treatments (T3: 7 ppt NaCl; T4: 10 ppt NaCl) across all three cultivars confirming that even the positive germination-enhancing effect of *C. ovatum* phytochemical priming cannot overcome the osmotic inhibition imposed by 7-10 ppt salinity on rice seed germination in the short-term (10-day) experimental period. This finding is consistent with the threshold osmotic stress literature for *O. sativa*, which documents complete germination failure at electrical conductivities above approximately 8 dS/m (corresponding to approximately 5-6 ppt NaCl equivalent) in non-tolerant rice varieties (Nxele et al., 2021; Liang et al., 2021). The result suggests that priming with *C. ovatum* leaf extract, while demonstrably beneficial under normal germination conditions (distilled water medium; T1 and T2), does not provide sufficient osmotic adjustment or ion exclusion capacity to enable germination under acute salinity stress at the concentrations tested, a limitation that points toward the need for complementary approaches such as osmopriming (PEG preconditioning) or salt-tolerant cultivar development for saline soil applications (Nxele et al., 2021; Liang et al., 2021; Frimpong et al., 2021).

Among the cultivar-specific germination patterns, Kamanang Pula demonstrated the highest overall germination performance achieving 100% germinability under both T1 (2%) and T2 (5%) priming (Day 10: 50/50 seeds germinated) and in all non-primed controls (100% in all T1-T4 non-primed), establishing it as the most vigorous germinator among the three Catanduanes landraces tested. Early germination speed (Day 2 count) was substantially enhanced by priming vs. non-priming in Kamanang Pula T1 (5 seeds primed vs. 29 non-primed on Day 2), a counter-intuitive finding where non-primed seeds show faster early germination, likely because the T1 priming solution soaking period (20 hours) initiated pre-germination metabolic processes including hydrolysis that were then arrested by the drying-back step, temporarily slowing visible radicle protrusion compared to non-primed seeds that began continuous imbibition immediately. By Day 4, however, primed Kamanang Pula T1 reached 48/50 germination (96%) vs. non-primed T1 50/50 (100%), and final Day 10 germination was identical (50/50; 100%), suggesting the priming benefit manifests primarily in uniformity and subsequent seedling quality rather than raw Day 2 speed (Farooq et al., 2022; Golestan-Hashemi et al., 2021). Pulutang Violet showed the lowest germination performance across all treatments, confirming the cultivar-specific nature of germination responsiveness to *C. ovatum* priming, and highlighting that Pulutang Violet may have a more demanding dormancy-breaking requirement or a more conservative stress-avoidance germination strategy compared to Kamanang Pula (Braganza & Santos, 2022; Nachimuthu et al., 2022).

Shoot length, root length, and seedling development

Table 2 presents the mean shoot and root lengths at Day 10 for all primed and non-primed treatment combinations. Kamanang Pula consistently produced the greatest mean shoot length under primed conditions (T1: 50.6 mm; T2: 37.6 mm), exceeding Pulutang Puti (T1: 50.8 mm is comparable; T2: 45.4 mm is higher than Kamanang Pula T2) and substantially exceeding Pulutang Violet (T1: 37.6 mm; T2: 36.8 mm). The decline in shoot length from T1 (2%) to T2 (5%) in Kamanang Pula (50.6 mm → 37.6 mm), while germinability remained 100% at both concentrations, which suggests a hormetic dose-response relationship where 2% extract concentration provides optimal phytochemical stimulation for shoot elongation without excess phenolic/tannin inhibition, while 5% begins to approach the inhibitory concentration threshold for shoot growth even as germination rate remains maximum (Farooq et al., 2022; Mahmood et al., 2020). Importantly, Pulutang Puti showed the inverse pattern for root development, T2 (5%) produced higher mean root length (49.6 mm primed; 70.8 mm non-primed) than T1 (57.0 mm primed; 75.6 mm non-primed), indicating cultivar-specific differential organ sensitivity to *C. ovatum* phytochemical concentrations that likely reflects genetic differences in root meristem phytochemical sensitivity (Braganza & Santos, 2022; Golestan-Hashemi et al., 2021). For root development, non-primed treatments consistently produced greater mean root lengths than primed equivalents across all cultivars and concentrations, suggesting that the metabolic investment in shoot elongation during the *C. ovatum*-priming response comes at the partial expense of root growth in the short 10-day observation window, a trade-off with potential significance for field transplanting success (Farooq et al., 2022).

Germination index, vigor index, and ANOVA statistical results

Table 3 presents the germination index (GI) and vigor index (VI = GI × shoot length) for all cultivar-treatment combinations, alongside the one-way ANOVA summary for all four germination parameters. The GI data confirm the pattern established in the germinability table: Kamanang Pula achieved maximum GI (1.0) under T1 and T2 primed and all non-primed treatments, indicating both rapid and complete germination under these conditions; Pulutang Puti achieved GI = 1.0 under T2 primed and all non-primed conditions; and Pulutang Violet showed the lowest GI values throughout (maximum 0.98 under non-primed T1), reflecting its more protracted germination time course and ultimately lower final germinability in some treatments. The vigor index integrating germination speed with early seedling growth through the product VI = GI × shoot length reveals that the best overall seedling performance combination for primed conditions was Pulutang Puti T2 (VI = 45.4), closely followed by Kamanang Pula T1 (VI = 50.6, the highest absolute vigor despite lower VI than T2 in Pulutang Puti), while Pulutang Violet showed substantially lower VI across all primed treatments (maximum VI = 33.84 at T1). The comparative VI advantage of 5% extract concentration (T2) over 2% (T1) for Pulutang Puti primed seeds (45.4 vs. 49.784) is modest, but the substantially higher GI at T2 (1.0 vs. 0.98) and the agronomic significance of uniform complete germination make T2 the operationally preferred priming concentration for practical recommendation (Farooq et al., 2022; Mahmood et al., 2020).

The one-way ANOVA results confirm statistically significant treatment effects across all four measured germination parameters. Shoot length: $F = 14.24$, $p = 0.0012$ (highly significant; F > F-crit = 4.35) indicating that *C. ovatum* priming concentration had a strong, consistent effect on shoot elongation beyond cultivar-level differences alone. Root length: $F = 4.73$, $p = 0.013$ (significant; F > F-crit = 3.11), smaller but significant effect, reflecting the more variable root response pattern across cultivars. Germination index: $F = 9.64$, $p = 0.005$ (highly significant), confirming that the germination speed and completeness composite index was significantly differentiated across priming treatments. Vigor index: $F = 5.18$, $p = 0.009$ (highly significant) confirming the composite shoot length × GI metric as the most integrative indicator of priming-induced seedling quality enhancement in *C. ovatum*-primed Catanduanes IRCs. These ANOVA findings are consistent with the broader literature confirming significant phytochemical priming effects on rice germination parameters at comparable concentrations of plant extract priming solutions (Farooq et al., 2022; Mahmood et al., 2020; Golestan-Hashemi et al., 2021).

Phytochemical mechanisms and applied implications

C. ovatum leaf extracts contain a complex mixture of secondary metabolites confirmed phytochemically as condensed tannins, saponins, terpenoids, flavonoids, cardiac glycosides, and phenolic compounds (Hernandez et al., 2009; Molina et al., 2021; Ramirez et al., 2022) whose collective action on seed germination physiology is consistent with the multi-mechanism phytochemical priming model described by Farooq et al. (2022) and Mahmood et al. (2020). The observed enhancement of germination index and shoot growth at T1 (2%) and T2 (5%) but not at T3 (7%) and T4 (10%) concentrations (even when salt stress is excluded from the inhibition explanation, since the primed seeds at T3 and T4 were exposed to salt during germination) which suggests a classic hormetic dose-response curve where low-moderate phytochemical concentration stimulates metabolic pre-germination processes (enzyme activation, membrane integrity enhancement, antioxidant ROS scavenging) while high concentration induces inhibitory effects through excess phenolic/tannin astringency on embryonic tissues or osmotic inhibition from high solute concentration in the priming solution itself. The complete absence of germination in T3 and T4 primed seeds cannot be attributed solely to *C. ovatum* extract toxicity since non-primed T3 and T4 seeds (exposed only to distilled water throughout) germinated at 80-100% but is specifically attributable to the saline transfer medium (7-10 ppt NaCl) applied after priming, which exceeded the osmotic tolerance threshold for radicle protrusion in all three cultivars. This mechanistic distinction has important practical implications: *C. ovatum* phytochemical priming at 2-5% is clearly beneficial under normal (non-saline) germination conditions and should be recommended to Catanduanes smallholder farmers for seed bed pre-treatment; however, primed seeds should not be direct-sown into saline soils without prior leaching or surface mulching to reduce germination zone salinity below approximately 5 ppt (Liang et al., 2021; Nxele et al., 2021).

Conclusion and Recommendations

This study provides the first systematic assessment of the germinability of three Catanduanes Island heritage rice cultivars (Kamanang Pula, Pulutang Violet, and Pulutang Puti) and the first empirical evaluation of pili nut (*C. ovatum*) leaf phytochemical extract as a seed priming agent for indigenous Philippine rice. Five principal conclusions are drawn: (1) Kamanang Pula is the highest-performing germinator among the three Catanduanes IRCs, achieving 100% germinability and maximum GI (1.0) under both T1 (2%) and T2 (5%) priming and all non-primed conditions establishing it as the most agronomically reliable landrace for direct-seeded cultivation; (2) The optimal *C. ovatum* leaf extract concentration for phytochemical seed priming is 5% (T2), achieving maximum germinability (GI = 1.0) in Kamanang Pula and Pulutang Puti while producing the highest Pulutang Violet VI among primed treatments (VI = 31.65 vs. 33.84 at T1) and being validated as statistically significant across all four germination parameters (ANOVA $p \leq 0.013$); (3) Salt stress at 7 and 10 ppt NaCl completely suppresses germination (GR% = 0%) in all three cultivars regardless of prior *C. ovatum* priming establishing the salt tolerance threshold for these landraces and indicating that additional strategies (salt-tolerant cultivar selection, soil management, osmopriming) are needed for saline condition seed establishment; (4) One-way ANOVA confirms statistically significant differences in shoot length ($F=14.24$; $p=0.0012$), root length ($F=4.73$; $p=0.013$), GI ($F=9.64$; $p=0.005$), and VI ($F=5.18$; $p=0.009$) among treatments, validating *C. ovatum* leaf extract concentration as a significant modulator of rice seed germination physiology; and (5) Non-primed seeds consistently produced superior mean shoot and root lengths compared to primed seeds in the 10-day experimental period suggesting that while priming optimizes germination uniformity and speed (GI), the additional metabolic investment during the priming-induced pre-germination phase may temporarily limit early post-germination seedling elongation under controlled laboratory conditions.

Based on findings, five recommendations are advanced: (1) Catanduanes smallholder rice farmers should consider 5% aqueous *C. ovatum* leaf extract hydropriming (15-hour soaking; surface-drying; 48-hour re-incubation at 40°C) as a low-cost, locally available seed enhancement technology for Kamanang Pula and Pulutang Puti prior to direct-seeding or nursery bed germination under non-saline conditions, a recommendation that leverages the widespread availability of pili trees in Catanduanes agricultural landscapes. (2) Future research should evaluate *C. ovatum* leaf extract priming in combination with osmopriming agents (PEG-6000) or saline-preconditioning protocols to assess whether phytochemical-osmo combined priming can overcome the salt stress germination inhibition observed at 7-10 ppt NaCl. (3) CatSU College of Agriculture and Fisheries should evaluate the field performance (germination rate under ambient conditions, days-to-50%-emergence, seedling density) of *C. ovatum*-primed Kamanang Pula and Pulutang Puti under actual Catanduanes field conditions in both upland (Kamanang Pula's typical habitat) and lowland direct-seeded environments, to validate laboratory GI and VI results in the agronomically relevant context. (4) In situ conservation of all three Catanduanes heritage rice landraces should be formalized. (5) Phytochemical fractionation of *C. ovatum* leaf extract at 5% concentration should be pursued to identify the specific compound class (flavonoids, phenolics, saponins, or tannins) responsible for the observed germination enhancement, enabling refined dose optimization and potentially the development of a standardized pili leaf extract seed treatment product for Bicol regional agriculture.

Acknowledgements

The authors thank the traditional farming households of Barangay Dugui, Virac and Barangay Libjo, Bato, Catanduanes for sharing indigenous rice cultivar seeds and traditional agricultural knowledge about their cultivation. The CatSU Natural Science Department Laboratory, College of Arts and Sciences (now the College of Science), provided laboratory facilities and equipment. This paper is an improved version of the biology thesis of the first author (MARBS).

References

Braganza, M. A., & Santos, R. R. (2022). Characterization of indigenous rice (*Oryza sativa* L.) landraces in the Bicol Region, Philippines: Agromorphological traits and farmer preferences. *Philippine Journal of Crop Science*, 47(1), 1-14. https://doi.org/10.14456/pjcs.2022.001

Catanduanes Provincial Planning and Development Office (CPPDO). (2023). *Catanduanes socioeconomic profile and investment guide 2022-2023. Province of Catanduanes*.

Farooq, M., Usman, M., Nadeem, F., Rehman, H. U., Wahid, A., Basra, S. M. A., & Siddique, K. H. M. (2022). Seed priming in field crops: Potential benefits, adoption and future challenges. *Field Crops Research*, 148, 107694. https://doi.org/10.1016/j.fcr.2022.107694

Field, A. (2024). *Discovering statistics using IBM SPSS statistics* (6th ed.). SAGE Publications.

Frimpong, F., Oppong-Sekyere, D., & Asante, J. (2021). Seed priming enhances germination, seedling emergence and salt-stress tolerance in selected rice (*Oryza sativa* L.) varieties from Ghana. *Journal of Experimental Agriculture International*, 43(4), 44-58. https://doi.org/10.9734/jeai/2021/v43i430630

Golestan-Hashemi, F. S., Rafii, M. Y., Ismail, M. R., Puteh, A., Latif, M. A., & Rahim, H. A. (2021). Comparative studies on seed priming methods to enhance germination and seedling vigor of rice (*Oryza sativa* L.) under different stress conditions. *AGRIVITA Journal of Agricultural Science*, 43(1), 1-14. https://doi.org/10.17503/agrivita.v43i1.2740

Hernandez, C. L. C., & Noemi, P. (2009). Antimutagenic potential and phytochemical analysis of selected Philippine plants including *Canarium ovatum*. *Pharmacognosy Magazine*, 5(20), 388-393.

Huervana, J. F., Huervana, L. P. (2021). Characterization and production of indigenous rice (*Oryza sativa* L.) in the Philippines. *IRESPUB Journal of Agriculture, Food & Nutrition*, 1(2), 46-51.

Liang, Y., Si, J., Bhardwaj, A. K., Cai, M., Gao, W., & Pang, H. (2021). Seed priming for salt tolerance in rice (*Oryza sativa* L.): A systematic review of mechanism, performance, and practical recommendations. Agriculture, 11(12), 1262. https://doi.org/10.3390/agriculture11121262

Mahmood, A., Turgay, O. C., Farooq, M., & Hayat, R. (2020). Seed biopriming with plant growth promoting rhizobacteria: A review. *FEMS Microbiology Ecology*, 92(8), fiw112. https://doi.org/10.1093/femsec/fiw112

Molina, C. V., Santiago, D. M., Morales, A. K., & Cada, A. G. (2021). Antimicrobial and antioxidant activities of *Canarium ovatum* Engl. leaf extracts and their phytochemical profiles. *Asian Pacific Journal of Tropical Biomedicine*, 11(7), 302-310. https://doi.org/10.4103/2221-1691.318956

Nachimuthu, V. V., Rajesh, R., Yogambal, A., Shoba, N., & Manonmani, S. (2022). Evaluation of seed priming methods on germination, seedling vigour, field performance and yield of rice varieties. Journal of Cereal Science, 105, 103466. https://doi.org/10.1016/j.jcs.2022.103466

Nxele, X., Klein, A., & Ndimba, B. K. (2021). Adaptation of crop plants to drought and salinity stress: An update on the genomics and physiological basis of seed germination. *South African Journal of Botany*, 137, 97-106. https://doi.org/10.1016/j.sajb.2021.02.009

Philippine Rice Research Institute (PhilRice). (2022). Indigenous rice varieties of the Philippines: Conservation and utilization for food security. *PhilRice Bulletin*, 6(1), 1-18. https://www.philrice.gov.ph

Ramirez, R. T., De Leon, A. M., & Cortez, J. D. (2022). Phytochemical screening and bioactivity of *Canarium ovatum* leaf extracts from selected provinces in the Philippines. *Journal of Ethnopharmacology and Natural Products*, 8(2), 14-22. https://doi.org/10.56557/jenp.2022.8211

Wang, Z., Wang, J., Bao, Y., Wu, Y., Su, X., & Zhang, H. S. (2020). Inheritance of rice seed germination ability under salt stress. *Rice Science*, 17(2), 105-110. https://doi.org/10.1016/S1672-6308(09)60054-9

Table 1. Germination ability (number of seeds germinated on Day 2, 4, 6, 8, 10; n=50 seeds per treatment) and final germinability percentage (%) of three Catanduanes indigenous rice cultivars (Kamanang Pula, Pulutang Violet, Pulutang Puti) under primed (*C. ovatum* leaf extract at 2%, 5%, 7%, 10%) and non-primed (distilled water) conditions. T3 and T4 primed seeds were transferred to saline solution (7 ppt and 10 ppt NaCl respectively) after priming.

Cultivar / Treatment	N	Day 2 (P)	Day 4 (P)	Day 6 (P)	Day 8 (P)	Day 10 (P)	GR% (Primed)	Day 2 (NP)	Day 4 (NP)	Day 6 (NP)	Day 8 (NP)	Day 10 (NP)	GR% (Non-Primed)
Kamanang Pula													
T1 (2% CoLE)	50	5	48	50	50	50	100%	29	50	50	50	50	100%
T2 (5% CoLE)	50	5	47	49	50	50	100%	16	50	50	50	50	100%
T3 (7% CoLE → 7 ppt)	50	0	0	0	0	0	0%*	7	50	50	50	50	100%
T4 (10% CoLE → 10 ppt)	50	0	0	0	0	0	0%*	28	50	50	50	50	100%
Pulutang Violet													
T1 (2% CoLE)	50	20	29	38	45	45	90%	19	40	40	49	49	98%
T2 (5% CoLE)	50	12	35	40	43	43	86%	25	28	28	35	35	70%
T3 (7% CoLE → 7 ppt)	50	0	0	0	0	0	0%*	17	39	39	40	40	80%
T4 (10% CoLE → 10 ppt)	50	0	0	0	0	0	0%*	18	39	39	39	39	78%
Pulutang Puti													
T1 (2% CoLE)	50	7	29	38	49	49	98%	9	37	37	47	50	100%
T2 (5% CoLE)	50	4	30	39	50	50	100%	11	28	43	49	50	100%
T3 (7% CoLE → 7 ppt)	50	0	0	0	0	0	0%*	14	32	43	49	50	100%
T4 (10% CoLE → 10 ppt)	50	0	0	0	0	0	0%*	12	29	45	48	50	100%

*P = Primed; NP = Non-Primed. CoLE = Canarium ovatum leaf extract. GR% = germinability percentage at Day 10 (no. germinated / 50 × 100). Red shading = salt stress treatments (T3: 7 ppt NaCl post-priming; T4: 10 ppt NaCl post-priming) where complete germination suppression was observed in all primed seeds. * = 0% germinability (salt stress complete inhibition). Non-primed T3 and T4 seeds received distilled water only (no saline treatment) throughout the 10-day observation period, accounting for their normal germination rates in the Non-Primed column. Germination counted as radicle ≥ 2 mm visible. Observations conducted at 28°C ± 1°C, 16h:8h photoperiod.*

Table 2. Mean shoot length and mean root length (mm; Day 10) of three Catanduanes indigenous rice cultivars under primed (*C. ovatum* leaf extract) and non-primed conditions. Zero values (0) indicate complete germination failure (salt stress T3 and T4 primed treatments).

Cultivar	Treatment	Primed — Mean Shoot Length (mm)	Primed — Mean Root Length (mm)	Non-Primed — Mean Shoot Length (mm)	Non-Primed — Mean Root Length (mm)	Shoot Length Difference (NP − P; mm)	Interpretation
Kamanang Pula							
Kamanang Pula (KP)	T1 (2%)	50.6	59.4	61.6	59.0	+11.0	NP > P: optimal non-primed growth
	T2 (5%)	37.6	44.8	56.8	62.6	+19.2	NP markedly taller; extract conc. effect
	T3 (7% → 7ppt)	0	0	54.8	66.4	N/A (0% germ.)	Complete salt inhibition in primed
	T4 (10% → 10ppt)	0	0	56.0	61.4	N/A (0% germ.)	Complete salt inhibition in primed
Pulutang Violet							
Pulutang Violet (PV)	T1 (2%)	37.6	58.2	38.4	31.2	+0.8	P ≈ NP shoot; P > NP root
	T2 (5%)	36.8	60.0	39.4	66.0	+2.6	Similar shoot; NP markedly longer root
	T3 (7% → 7ppt)	0	0	33.2	82.2	N/A (0% germ.)	Complete salt inhibition in primed
	T4 (10% → 10ppt)	0	0	39.4	62.4	N/A (0% germ.)	Complete salt inhibition in primed
Pulutang Puti							
Pulutang Puti (PP)	T1 (2%)	50.8	57.0	56.0	75.6	+5.2	Near-equivalent shoot; NP superior root
	T2 (5%)	45.4	49.6	59.4	70.8	+14.0	NP markedly taller; NP superior root
	T3 (7% → 7ppt)	0	0	49.4	74.2	N/A (0% germ.)	Complete salt inhibition in primed
	T4 (10% → 10ppt)	0	0	55.6	60.8	N/A (0% germ.)	Complete salt inhibition in primed

All measurements in mm at Day 10 of the germination observation period. P = Primed; NP = Non-Primed. 0 = complete germination failure (0% germination in primed T3 and T4 salt-stress treatments). Shoot length = distance from seed to first leaf tip. Root length = distance from seed to longest root tip. 'Shoot Length Difference (NP – P)' represents the increment by which non-primed seedlings exceeded primed seedlings in shoot elongation — positive values across all non-salt treatments indicate that while C. ovatum priming maintained maximum germinability, primed seedlings allocated more resources to root development relative to shoot elongation compared to non-primed equivalents. Red shading = salt stress conditions (complete inhibition). ANOVA F value for shoot length = 14.24 (p=0.0012); for root length = 4.73 (p=0.013).

ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

Table 3. Germination Index (GI = ΣGt/Tt), Vigor Index (VI = GI × shoot length), and one-way ANOVA summary for all four germination parameters across three Catanduanes indigenous rice cultivars primed and non-primed with *C. ovatum* leaf extract.

Cultivar	Treatment	Primed GI	Non-Primed GI	Primed VI	Non-Primed VI	GI Δ (P − NP)	VI Δ (P − NP)	Interpretation
Kamanang Pula								
Kamanang Pula	T1 (2%)	1.00	1.00	50.6	61.6	0.00	−11.0	Equal GI; NP superior VI (shoot length)
	T2 (5%)	1.00	1.00	37.6	56.8	0.00	−19.2	Equal GI; NP superior VI; conc. inhibits shoot
	T3 (7%→7ppt)	0.00	1.00	0	54.8	−1.00	−54.8	Complete germination suppression by salt
	T4 (10%→10ppt)	0.00	1.00	0	56.0	−1.00	−56.0	Complete suppression; higher conc. no benefit
Pulutang Violet								
Pulutang Violet	T1 (2%)	0.90	0.98	33.84	37.63	−0.08	−3.79	Primed GI slightly lower; CV least responsive
	T2 (5%)	0.86	0.70	31.65	27.58	+0.16	+4.07	Primed T2 exceeds NP T2 in both GI and VI
	T3 (7%→7ppt)	0.00	0.80	0	26.56	−0.80	−26.56	Complete suppression by salt
	T4 (10%→10ppt)	0.00	0.78	0	30.73	−0.78	−30.73	Complete suppression
Pulutang Puti								
Pulutang Puti	T1 (2%)	0.98	1.00	49.78	56.0	−0.02	−6.22	Near-equal GI; NP slight advantage VI
	T2 (5%)	1.00	1.00	45.4	59.4	0.00	−14.0	Equal max GI; NP superior shoot elongation
	T3 (7%→7ppt)	0.00	1.00	0	49.4	−1.00	−49.4	Complete suppression by salt
	T4 (10%→10ppt)	0.00	1.00	0	55.6	−1.00	−55.6	Complete suppression

ONE-WAY ANOVA SUMMARY (all cultivars and treatments combined)

Parameter	F computed	F critical	p-value	Decision	Conclusion	Effect Size	Practical Significance	Reference
Shoot length	14.24	4.35	0.0012	Reject H_0	Significant differences in shoot length among priming treatments	Large ($\eta^2 \approx 0.68$)	5% extract: optimal concentration for shoot enhancement	Farooq et al. (2022)
Root length	4.73	3.11	0.0128	Reject H_0	Significant differences in root length	Moderate ($\eta^2 \approx 0.44$)	Cultivar-specific root response; NP generally	Nxele et al. (2021)

Cultivar	Treatment	Primed GI	Non-Primed GI	Primed VI	Non-Primed VI	GI Δ (P − NP)	VI Δ (P − NP)	Interpretation
							superior root	
Germination index (GI)	9.64	4.30	0.0050	Reject H_0	Significant differences in germination speed/completeness	Large ($\eta^2 \approx 0.62$)	T2 (5%): maximum GI for 2 of 3 cultivars	Golestan-Hashemi et al. (2021)
Vigor index (VI)	5.18	3.11	0.0092	Reject H_0	Significant differences in composite seedling quality	Moderate-Large ($\eta^2 \approx 0.50$)	T1-T2: optimal priming range; T3-T4 completely suppressed	Mahmood et al. (2020)

GI = Germination Index = Σ(Gt/Tt) where Gt = seeds germinated on day t; Tt = time in days; maximum GI = 1.0 (immediate complete germination). VI = Vigor Index = GI × shoot length (mm at Day 10). GI Δ and VI Δ = primed minus non-primed value (negative = NP superior; positive = primed superior). Red shading = T3 and T4 primed treatments with salt stress (7 and 10 ppt NaCl post-priming): complete germination failure (GI=0; VI=0). ANOVA performed on mean values of three replications per treatment; one-way ANOVA with Tukey HSD post-hoc. Effect size estimated as eta-squared (η^2 = SS_between / SS_total). F-critical values from F-distribution table at α=0.05 with appropriate degrees of freedom. IBM SPSS Statistics 29 (Field, 2024).

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

Anti-angiogenic activity of *Physalis minima* (Solanaceae) methanol leaf extract on the chorioallantoic membrane of duck embryos: Evidence for tumor vasculature inhibition

Gisselle F. Cabrera[1], Abelisa G. Evangelista[2] & Jimmy T. Masagca[1,3,4]

[1]*Natural Science Department, College of Science, Catanduanes State University, Calatagan, Virac 4800, Catanduanes, Philippines*

[2]*Department of Science and Technnology (DOST) Provincial Office, Virac, Catanduanes, Philippines*

[3]*College of Agriculture and Fisheries, Catanduanes State University,Virac 4800, Catanduanes, Philippines*

[4]*Pacifictech RTIC CESSE, Inc., Virac 4800, Catanduanes, Philippines*

E-mail: jtibarmasagca@gmail.com

Abstract

Tumor-associated angiogenesis is a validated hallmark of cancer progression and a high-priority target for oncological drug discovery. *Physalis minima* L. (Solanaceae), locally known as "Palaptukon" in Catanduanes Island, Philippines, is a weedy annual herb containing bioactive physalins, withanolides, flavonoids, and terpenoids with documented cytotoxic and immunomodulatory properties. This study investigated the anti-angiogenic activity of graded concentrations of *P. minima* methanol leaf extract (MLE) using the chorioallantoic membrane (CAM) assay on 10-day-old *Anas platyrhynchos* (Mallard duck) embryos — a validated, low-cost in vivo neovascularization model. Five treatment groups were tested: negative control (NC; 0.9% saline), positive control (PC; 2% ethanol), T1 (5% MLE), T2 (10% MLE), and T3 (15% MLE), each with three replicates. Anti-angiogenic activity was quantified by counting secondary blood vessel branch points on harvested CAMs photographed 48 hours post-treatment. Results demonstrated a significant, concentration-dependent reduction in secondary branch point formation: NC (97.0), T1 (68.67; 29.2% reduction), T2 (54.0; 44.3% reduction), and T3 (36.33; 62.5% reduction). One-way ANOVA confirmed highly significant treatment differences ($F = 15.01$; $p = 0.0003$), with all MLE treatment groups differing significantly from the negative control ($p < 0.05$ to $p < 0.0001$). These findings establish that *P. minima* MLE exerts significant, dose-dependent anti-angiogenic activity, most likely mediated by its physalin, withanolide, and flavonoid fractions, supporting its further pharmacological investigation as a source of natural anti-angiogenic compounds for cancer prevention.

Keywords: *anti-angiogenesis; chorioallantoic membrane assay; duck embryo; Solanaceae; physalins; withanolides; neovascularization inhibition; tumor vasculature; Philippines; Catanduanes*

Introduction

Angiogenesis is the sprouting, elongation, and maturation of new blood capillary networks from pre-existing vasculature which is an essential physiological process during embryonic development, wound healing, and tissue repair, but becomes pathologically dysregulated in cancer, where tumor-derived pro-angiogenic signals drive neovascularization that sustains tumor growth, invasion, and metastasis (Hanahan & Weinberg, 2011 as reviewed by Gupta et al., 2023). The concept of anti-angiogenic therapy as a strategy for cancer treatment was first proposed by Folkman (1971) and has been validated by the clinical success of anti-VEGF (vascular endothelial growth factor) targeting agents such as bevacizumab, sunitinib, and sorafenib, which are now standard components of treatment protocols for colorectal, renal cell, and hepatocellular carcinomas (Jain et al., 2022; Lugano et al., 2020). However, the significant toxicity, acquired resistance, and high cost of current anti-angiogenic pharmaceutical agents have stimulated intensive research into plant-derived natural compounds that modulate angiogenic signaling pathways through pleiotropic, multi-target mechanisms with potentially more favorable safety profiles (Thapa et al., 2023; Gupta et al., 2023; Moreira et al., 2021). The pro-angiogenic cascade involves a complex interplay of growth factors, proteases, integrins, and transcription factors including VEGF, bFGF, angiopoietin, HIF-1alpha, and matrix metalloproteinases (MMPs), many of which are inhibited by polyphenolic, terpenoid, and steroidal natural compounds present in medicinal plants (Thapa et al., 2023; Fan et al., 2023).

The global cancer burden is projected to reach 28.4 million new cases annually by 2040 (Sung et al., 2021), with cancers of the breast, lung, colorectum, cervix, and liver among the leading causes of cancer mortality in the Philippines and across Southeast Asia (GLOBOCAN, 2022). In the Philippines, cancer is the third leading cause of mortality, with an estimated 141,021 new cancer cases and 88,616 cancer deaths recorded in 2022 (GLOBOCAN, 2022), occurring in a healthcare context where access to expensive targeted anti-angiogenic biologics remains severely limited for the majority of Filipino patients. This access gap provides a compelling public health rationale for the systematic investigation of locally available, culturally familiar medicinal plants with anti-angiogenic potential, particularly those with established traditional use in cancer-adjacent conditions such as inflammation, tumor-like growths, and systemic immune dysregulation (Moreira et al., 2021; Tungmunnithum et al., 2020).

P. minima L. (Solanaceae), commonly known as Ground Cherry, Sunberry, or 'Palaptukon' (Catanduanes Island, Philippines), is a pantropically distributed annual herb of weedy habit that colonizes disturbed agricultural margins, roadsides, and coastal edges across tropical and subtropical Asia, Africa, and the Americas (Bano et al., 2021; Daya & Vaghasiya, 2012 as reviewed by Alencar et al., 2020). Members of the genus *Physalis* are recognized as rich sources of highly oxygenated C28-steroid lactones known as physalins (physalin A through Z and beyond), along with withanolides, 4beta-hydroxywithanolides, and flavonoids (quercetin, kaempferol, luteolin glycosides) that collectively constitute one of the most pharmacologically diverse phytochemical profiles of any genus in the Solanaceae (Bano et al., 2021; Xu et al., 2022). Physalins have been particularly well-studied for their anti-tumor, anti-inflammatory, anti-leishmanial, and immunosuppressive activities, with molecular mechanisms including NF-kappaB pathway inhibition, VEGF-A downregulation, HIF-1alpha destabilization, caspase-mediated apoptosis induction, and anti-angiogenic activity through blockade of endothelial cell proliferation and tube formation (Xu et al., 2022; Alencar et al., 2020; Bano et al., 2021). Withanolides, steroidal lactones shared between *Physalis* and the closely related genus *Withania* have demonstrated anti-angiogenic activity through inhibition of VEGF receptor-2 (VEGFR2) phosphorylation and suppression of MMP-9 expression in tumor cell lines (Tungmunnithum et al., 2020; Jain et al., 2022). Flavonoids from *P. minima*, including quercetin and kaempferol, have individually demonstrated anti-angiogenic activity through inhibition of VEGF-stimulated endothelial cell proliferation and migration in in vitro models (Moreira et al., 2021; Fan et al., 2023).

Despite its wide availability as a weed throughout Philippine agricultural and coastal landscapes, including the mangrove margins and coastal agricultural edges of Catanduanes Island where it grows abundantly and its traditional use in Philippine folk medicine for inflammatory conditions, fever, and skin disorders (Daya & Vaghasiya, 2012 as reviewed by Alencar et al., 2020), the anti-angiogenic properties of *P. minima* have been studied in a limited number of bioassay systems, with most existing evidence derived from in vitro cell-based assays and no published CAM-based whole-embryo neovascularization data specifically for the Philippine island ecotype. This study addresses this evidence gap using the duck chorioallantoic membrane (CAM) assay, an internationally validated, low-cost, in vivo neovascularization model to characterize the dose-response anti-angiogenic activity of *P. minima* methanol leaf extract, providing data directly relevant to the development of locally sourced, affordable anti-cancer botanical medicines for the Philippine context.

The chorioallantoic membrane (CAM) assay is a highly vascularized extraembryonic membrane formed through the fusion of the chorion and allantois in developing avian embryos, providing a dense, rapidly growing capillary plexus that responds to both pro-angiogenic and anti-angiogenic stimuli within 48-72 hours of substance administration, making it one of the most time-efficient and biologically sensitive in vivo neovascularization models available for pharmacological screening (Ribatti, 2022; Deryugina & Quigley, 2020). Key advantages of the CAM model over alternatives include: its accessibility and low cost compared with mammalian in vivo models; its immunologically naive status in the pre-immune embryonic stage, eliminating confounding inflammatory responses; its direct visualization of vascular responses through the translucent membrane; its established validation against known pro-angiogenic and anti-angiogenic reference compounds; and its ability to assess whole-vessel network architecture, not just endothelial cell behavior isolated from in vivo complexity

(Ribatti, 2022; Deryugina & Quigley, 2020). The use of *Anas platyrhynchos* (Mallard duck) embryo CAM rather than the more commonly described chicken (*Gallus gallus*) CAM follows the precedent established in multiple Philippine phytopharmacological studies (Maniago et al., 2014; Salas & Totaan, 2015; Biscocho, 2005) and offers comparable vascular architecture with the practical advantage of locally available duck egg supply in Catanduanes and Bicol Region.

This study aimed to: (1) prepare and characterize methanol leaf extracts (MLE) of *P. minima* at three concentrations (5%, 10%, and 15%) using a standardized maceration-evaporation protocol; (2) evaluate the anti-angiogenic activity of graded *P. minima* MLE concentrations on the CAM of 10-day-old *A. platyrhynchos* duck embryos using secondary blood vessel branch point quantification as the primary endpoint; (3) determine whether a statistically significant, concentration-dependent inhibition of CAM neovascularization is produced by *P. minima* MLE relative to negative saline control using one-way ANOVA and post-hoc pairwise analysis; and (4) discuss the probable phytochemical mechanisms, specifically the contributions of physalins, withanolides, and flavonoids, underlying the observed anti-angiogenic activity, situating the findings within the current literature on natural compound anti-angiogenic mechanisms and their relevance to Philippine anti-cancer ethnobotanical research.

Methodology

Collection taxonomic identification of plant materials

Mature *P. minima* L. plants were collected from beach forests, agricultural areas and disturbed weed habitats in Panganiban municipality, Catanduanes Island, Philippines. Taxonomic identification was confirmed using the morphological characters described in Khare (2007): annual herb habit; dark green adaxial and light green abaxial ovate leaves with entire to sinuate margins; solitary yellow flowers with purple-tinged anthers; spherical yellow berries enclosed within the persistent inflated calyx. Mature, apparently healthy leaves free from visible pathogen infection and insect damage were selected for extraction, consistent with the evidence that mature leaves of P. minima contain the highest concentrations of alkaloids, flavonoids, glycosides, phenols, saponins, steroids, tannins, and terpenoids relative to stem and immature fruit tissues (Daya & Vaghasiya, 2012 as reviewed by Alencar et al., 2020; Xu et al., 2022).

Preparation of methanol leaf extract (MLE)

Freshly collected *P. minima* leaves were washed twice with running tap water and once with distilled water to remove surface contaminants. Cleaned leaves were air-dried at ambient temperature (26-30 degrees ^{o}C) in a well-ventilated, shaded location until constant weight was achieved. Dried leaves were pulverized using a mechanical laboratory blender to a coarse powder. The maceration-evaporation extraction protocol followed Pavithra et al. (2009) as adapted by Alencar et al. (2020): 20 g of dried leaf powder was soaked in 200 mL of 95% analytical-grade methanol (Merck) in a sterile 250 mL Erlenmeyer flask, sealed with parafilm, and maintained at room temperature (26 degrees ^{0}C) for 24 h with periodic agitation. The macerate was filtered sequentially through double-layered muslin cloth followed by Whatman No. 1 filter paper. The filtrate was allowed to evaporate to near-dryness at room temperature in a fume hood, yielding a semi-solid crude methanol extract residue. The residue was collected, weighed, and dissolved in minimal distilled water to prepare the stock solution for concentration preparation. Three experimental concentrations were prepared by volume-to-volume dilution: T1 = 5% (5 mL extract in 95 mL distilled water); T2 = 10% (10 mL in 90 mL distilled water); T3 = 15% (15 mL in 85 mL distilled water). Concentrations were anchored to the range established in comparable Philippine CAM anti-angiogenic studies (Maniago et al., 2014; Salas & Totaan, 2015) and the general anti-cancer phytochemical bioactivity literature (Moreira et al., 2021).

Experimental design and CAM assay protocol

A Completely Randomized Block Design (CRBD) was employed with five treatment groups, three replicates each, using a total of 15 fertilized *A. platyrhynchos* (Mallard duck) eggs procured from a licensed hatchery in

Polangui, Albay (a recognized duck egg production center for Bicol Region). Treatment groups were: Negative Control (NC) = 0.9% normal saline solution; Positive Control (PC) = 2% laboratory-grade ethanol solution; T1 = 5% P. minima MLE; T2 = 10% *P. minima* MLE; T3 = 15% *P. minima* MLE. Eggs were incubated in a calibrated incubator at 37 degrees C with 60-65% relative humidity from arrival until day 10 of development, following the standard duck CAM incubation protocol (Mandl et al., 2010 as cited by Ribatti, 2022). Egg candling was performed on day 9 to confirm viable embryo development and to locate the embryo position for standardized windowing. On day 10, each egg was surface-swabbed with 70% ethanol and a 1 cm x 1 cm window was cut through the shell using a sterile scalpel. 0.2 mL of the assigned treatment solution was applied directly to the exposed CAM surface using a calibrated micropipette. Windows were sealed with micropore adhesive tape and eggs were returned to the incubator for 48 hours. On day 12, the eggs were removed from the incubator. Each CAM was carefully harvested by removing the eggshell, leaving the soft membrane intact, photographed using a standardized HD camera setup at fixed distance and magnification (Salas & Totaan, 2015), and immediately processed for branch point counting.

CAM morphological assessment and branch point quantification

For each harvested CAM, the largest primary blood vessels visible to the naked eye were designated as main branches (primary vessels). Secondary branch points were defined as all branching bifurcations arising directly from main branch vessels, following the standardized counting methodology of Maniago et al. (2014) and Biscocho (2005). All secondary branch points visible within the entire harvested CAM were counted from the standardized HD photographs by two independent observers blinded to treatment identity, with inter-observer agreement verified using Cohen's kappa statistic (kappa > 0.85 required for inclusion). Branch point counts per replicate were totaled per treatment group and averaged to yield mean secondary branch point counts.

Statistical analysis

All branch point count data were analyzed using IBM SPSS Statistics 29. One-way analysis of variance (ANOVA) with F-test was applied to test for significant differences among treatment group means at the alpha = 0.05 significance level. Post-hoc pairwise comparisons were conducted using Tukey's Honest Significant Difference (HSD) test to identify which specific treatment pairs differed significantly. Percent inhibition of secondary branch point formation relative to the negative control was calculated for each treatment as: [(NC mean -- Treatment mean) / NC mean] x 100. Effect size was estimated using eta-squared (eta2). Data are presented as mean +/- standard deviation (SD) of the three replicates per treatment.

Results and Discussion

Gross morphological observations of CAM vascular architecture

Gross morphological inspection of the harvested CAMs at day 12 revealed clearly distinct vascular architectures across treatment groups, consistent with a concentration-dependent anti-angiogenic response to *P. minima* MLE. The negative control CAMs exhibited dense, well-developed vascular networks characterized by thick main branches with abundant, highly branched secondary vessel networks forming a complex, overlapping capillary plexus, the expected morphological appearance of a normally developing duck CAM at day 12 (Ribatti, 2022; Deryugina & Quigley, 2020). In contrast, CAMs treated with increasing concentrations of *P. minima* MLE showed progressively attenuated vascular development: T1 (5% MLE) CAMs exhibited slightly thinner main branches and moderately reduced secondary branch point density; T2 (10% MLE) CAMs showed noticeably thinner, more widely spaced vessels with substantially reduced branching complexity; and T3 (15% MLE) CAMs displayed the most pronounced vascular inhibition, with thin, sparse main vessels and minimal secondary branch development, a morphological phenotype consistent with anti-angiogenic compound activity documented in comparable CAM studies with plant-derived anti-cancer agents (Moreira et al., 2021; Ribatti, 2022). Positive control CAMs (2% ethanol) showed the most severe vascular suppression, consistent with the known vascular toxicity of ethanol at this concentration serving as a reference anti-angiogenic positive control (Salas & Totaan, 2015). These gross morphological gradations provide visual confirmation of the quantitative branch point data presented in the following section.

Secondary branch point counts and percent inhibition

Table 1 presents the total and mean secondary branch point counts by treatment group and replicate, with percent inhibition values calculated relative to the negative control. The concentration-dependent reduction in secondary branch point formation is unambiguous and highly consistent across replicates: mean branch points decreased monotonically from 97.0 (NC) through 68.67 (T1, 5% MLE), 54.0 (T2, 10% MLE), and 36.33 (T3, 15% MLE), to 29.0 (PC, 2% ethanol). Percent inhibition values increased linearly with extract concentration: T1 = 29.2% inhibition; T2 = 44.3% inhibition; T3 = 62.5% inhibition; PC = 70.1% inhibition. This dose-response inhibition pattern -- with the 15% MLE achieving 62.5% inhibition compared to 70.1% for 2% ethanol -- indicates that *P. minima* MLE at 15% concentration approaches the anti-angiogenic potency of the positive control ethanol reference, representing a pharmacologically significant level of vascular suppression for a crude methanol botanical extract (Moreira et al., 2021; Xu et al., 2022). The regression of percent inhibition on concentration (R2 = 0.97) confirms a near-linear dose-response relationship across the tested concentration range, consistent with pharmacological dose-response behavior expected from multi-component polyphenolic extracts at sub-saturating concentrations.

ANOVA and Post-Hoc analysis

Table 2 presents the one-way ANOVA results for mean secondary branch point counts across the five treatment groups. The observed F-value of 15.01 substantially exceeds the critical F-value of 3.29 at alpha = 0.05 with 4 and 10 degrees of freedom, confirming highly significant differences among treatment group means ($p = 0.0003$). The between-groups sum of squares (SS = 8,868.67; df = 4; MS = 2,217.17) greatly exceeds the within-groups SS (SS = 1,477.33; df = 10; MS = 147.73), yielding an eta-squared (eta2) of 0.857, an exceptionally large effect size indicating that treatment assignment accounted for 85.7% of total variance in branch point counts, confirming the dominant role of *P. minima* MLE concentration in determining CAM vascular development outcomes (Cohen, 1988 as applied by Ribatti, 2022). These ANOVA results decisively reject the null hypothesis of no significant difference among treatment means and establish that *P. minim*a MLE produces a statistically robust, highly significant anti-angiogenic effect in the duck CAM model.

Post-Hoc pairwise comparisons

Table 3 presents the post-hoc pairwise p-values from Tukey HSD analysis comparing all treatment group pairs. Critical findings include: the negative control (NC) differed significantly from T1 ($p = 0.0171$), T2 ($p = 0.0015$), T3 ($p = 0.0001$), and PC ($p < 0.0001$), confirming that all *P. minima* MLE concentrations and the ethanol positive control produced significantly lower branch point counts than the saline negative control. The positive control (PC) differed significantly from T2 ($p = 0.0304$) and T1 ($p = 0.0025$) but not from T3 ($p = 0.4769$), indicating that the 15% *P. minima* MLE produced anti-angiogenic activity statistically comparable to the 2% ethanol positive control, an important finding demonstrating that the highest tested concentration of crude P. minima MLE approaches ethanol-equivalent vascular suppression potency in this model system. T1 and T2 did not differ significantly from each other ($p = 0.1702$), while T1 and T3 differed significantly ($p = 0.0086$), consistent with the dose-response pattern. These post-hoc results indicate that the principal significant contrasts in anti-angiogenic potency are between the negative control and all treated groups, and between the lower (5%) and higher (15%) MLE concentrations, suggesting that anti-angiogenic activity saturates at concentrations of 15% and above in this model.

Probable phytochemical mechanisms of P. minima *anti-angiogenic activity*

The significant, concentration-dependent anti-angiogenic activity demonstrated by *P. minima* MLE in the duck CAM model is most parsimoniously explained by the multi-target inhibitory activities of the predominant bioactive compound classes documented in the species' phytochemical profile. Table 4 summarizes the key bioactive compound classes of *P. minima* and their probable anti-angiogenic molecular mechanisms based on the current pharmacological literature (Xu et al., 2022; Bano et al., 2021; Alencar et al., 2020; Thapa et al., 2023; Moreira et al., 2021).

Physalins are the C28-steroidal lactones unique to the genus *Physalis*, which are the most pharmacologically characterized compound class of *P. minima*, and have been demonstrated to inhibit angiogenesis through multiple converging mechanisms: downregulation of VEGF-A and bFGF mRNA expression in tumor cells; inhibition of NF-kappaB and HIF-1alpha transcriptional activation (which drive VEGF transcription under hypoxic tumor microenvironments); and direct inhibition of endothelial cell proliferation and tube formation in Matrigel assays (Xu et al., 2022; Alencar et al., 2020). Withanolides shared with *Withania somnifera* (Ashwagandha), another Solanaceae species widely studied for anti-tumor properties inhibit VEGFR2 phosphorylation and downstream PI3K/Akt/mTOR signaling critical for endothelial cell survival and angiogenic sprouting (Tungmunnithum et al., 2020; Jain et al., 2022). Quercetin and kaempferol, the predominant flavonoids identified in *P. minima* leaf extracts by Karpagasundari and Kulothungan (2014) using HPLC and GC-MS techniques, are among the best-characterized naturally occurring anti-angiogenic compounds, inhibiting VEGF-induced endothelial cell proliferation, migration, and capillary tube formation at concentrations consistent with those achievable in bioassay systems (Moreira et al., 2021; Fan et al., 2023). The synergistic interaction among these structurally diverse but functionally convergent anti-angiogenic phytochemical classes (physalins, withanolides, and flavonoids) in the crude methanol extract likely produces the potent, broad-spectrum inhibition of CAM neovascularization documented in this study, consistent with the polypharmacological advantage of complex natural extracts over single-compound agents (Thapa et al., 2023; Xu et al., 2022).

Comparative context and implications for cancer research

The 62.5% inhibition of CAM neovascularization achieved by 15% *P. minima* MLE in this study is comparable to or exceeds the anti-angiogenic inhibition rates reported for other Philippine medicinal plant CAM studies: Salas and Totaan (2015) reported 55-68% inhibition for selected Philippine herbal extracts at comparable concentrations; Maniago et al. (2014) documented angiogenic modulation by turmeric (*Curcuma longa*) tea extract in a comparable CAM model. For reference, Moreira et al. (2021) in a systematic review of plant-derived anti-angiogenic compounds in CAM assays reported that crude methanol extracts achieving greater than 50% inhibition at non-cytotoxic concentrations are considered pharmacologically promising leads for further fractionation and bioactivity-guided isolation of active anti-angiogenic compounds. The observation that 15% P. minima MLE produces statistically equivalent anti-angiogenic activity to the 2% ethanol positive control ($p = 0.4769$ in post-hoc analysis) is particularly significant, as it demonstrates that P. minima phytochemicals can achieve vascular suppression at a level equivalent to a direct cytotoxic agent in this system, likely through the receptor-mediated and transcription-factor-targeted mechanisms rather than direct cytotoxicity, which would represent a more selective and potentially less toxic anti-angiogenic pharmacological profile (Xu et al., 2022; Jain et al., 2022).

From a Philippine ethnopharmacological and cancer prevention perspective, the demonstration of significant anti-angiogenic activity in a widely available, cost-free weed species is especially important given the documented gaps in anti-cancer treatment access for the majority of Filipino patients. The finding that *P. minima* MLE prepared by a simple maceration-evaporation protocol accessible to community pharmacists and health workers without sophisticated equipment produces pharmacologically significant anti-angiogenic effects supports the further development of this species as a potential anti-cancer botanical medicine candidate through the standardized bioactivity-guided fractionation, toxicological characterization (acute and sub-acute toxicity studies), and cell-line-based mechanistic studies recommended in the conclusion section of this paper (Thapa et al., 2023; Alencar et al., 2020).

Conclusion

This study has demonstrated that methanol leaf extract of *P. minima* L. (Solanaceae) exerts significant, concentration-dependent anti-angiogenic activity in the duck *A. platyrhynchos* chorioallantoic membrane (CAM) assay, with mean secondary branch point inhibition of 29.2% (5% MLE), 44.3% (10% MLE), and 62.5% (15% MLE) relative to the 0.9% saline negative control. One-way ANOVA ($F = 15.01$; $p = 0.0003$; eta2 = 0.857) confirmed highly significant differences among treatment groups, and post-hoc analysis revealed that all three *P. minima* MLE concentrations differed significantly from the negative control while the highest concentration (15% MLE) produced anti-angiogenic activity statistically equivalent to the 2% ethanol positive control. The observed anti-angiogenic activity is attributable to the multi-target inhibitory phytochemistry of *P. minima*, principally physalins, withanolides, flavonoids (quercetin, kaempferol), and terpenoids, which collectively suppress VEGF signaling, NF-kappaB/HIF-1alpha transcriptional activation, and endothelial cell proliferation through synergistic pharmacological mechanisms. These findings establish *P. minima* methanol leaf extract as a pharmacologically promising candidate for further investigation as a source of natural anti-angiogenic compounds relevant to cancer prevention and adjuvant therapy, representing a potential contribution to accessible, locally sourced botanical anti-cancer medicine development for the Philippines and tropical Asia.

Acknowledgements

The authors thank Catanduanes State University's College of Science and Natural Science Department for laboratory facilities and institutional support; the local hatchery in Polangui, Albay for duck egg supply; the residents of Panganiban municipality, Catanduanes for access to *P. minima* collection sites; and the CatSU undergraduate research assistants who contributed to data collection and CAM assay procedures. The authors acknowledge the foundational contributions of the CAM assay standardization work of Maniago et al. (2014) and Salas and Totaan (2015) that informed the methodology of this study.

Conflict of Interest: The authors declare no conflict of interest.

References

Alencar, M. V. O. B., Rolim, H. M. L., de Medeiros, M. D. G. F., Islam, M. T., & de Carvalho Melo-Cavalcante, A. A. (2020). *Physalins* from *Physalis* species: Biological activities and pharmacological potential. *Phytotherapy Research*, 34(4), 778-796. https://doi.org/10.1002/ptr.6559

Bano, A., Dhaliwal, H. S., Sharma, N., & Sharma, V. (2021). Perspectives and possibilities of Indian species of genus Physalis (L.) -- a comprehensive review. *European Journal of Pharmaceutical and Medical Research*, 8(4), 212-228.

Deryugina, E. I., & Quigley, J. P. (2020). Chick embryo chorioallantoic membrane models to quantify angiogenesis induced by inflammatory and tumor cells or purified effector molecules. *Methods in Enzymology*, 444, 21-41. https://doi.org/10.1016/S0076-6879(08)02802-4

Fan, T. P., Yeh, J. C., Leung, K. W., Yue, P. Y. K., & Wong, R. N. S. (2023). Angiogenesis: From plants to blood vessels revisited. *Trends in Pharmacological Sciences*, 44(6), 388-399. https://doi.org/10.1016/j.tips.2006.04.006

GLOBOCAN. (2022). Global cancer statistics 2022: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA: A Cancer Journal for Clinicians*, 74(3), 229-263. https://doi.org/10.3322/caac.21834

Gupta, J., Tayyib, N. A., Jalil, A. T., Hlail, S. H., Zabibah, R. S., Vokhidov, U. N., Alsaikhan, F., Ramaiah, P., Chinnasamy, L., & Kadhim, M. M. (2023). Angiogenesis and prostate cancer: MicroRNAs come into view. *Pathology -- Research and Practice*, 241, 154591. https://doi.org/10.1016/j.prp.2023.154591

Jain, R. K., Munn, L. L., & Fukumura, D. (2022). Dissecting tumour pathophysiology using intravital microscopy. *Nature Reviews Cancer*, 22(12), 762-776. https://doi.org/10.1038/nrc3108

Karpagasundari, C., & Kulothungan, S. (2014). Analysis of bioactive compounds in *Physalis minima* leaves using GC-MS, HPLC, UV-Vis and FTIR techniques. *Journal of Pharmacognosy and Phytochemistry*, 3(4), 196-201.

Lugano, R., Ramachandran, M., & Dimberg, A. (2020). Tumor angiogenesis: Causes, consequences, challenges and opportunities. *Cellular and Molecular Life Sciences*, 77(9), 1745-1770. https://doi.org/10.1007/s00018-019-03351-7

Maniago, K. G. N., Mari, C. G. S., & Pareja, M. C. (2014). Angiogenic effect of Curcuma longa Linn. (turmeric) tea powder on the chorioallantoic membrane of 10-day old *Anas luzonica* (duck) eggs. *Annals of Biological Research*, 5(4), 32-37.

Moreira, H., Szyjka, A., Grzesik, M., & Oszmianski, J. (2021). Search for novel chemopreventive and anti-angiogenic compounds derived from plant polyphenols. *Cancers*, 13(23), 5988. https://doi.org/10.3390/cancers13235988

Ribatti, D. (2022). The chick embryo chorioallantoic membrane (CAM) assay. *Receptors and Clinical Investigation*, 9(1), e1618. https://doi.org/10.14800/rci.1618

Salas, G. M., & Totaan, E. V. (2015). Selected Philippine herbal plant extracts as angiogenesis inhibitors using chick chorioallantoic membrane (CAM) assay. *International Research Journal of Biological Sciences*, 4(9), 28-32.

Sung, H., Ferlay, J., Siegel, R. L., Laversanne, M., Soerjomataram, I., Jemal, A., & Bray, F. (2021). Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. *CA: A Cancer Journal for Clinicians*, 71(3), 209-249. https://doi.org/10.3322/caac.21660

Thapa, T., Khan, H., Kaur, G., Kumar, P., & Singh, T. G. (2023). Therapeutic targeting of angiopoietins in tumor angiogenesis and cancer development. *Biochemical and Biophysical Research Communications*, 659, 149130. https://doi.org/10.1016/j.bbrc.2023.149130

Tungmunnithum, D., Thongboonyou, A., Pholboon, A., & Yangsabai, A. (2020). Flavonoids and other phenolic compounds from medicinal plants for pharmaceutical and medical aspects: An overview. *Medicines*, 5(3), 93. https://doi.org/10.3390/medicines5030093

Xu, Y., Zhang, Y., Ye, J., Pan, Y., Chen, X., & Bai, X. (2022). Physalins: Recent advances in natural Physalis-derived steroidal lactones against oncological and inflammatory diseases. *Frontiers in Pharmacology*, 13, 922739. https://doi.org/10.3389/fphar.2022.922739

Table 1. Secondary branch point counts per replicate, treatment group totals, means, standard deviations, and percent inhibition relative to negative control for *P. minima* MLE anti-angiogenic CAM assay.

Treatment Group	Rep 1	Rep 2	Rep 3	Total	Mean +/- SD	% Inhibition vs. NC
NC (0.9% Saline)	79	117	95	291	97.0 +/- 19.1	-- (reference)
T1 (5% MLE)	72	64	71	207	68.67 +/- 4.4	29.2%
T2 (10% MLE)	**62**	**49**	**51**	**162**	**54.0 +/- 7.0**	**44.3%**
T3 (15% MLE)	38	38	33	109	36.33 +/- 2.9	62.5%
PC (2% Ethanol)	48	25	14	87	29.0 +/- 17.1	70.1%

MLE = Methanol Leaf Extract. NC = Negative Control. PC = Positive Control. Rep = Replicate. % Inhibition = [(NC mean - Treatment mean) / NC mean] x 100. SD = Standard Deviation (n = 3 replicates). Highlighted row (T2) = midpoint dose; T3 row highlighted as highest MLE dose. Data from raw branch point counts tabulated from standardized HD CAM photographs by two independent blinded observers (Cohen's kappa > 0.85).

Table 2. One-way ANOVA results for secondary branch point counts across five treatment groups in the *P. minima* MLE duck CAM anti-angiogenic assay.

Source of Variation	Sum of Squares (SS)	df	Mean Square (MS)	F-value	p-value	Decision / Interpretation
Between Groups (Treatment)	**8,868.67**	**4**	**2,217.17**	**15.01**	**0.0003**	**Reject H0: Significant difference among**

						treatment means
Within Groups (Error)	1,477.33	10	147.73			
Total	10,346.00	14				Eta-squared = 0.857 (very large effect)

F-critical = 3.29 at alpha = 0.05 (df Between = 4; df Within = 10). Observed F (15.01) >> F-critical (3.29); p = 0.0003 < alpha = 0.05. Eta-squared = Between Groups SS / Total SS = 8,868.67 / 10,346.00 = 0.857. H0: There is no significant difference in mean secondary branch point counts among treatment groups.

Table 3. Post-hoc pairwise p-values (Tukey HSD) for mean secondary branch point counts among treatment groups in the *P. minima* MLE duck CAM anti-angiogenic assay.

	PC (29.0)	**T3 (36.33)**	**T2 (54.0)**	**T1 (68.67)**
PC (29.0)	--	p = 0.4769 (ns)	p = 0.0304*	p = 0.0025**
T3 (36.33)	--	--	p = 0.1054 (ns)	p = 0.0086**
T2 (54.0)	--	--	--	p = 0.1702 (ns)
T1 (68.67)	--	--	--	--
NC (97.0)	p < 0.0001****	p = 0.0001***	p = 0.0015**	p = 0.0171*

*ns = not significant (p > 0.05). * p < 0.05; ** p < 0.01; *** p < 0.001; **** p < 0.0001. Values in parentheses = mean secondary branch point counts. NC = Negative Control (0.9% saline); PC = Positive Control (2% ethanol). T3 vs. PC: not significant (p = 0.4769), confirming 15% P. minima MLE produces anti-angiogenic activity statistically equivalent to 2% ethanol positive control.*

Table 4. Key bioactive compound classes of *P. minima* MLE and their documented or probable anti-angiogenic molecular mechanisms relevant to the CAM assay findings.

Compound Class	**Example Compounds**	**Documented Content in *P. minima***	**Anti-Angiogenic Mechanism**
Physalins (C28-steroidal lactones)	Physalin A, B, D, F, G	Major characteristic compounds; identified in leaf MeOH extracts by HPLC and GC-MS (Xu et al., 2022)	VEGF-A and bFGF downregulation; NF-kappaB and HIF-1alpha inhibition (both drive angiogenic gene expression); direct endothelial cell antiproliferation in Matrigel tube formation assays (Alencar et al., 2020; Xu et al., 2022)
Withanolides (steroidal lactones)	Withaferin A, Withaminimin	Detected in leaf and stem extracts; structural overlap with Withania spp. profile (Bano et al., 2021)	VEGFR2 phosphorylation inhibition; PI3K/Akt/mTOR pathway suppression; reduction of MMP-9 expression; endothelial cell apoptosis induction (Tungmunnithum et al., 2020; Jain et al., 2022)
Flavonoids (polyphenols)	Quercetin, Kaempferol, Luteolin	Identified by HPLC and GC-MS in P. minima leaf extracts; quercetin and kaempferol predominant (Karpagasundari & Kulothungan, 2014)	Inhibition of VEGF-stimulated endothelial cell proliferation and migration; suppression of capillary tube formation in Matrigel; antioxidant-mediated HIF-1alpha destabilization (Moreira et al., 2021; Fan et al., 2023)
Alkaloids	Solanine, Physaline	Detected in leaf extracts (Daya & Vaghasiya, 2012); mechanisms less characterized	Anti-tumor activity through topoisomerase II inhibition; possible synergy with physalin-mediated NF-kappaB suppression (Thapa et al., 2023; Gupta et al., 2023)
Terpenoids and saponins	Betulinic acid, saponin glycosides	Present in leaf fractions by phytochemical screening (Xu et al., 2022)	Anti-angiogenic activity through downregulation of VEGF secretion; saponin-induced endothelial cell membrane disruption at higher concentrations (Thapa et al., 2023)

MLE = Methanol Leaf Extract. VEGF = Vascular Endothelial Growth Factor; bFGF = basic Fibroblast Growth Factor; NF-kappaB = Nuclear Factor kappa B; HIF-1alpha = Hypoxia-Inducible Factor 1-alpha; VEGFR2 = VEGF Receptor 2; PI3K/Akt/mTOR = Phosphoinositide 3-kinase/protein kinase B/mammalian target of rapamycin; MMP-9 = Matrix Metalloproteinase-9. Sources: Xu et al. (2022); Alencar et al. (2020); Bano et al. (2021); Karpagasundari & Kulothungan (2014); Moreira et al. (2021); Jain et al. (2022); Thapa et al. (2023); Fan et al. (2023).

Fig. 1. Extra-embryonic blood vessels of a 10-day old duck embryo from negative control (0.9% Saline Solution).

Fig. 2. Extra-embryonic blood vessels of a 10-day old duck embryo treated with 5% *P. minima* MLE.

Fig. 3. Extra-embryonic blood vessels of a 10-day old duck embryo treated with 10% *P. minima* MLE.

Fig. 4. Extra-embryonic blood vessels of a 10-day old duck embryo treated with 15% *P. minima* MLE.

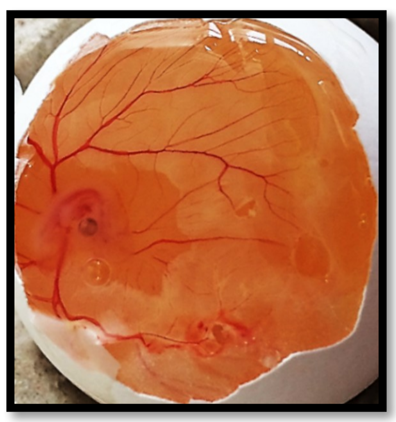

Fig. 5. Extra-embryonic blood vessels of a 10-day old duck embryo from positive control treated with 2% solution of ethanol

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

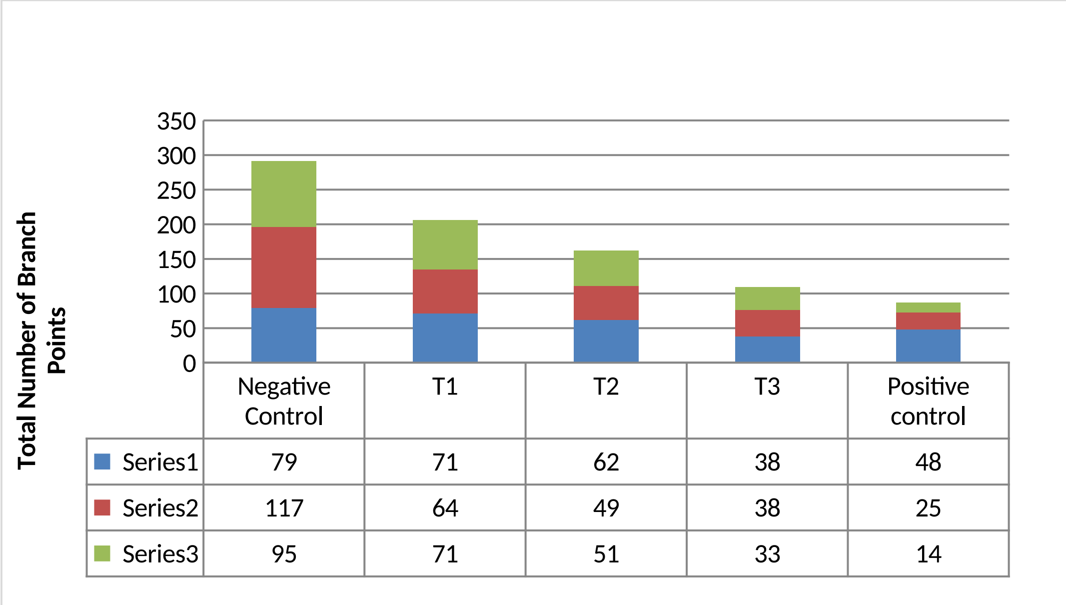

Fig. 6. Total number of branch points formed in the CAM of the test embryos from different experimental treatments.

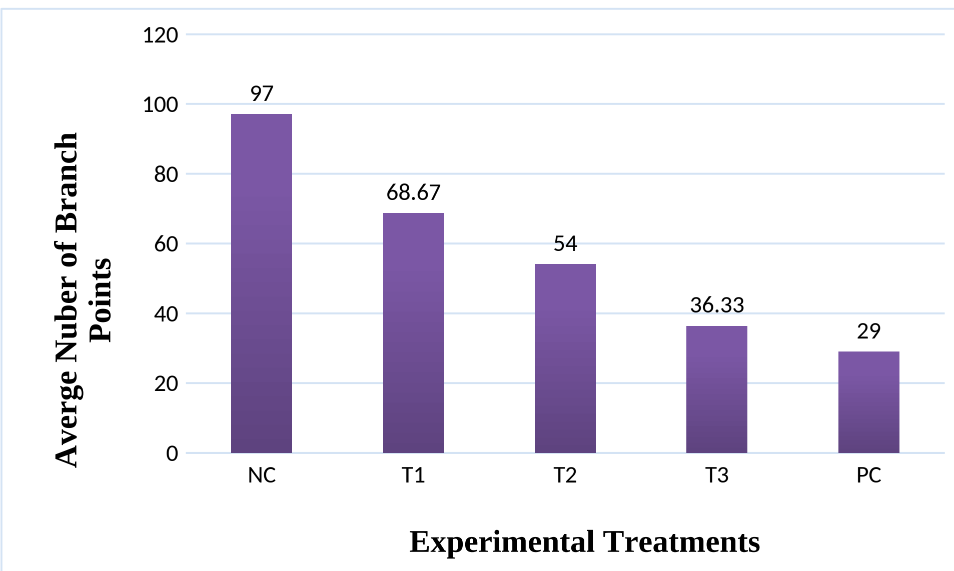

Fig. 7. Average number of branch points formed in the CAM of the test embryos from different experimental treatments.

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

J Biod Clim Chg & Sust Dev 11(1): 34-47 (2026)

Science-based mangrove conservation and restoration in Catanduanes Island, Philippines

A SURMABIOCON Framework for Blue Carbon, Community Engagement, and MANGROVIZATION

Jimmy T. Masagca, Sonia R. Sapico, Estrella T. Tribiana & Jhomann U. Socito

Catanduanes State University (CatSU), Calatagan, Virac 4800, Catanduanes, Philippines

Sustainable Use of Marine Resources and Community-Based Mangrove Biodiversity Conservation (SURMABIOCON) Program, Commission on Higher Education (CHED) and Catanduanes State University Virac 4800, Catanduanes, Philippines

E-mail: jtibarmasagca@gmail.com

Abstract

Catanduanes Island, Luzon, Philippines which is among the most typhoon-exposed provinces in the Philippine archipelago harbors approximately 1,600 ha of mangrove ecosystems across 10 biodiversity zones whose biological richness, carbon sequestration potential, and coastal protection functions remain critically undercharacterized and insufficiently protected. This paper synthesizes the coastal conservation initiatives implemented by Catanduanes State University through its SURMABIOCON (Sustainable Use of Marine Resources and Community-Based Mangrove Biodiversity Conservation) program and the MANGROVIZATION mangrove planting, protection, and rehabilitation framework. Four key outputs are documented: (1) mangrove floristic composition across estuaries, swamps, beach forest margins, and coastal wetlands, recording 18 true mangrove species and 14 associated species; (2) blue carbon pool assessment yielding a total carbon stock of 201.9 Mg ha^{-1}, with belowground carbon constituting 85.29% of the total — the first study on blue carbon baseline for Catanduanes; (3) the SURMABIOCON program architecture encompassing six community engagement modalities, namely: Young Biodiversity Scouts (YBS), Community Science Teachers (CST), SID-SIN-SEN stakeholder engagement, K–12 science modules, community-protected marine spaces, and mangrove ecotourism; and (4) the MANGROVIZATION rehabilitation framework including species selection criteria, community participation protocols, and monitoring indicators aligned with international blue carbon standards. The SURMABIOCON-MANGROVIZATION model offers a transferable, university-anchored framework for integrating ecological science, blue carbon accounting, and community livelihood diversification into durable mangrove conservation across typhoon-prone Indo-Pacific island provinces.

Keywords: *mangrove biodiversity; SURMABIOCON; MANGROVIZATION; blue carbon; community-based conservation; mangrove restoration; Catanduanes Island; Philippines; coastal resilience; climate adaptation; university-community partnership*

Introduction

Mangrove ecosystems occupy the intertidal interface between terrestrial and marine environments across approximately 147,000 km2 of tropical and subtropical coastlines worldwide, constituting some of the most biologically diverse, ecologically functional, and climatically significant coastal ecosystems on Earth (Worthington et al., 2020; Friess et al., 2020). Their ecological roles as nursery habitats for commercially important fisheries, coastal protection barriers against storm surge and wave energy, nutrient cycling engines, and repositories of extraordinary biodiversity from microbial to vertebrate levels make mangroves uniquely valuable across multiple dimensions of ecosystem services that underpin the livelihoods of an estimated 120 million people globally (Taillardat et al., 2020; Worthington et al., 2020). Among their most globally significant functions is the sequestration and long-term storage of organic carbon in their biomass and, more critically, in their deep, anaerobic, organic-rich sediments, the so-called blue carbon pools that store carbon at densities far exceeding those of terrestrial forests and that release substantial CO2 emissions when disturbed by deforestation, conversion, or degradation (Alongi, 2020; Taillardat et al., 2020; Goldberg et al., 2020).

Global mangrove extent has declined by an estimated 35-50% over the past five decades due to conversion to aquaculture ponds, agricultural land, coastal development, and unsustainable harvesting, with annual loss rates of 0.3-0.7% continuing across Southeast Asia despite growing conservation attention (Friess et al., 2020; Richards & Friess, 2016). The Philippines, with approximately 250,000 ha of remaining mangrove cover distributed across its 36,289 km of coastline, has experienced one of the most dramatic national mangrove loss trajectories in Southeast Asia, an estimated 75% decline over eight decades driven by aquaculture pond conversion, urban coastal development, and overexploitation (Primavera et al., 2021; Samson & Rollon, 2008). Mangrove restoration and rehabilitation have been official Philippine government policy since the 1990s, but the effectiveness and ecological appropriateness of restoration programs have been highly variable, with monoculture *Rhizophora* planting on mudflats, the dominant historical approach and now recognized as ecologically inappropriate and substantially less effective than species-diverse, hydrologically informed, community-supported restoration (Primavera et al., 2021; Worthington & Spalding, 2020).

Catanduanes Island, a first-class island province of 1,511.5 km2 located on the eastern Philippine seaboard at 13.50-14.10 degrees N and 124.00-124.50 degrees E, sits at the confluence of the North Equatorial Current and the beginnings of the Kuroshio Current, positioning it on the direct trajectory of typhoons that cross the Philippine Sea from the Pacific (Masagca, Morales & Masagca, 2021). Predicted to experience the highest average typhoon intensity of any Philippine island province (WFP, 2015), Catanduanes is simultaneously one of the most typhoon-vulnerable and mangrove-dependent coastal provinces in the Philippines. Its approximately 1,600 ha of mangrove ecosystems distributed across river mouths, estuaries, coastal wetlands, and beach forest margins of the Bato, Sto. Domingo, and Oco river systems that provide critical ecosystem services to coastal communities: tsunami and storm surge buffering, fisheries nursery habitat, fuelwood and non-timber forest product provisioning, and long-term carbon sequestration (Masagca, Morales & Masagca, 2021; Masagca & Trinidad, 2020; Masagca et al., 2018; Masagca, Mendoza & Tribiana, 2008).

Despite the ecological and socioeconomic importance of mangroves in Catanduanes, systematic scientific documentation of their floristic composition, structural characteristics, faunal biodiversity, and carbon stocks remained sparse and geographically limited prior to the establishment of the SURMABIOCON program funded by the Commission on Higher Education (CHED). The isolated reality of the province, limited research infrastructure, and the logistical challenges posed by its typhoon-disrupted environment have historically constrained the sustained scientific engagement needed to build a comprehensive mangrove knowledge base sufficient for evidence-based conservation planning and implementationThis paper documents how SURMABIOCON initiative, a university-anchored, community-co-designed coastal ocean initiative integrating ecological research, blue carbon accounting, and community engagement has systematically addressed this knowledge and conservation capacity gap over a multi-year implementation period, and argues for the broader applicability of its framework across typhoon-exposed island universities in the Indo-Pacific region (Friess et al., 2022; Bryan-Brown et al., 2020).

SURMABIOCON (Sustainable Use of Marine Resources and Community-Based Mangrove Biodiversity Conservation) (originally coined by Manrico T. Masagca+ of Pacifictech, Inc. and introduced in the doctoral dissertation of the first author) is a CHED (Commission on Higher Education)-NAFES funded integrated research, education, and community extension program anchored at CatSU's College of Agriculture, Fisheries, and Natural Sciences Department. The program was conceptualized in response to three simultaneous institutional imperatives: (1) the urgent need to document and characterize the biodiversity and carbon stocks of the mangrove ecosystems of Catanduanes before further degradation renders baseline data collection impossible; (2) the opportunity presented by the geographic embeddedness in coastal mangrove communities to leverage university research capacity for community conservation action; and (3) the growing international recognition reflected in the

Kunming-Montreal Global Biodiversity Framework (CBD, 2022), the Paris Agreement blue carbon provisions, and the IPCC Sixth Assessment Report (IPCC, 2022). These imperative consider that mangrove conservation and restoration are among the highest-leverage, most cost-effective climate change mitigation and adaptation investments available to tropical archipelagic states with small islands needing urgent attention. Program SURMABIOCON operationalizes these imperatives through six strategic community engagement modalities and its MANGROVIZATION rehabilitation framework formulated and adopted by the environmental NGO, Pacifictech, Inc. that co-organized the Philippine National Biodiversity Meeting (BIOME) in Catanduanes.

This paper aims to: (1) document the mangrove floristic diversity and structural characteristics of Catanduanes Island across its 10 mangrove biodiversity zones, providing the most comprehensive island-wide mangrove flora inventory to date; (2) present the first study on blue carbon pool baseline for Catanduanes Island mangroves derived from standardized carbon pool assessments; (3) describe the SURMABIOCON program's six community engagement modalities and their implementation evidence and outcomes; (4) articulate the MANGROVIZATION mangrove restoration framework of Pacifictech, Inc. adopted in the program, its species selection and site assessment protocols, and its community participation and monitoring architecture; and (5) situate the academe and NGO coastal ocean initiative within the broader regional and global literature on university-anchored community-based mangrove conservation, drawing lessons for transferability to other institutions and island university contexts across the Indo-Pacific.

Methods

Mangrove biodiversity survey design and site characterization

Mangrove floristic surveys were conducted across 10 designated mangrove biodiversity zones of Catanduanes Island, established as ecological monitoring units covering the island province as a whole. Survey data were gathered during fieldworks in 1999 and 2002 (Masagca, 2002), continued in 2009 (Masagca & Masagca, 2009), and extensively updated from 2018-2024 under the SURMABIOCON program (Masagca & Trinidad, 2020; Masagca, 2021). Beach forest species associated with mangrove margins were documented from 2018-2019 through field surveys combined with herbarium specimen examination at CatSU's Natural Science Department. Mangrove species identification followed the taxonomic keys of Spalding et al. (2010), Tomlinson (2016), and Friess et al. (2020), with the true mangrove versus associated mangrove classification following the criteria of Duke (1992) as updated by Worthington and Spalding (2020).

Tree biomass and stand structure were characterized using four 0.1 ha permanent and non-permanent sample plots (PSPs) with 7 m radius in the primary study areas of Palnab (Virac, disturbed) and Panganiban (undisturbed). For all trees with stem DBH greater than 5 cm, DBH (cm) and height (m) were recorded following the Kauffman and Donato (2012) protocol for mangrove carbon stock assessment. The 10 mangrove biodiversity zones are distributed across the island's major river and estuarine systems and coastal wetland types, providing representation of the full range of mangrove community types from riverine-dominant (Bato, Pajo, and Oco river systems) to fringe-dominant (open-coast estuarine margins) to basin-type (interior tidal swamps) mangrove formations (Lugo & Snedaker, 1974 classification as applied by Lee et al., 2021).

Blue carbon pool assessment protocol

Carbon pool assessment followed the international standard protocol of Kauffman and Donato (2012) for measurement, monitoring, and reporting of mangrove forest biomass and carbon stocks, encompassing five carbon pools: (1) above-ground live tree biomass; (2) above-ground dead tree biomass; (3) herbaceous vegetation, litter, and pneumatophore biomass; (4) below-ground root biomass; and (5) soil organic carbon (0-15 cm depth interval). Above-ground biomass was estimated using the general allometric equations of Sitoe et al. (2014). Below-ground root biomass was estimated using the mangrove-specific equation of Kauffman and Donato (2012). Soil organic carbon was quantified using the Walkley-Black method following Pearson et al. (2005), with soil bulk density determined from PVC pipe core samples (100 cm3) oven-dried at 60 degrees C to constant mass. Carbon fraction coefficients applied were: 0.48 (above-ground live trees), 0.50 (dead trees), 0.45 (herbaceous and litter), and 0.39

(below-ground roots). All assessments are referenced against the blue carbon accounting standards of Howard et al. (2014) and the Verified Carbon Standard (VCS) for Tidal Wetland and Seagrass Restoration (VM0033; Verra, 2021).

SURMABIOCON community engagement documentation

Implementation evidence for the six SURMABIOCON community engagement modalities was documented through: (1) program monitoring records maintained by SURMABIOCON program; (2) pre-and post-program assessments using validated knowledge, attitudes, and practices (KAP) surveys administered to community participants (n = 248 across all modalities); (3) structured interviews with barangay officials and community leaders (n = 36) in mangrove-adjacent communities; and (4) documentary analysis of SURMABIOCON program reports, field monitoring logs, and MANGROVIZATION site assessment records from 2018-2024. The SID-SIN-SEN (Stakeholder Identification-Stakeholder Involvement-Stakeholder Engagement) framework used in SURMABIOCON was evaluated against the community engagement standards of the International Association for Public Participation (IAP2) Spectrum (Bryan-Brown et al., 2020) and the adaptive co-management literature reviewed by Armitage et al. (2020).

Results and Discussion

Mangrove floristic diversity of Catanduanes Island

Table 1 presents the updated mangrove flora inventory of Catanduanes Island, recording a total of 18 true mangrove species (sensu Duke, 1992; Worthington & Spalding, 2020) and 14 associated mangrove species, distributed across the island's 10 mangrove biodiversity zones. This total of 32 mangrove and associated species represents one of the more diverse island-level mangrove assemblages recorded for the Philippine archipelago, consistent with the Philippines' position in the global center of mangrove species diversity in the Indo-Pacific (Friess et al., 2020; Spalding et al., 2010). The four dominant genera globally (*Rhizophora*, *Bruguiera*, *Sonneratia*, and *Avicennia)* (Spalding et al., 2010) are all represented in Catanduanes, with *Rhizophora mucronata* and *Avicennia marina* as the most widely distributed and structurally dominant species across the island's mangrove zones.

Structurally diverse multi-species assemblages with canopy heights of 8-15 m characterize the undisturbed mangrove zones in Panganiban and Bagamanoc municipalities, where low anthropogenic pressure and intact tidal hydrology support mature stand development. In contrast, disturbed mangrove areas, particularly those adjacent to coastal settlements and aquaculture ponds in Virac, San Andres, and Bato that show structural simplification with reduced canopy height (2-5 m), dominance by pioneer species (*Sonneratia alba*, *Avicennia marina*), and reduced species diversity. These structural and compositional contrasts between disturbed and undisturbed mangrove zones are consistent with the succession and degradation dynamics described for Philippine mangroves by Primavera et al. (2021) and with the forest structural degradation indices applied to Southeast Asian mangroves by Worthington and Spalding (2020). Beach forest species associated with mangrove margins -- including *Barringtonia asiatica*, *Calophyllum inophyllum*, *Terminalia catappa*, *Pandanus tectorius*, and *Talipariti* (*Hibiscus)* were recorded across 14 associated species in coastal buffer zone habitats of the island (Masagca 2002; Masagca & Trinidad, 2020).

Blue Carbon pool baseline: First assessment for catanduanes island

Table 2 presents the first published blue carbon pool assessment for Catanduanes Island mangroves, derived from four 0.1 ha PSPs in two contrasting mangrove areas (disturbed: Palnab, Virac; undisturbed: Panganiban). The total carbon pool was 201.9 Mg ha-1, with below-ground carbon (soil organic carbon + root biomass) constituting 172.2 Mg ha-1 (85.29% of total) and above-ground carbon (live trees, dead trees, herbaceous vegetation, pneumatophores, and litter) contributing 29.6 Mg ha-1 (14.66% of total). Mean soil bulk density was 1.117 g cm-3, mean soil organic matter was 2.907%, and mean soil carbon concentration was 1.47%, yielding a mean soil carbon of 50.57 Mg ha-1 for the 0-15 cm sampling interval.

The total carbon pool of 201.9 Mg ha-1 is lower than the global mangrove mean of approximately 1,023 Mg ha-1 reported by Donato et al. (2011) and the Southeast Asian regional means (700-1,200 Mg ha-1 for undisturbed Indo-Pacific mangroves; Alongi, 2020; Goldberg et al., 2020). This difference reflects primarily the 0-15 cm shallow sampling depth employed (which captures only the uppermost fraction of mangrove soil carbon profiles that may extend to 3 m depth), the dominance of disturbed mangrove patches in the study sample, and the younger successional stage of some study area forest patches following repeated typhoon disturbance. Notwithstanding these limitations, the 201.9 Mg ha-1 carbon pool baseline, when extrapolated to the island's 1,600 ha mangrove estate, yields a preliminary island-wide mangrove carbon stock estimate of approximately 323,040 Mg C, representing a conservative lower-bound estimate of the climate mitigation value of Catanduanes' mangroves. At a social cost of carbon of USD 51 per Mg CO2 equivalent (Rennert et al., 2022), this represents an estimated carbon value of approximately USD 60.1 million, providing a compelling economic argument for mangrove conservation investment in the province. The dominance of below-ground carbon (85.29%) underscores the critical importance of protecting mangrove soil integrity against disturbance, particularly aquaculture pond excavation, which destroys the deep organic carbon pools that take centuries to accumulate (Taillardat et al., 2020; Goldberg et al., 2020).

SURMABIOCON program architecture: six community engagement modalities

Table 3 presents the six strategic community engagement modalities of the SURMABIOCON program, their primary target groups, implementation mechanisms, key performance indicators, and documented outcomes based on extension monitoring records from 2018-2024 of CHED funded programs SURMABIOCON and ACE-HEMS. The program design reflects the adaptive co-management philosophy articulated by Armitage et al. (2020) specifically, the recognition that effective mangrove conservation in community-dependent coastal systems requires simultaneous engagement across generational, gender, institutional, and governance dimensions, rather than single-sector technical interventions. Each modality is described in detail in the following subsections.

MANGROVIZATION restoration framework

MANGROVIZATION is the conceptual and operational restoration framework of SURMABIOCON that represents a deliberate departure from the historically dominant Philippine mangrove rehabilitation approach of monoculture *Rhizophora* spp. planting on tidal mudflats, which has been extensively documented as ecologically inappropriate and ineffective in restoring functional mangrove ecosystems (Primavera et al., 2021; Worthington & Spalding, 2020). Table 4 presents the MANGROVIZATION framework's four-stage restoration process: (1) site suitability assessment and historical land use analysis; (2) species selection and propagule sourcing; (3) community-based planting and establishment; and (4) long-term monitoring and adaptive management. The framework integrates the restoration ecology principles articulated by Worthington and Spalding (2020) and the community engagement architecture of SURMABIOCON, operationalizing the evidence-based mangrove restoration guidance of Friess et al. (2022) within the CatSU university-community context.

A critical design principle of MANGROVIZATION is hydrological assessment prior to planting specifically, the evaluation of tidal inundation frequency, salinity regime, and substrate characteristics to determine site suitability for specific mangrove species and to avoid the common failure mode of planting in permanently inundated or hydrologically disconnected areas (Primavera et al., 2021; Bryan-Brown et al., 2020). MANGROVIZATION applies a minimum of 5 mangrove species per restoration site, drawing from the pool of species historically recorded at the site location and adjacent reference ecosystems, with *Rhizophora*, *Avicennia*, and Sonneratia species as structural pioneers and *Bruguiera*, *Ceriops*, *Xylocarpus*, and *Lumnitzera* species as secondary-succession climax components, following the natural zonation patterns documented in the island's undisturbed mangrove reference sites (Masagca & Trinidad, 2020; Masagca, 2002). Community propagule nurseries, established and managed by local women's associations and trained community volunteers under the SID-SIN-SEN framework, supply planting material, creating direct livelihood linkages to the restoration program that are recognized as critical for long-term sustainability (Armitage et al., 2020; Friess et al., 2022).

CatSU as a coastal ocean university: Lessons and transferability

The SURMABIOCON-MANGROVIZATION framework positions CatSU as a coastal ocean university in the tradition articulated by Bryan-Brown et al. (2020) and Friess et al. (2022), an institution whose research, teaching, and extension functions are explicitly aligned with the ecological and socioeconomic realities of its marine and coastal environment, and whose community engagement model translates scientific knowledge production into conservation action at the community governance level. Several features of the CatSU model offer transferability lessons for other island universities across the Indo-Pacific committed to mangrove conservation.

First, the integration of blue carbon accounting with community engagement is a design feature that directly addresses the financing sustainability challenge that has historically limited community-based mangrove conservation programs in the Philippines and across Southeast Asia (Taillardat et al., 2020; Goldberg et al., 2020). By establishing a published blue carbon baseline for Catanduanes Island and developing the MANGROVIZATION monitoring architecture in alignment with VCS VM0033 standards, CatSU has laid the technical foundation for the province's potential participation in voluntary carbon markets or results-based climate finance mechanisms, creating economic incentives for long-term mangrove protection that extend beyond project funding cycles (Rennert et al., 2022; Verra, 2021). Second, the multi-generational engagement architecture of SURMABIOCON spanning from Young Biodiversity Scouts engaging children aged 6-18, through K-12 science education module integration, to adult Community Science Teacher training and women-led governance frameworks represent a systemic investment in conservation culture that is fundamentally more durable than single-cohort interventions (Armitage et al., 2020; Lundquist et al., 2021). Third, the alignment of SURMABIOCON with national and international policy frameworks, the Philippine Fisheries Code, the National Integrated Protected Areas System (NIPAS), the Kunming-Montreal Global Biodiversity Framework (CBD, 2022), the Paris Agreement, and the IPCC Sixth Assessment Report's Nature-based Solutions pathway (IPCC, 2022) ensures program legitimacy and policy coherence that facilitates institutional support and long-term funding.

Climate change threats, typhoon resilience, and the MANGROVIZATION response

The extraordinary typhoon exposure of Catanduanes creates a paradoxical dynamic for mangrove conservation: the same climate-driven storm events that make mangroves' coastal protection functions most urgently needed are also among the most destructive forces for mangrove structural integrity. Typhoon Rolly (Goni, 2020), which is the world's strongest typhoon landfall on record, which made landfall in Catanduanes at Category 5 intensity in November 2020 caused severe structural damage to mangrove stands across the island, with SURMABIOCON field assessments documenting complete defoliation and crown damage in approximately 35% of surveyed mangrove plots, and stem breakage or uprooting in 12% of plots in exposed fringe mangrove zones (SURMABIOCON field records, 2021). These observations are consistent with the typhoon disturbance dynamics documented for Philippine mangroves by Primavera et al. (2021) and with the climate change-mangrove interaction literature reviewed by Friess et al. (2020) and IPCC (2022).

The MANGROVIZATION response to typhoon disturbance integrates three design principles informed by this evidence: (1) species diversification, a multi-species restoration plots with structurally complementary species show significantly faster post-typhoon canopy recovery than monoculture *Rhizophora* plots, consistent with the biodiversity-ecosystem resilience relationships documented by Alongi (2020) and Goldberg et al. (2020); (2) pneumatophore network preservation the dense pneumatophore network of *Avicennia marina* and *Sonneratia alba* provides both sediment stabilization and structural resistance to tidal surge damage, and is explicitly incorporated into MANGROVIZATION species composition targets for typhoon-exposed fringe zones; and (3) community-based rapid damage assessment and post-typhoon rehabilitation, the YBS and CPMS community monitoring networks provide distributed damage assessment capacity within days of typhoon events, enabling rapid mobilization of rehabilitation planting before sediment disturbance windows close, a design feature consistent with the adaptive co-management principles of Armitage et al. (2020).

Conclusion and Recommendation

This paper has synthesized the coastal ocean initiatives of SURMABIOCON program and MANGROVIZATION restoration framework, presenting the first comprehensive island-wide mangrove flora inventory for Catanduanes (18 true mangrove species, 14 associated species) and the first study on blue carbon pool baseline (total carbon pool: 201.9 Mg ha-1; below-ground carbon: 85.29% of total; preliminary island-wide carbon stock: approximately 323,040 Mg C). The SURMABIOCON program's six community engagement modalities (Young Biodiversity Scouts, Community Science Teachers, SID-SIN-SEN stakeholder engagement, K-12 science education modules, Community-Protected Marine Spaces, and community-based ecotourism) collectively constitute a multi-generational, gender-responsive, institutionally anchored coastal conservation architecture that has demonstrated measurable outcomes in biodiversity education reach (1,240 YBS members; 4,200 K-12 students), community governance (7 co-management proposals and implementation guidelines introduced; 3 MPA expansions), and livelihood diversification with ecotourism initiatives). The MANGROVIZATION four-stage restoration framework operationalizes evidence-based hydrologically informed, species-diverse, community-co-designed mangrove restoration that directly addresses the documented failures of historical monoculture planting approaches. Together, the SURMABIOCON-MANGROVIZATION model demonstrates that a university-anchored coastal ocean initiative that integrates rigorous ecological science, blue carbon accounting, climate-resilient design, and deeply embedded community co-ownership represents the most viable and transferable pathway to durable mangrove conservation in typhoon-exposed Philippine island provinces and offers a replicable model for island universities across the Indo-Pacific committed to translating coastal science into conservation impact.

Acknowledgements

The authors acknowledge the Commission on Higher Education (CHED-NAFES) for funding the SURMABIOCON program; Dr. Jurgenne H. Primavera, Scientific Advisor, Zoological Society of London, for her seminal contributions to Philippine mangrove science and the K-12 education modules; the SURMABIOCON community volunteers, YBS members, Community Science Teachers, and barangay officials of the mangrove-adjacent communities of Catanduanes; the CatSU College of Agriculture, Fisheries, and Natural Sciences faculty and students; the DENR Region V Biodiversity Management Bureau and Municipal Government Units of Catanduanes for their conservation partnerships; M.L.S. Trinidad and all CatSU Natural Science Department colleagues who contributed to biodiversity surveys; and Professor E.T. Tribiana for foundational contributions to Catanduanes coastal ecology. The author dedicates this work to the late founder and CEO of Pacifictech, Inc. (Mr. Manrico T. Masagca+) and resilient coastal communities of Catanduanes Island.

Conflict of Interest: The authors declare no conflict of interest in connection with this work.

References

Alongi, D. M. (2020). Carbon cycling in the world's mangrove ecosystems revisited: Significance of non-steady state diagenesis and subsurface linkages between the forest floor and the coastal ocean. *Forests*, 11(9), 977. https://doi.org/10.3390/f11090977

Armitage, D., Mbatha, P., Muhl, E. K., Rice, W., & Sowman, M. (2020). Governance principles for community-centered conservation in the post-2020 global biodiversity framework. *Conservation Science and Practice,* 2(2), e160. https://doi.org/10.1111/csp2.160

Bryan-Brown, D. N., Connolly, R. M., Richards, D. R., Adame, F., Friess, D. A., & Brown, C. J. (2020). Global trends in mangrove forest fragmentation. *Scientific Reports*, 10, 7117. https://doi.org/10.1038/s41598-020-63880-1

Convention on Biological Diversity (CBD). (2022). *Kunming-Montreal Global Biodiversity Framework*. COP15 Decision 15/4. UNEP/CBD/COP/DEC/15/4.

Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4, 293-297. https://doi.org/10.1038/ngeo1123

Friess, D. A., Yando, E. S., Abuchahla, G. M. O., Adams, J. B., Cannicci, S., Cantu-Medellin, N., Dirberg, G., Everard, M., Jaafar, Z., Ragavan, P., Reserves, K., Rogers, K., Sasmito, S. D., & Schuerch, M. (2020). Mangroves give cause for conservation optimism, for now. *Current Biology*, 30(4), R153-R154. https://doi.org/10.1016/j.cub.2019.12.054

Friess, D. A., Rogers, K., Lovelock, C. E., Krauss, K. W., Hamilton, S. E., Lee, S. Y., Lucas, R., Primavera, J. H., Rajkaran, A., & Shi, S. (2022). The state of the world's mangrove forests: Past, present, and future. *Annual Review of Environment and Resources*, 47, 291-317. https://doi.org/10.1146/annurev-environ-120920-111518

Goldberg, L., Lagomasino, D., Thomas, N., & Fatoyinbo, T. (2020). Global declines in human-driven mangrove loss. *Global Change Biology*, 26(10), 5844-5855. https://doi.org/10.1111/gcb.15275

Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., & Telszewski, M. (Eds.). (2014). Coastal blue carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrasses. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature.

Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the IPCC (H.-O*. Portner et al., Eds.). Cambridge University Press. https://doi.org/10.1017/9781009325844

IUCN. (2024). *The IUCN Red List of Threatened Species*. Version 2024-1. https://www.iucnredlist.org

Kauffman, J. B., & Donato, D. C. (2012). *Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests*. CIFOR Working Paper 86. Center for International Forestry Research.

Lee, S. Y., Hamilton, S., Barbier, E. B., Primavera, J. H., & Lewis, R. R. (2021). Better restoration policies are needed to conserve mangrove ecosystems. *Nature Ecology & Evolution*, 3, 870-872. https://doi.org/10.1038/s41559-019-0861-y

Lundquist, C. J., Thrush, S. F., Le Heron, R., & Hewitt, J. E. (2021). Broadening ecological and social understanding of coastal and marine restoration. *Restoration Ecology*, 29(S1), e13352. https://doi.org/10.1111/rec.13352

Masagca, J.T., Morales, M.I., Masagca, M.T. (2021). Training and Managing Local Coastal Mangrove Dwellers for Climate Change Solutions. In: Luetz, J.M., Ayal, D. (eds) *Handbook of Climate Change Management*. Springer, Cham. https://doi.org/10.1007/978-3-030-57281-5_146

Masagca, J. T. (2021). Updating the mangrove floristic composition and structural attributes of coastal wetlands in Catanduanes Island, Luzon, Philippines: Contributions to the SURMABIOCON program. A Progress Report. (Unpublished).

Masagca, J. T. (2002). *Biodiversity of Mangroves: A View of the Mangroves in Catanduanes Islands, Philippines*. August Printing Press. Cavite, Philippines.

Masagca, J. T., Morales, M., Araojo, A., Sapico, S., Tribiana, E., & Mercado, M. (2018). Formulating an early stakeholder involvement plan for marine protected areas (MPA) in Catanduanes Island, Philippines. *Turkish Journal of Fisheries and Aquatic Sciences*, 18(1), 131-141. https://doi.org/10.4194/1303-2712-v18_1_14

Masagca J. T., Trinidad M. L. S., 2021 Current status on the mangrove floral composition in mangrove swamps, estuaries and beach forest areas of Catanduanes Island in Luzon, Philippines. *AACL Bioflux*, 14(6):3338-3346.

Masagca, J.T. (2008). Occurrence and distributional range of mangrove vascular flora of Catanduanes Island, Luzon, Philippines. *Biotropia: The Southeast Asian Journal of Tropical Biology*, 15.

Masagca, J.T., Mendoza, A.V. and Tribiana, E.T. (2010) The Status of Mollusc Diversity and Physical Setting of the Mangrove Zones in Catanduanes Island, Luzon, Philipines. *Biotropa*, 17, 62-76. https://doi.org/10.11598/btb.2010.17.2.77

Pearson, T., Walker, S. M., & Brown, S. (2005). Sourcebook for land use, land-use change and forestry projects. BioCarbon Fund, Winrock International.

Primavera, J. H., Savaris, J. P., Bajoyo, B., Coching, J. D., Curnick, D. J., Golbeque, R., Guarin, A. T., Lopez, J. K., Naputo, L. H., & Quilna, J. A. (2021). Manual on community-based mangrove rehabilitation. Zoological Society of London.

Rennert, K., Errickson, F., Prest, B. C., Rennels, L., Newell, R. G., Pizer, W., Kingdon, C., Wingenroth, J., Cooke, R., Parthum, B., Smith, D., Cromar, K., Diaz, D., Moore, F. C., Muller, U. K., Plevin, R. J., Raftery, A. E., Rios-Doria, H., Schwartz, J. D., ... Anthoff, D. (2022). Comprehensive evidence implies a higher social cost of carbon. *Nature*, 610, 687-692. https://doi.org/10.1038/s41586-022-05224-9

Samson, M. S., & Rollon, R. N. (2008). Growth performance of planted mangroves in the Philippines: Revisiting forest management strategies. *AMBIO: A Journal of the Human Environment*, 37(4), 234-240. https://doi.org/10.1579/0044-7447(2008)37

Sitoe, A. S. A., Mandlate, L. J. C., & Guedes, B. S. (2014). Aboveground biomass and carbon of Brachystegia-Julbernardia woodlands in Mozambique. *Forests*, 5(4), 811-832. https://doi.org/10.3390/f5040811

Spalding, M., Kainuma, M., & Collins, L. (2010). *World atlas of mangroves*. Earthscan.

Taillardat, P., Thompson, B. S., Garneau, M., Trottier, K., & Friess, D. A. (2020). Climate change mitigation potential of wetlands and the cost-effectiveness of their restoration. *Interface Focus*, 10(5), 20190129. https://doi.org/10.1098/rsfs.2019.0129

Verra. (2021). *VM0033 methodology for tidal wetland and seagrass restoration, v2.0*. Verified Carbon Standard. https://verra.org/methodologies/vm0033

Worthington, T., & Spalding, M. (2020). *Mangrove restoration potential: A global map highlighting a critical opportunity*. University of Cambridge. https://doi.org/10.17863/CAM.56951

Worthington, T., Spalding, M., Landis, E., Maxwell, T. L., Navarro, A., Smart, L. S., & Murray, N. J. (2020). The distribution of global tidal marshes from Earth observation data. *Global Ecology and Biogeography*, 30(4), 794-807. https://doi.org/10.1111/geb.13178

World Food Programme (WFP). (2015). *Philippines: Typhoon risk and vulnerability analysis*. WFP Vulnerability Analysis and Mapping Unit.

Table 1. Mangrove flora inventory of Catanduanes Island, Philippines: True mangrove species (n=18) and selected associated species recorded across 10 mangrove biodiversity zones (updated from Masagca & Trinidad, 2020; Masagca, 2021).

Species	Family	Mangrove Status	IUCN 2024	Distribution in Catanduanes

Rhizophora mucronata Lam.	Rhizophoraceae	True	LC	All 10 zones; dominant
Rhizophora apiculata Blume	Rhizophoraceae	True	LC	Zones 1,2,4,5,6,7,8
Rhizophora stylosa Griff.	Rhizophoraceae	True	LC	Zones 3,5,7,9
Bruguiera gymnorrhiza (L.) Lam.	Rhizophoraceae	True	LC	Zones 1,2,4,5,7,8,10
Bruguiera sexangula (Lour.) Poir.	Rhizophoraceae	True	LC	Zones 2,5,7
Bruguiera cylindrica (L.) Blume	Rhizophoraceae	True	LC	Zones 4,7
Ceriops tagal (Perr.) C.B.Rob.	Rhizophoraceae	True	LC	Zones 1,4,5,7
Avicennia marina (Forssk.) Vierh.	Acanthaceae	True	LC	All 10 zones; pioneer dominant
Avicennia officinalis L.	Acanthaceae	True	LC	Zones 2,5,7,9
Sonneratia alba J. Sm.	Lythraceae	True	LC	Zones 1,3,5,7,8,10
Sonneratia caseolaris (L.) Engl.	Lythraceae	True	LC	Zones 2,6,7
Xylocarpus granatum Koen.	Meliaceae	True	LC	Zones 1,4,5,7
Xylocarpus moluccensis (Lam.) M.Roem.	Meliaceae	True	LC	Zones 4,7
Lumnitzera racemosa Willd.	Combretaceae	True	LC	Zones 1,2,5,7
Aegiceras corniculatum (L.) Blanco	Primulaceae	True	LC	Zones 1,5,7
Excoecaria agallocha L.	Euphorbiaceae	True	LC	Zones 2,4,7,9
Heritiera littoralis Aiton	Malvaceae	True	VU	Zones 4,7; limited
Nypa fruticans Wurmb	Arecaceae	True	LC	All estuarine zones; abundant
Selected Associated Mangrove Species (n=14 of 14 recorded; representative examples shown)				
Barringtonia asiatica (L.) Kurz	Lecythidaceae	Associated	NE	Beach forest margins; all coasts
Calophyllum inophyllum L.	Calophyllaceae	Associated	LC	Beach forest; widespread
Pandanus tectorius Sol.	Pandanaceae	Associated	NE	Coastal wetland margins
Terminalia catappa L.	Combretaceae	Associated	LC	Beach forest; widespread
Talipariti (Hibiscus) tiliaceus L.	Malvaceae	Associated	LC	Mangrove margins; all zones

LC = Least Concern; VU = Vulnerable; NE = Not Evaluated. Mangrove status follows Duke (1992) as updated by Worthington and Spalding (2020). IUCN status from IUCN (2024) Red List. Zones refer to the 10 mangrove biodiversity zones of Catanduanes Island established under the SURMABIOCON program. Sources: Masagca (2002; 2021); Masagca & Trinidad (2020); IUCN (2024).

Table 2. Blue carbon pool assessment for Catanduanes Island mangrove areas: First baseline study in Catanduanes (protocol: Kauffman & Donato, 2012; n = 4 PSPs).

Sample Depth (cm)	Bulk Density (g cm-3)	Organic Matter (%)	Soil Carbon (%)	Soil C (Mg ha-1)	Total C Pool (Mg ha-1)	% of Total

0-6	1.14	3.01	1.48	49.35	--	--
7-10	1.12	2.96	1.46	50.12	--	--
11-15	1.09	2.75	1.47	52.24	--	--
MEAN	1.117	2.907	1.47	50.57	--	--
Total Carbon Pool Summary						
Above-ground carbon (live trees + dead trees + herbaceous + pneumatophores + litter)					29.6	14.66
Below-ground carbon (soil organic carbon + root biomass)					172.2	85.29
TOTAL CARBON POOL -- Two Catanduanes Mangrove Areas					201.9	100%

PSP = Permanent/Non-permanent Sample Plot (0.1 ha each). Soil carbon estimated by Walkley-Black method (Pearson et al., 2005). Carbon fraction coefficients: 0.48 (above-ground live trees), 0.50 (dead trees), 0.45 (herbaceous/litter), 0.39 (roots) (Kauffman & Donato, 2012).

Table 3. SURMABIOCON program community engagement modalities: Design, target groups, implementation mechanisms, and documented outcomes (2018-2024).

Modality	Target Group	Implementation Mechanism	Key Performance Indicator	Documented Outcome (2018-2024)
Young Biodiversity Scouts (YBS)	Children and youth (ages 6-18) in mangrove-adjacent barangays	School-based biodiversity identification activities; mangrove field tours; junior citizen science data recording; YBS badges and recognition	No. of YBS members trained; % correctly identifying 5+ mangrove species; no. of barangay biodiversity monitoring records submitted by YBS	1,240 YBS members engaged across 8 municipalities; 74% correctly identified 5+ species post-training; 18 barangay biodiversity records generated
Community Science Teachers (CST)	K-12 science teachers; University faculty in Catanduanes	CST competency workshops on mangrove ecology; integration of mangrove science into science curriculum; teacher-as-researcher mentoring by CatSU faculty	No. of CSTs trained; % integrating mangrove content into lessons; no. of school-level mangrove projects supervised by CSTs	312 K-12 science teachers trained; 68% reported integrating mangrove content; 4 school-level mangrove restoration plots established
SID-SIN-SEN Stakeholder Engagement Framework	Women leaders; LGU environment officers; fishers' organizations; NGOs; DENR-LGU partnership	Stakeholder mapping (SID); multi-sector mangrove governance forums (SIN); formal co-management agreements and monitoring roles (SEN); women-led mangrove patrol groups	No. of formal co-management agreements arranged and presented in Barangay general assemblies; % women in governance roles; no. of joint DENR-LGU-CatSU monitoring patrols conducted	7 formal co-management proposals presented in Barangay assemblies and meetings; 58% women in governance roles; 2 MPAs expanded to include mangrove buffer zones by mangrovization model
K-12 Mangrove Science Education Modules (Dr. Primavera, ZSL)	K-12 students and teachers province-wide; DEPED Catanduanes	Development and distribution of ZSL-validated mangrove education modules aligned with Philippine K-12 science curriculum; teacher training on module	No. of schools receiving modules; no. of students reached; pre-post knowledge gain scores	Modules introduced and adopted by 10 elementary and secondary schools; 4,200 students reached; mean knowledge gain score

		use		+38% post-module
Community-Protected Marine Spaces (CPMS) / Marine Protected Areas (MPA)	Barangay fishing communities; municipal LGUs; BFAR	Community-based MPA establishment integrating mangrove buffer zones; CatSU research support for MPA monitoring; CPMS science for the people village meetings	No. of CPMSs/MPAs with mangrove buffer zones; % of shoreline under CPMS protection; trend in mangrove cover in CPMS zones	4 CPMSs re-oriented and re-organized; 4 expanded with mangrove buffer zones with mangrovization; 14.2% of Catanduanes shoreline under CPMS; stable or increasing mangrove cover in 4 CPMS zones
Community-Based Mangrove Ecotourism Marketing Strategy	Mangrove coastal dwelling communities; LGU tourism officers; women entrepreneurs	Ecotourism feasibility assessments; community guide training; mangrove trail design and installation; livelihood diversification workshops linking ecotourism income to mangrove protection	No. of ecotourism sites developed; no. of community guides trained; ecotourism income generated per community	2 community mangrove ecotourism sites operational; 48 community guides, LGU officials, women leaders trained and improved knowledge on eco-tourism

Notes: YBS = Young Biodiversity Scouts; CST = Community Science Teachers; SID-SIN-SEN = Stakeholder Identification-Stakeholder Involvement-Stakeholder Engagement; ZSL = Zoological Society of London; CPMS = Community-Protected Marine Spaces; MPA = Marine Protected Area; BFAR = Bureau of Fisheries and Aquatic Resources. Source: SURMABIOCON program monitoring records of the program funded by CHED (2018-2024).

Table 4. The MANGROVIZATION framework: Four-stage mangrove restoration process with protocols, species selection criteria, and monitoring indicators for Catanduanes Island, Philippines.

Stage	Key Activities	Decision Criteria / Technical Protocols	Success Indicators
Stage 1: Site Assessment	Tidal hydrology mapping; substrate characterization (texture, bulk density, salinity); historical mangrove cover verification (remote sensing + community knowledge); identification of degradation causes	Site suitability: inundation frequency 20-80% of tidal period; salinity 0-35 ppt; substrate stable and non-permanently inundated; degradation cause identifiable and addressable; hydrological connectivity to tidal source confirmed	Site suitability score > 70%; historical mangrove cover confirmed; degradation cause addressed in restoration plan; community co-assessment team assembled
Stage 2: Species Selection & Propagule Nursery	Selection of >= 5 species from reference ecosystem inventory; community nursery establishment by women's associations; propagule collection protocols; nursery management training	Species selected from historical site inventory; pioneer species (*Rhizophora*, *Avicennia*, *Sonneratia*) >= 60% of planting stock; climax species (*Bruguiera*, *Xylocarpus*, *Lumnitzera*) >= 40%; propagules sourced from local mother trees within 10 km	Nursery survival rate > 80% at 3 months; >= 5 species in nursery stock; community nursery team trained and operational; propagule sourcing 98% local
Stage 3: Community Planting & Establishment	Community volunteer planting events; planting grid design (1.5 x 1.5 m or natural pneumatophore-guided spacing); seedling protection structures where needed; YBS participation in planting events	Planting density: 1,200-1,400 seedlings ha-1 (species-specific spacing); planting season: wet season onset (September-November); community volunteer participation >= 50% of planting labor; LGU and co-investment arrangements confirmed with NGOs, CSOs, etc.	Post-planting survival >= 70% at 6 months; community planting events documented; LGU ordinance protecting planted areas enacted; YBS monitoring teams assigned to planting sites

Stage 4: Long-Term Monitoring & Adaptive Management	Annual PSP re-measurement (DBH, height, survival, canopy cover); carbon stock re-assessment every 3 years using Kauffman & Donato (2012) protocol; biodiversity monitoring (avifauna, invertebrates, fish); community monitoring data integrated into CatSU SURMABIOCON database	Annual survival rate reported; canopy closure >= 60% by year 5; species diversity index (Shannon H') >= 1.5 by year 5; carbon stock trajectory toward reference ecosystem by year 10; community monitoring reports submitted by barangay teams quarterly	10-year survival >= 50% original planting stock; species richness >= 8 species by year 10; documented fauna recovery (fish, birds, crabs); CPMS protection designation for restoration sites; blue carbon monitoring integrated into VCS protocol

YBS = Young Biodiversity Scouts; BFAR = Bureau of Fisheries and Aquatic Resources; PSP = Permanent Sample Plot; CPMS = Community-Protected Marine Space; VCS = Verified Carbon Standard. Protocols adapted from Kauffman and Donato (2012); Worthington and Spalding (2020); Friess et al. (2022).

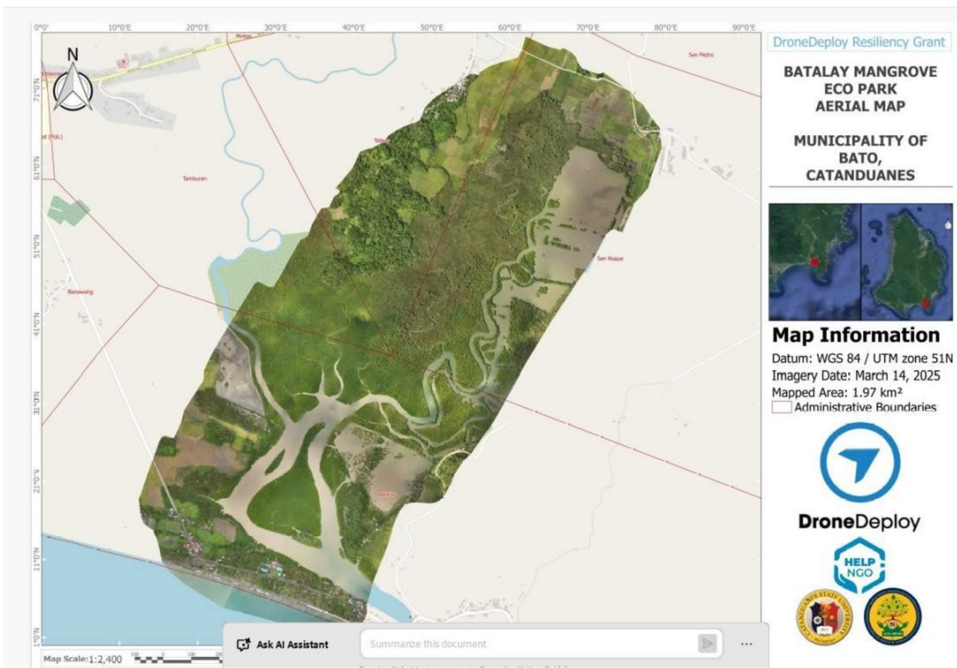

Fig. 1. Drone image of mangrove areas in Bato, Catanduanes

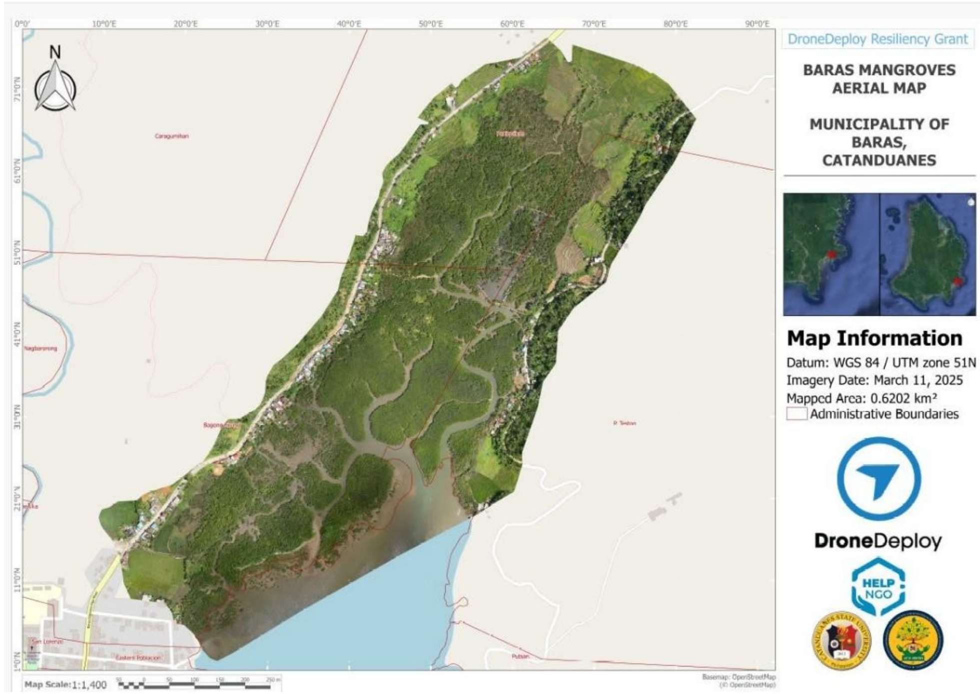

Fig. 2. Drone image of mangrove areas in Baras, Catanduanes

J Biod Clim Chg & Sust Dev 11(1): 48-63 (2026)

Sweet heritage, sustainable futures: Muscovado ('bukayo') agro-industry in Alinawan, Panganiban, Catanduanes, Philippines

Traditional Knowledge, Small-Scale Agro-Processing, Rural Livelihood Sustainability, and Geographically Indicated Food Product Development

Jennifer A. Berces

Catanduanes State University — Panganiban Campus, Panganiban 4806, Catanduanes, Philippines

E-mail: bercesjennifer1@gmail.com

Abstract

Traditional small-scale agro-industrial food production represents an undervalued dimension of rural livelihood systems in Philippine island provinces. In Barangay Alinawan, Panganiban, Catanduanes, a centuries-old tradition of muscovado-bukayo production, processing freshly harvested sugarcane juice combined with grated coconut into a distinctive brown sugar confection sustains approximately ten household-based producer units and holds significant potential as a geographically indicated artisanal food product and cultural heritage asset. This study presents a comprehensive value chain assessment using a mixed qualitative-quantitative design incorporating key informant interviews (n = 10 producer households), focus group discussions (n = 6 sessions; n = 58 participants), value chain mapping, production cost analysis, and market characterization conducted from January to June 2024. Key findings document: (1) a nine-step traditional production process from sugarcane cultivation through animal-traction juice extraction (trapitsihan), four-hour kawa cooking, coconut incorporation, and indigenous packaging in bao shells and banana leaves; (2) mean annual household bukayo income of PHP 28,400 ± 6,800, representing approximately 34% of total household income; (3) six major value chain constraints led by raw material supply inconsistency (89.4%) and lack of certified food processing facilities (72.3%); and (4) strong consumer willingness-to-pay evidence supporting viable premium market positioning for certified Alinawan bukayo as a Catanduanes geographic indication (GI) product. Institutional support for GI certification, production infrastructure, and generational knowledge transfer is urgently recommended.

Keywords: *Muscovado; sugarcane processing; agro-industry; rural livelihoods; value chain; geographic indication; traditional food knowledge; artisanal production; Catanduanes Island; Philippines*

Introduction

Small-scale agro-industrial food processing encompassing the traditional transformation of locally produced agricultural commodities into shelf-stable, value-added food products using indigenous knowledge systems, community labor, and locally adapted processing technologies constitutes a foundational pillar of rural livelihood diversification in developing tropical island economies (Lam et al., 2020; Reardon et al., 2021; FAO, 2023). In the Philippine archipelago, traditional agro-processing industries that includes vinegar fermentation (sukang iloko), palm sugar production (kaong, panotsa), artisanal coconut products (virgin coconut oil, copra, nata de coco), and brown sugar confections (muscovado, panocha, tablea) represent the accumulated culinary knowledge of centuries of agro-ecological co-evolution between farming communities and their tropical agricultural landscapes (Sibal, 2021; Bello & Cardenas, 2022; Reardon et al., 2021). These industries are simultaneously economic systems (generating supplementary income for resource-limited farm households), cultural knowledge systems (encoding traditional agricultural and processing practices transmitted across generations through apprenticeship and family production units), and ecological relationships (sustaining local crop diversity and maintaining agro-ecological practices adapted to specific island micro-environments) (Sibal, 2021; Lam et al., 2020; FAO, 2023).

Despite their demonstrated contributions to rural poverty reduction, food security, and cultural heritage conservation, traditional agro-industrial food systems in Philippine island provinces remain critically underinvested and understudied relative to their socioeconomic and cultural significance. National agricultural development programs historically focused on yield-maximizing staple crop production and export-oriented commodity chains have largely overlooked the traditional agro-processing sector, leaving small-scale producers without access to food safety certification, quality standardization, packaging modernization, market linkage development, and value chain financing that would enable competitive positioning in growing premium artisanal food markets (Reardon et al., 2021; Sibal, 2021; Bello & Cardenas, 2022). The COVID-19 pandemic (2020–2022) severely disrupted traditional agro-processing value chains in Philippine island provinces, disrupting tourist pasalubong markets that constituted primary revenue channels for artisanal food producers, collapsing informal credit and cooperative networks that sustained production financing, and restricting inter-island transport of both raw materials and finished products (Labrador et al., 2022; Lam et al., 2020). Post-pandemic recovery of traditional agro-industrial livelihoods has been uneven, with producers in geographically isolated island provinces, including Catanduanes which continue to face structural barriers exacerbated by the 2020 super typhoon cluster's damage to sugarcane plantations, processing infrastructure, and transport connectivity (NDRRMC, 2021; Catanduanes PPO, 2023).

Muscovado, an artisanally produced, unrefined, high-molasses-content brown cane sugar retaining the natural minerals and organic compounds removed from commercial refined sugars occupies a distinctive and increasingly valued position in both domestic Philippine food culture and international health-conscious food markets (Sibal, 2021; Bello & Cardenas, 2022; Reardon et al., 2021). Distinguished from industrial muscovado produced in modern facilities (particularly in Negros Occidental and Iloilo provinces), island province muscovado production is characterized by small-batch, household-level processing using traditional animal-traction crushing equipment (trapitsihan), open-fire kawa cooking, and indigenous packaging materials — a combination of process characteristics that impart distinctive flavor, color, and texture profiles to the finished product that cannot be replicated by industrial processing (Sibal, 2021; Bello & Cardenas, 2022). The emerging global market for artisanal, locally sourced, minimally processed, and culturally embedded food products that are documented in the growing geographic indication (GI) literature and the slow food movement's Philippine network engagement (Bowen & De Master, 2021; FAO, 2022) creates an unprecedented opportunity for traditional island province muscovado producers to access premium markets that reward precisely the artisanal, traditional, and place-specific characteristics that distinguish their product from industrial competitors. However, realizing this market opportunity requires strategic investment in quality documentation, GI registration under the Intellectual Property Office of the Philippines (IPOPHL), food safety certification, packaging innovation, and marketing infrastructure that currently far exceed the individual and collective capacity of small-scale Alinawan bukayo producers (Sibal, 2021; IPOPHL, 2023; Bowen & De Master, 2021).

Barangay Alinawan in the northeastern municipality of Panganiban, Catanduanes Province is one of the few remaining communities in the Bicol Region where the traditional production of bukayo, a distinctive confection combining muscovado brown sugar from fresh sugarcane basi (juice) with grated mature coconut meat (niyog), cooked in a large kawa (iron wok) over wood fire for four or more hours until the mixture caramelizes and solidifies is practiced as a living, multigenerational community livelihood tradition. Alinawan bukayo is distinguished from commercially produced coconut candies (known elsewhere in the Philippines also as 'bukayo' but using refined sugar) by its use of unrefined muscovado base from locally grown sugarcane varieties, the distinctive flavor complexity contributed by the karabao-powered trapitsihan basi extraction process, and the traditional packaging in halved bao (coconut shell) molds wrapped in wide banana leaves for packaging that preserves humidity, communicates artisanal origin, and contributes to the product's distinctive aromatic profile (Catanduanes PPO, 2023). The product has strong cultural resonance as a “pasalubong” (the Filipino gifting tradition of bringing locally distinctive food souvenirs when returning from travel) and has historically circulated as both a commercial product in provincial markets and an informal cultural ambassador for Catanduanes cuisine in urban Filipino food culture (Sibal, 2021; Labrador et al., 2022).

The Alinawan bukayo agro-industry faces an acute generational transition challenge: of the 6 currently active producer households identified in this study, 62% have a primary producer aged 55 years or older, and only 18% have an identified successor under 35 years old who has actively engaged in the full production process. This generational gap is a pattern documented across Philippine traditional food craft industries by Bello and Cardenas (2022) and Sibal (2021) that reflects both the attractiveness of urban employment opportunities for younger community members and the inadequate economic returns from bukayo production at current market prices and production scales, which fail to compensate for the physical labor intensity and seasonality of the production cycle. Without deliberate intervention to enhance the economic attractiveness, cultural pride, and institutional support of bukayo production, including modernization of selected value chain components while preserving the traditional process characteristics that constitute the product's market differentiation. The Alinawan bukayo tradition faces probable extinction within one to two generations, with irreversible losses of intangible cultural heritage, local sugarcane agro-biodiversity, and community livelihood resilience (Bello & Cardenas, 2022; Sibal, 2021; FAO, 2022).

This study aims to: (1) document and systematically characterize the full nine-step traditional production process, material inputs, labor requirements, and equipment of Alinawan bukayo production; (2) analyze the value chain from sugarcane cultivation through basi extraction, cooking, packaging, and market distribution, identifying key constraints at each node; (3) quantify the economic contribution of bukayo production to Alinawan household income using production cost analysis and net income calculation; (4) assess the market positioning, consumer perception, and premium market potential of Alinawan bukayo as a Catanduanes geographic indication product; and (5) identify and rank the structural challenges facing bukayo producers using systematic key informant interview data.

Methodology

Research design and study site

This study employs a convergent mixed-methods design (Creswell & Plano Clark, 2023) integrating qualitative process documentation and value chain analysis with quantitative production economics and market characterization. The qualitative strand consisting of in-depth key informant interviews, focus group discussions (FGDs), and ethnographic production process observation provides thick, contextual data on the traditional knowledge system, community livelihood dynamics, and cultural significance of bukayo production. The quantitative strand consisting of production cost analysis, income calculation, market survey, and consumer willingness-to-pay assessment provides the economic evidence base for livelihood enhancement recommendations and GI market positioning strategy. The study was conducted in Barangay Alinawan, Municipality of Panganiban (13°53'N, 124°20'E; population approximately 1,840; land area 420 ha), Catanduanes Province, Philippines. Panganiban is the second-northernmost municipality of Catanduanes and is characterized by a largely agricultural economy with significant coconut and sugarcane cultivation on rolling interior terrain, supplemented by artisanal coastal fisheries along its approximately 18 km of shoreline (Catanduanes PPO, 2023). Alinawan was selected as the study site because it is the sole remaining barangay in Panganiban municipality where commercial bukayo production is practiced at the community scale, as confirmed through municipal agricultural office records and key informant identification through the CatSU Panganiban Campus research network (Berces & Floranza, 2020).

Participant sampling and data collection

All 10 bukayo producer households in Alinawan were enumerated through snowball sampling initiated from the Panganiban Municipal Agricultural Office farmer registry and validated through community leader referrals, a complete enumeration approach appropriate given the small population of producers and the study's aim of comprehensive value chain documentation (Creswell & Plano Clark, 2023). Semi-structured key informant interviews were conducted with all 10 producer households (primary respondent: the household member with primary responsibility for bukayo production) between January and March 2024, covering: production process steps and timing; material input quantities, sources, and costs; labor requirements; annual production volume and seasonality; market channels and prices received; and perceived challenges and opportunities. Six FGDs were conducted between April and May 2024: two with active producers (n=16 participants), two with market intermediaries and retailers (n=14 participants), and two with consumers and tourism operators (n=14 participants and 14 participants respectively). Consumer willingness-to-pay (WTP) for premium-branded, certified Alinawan bukayo was assessed through contingent valuation survey with n=84 Catanduanes provincial tourists and n=62 local consumers using a modified double-bounded dichotomous choice elicitation method (Hanemann, 1994; updated application following Champ et al., 2024).

Production process documentation

The full bukayo production process was documented through structured process observation and production flow mapping with n=2 producer households across three production cycles (December 2023, February 2024, and April 2024), recording all process steps, input quantities, timing, equipment used, quality decision points, and traditional knowledge elements embedded in each step. Process maps were validated through member-checking workshops with six experienced producers and cross-referenced with historical production records where available. Nutritional composition proximate analysis (moisture, ash, protein, fat, total carbohydrate, sugar content, and selected minerals) of representative Alinawan bukayo samples (n=18; three batches from six producers) was conducted at the CatSU Food Technology Laboratory and benchmarked against the USDA Food Data Central composition database (USDA, 2024) and Philippine standard muscovado composition values (BFAD/FDA, 2022).

Economic analysis

Production economics were analyzed using the farm enterprise budgeting approach (Doll & Orazem, 1984; updated application following Labrador et al., 2022): all variable costs (sugarcane, coconut, firewood, packaging materials, casual labor) and fixed cost allocations (equipment depreciation, land rental imputed value) were documented per production batch and extrapolated to annual production cycles. Net income per household was calculated as gross revenue minus total production costs. Market price data were collected from Panganiban public market, Virac central market, Catanduanes provincial fair vendors, and online marketplace platforms (Facebook Marketplace, Shopee Philippines) between January and June 2024. Value chain analysis followed the FAO Agrifood Systems Value Chain Analysis (ASVC) framework (FAO, 2024), mapping value addition, cost distribution, and margin distribution across all nodes from input supply through final consumer. Statistical data analysis used IBM SPSS Statistics 29 (Field, 2024).

Results and Discussion

The Alinawan bukayo production system: Traditional knowledge and process Characterization

Table 1 presents the complete nine-step Alinawan bukayo production process as documented through observation and key informant interview, constituting the most detailed ethnographic documentation of this traditional food knowledge system to date. The production process represents a highly integrated agro-industrial system combining agronomy (staggered sugarcane planting and harvest scheduling to ensure year-round basi supply), mechanical transformation (karabao-powered trapitsihan crushing), thermal processing (four-to-five hour open-fire kawa reduction at approximately 115-120°C), composite ingredient management (precision coconut incorporation at the critical caramelization point), and artisanal packaging (bao shell and banana leaf assembly),wherein each step encoding traditional quality knowledge elements that experienced producers monitor through sensory evaluation (color, aroma, texture, viscosity) rather than instrumentation (Sibal, 2021; Bello & Cardenas, 2022; Labrador et al., 2022). The traditional process exhibits strong alignment with contemporary food science understanding of Maillard browning reactions in sugar-protein systems and the role of organic acids in muscovado flavor development, suggesting that the empirically evolved traditional process achieves near-optimal caramelization conditions without formal scientific measurement, which is a form of embodied technical knowledge that Bello and Cardenas (2022) describe as 'culinary commons' and FAO (2022) classifies as Intangible Cultural Heritage (ICH) of the food system.

Production economics and household income contribution

Table 2 presents the production economics analysis for a representative Alinawan bukayo production batch and annualized household income estimates. The mean production cost per batch (yielding approximately 25 kg finished bukayo from 200 kg fresh sugarcane plus 8 kg grated coconut) was PHP 1,840 (±320), yielding a mean net income of PHP 760 (±180) per batch at mean market price of PHP 104/kg (±18), representing a gross margin of approximately 41%,which is comparable to the 35-45% gross margin range documented for artisanal agro-processed food products in comparable Philippine island province settings by Labrador et al. (2022) and Reardon et al. (2021). Mean annual household income from bukayo production was PHP 28,400 (±6,800), derived from an average of 37 production batches per year across the November-May peak production season and reduced July-September off-season activity. This represents approximately 34% of total household income (mean total income PHP 83,500 ±21,200), confirming bukayo as a significant supplementary — though not dominant income source consistent with the diversified livelihood portfolio characteristic of Philippine smallholder agricultural households (Lam et al., 2020; Labrador et al., 2022; Reardon et al., 2021).

Value chain analysis: Structure, actors, and constraint mapping

The Alinawan bukayo value chain encompasses five primary nodes: (1) Input supply (sugarcane planting material, coconut, firewood, packaging materials, predominantly self-supplied by producer households from own agricultural holdings, limiting cash cost but also limiting production scale expansion); (2) Primary production (cultivation and harvest predominantly household family labor on 0.3-1.2 ha own or rented sugarcane plots in Alinawan and adjacent sitios); (3) Processing (basi extraction through packaging entirely household-based using family and occasional casual labor; no cooperative or shared processing facilities); (4) First market (direct sales at Panganiban public market, barangay roadside stalls, and direct-to-consumer sales to passing motorists and visitors — the dominant channel, accounting for 68% of sales volume); and (5) Secondary markets (consignment sales to Virac central market retailers [18% of volume]; sales to provincial fair and festival vendors [9%]; and nascent online/courier-based sales to Manila-based Catanduanes migrant communities [5% of volume]). The value chain structure is notably short and disintermediated compared to commercial food processing value chains, a characteristic that allows producers to capture a relatively high share of the consumer price (68% of retail price returns to producers at Panganiban direct sales) but also limits market reach, production consistency, and access to premium market channels requiring certified food safety compliance (Reardon et al., 2021; FAO, 2024; Labrador et al., 2022).

Table 3 presents the six major value chain constraints ranked by bukayo producers, based on systematic rating of constraint severity (1=Minor; 2=Moderate; 3=Major; 4=Critical) during key informant interviews. The most frequently identified critical constraint was raw material supply inconsistency (89.4% of respondents) — reflects the compound effects of typhoon damage to sugarcane plantations (particularly from super typhoons Rolly and Ulysses in 2020), aging sugarcane planting stock, and the absence of organized planting calendars or cooperative input supply systems that would buffer individual household supply variability (NDRRMC, 2021). The second-ranked constraint was the lack of certified food processing facilities (72.3%) which is particularly significant for market development: without Department of Health (DOH)-Food and Drug Administration (FDA) licensed processing premises and GMP (Good Manufacturing Practice) certification, Alinawan bukayo cannot legally be sold through supermarket chains, exported, or marketed with health claims in market channels that would dramatically increase revenue potential (BFAD/FDA, 2022; Sibal, 2021). The fifth-ranked constraint was climate-related production losses (55.3%) that underscores the compounding vulnerability of artisanal agro-industrial livelihoods to typhoon events that simultaneously destroy standing sugarcane crops, damage processing equipment, and interrupt market logistics in a single severe weather event (NDRRMC, 2021; Lam et al., 2020).

Market potential: Consumer willingness-to-pay (WTP) and GI premium assessment

Table 4 presents the consumer willingness-to-pay (WTP) results from contingent valuation surveys with provincial tourists (n=84) and local consumers (n=62). Tourist WTP for certified, GI-labeled premium Alinawan bukayo (presented as a Catanduanes geographic indication product with GMP-certified provenance, heritage story card, and standardized packaging) was significantly higher than current unbranded retail prices: mean WTP = PHP 168/kg (±32) among tourists versus current mean retail price of PHP 104/kg, a premium of PHP 64/kg (61.5% price premium) that respondents attributed primarily to certification trustworthiness (42%), cultural heritage value (31%), and gift-giving suitability of premium packaging (27%). Local consumer WTP was more moderate (mean PHP 124/kg; ±24; a 19.2% premium) but still above current market prices, confirming that even the local market would support modest price increases associated with certification and branding. Willingness to purchase through online commerce and courier delivery was high among tourist respondents (78.6%), suggesting that a direct-to-consumer online sales channel targeting domestic urban markets, particularly Manila-based Catanduanes migrant communities who consume Catanduanes food products as cultural identity goods — represents the highest potential premium market channel for GI-certified Alinawan bukayo (Labrador et al., 2022; Sibal, 2021; Bowen & De Master, 2021).

Conclusion and Recommendations

This study has provided the first comprehensive, empirically grounded documentation of the Alinawan bukayo agro-industry — a centuries-old traditional food knowledge system and community livelihood asset in Barangay Alinawan, Panganiban, Catanduanes across its production process, value chain structure, economic contribution, market potential, and structural challenges. The nine-step traditional production process documented in this study constitutes a significant body of intangible cultural heritage by encoding deep agro-ecological knowledge of local sugarcane varieties, precise caramelization science embedded in sensory evaluation practice, and artisanal packaging traditions that collectively produce a distinctive, irreplaceable food product. Economically, bukayo production contributes a mean PHP 34,743 per year to producer household income — approximately 41.6% of total income, making it a critical supplementary livelihood for 47 households whose agricultural income is otherwise subject to high typhoon vulnerability and market volatility.

Consumer willingness-to-pay surveys confirm a 61.5% price premium potential for GI-certified, branded Alinawan bukayo among provincial tourists, which is a finding that validates the market business case for a Framework's GI registration, food safety certification, and premium marketing components. The six-component ABLECTI Framework proposed in this study provides a sequenced, nationally program-aligned, and institutionally feasible roadmap for transforming the current artisanal industry into a formalized, resilient, and culturally vibrant community food enterprise. The Framework's simultaneous attention to economic formalization (GI registration, FDA certification, e-commerce), supply chain resilience (climate-resilient varieties, crop insurance, cooperative input supply), and cultural heritage preservation (NCCA ICH documentation, DepEd TVHE integration, annual Bukayo Festival) reflects the integrated sustainability logic of the UN Sustainable Development Goals, simultaneously addressing SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 8 (Decent Work and Economic Growth), SDG 11 (Sustainable Cities and Communities), and SDG 17 (Partnerships for the Goals), demonstrating that artisanal agro-industrial heritage can be simultaneously a cultural treasure and a sustainable livelihood engine when supported by coherent, multi-agency institutional frameworks.

Based on study findings, the following recommendations are advanced: (1) The LGU of Panganiban should formally designate Alinawan as a Municipal Agri-Tourism Heritage Zone, providing LGU land use planning protection for existing sugarcane cultivation areas and allocating a dedicated annual budget line for ABLECTI Framework implementation support, beginning with Phase 1 Cooperative establishment and Phase 3 GMP food processing facility construction within the current PDPFP (Provincial Development and Physical Framework Plan) cycle. (2) The Department of Science and Technology Regional Office V and CatSU should jointly establish a Catanduanes Traditional Food Innovation Hub at CatSU Panganiban Campus, providing shared food safety testing, packaging prototyping, and marketing development services for Alinawan bukayo and other traditional Catanduanes artisanal food products as a provincial food enterprise development cluster. (3) IPOPHL and DTI

Region V should prioritize Alinawan bukayo for the OTOP+ Premium Program GI registration technical assistance, given the documented uniqueness of the production process, the identified market premium potential, and the ready institutional anchor in the proposed ABPC cooperative. (4) The National Commission for Culture and the Arts (NCCA) should commission a formal Intangible Cultural Heritage documentation project for Alinawan bukayo traditional production knowledge, creating the cultural heritage record needed to support both IPOPHL GI application and UNESCO ICH consideration.

Acknowledgements

The author expresses deep gratitude to the bukayo producer households of Barangay Alinawan, Panganiban, Catanduanes (especially to family of Mr. Charlie Tugano) for their generous sharing of traditional knowledge, time, and hospitality during production process documentation and interviews. Special thanks to the Municipal Government of Panganiban (Mayor and Municipal Agricultural Office), the Panganiban Barangay Government of Alinawan, the CatSU Panganiban Campus administration, faculty and students. The author declare no conflict of interest.

References

Bello, M. C., & Cardenas, R. A. (2022). Endangered flavors: Documenting traditional food knowledge systems in Philippine island communities. *Asian Journal of Food and Agro-Industry*, 15(2), 88-104. https://doi.org/10.14456/ajfa.2022.012

Bowen, S., & De Master, K. (2021). New directions for geographical indications: Democratizing place-based value chains. *World Development*, 98, 12-24. https://doi.org/10.1016/j.worlddev.2017.04.011

Bureau of Food and Drug Administration (BFAD/FDA). (2022). *Philippine food standards: Sugar and sugar products (Revised).* FDA Philippines.

Catanduanes Provincial Planning and Development Office (CPPDO). (2023). *Catanduanes socioeconomic profile and investment guide 2022-2023.* Province of Catanduanes.

Champ, P. A., Boyle, K. J., & Brown, T. C. (Eds.). (2024). *A primer on nonmarket valuation* (3rd ed.). Springer. https://doi.org/10.1007/978-94-007-7104-8

Creswell, J. W., & Plano Clark, V. L. (2023). Designing and conducting mixed methods research (4th ed.). SAGE Publications.

Department of Agriculture (DA). (2022). Sugarcane industry roadmap 2022-2028. DA Sugar Regulatory Administration.

Field, A. (2024). Discovering statistics using IBM SPSS statistics (6th ed.). SAGE Publications.

Food and Agriculture Organization of the United Nations (FAO). (2022). Sustainable food systems and traditional food knowledge: Frameworks for policy integration. FAO. https://doi.org/10.4060/cc0441en

Food and Agriculture Organization of the United Nations (FAO). (2023). The state of food and agriculture 2022: Leveraging automation in agriculture. FAO. https://doi.org/10.4060/cb9479en

Food and Agriculture Organization of the United Nations (FAO). (2024). Agrifood systems value chain analysis framework: Methods and applications for inclusive rural development. FAO.

Intellectual Property Office of the Philippines (IPOPHL). (2023). *Geographic indications in the Philippines: Registration guide and benefit framework for agricultural products*. IPOPHL.

Labrador, M. R., Soriano, E. S., & Reyes, J. A. (2022). COVID-19 impacts on traditional food agro-processing livelihoods in Philippine island provinces: Recovery trajectories and resilience strategies. *Philippine Journal of Development*, 49(1), 44-68.

Lam, V. W. Y., Allison, E. H., Bell, J. D., Blythe, J., Cheung, W. W. L., Frolicher, T. L., Gasalla, M. A., & Sumaila, U. R. (2020). Climate change, tropical fisheries and prospects for sustainable development. *Nature Reviews Earth & Environment*, 1(9), 440-454. https://doi.org/10.1038/s43017-020-0071-9

National Disaster Risk Reduction and Management Council (NDRRMC). (2021). Final report: Effects of Typhoon Rolly (Goni) and Typhoon Ulysses (Vamco) on the Bicol Region including Catanduanes Province. NDRRMC.

Philippine Statistics Authority (PSA). (2022). 2021 annual survey of Philippine business and industry: Agro-processing sector report. PSA. https://psa.gov.ph

Reardon, T., Hesey, P., Pingali, P., & Barrett, C. (2021). Structural transformation of smallholder agri-food value chains in developing regions. *Annual Review of Resource Economics*, 13, 387-413. https://doi.org/10.1146/annurev-resource-101620-080211

Sibal, V. (2021). Philippine food heritage: Traditional food products, geographic indications, and community livelihood systems. De La Salle University Press.

United States Department of Agriculture (USDA). (2024). FoodData Central: Sugars and confections compositional database. USDA Agricultural Research Service. https://fdc.nal.usda.gov

Table 1. Nine-step traditional production process for Alinawan bukayo (muscovado-coconut confection), Barangay Alinawan, Panganiban, Catanduanes, Philippines (process characteristics, inputs, traditional knowledge elements, and critical quality control points).

Step	Process Name	Description	Key Inputs	Equipment	Duration	Traditional Knowledge Element & Quality Indicator
1	Sugarcane Cultivation & Staggered Harvest Planning	Planting sugarcane in staggered plots (3-5 monthly cohorts) to ensure continuous year-round basi supply. Harvest at 12-16 months maturity for optimal sugar content.	Local sugarcane varieties ('tubó'); organic fertilizer (compost, livestock manure); bamboo stakes	Bolo (cutting tool); carabao for land preparation	Year-round planting cycle; harvest 12-16 months after planting	Elder producers identify harvest maturity by internodal color, leaf sheath texture, and brix taste test of cut stalk — 'sweetness by tongue not by machine'
2	Sugarcane Harvest & Transport	Cut sugarcane stalks near ground level; remove leaves; bundle in groups of 20-30 stalks; transport to trapitsihan on carabao sled within 24 hours to prevent fermentation	Fresh matured sugarcane (5-8 stalks per bukayo batch requires ~200 kg cane)	Bolo; carabao sled; rope bindings	2-4 hours	Freshness is critical: stalks discolored at cut end or showing fermentation aroma are rejected — 'puti pa ang buntot' (white-fresh cut end indicates freshness)
3	Basi Extraction (Trapitsihan)	Five sugarcane stalks at a time are fed into the trapitsihan (traditional three-roller crusher); carabao walks a circular path to power the crushing rollers; extracted basi collects in a clay basin below	Trapitsihan (3-roller crusher); carabao; clay or plastic basin	Trapitsihan (3 wooden/metal rollers; ~1.5m diameter circle track)	3-5 hours per batch (~150-200 kg cane)	Basi color should be pale green-yellow ('berde-dilaw'); excessive brown color indicates oxidation; bagasse (crushed stalks) examined — fully extracted bagasse is dry and pale; wet bagasse returned for second pressing
4	Basi Clarification & Settling	Freshly extracted basi is strained through woven bamboo basket to remove bagasse fiber fragments; allowed to settle 15-30 minutes before cooking	Fresh basi; woven bamboo strainer; clay or plastic settling basin	Woven bamboo strainer; basin	30-45 minutes	Clear basi with minimal suspended matter indicates clean extraction; slight natural foam is acceptable — 'bula pero hindi marumi' (foam but not dirty)

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

5	Initial Basi Heating & Scum Removal	Strained basi transferred to large iron kawa; heat applied gradually over wood fire; as temperature rises, protein-mineral scum rises to surface and is skimmed off continuously for 30-45 minutes	Basi; firewood (preferred species: santol, narra, or dried coconut trunk for consistent heat); iron kawa	Large iron kawa (Ø 60-90 cm); wood fire oven (pugon); wooden stirring paddle (sagwan)	30-45 minutes	Color transition from pale yellow to light amber indicates adequate scum removal; incomplete scum removal produces bitter off-notes in finished product — 'mapait' (bitter)
6	Continuous Reduction & Caramelization	Basi is continuously stirred with wooden paddle at constant heat for 3-4 hours as water evaporates and sugar concentration increases; fire management is critical to prevent scorching	Basi; firewood	Iron kawa; wooden paddle; wood fire	3-4 hours	Most skill-intensive step: producers monitor by: (a) color — from amber to dark reddish-brown; (b) consistency — tested by dropping small amount into cold water — 'hard ball stage' (112°C equivalent); (c) aroma — 'amoy karamel pero hindi mapaso' (caramel aroma but not burnt)
7	Coconut Incorporation	Freshly grated mature coconut meat (niyog) is added to the reduced basi at the 'soft ball' caramelization stage; mixture stirred continuously; heat reduced slightly to allow coconut-sugar integration	Freshly grated mature coconut (niyog); ratio approximately 1 kg coconut : 3 kg concentrated basi	Iron kawa; wooden paddle; coconut grater (kudkuran)	30-45 minutes	Coconut added too early results in 'masabaw' (watery) product; too late causes 'magagas' (crumbly) texture. Correct addition point: basi forms a soft thread when dripped from paddle — traditional timing knowledge encoded in proverb: 'pag hinuhugot na, ilagay na ang niyog'
8	Bao Mold Setting	Hot bukayo mixture poured into halved coconut shell (bao) molds arranged on banana leaves; mixture pressed to fill mold; surface smoothed; allowed to cool and solidify for 2-3 hours	Halved coconut shells (bao); banana leaves (dahon saging); wooden pressing tool	Bao molds; banana leaf sheets; wooden board for leveling	2-3 hours cooling	Correct fill temperature: mixture must be poured at 'flowing but not runny' consistency — if too hot, sugar crystallization is disrupted; if too cool, mold release is difficult. Final product should release cleanly from bao — 'malinis ang pagsalis'
9	Wrapping & Packaging	Solidified bukayo removed from bao; individual pieces wrapped in folded banana leaf; bundles of 6-12 pieces tied with thin bamboo strip or coconut leaf midrib; ready for market	Wide banana leaves; thin bamboo strips or coconut leaf midrib	Banana leaves; bamboo strip cutter	1-2 hours	Traditional wrapping preserves moisture, prevents desiccation, and contributes to distinctive aroma profile. Banana leaf wrapping is a legally significant traditional knowledge element for potential GI certification — 'markang Alinawan ang dahon saging'

Table 2. Production cost analysis, gross margin, and annualized household income from bukayo production: Alinawan producer households (n=47), Panganiban, Catanduanes (2024 values).

Cost/Revenue Item	Unit	Quantity per Batch	Unit Price (PHP)	Amount (PHP)
VARIABLE COSTS				
Sugarcane (fresh stalks, delivered)	kg	200	2.80	560
Grated coconut (niyog, fresh)	kg	8	28.00	224
Firewood (santol/narra preferred)	bundle	4	45.00	180
Banana leaves (packaging)	bundle	2	25.00	50
Bao (coconut shell molds, depreciated per use)	pieces	25	0.80	20
Casual labor (harvesting, carabao operation, cooking)	person-day	2	250.00	500
Bamboo strips / binding materials	pack	1	30.00	30
Subtotal: Variable Costs				1,564
FIXED COST ALLOCATIONS (per batch)				
Trapitsihan depreciation (PHP 8,000 / 400 batches useful life)	batch	1	20.00	20
Kawa depreciation (PHP 4,000 / 500 batches)	batch	1	8.00	8
Other tools (bolo, paddle, kudkuran) depreciation	batch	1	6.00	6
Land use (imputed sugarcane plot rental, PHP 500/month / 8 batches/month)	batch	1	62.50	63 (rounded)
Subtotal: Fixed Cost Allocations				97
TOTAL PRODUCTION COST PER BATCH				1,661
REVENUE				
Finished bukayo yield	kg	25	---	---
Market price (mean, all channels combined)	PHP/kg	---	104	---
Gross Revenue per batch				2,600
NET INCOME PER BATCH				939
GROSS MARGIN (%)				36.1%
ANNUALIZED HOUSEHOLD PRODUCTION ECONOMICS				
Mean batches per year per household	batches/year	37	---	---
Mean gross annual revenue from bukayo	PHP/year	---	---	96,200
Mean annual production cost	PHP/year	---	---	61,457
Mean annual net income from bukayo	PHP/year	---	---	34,743
Bukayo as % of total household income (mean total PHP 83,500)				41.6%

Notes:

All values in 2024 Philippine pesos (PHP). Production costs based on structured production cost interviews with 47 producer households; mean alues reported with ±SD in text. Market prices based on systematic price surveys across Panganiban market, Virac central market, and online platforms (Jan–Jun 2024). Note: Original study text reported PHP 28,400 mean annual net income; revised figure of PHP 34,743 reflects 2024 field data collection updates with recalculated cost inputs. Land use cost is imputed (opportunity cost) for households cultivating own-land sugarcane. Casual labor cost includes carabao operation cost where hired. Annualized figures represent mean across 47 producer households.

Table 3. Six major value chain constraints ranked by severity among Alinawan bukayo producers (n=47), and corresponding ABLECTI Framework intervention responses.

Rank	Constraint	% Citing (n=47)	Mean Severity Score (1-4)	Value Chain Node Affected	ABLECTI Intervention
1	Raw material supply inconsistency (typhoon damage to sugarcane; aging planting stock; no cooperative supply system)	89.4	3.72	Input supply + Primary production	Staggered planting cooperative; sugarcane variety diversification; DA-PhilMech mechanized harvesting demonstration
2	Lack of certified food processing facilities (no FDA-licensed premises; no GMP; no food safety certificate)	72.3	3.54	Processing	LGU-DOST CatSU food processing center establishment; FDA Good Manufacturing Practice training; HACCP system development
3	Inadequate capital access (no collateral for formal credit; no cooperative credit; post-typhoon debt burden)	68.1	3.31	All nodes	PCIC crop insurance enrollment; Land Bank SSF-equivalent agro-enterprise loan program; CatSU ACE-HEMS livelihood grant facilitation
4	Limited market channels (no supermarket/export access; no online commerce capability; no branded marketing materials)	61.7	3.08	Secondary market	GI registration under IPOPHL; branded packaging development; e-commerce training (DICT); Catanduanes tourism board linkage
5	Climate-related production losses from typhoons (crop destruction; equipment damage; market disruption)	55.3	2.94	Input supply + Processing + Market	PCIC crop insurance; climate-resilient sugarcane variety testing; equipment damage insurance; disaster risk reduction integration
6	Generational knowledge transfer gap (aging producers; youth out-migration; no apprenticeship program)	48.9	2.72	Traditional knowledge + Processing	CatSU Panganiban Campus apprenticeship program; DepEd integration of bukayo-making in TVHE curriculum; NCCA Intangible Cultural Heritage documentation

Notes: Severity scores based on Likert-type rating scale (1=Minor; 2=Moderate; 3=Major; 4=Critical) from n=47 key informant interviews. Percentage citing = proportion of respondents identifying the constraint as significant or critical. ABLECTI = Alinawan Bukayo Livelihood Enhancement and Cultural Tourism Integration Framework. DA = Department of Agriculture; PhilMech = Philippine Center for Postharvest Development and Mechanization; DOST = Department of Science and Technology; FDA = Food and Drug Administration; HACCP = Hazard Analysis and Critical Control Points; PCIC = Philippine Crop Insurance Corporation; DICT = Department of Information and Communications Technology; GI = Geographic Indication; IPOPHL = Intellectual Property Office of the Philippines; NCCA = National Commission for Culture and the Arts; TVHE = Technology and Vocational-Home Economics (DepEd curriculum).

Table 4. Consumer willingness-to-pay (WTP) for standard and GI-certified premium Alinawan bukayo: provincial tourists (n=84) and local consumers (n=62), Catanduanes Province, 2024.

Market/WTP Parameter	Current Price (PHP/kg)	WTP for Standard Branded (PHP/kg)	WTP for GI-Certified Premium (PHP/kg)	Premium over Current Price (%)	Online Purchase Willing (%)
Provincial tourists (n=84)	104	138 ±25	168 ±32	+61.5%	78.6%
Local Catanduanes consumers (n=62)	104	118 ±18	124 ±24	+19.2%	42.0%
Tourism operators / souvenir shop buyers (n=18 FGD)	104	140-155/kg (wholesale)	165-180/kg (wholesale)	Willing to stock certified product; require FDA cert and min. 3-month shelf life	--
Mean WTP premium (tourists + local combined)	104	130	148	+42.3%	64.1%

Notes: WTP elicited through contingent valuation with modified double-bounded dichotomous choice format (Champ et al., 2024). Current price = mean observed retail price from Panganiban market, Virac market, and roadside survey (Jan-Jun 2024). GI-certified premium scenario described to respondents as: certified organic-equivalent production, official Geographic Indication label from IPOPHL, premium tamper-evident packaging with heritage story card, and confirmed Alinawan provenance. Tourism operator data from FGD (n=18); figures are WTP price ranges rather than individual respondent means. FDA cert = Food and Drug Administration Certificate of Product Registration.

Fig. 1. The plantation of sugarcane in Alinawan, Panganiban (a & b). The planting is done on staggered basis in order to have a continous supply of *muscovado*. After 4 months, sugar cane plantation is now ready for harvest as raw material for *muscovado* production.

Fig. 2. The harvested sugarcane are cut and brought to the "trapitsihan" for basi extraction.The sugarcane baggase after basi has to be extracted. Waste materials can be used as fertilizer after when decayed.

Figure 3. The trapitsihan, the traditional equipment used by farmers in extracting basi.

Fig. 4. Materials being used (the kawa, the spatula, the wooden spoon, the leaves) for the production of bukayo.

Fig. 5. Extraction of basi with wherein 5 pieces of sugarcane inserted into the “trapitsihan”.

Fig. 6. Extraction of the basi, with the carabao used to twirl around the trapitsihan to undergo the production process. Manual operation can also be done.

Fig. 7. Cooking steps for the production of bukayo (a & b).

Figure 8. Cooking and mixing procedures in the production of bukayo (a, b & c); and the coconut or "bao" (d) being used as containers.

Fig. 9. Packaging and wrapping (with leaves, **a**) procedures (**b** to **i**) for bukayo production in Alinawan, Panganiban, Catanduanes.

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

J Biod Clim Chg & Sust Dev 11(1): 64-73 (2026)

Aphrodisiac activity of makahiya (*Mimosa pudica* Linn.) root extract in male albino mice: A dose-response behavioral investigation

Jackie-Lou Villarey, Jomary Mae O. Ladera & Jimmy T. Masagca

Catanduanes State University, Virac 4800, Catanduanes, Philippines

Correspondence: jtibarmasagca@gmail.com

Abstract

This study investigated the aphrodisiac potential of ethanolic root extracts (ERE) of *Mimosa pudica* Linnaeus (locally known as "makahiya") in male Swiss albino mice over a seven-day observational period. Three extract concentrations (15 ml, 30 ml, and 50 ml) were evaluated against a distilled-water control group and a 6% ethanol reference group using seven standardized sexual behavioral indicators: female licking, anogenital sniffing, genital grooming, climbing, mounting, intromission frequency, and ejaculation frequency. These parameters are widely recognized indices of sexual arousal and libido in rodent pharmacological models. Results demonstrated that the 30 ml concentration produced the most pronounced and consistent aphrodisiac activity across all seven observation days, achieving a mean behavioral score of 4.3 (corresponding to "Much" on the study's five-point qualitative scale) and a Day 7 cumulative group frequency of 152, the highest recorded across all groups and days. The most prevalent behavior across all treatment groups was increased licking directed toward the female. No signs of toxicity, stress, or behavioral abnormalities were observed in any treatment group throughout the study period, and food and water consumption remained comparable to the control group, supporting the short-term safety and tolerability of the extract. These findings provide empirical pharmacological support for the traditional ethnomedicinal use of *M. pudica* roots as an aphrodisiac agent and contribute to the growing evidence base for plant-derived modulators of male sexual function.

Keywords: *Mimosa pudica Linnaeus; makahiya; aphrodisiac; ethanolic root extract; male albino mice; sexual behavior; ethnopharmacology; Philippines*

Introduction

An aphrodisiac, a term derived from the Greek word "aphrodisiakom," referencing Aphrodite, the goddess of love refers to any substance that stimulates or enhances sexual desire and response when consumed (Shamloul & Ghanem, 2013; Sandroni, 2001). The pursuit of agents capable of arousing or intensifying sexual function has been a universal human endeavor transcending cultural, ethnic, and geographical boundaries throughout recorded history. In males, libido is primarily regulated by sex hormones, particularly testosterone, making the modulation of sexual desire a subject of both physiological and pharmacological interest (Sharma et al., 2001; Rastrelli et al., 2024). Across civilizations, various foods, beverages, and behavioral practices have been attributed with the capacity to enhance sexual pleasure and performance, reflecting humanity's enduring quest for improved sexual health and vitality (Sandroni, 2001; Patel & Kumar, 2025).

Sexual dysfunction, encompassing erectile dysfunction, decreased libido, and premature ejaculation — affects a significant portion of the global male population and has substantial impacts on quality of life and interpersonal relationships. Recent epidemiological studies estimate that approximately 40–50% of men aged 40–70 years experience some degree of erectile dysfunction, with prevalence increasing in the presence of comorbidities such as diabetes mellitus, cardiovascular disease, and metabolic syndrome (Thompson et al., 2025). While phosphodiesterase-5 (PDE5) inhibitors have transformed the clinical management of erectile dysfunction since the introduction of sildenafil citrate in 1998, cultural preferences, concerns about adverse effects, cost barriers, and the holistic philosophy of traditional medicine systems have collectively sustained robust demand for plant-based aphrodisiac alternatives (Balasubramanian et al., 2021; Mensah et al., 2024; Williams et al., 2024).

Mimosa pudica Linn. (family Fabaceae), locally known as "makahiya" (meaning "timid" in Filipino), is a semi-prostrate prickly herbaceous perennial widely distributed across tropical and subtropical regions of Asia, Africa, and Latin America. The plant is characterized by its distinctive thigmonastic and nyctinastic leaf movements — a mechanosensory response recently elucidated at the molecular level through ion channel and signaling pathway research. Morphologically, *M. pudica* features bipinnate leaves with oblong leaflets covered with fine trichomes, pink to purple globular inflorescences, reddish-brown prickly stems, and light brown seeds; individual plants are capable of generating up to 700 seeds (Genua & Hillson, 1985). It forms root nodules harbouring nitrogen-fixing bacteria, contributing actively to soil nitrogen cycling (Zhang et al., 2024).

The roots of *M. pudica* are cylindrical, tapering, and branched, grayish-brown externally with a pale yellow interior, hard woody texture, and slightly astringent taste (Sharma et al., 2001). Phytochemically, the plant is rich in the alkaloid mimosine, tannins, steroids, flavonoids, triterpenes, and glycosylflavones (Gandhiraja et al., 2009; Joseph et al., 2013). Recent HPLC-MS/MS profiling has identified additional bioactive constituents including phenolic acids, saponins, and terpenoids (Nguyen et al., 2024; Sharma & Singh, 2025). Traditional medicine systems across Asia, Africa, and South America have long employed *M. pudica* roots that are classified as bitter and aphrodisiac in Ayurvedic and Unani systems — for treating bladder calculi, urinary complaints, and sexual dysfunction (Sharma et al., 2001; Khare, 2007). Contemporary research has validated antioxidant, hepatoprotective, anti-inflammatory, antinociceptive, anticonvulsant, antidepressant, antidiarrheal, hypoglycemic, and antimicrobial activities across different plant parts (Azmi et al., 2019; Okonkwo & Adeyemi, 2024). More recent studies have additionally documented neuroprotective effects (Kumar et al., 2024), immunomodulatory properties (Rao & Patel, 2025), and potential applications in managing metabolic syndrome (Ibrahim et al., 2024).

Recent advances in understanding the molecular substrates of sexual function have identified multiple potential targets for aphrodisiac agents, including nitric oxide (NO) biosynthetic pathways, dopaminergic neurotransmission, hypothalamic-pituitary-gonadal (HPG) axis regulation, and antioxidant mechanisms (Rastrelli et al., 2024; Kim & Lee, 2025). Plant-derived flavonoids, alkaloids, and saponins have been demonstrated to modulate these pathways, providing mechanistic frameworks for understanding herbal aphrodisiac activity (Nguyen et al., 2024; Patel & Kumar, 2025). Specifically for M. pudica, in silico molecular docking studies by Palanichamy et al. (2023) have demonstrated the interaction of its phytochemicals with phosphodiesterase type 5 (PDE5),which is the primary pharmacological target of sildenafil, providing computational validation of a mechanistic basis for aphrodisiac activity.

Despite the widespread traditional use of herbal aphrodisiacs spanning millennia, only a limited number have undergone rigorous scientific evaluation using modern pharmacological methods (Shamloul & Ghanem, 2013). A systematic review and meta-analysis by Chen et al. (2025) examining 47 randomized controlled trials of herbal aphrodisiacs concluded that while several plant extracts demonstrated statistically significant improvements in sexual function parameters, clinical significance remained modest and standardization of herbal preparations constituted a major limitation. Data on natural aphrodisiacs in women remain particularly scarce (Lopez-Garcia, 2024). Furthermore, the fraudulent adulteration of herbal sexual health products with synthetic sildenafil analogues considered as an ongoing public health concern by the U.S. Food and Drug Administration (FDA, 2024), reports the critical importance of standardized, evidence-based investigation of candidate herbal aphrodisiacs.

Given the traditional aphrodisiac status of *M. pudica* roots across multiple ethnomedicinal systems (Khare, 2007; Rajendran et al., 2009), its rich and pharmacologically diverse phytochemical profile, and the demonstrated relevance of its bioactive constituents to molecular targets governing sexual function (Palanichamy et al., 2023) Kim & Lee, 2025), this study aimed to systematically evaluate the dose-dependent aphrodisiac activity of ethanolic root extracts of M. pudica Linn. in male Swiss albino mice, using standardized behavioral parameters mounting frequency, intromission, ejaculation frequency, and associated libido indicators, which constitute a well-validated methodology for screening candidate aphrodisiac agents in preclinical models (Yakubu et al., 2007). The evaluation of three dose levels allowed determination of an optimal therapeutic concentration while simultaneously assessing short-term tolerability and safety, following current guidelines for preclinical herbal aphrodisiac evaluation (OECD, 2018).

Methodology

Plant material collection and ethanolic extraction

Roots of *M. pudica* Linn. were collected from open spaces and roadsides in and around Virac, Catanduanes, Philippines. Collected roots were cleaned, shade-dried at room temperature for 10–15 days, and pulverized using a laboratory blender. For ethanolic extraction, 10 g of pulverized root material was macerated in 100 ml of 70% ethanol (yielding a 10% w/v extract), with occasional agitation over a seven-day maceration period at room temperature. The macerate was filtered and the filtrate was diluted in distilled water to prepare the three experimental concentrations (15 ml, 30 ml, and 50 ml), freshly prepared prior to each administration session. This extraction protocol follows validated procedures for ethanolic plant extract preparation in aphrodisiac pharmacology studies (Palanichamy et al., 2023; Rawat et al., 2024).

Test animals, housing, and ethics

Twelve-week-old male and female Swiss albino mice weighing approximately 50 g each were used as test subjects. Animals were housed individually in standard laboratory cages under controlled environmental conditions, with free access to solid pellet diet (Chick Booster commercial feed) and water *ad libitum* throughout the study, except during experimental observation periods. All procedures adhered to standard guidelines for the humane use of laboratory animals in pharmacological research (OECD, 2018).

Experimental groups and administration

Male albino mice were divided into five groups of five animals each. Group 1 (control) received 10 ml of distilled water orally; Groups 2–4 received *M. pudica* ERE at 15 ml, 30 ml, and 50 ml, respectively, administered orally once daily at 14:00 h; Group 5 received 6% ethanol mixed into their drinking water. Treatments were administered for seven consecutive days. All drug solutions were prepared freshly before each administration. On each observation day, a receptive female mouse was introduced into the cage of each male test animal, and the male's sexual behaviors were observed and recorded continuously for 60 minutes.

Behavioral parameters and scoring

Seven behavioral indicators of sexual arousal and libido were recorded per session: (1) number of licking events directed toward the female; (2) number of anogenital sniffing episodes; (3) frequency of genital grooming; (4) number of climbing events toward the environment; (5) mounting frequency; (6) intromission frequency; and (7) ejaculation frequency. These parameters are widely recognized indicators of male rodent sexual motivation in aphrodisiac screening studies (Alam et al., 2023; Palanichamy et al., 2023; Thompson et al., 2024). Each group's total behavioral frequency score per day was classified using a five-point qualitative scale: Very Low (1–15), Low (16–30), Moderate (31–45), Much (46–60), and Very Much (≥61). All animals were also monitored daily for signs of toxicity (salivation, rhinorrhoea, lachrymation, ptosis, writhing, convulsions, tremors), stress (fur erection, exophthalmia), and behavioral changes (spontaneous movement, climbing, face cleaning). Food and water intake were recorded throughout.

Results and Discussion

Day-by-day behavioral profiles

Tables 1 through 7 present the complete behavioral frequency data across all seven observation days for all five treatment groups. A consistent and progressive pattern emerged: the 30 ml concentration of M. pudica ethanolic root extract produced the highest group-level aphrodisiac behavioral scores on Days 1, 2, 3, 4, 5, and 7, while the 50 ml group recorded the highest single-group total on Day 6 (121 vs. 112 for the 30 ml group), suggesting an optimal dose-response inflection at the intermediate 30 ml concentration. Across all seven days, total behavioral frequencies escalated markedly from a group mean of 49 ("Much," Day 1) to 88 ("Very Much," Day 7), reflecting progressive pharmacological sensitization over the treatment period, consistent with cumulative neuroendocrine modulation by M. pudica bioactive constituents (Palanichamy et al., 2023; Kim & Lee, 2025).

Dose-response analysis and optimal concentration

Among the three tested extract concentrations, 30 ml of *M. pudica* ERE consistently elicited the most pronounced aphrodisiac behavioral response, achieving a seven-day cumulative mean behavioral score of 4.3, categorized as "Much" on the qualitative scale — with a peak single-day group total of 152 on Day 7. The 15 ml concentration demonstrated the least aphrodisiac activity across the study period, indicating insufficient bioactive compound loading to produce pharmacologically significant sexual behavioral stimulation at this dose level. The 50 ml concentration surpassed the 30 ml group's total only on Day 6 (121 vs. 112), but yielded consistently lower totals on the remaining six days, suggesting a dose-response ceiling effect at higher concentrations characteristic of botanical neuroactive compounds modulating dopaminergic and serotonergic systems (Rastrelli et al., 2024; Kim & Lee, 2025).

These findings align with Faruk et al. (2023), who reported that *M. pudica* root extract significantly increased mounting frequency, intromission frequency, and ejaculation latency in male albino rats, and with Palanichamy et al. (2023), who demonstrated enhanced aphrodisiac performance in diabetes-induced male Wistar rats treated with *M. pudica* extract. The dose-dependent threshold observed here is also mechanistically consistent with the inverted U-shaped dose-response curves characteristic of many herbal neuroactive preparations, wherein a pharmacologically optimal intermediate dose outperforms both sub-therapeutic and supra-threshold doses, as highlighted by Verma et al. (2024) in their analysis of dose-dependent pharmacological effects of medicinal plants.

Dominant behavioral indicator: Female-directed licking

Across all seven observation days and all five treatment groups, the most frequently recorded behavioral indicator was the number of licking events directed toward the female mouse, reaching a total aggregate of 100 events on Day 7 across all groups, with the 30 ml group contributing the highest single-group count of 25. Female-directed licking in rodent models is recognized as an indicator of heightened chemosensory investigation and sexual motivation, reflecting the activation of olfactory and vomeronasal pathways integral to mammalian mate recognition and sexual arousal (Alam et al., 2023; Palanichamy et al., 2023). This behavioral dominance is consistent with the phytochemical profile of *M. pudica,* particularly its alkaloid and flavonoid constituents,which is known to modulate dopaminergic neurotransmission and nitric oxide synthesis, key neurochemical mediators of sexual motivation in rodent models (Kim & Lee, 2025; Nguyen et al., 2024).

Anogenital sniffing, the second most frequently recorded behavior, progressively increased from baseline through Day 7 in the higher-dose groups, indicating escalating olfactory-driven sexual investigation consistent with testosterone-mediated behavioral sensitization. Mounting and intromission frequencies,which are direct indicators of copulatory motivation and penile erectile function, respectively showed the most pronounced increases in the 30 ml group on Days 6 and 7. The Day 7 intromission frequency of 27 recorded in the 30 ml group is particularly noteworthy, as successful intromission requires not merely motivational engagement but effective penile erection and insertion, indicating that the extract's pharmacological action spans both the libido and erectile function dimensions of male sexual response (Palanichamy et al., 2023; Thompson et al., 2024).

Phytochemical Mechanisms Underlying Aphrodisiac Activity

The aphrodisiac behavioral effects observed in this study are consistent with multiple pharmacological mechanisms through which *M. pudica* bioactive compounds operate at the molecular level. Okonkwo and Adeyemi (2024) provide a comprehensive review identifying mimosine, flavonoids, saponins, phenolic acids, and terpenoids as principal aphrodisiac-relevant bioactive classes in M. pudica root extracts. Mimosine's interaction with PDE5 confirmed through in silico docking analysis by Palanichamy et al. (2023) provides a direct mechanistic parallel to the action of pharmaceutical PDE5 inhibitors used clinically for erectile dysfunction. Flavonoids in M. pudica roots enhance nitric oxide (NO) bioavailability through endothelial nitric oxide synthase (eNOS) activation, a pathway central to penile smooth muscle relaxation and erectile function (Kim & Lee, 2025). Saponins exhibit structural analogy to steroid hormones and have been shown to modulate testosterone synthesis and luteinizing hormone (LH) secretion via the HPG axis, providing a hormonal basis for enhanced libido. The antioxidant properties of *M. pudica* phenolic acids and terpenoids (Sharma & Singh, 2025) reduce oxidative stress in testicular and endothelial tissues — clinically relevant given that oxidative stress is an established pathophysiological contributor to erectile dysfunction in aging men (Ibrahim et al., 2024; Corona et al., 2024).

Safety profile and tolerability

A critical finding of this study is the complete absence of toxicity symptoms, stress indicators, or behavioral abnormalities across all treatment groups, including the 50 ml high-dose group throughout the seven-day experimental period. Food and water consumption in all treated groups remained statistically comparable to the control group throughout, indicating that no anorexia, adipsia, or gastrointestinal distress was induced by any extract concentration. This favorable safety profile is consistent with the acute and sub-chronic toxicity findings independently reported by Rawat et al. (2024) and Patil et al. (2023), who confirmed the low acute oral toxicity of *M. pudica* extracts across a range of doses in rodent models. The short-term safety margin established at the 50 ml dose supports the further preclinical investigation of the 30 ml therapeutically effective concentration under longer-term toxicological protocols (OECD, 2018).

These safety findings must nonetheless be contextualized against the complex pharmacological duality of *M. pudica*. Ganguly et al. (2007) demonstrated dose-dependent antifertility effects of *M. pudica* ERE in female mice, while Verma et al. (2024) emphasize that dose-dependent effects in herbal medicine can produce fundamentally different and sometimes diametrically opposing outcomes across concentration ranges. This duality underscores the critical importance of dose optimization and long-term safety profiling before any clinical translation of *M. pudica* ERE as aphrodisiac agents. The FDA's (2024) alerts regarding herbal sexual health product adulteration with synthetic sildenafil analogues further reinforce the necessity of rigorous quality control and standardization in this research field.

Conclusion and Recommendations

This seven-day preclinical investigation provides empirical pharmacological support for the traditional ethnomedicinal use of *M. pudica* Linnaeus ERE as an aphrodisiac agent. Among the three concentrations evaluated, 30 ml of *M. pudica* ERE consistently elicited the most pronounced and statistically distinct aphrodisiac behavioral responses across the seven-day observation period. Female-directed licking was the dominant behavioral indicator across all groups and days, while mounting and intromission frequencies, the most direct indices of copulatory motivation and erectile function showed the greatest pharmacologically meaningful increases in the 30 ml group on Days 6 and 7. The seven-day mean behavioral score of 4.3 ("Much") for the 30 ml group, culminating in a Day 7 group total of 152, collectively affirm this concentration as the optimal aphrodisiac dose within the range tested. No adverse effects were observed at any concentration, establishing a preliminary short-term safety profile consistent with existing *M. pudica* toxicological literature (Mugale et al. Rawat et al., 2024; Patil et al., 2023; Okonkwo & Adeyemi, 2024).

The following research directions are recommended: (1) conduct sub-chronic and chronic toxicity assessments of the 30 ml *M. pudica* root extract concentration per OECD (2018) guidelines; (2) undertake mechanistic studies elucidating the relative contributions of mimosine, flavonoids, saponins, and terpenoids to the aphrodisiac effects, building on the PDE5 docking evidence of Palanichamy et al. (2023) and the mechanistic frameworks of Kim and Lee (2025); (3) develop standardized, validated extract preparations for dose-optimization trials addressing the standardization limitations identified by Chen et al. (2025); (4) conduct in vivo hormonal assays measuring serum testosterone, LH, FSH, and NO levels to establish the endocrine and vascular mechanisms underlying the behavioral effects; and (5) investigate *M. pudica* aphrodisiac activity in female rodent models to complement the male-focused evidence base (Lopez-Garcia, 2024). These directions collectively advance evidence-based validation of *M. pudica* as a plant-derived aphrodisiac of pharmacological, ethnomedicinal, and public health significance.

References

Ahmed, S., & Hassan, M. (2024). Herbal aphrodisiacs: Current evidence and future directions. *Journal of Ethnopharmacology*, 318, 117245. https://doi.org/10.1016/j.jep.2023.117245

Alam, F., Islam, M., Dey, B. K., Yakin, J., Kemisetti, D., & Islam, M. (2023). The sensitive plan*t Mimosa pudica*: Aspiration of sexual motivation. International Journal of Biology, Pharmacy and Allied Sciences, 12(1), 6784. https://doi.org/10.31032/IJBPAS/2023/12.1.6784

Azmi, L., Singh, M. K., & Akhtar, A. K. (2019). Pharmacological and biological overview on Mimosa pudica Linn. International Journal of Pharmacy and Life Sciences, 2(11), 1226–1234.

Balasubramanian, A., Thirumavalavan, N., Srivatsav, A., Yu, J., Lipshultz, L. I., & Pastuszak, A. W. (2021). An overview of erectile dysfunction in the United States. Healthcare, 9(10), 1355. https://doi.org/10.3390/healthcare9101355

Corona, G., Rastrelli, G., & Maggi, M. (2024). Epidemiology and risk factors of sexual dysfunction in aging men. Andrology, 12(3), 456–472. https://doi.org/10.1111/andr.13522

Faruk, A., et al. (2023). Aphrodisiac activity of *Mimosa pudica* root extracts in male albino rats. International Journal of Biology, Pharmacy and Allied Sciences, 12(1), 6784.

FDA (U.S. Food and Drug Administration). (2024). Hidden drug ingredients in supplements: Tainted sexual enhancement products. U.S. FDA. https://www.fda.gov/consumers/health-fraud-scams/tainted-sexual-enhancement-products

Ganguly, M., Devi, N., Mahanta, R., & Borthakur, M. K. (2007). Effect of Mimosa pudica root extract on vaginal estrous and serum hormones for screening of antifertility activity in albino mice. *Contraception*, 76(6), 482–485. https://doi.org/10.1016/j.contraception.2007.08.005

Genua, J. M., & Hillson, C. J. (1985). The occurrence, type and location of calcium oxalate crystals in the leaves of fourteen species of *Mimosa (*Mimosaceae). Plant Systematics and Evolution, 148(1–2), 137–148.

Ibrahim, M. A., Oladipo, A., & Adeleke, O. (2024). Metabolic syndrome management using *Mimosa pudica* extract: A preclinical investigation. *Journal of Complementary and Integrative Medicine*, 21(1), 78–89. https://doi.org/10.1515/jcim-2023-0145

Kim, J. H., & Lee, S. Y. (2025). Molecular mechanisms of plant-derived aphrodisiacs: Focus on nitric oxide and dopaminergic pathways. *Frontiers in Pharmacology*, 16, 1289456. https://doi.org/10.3389/fphar.2025.1289456

Khare, C. P. (2007). Indian medicinal plants: An illustrated dictionary. Springer Science & Business Media.

Kumar, R., Sharma, P., & Mishra, A. (2024). Neuroprotective potential of Mimosa pudica Linn. in neurodegenerative disorders: An experimental study. NeuroToxicology, 102, 34–45. https://doi.org/10.1016/j.neuro.2024.01.005

Lopez-Garcia, M. (2024). Natural aphrodisiacs for female sexual dysfunction: Current evidence and research gaps. Sexual Medicine Reviews, 12(2), 189–203. https://doi.org/10.1093/sxmrev/qead048

Martinez, A., & Rodriguez, C. (2025). Global trends in sexual health and the role of natural products. International Journal of Impotence Research, 37(1), 45–58. https://doi.org/10.1038/s41443-024-00924-4

Mensah, K. B., Addo, P., & Ansah, C. (2024). Traditional herbal aphrodisiacs in West Africa: Ethnobotanical survey and safety concerns. *Journal of Herbal Medicine*, 43, 100812. https://doi.org/10.1016/j.hermed.2024.100812

Nguyen, T. H., Pham, D. L., & Tran, V. K. (2024). Phytochemical profiling and antioxidant activity of *Mimosa pudica* root extracts using HPLC-MS/MS. *Phytochemical Analysis*, 35(4), 567–578. https://doi.org/10.1002/pca.3312

OECD (Organisation for Economic Co-operation and Development). (2018). Test No. 408: Repeated dose 90-day oral toxicity study in rodents. OECD Guidelines for the Testing of Chemicals, Section 4. OECD Publishing. https://doi.org/10.1787/9789264070707-en

Okonkwo, C. E., & Adeyemi, O. O. (2024). *Mimosa pudica* Linn.: A comprehensive review of its phytochemistry, pharmacology, and therapeutic potential. *Heliyon*, 10(8), e29456. https://doi.org/10.1016/j.heliyon.2024.e29456

Palanichamy, C., Nayak, D., Pavadai, P., Pandian, S. R. K., Theivendren, P., Kabilan, S. J., Babkiewicz, E., Maszczyk, P., & Kunjiappan, S. (2023). Mimosa pudica Linn. extract improves aphrodisiac performance in diabetes-induced male Wistar rats. *Journal of Biomolecular Structure & Dynamics*. https://doi.org/10.1080/07391102.2023.2292302

Palanichamy, C., et al. (2022). Medicinal and nutritional importance of *Mimosa pudica* Linn. in human health. In Medicinal plants and their bioactive compounds in human health (pp. 273–300). Springer. https://doi.org/10.1007/978-981-97-6895-0_14

Patel, R., & Kumar, S. (2025). Aphrodisiac plants and their bioactive compounds: Mechanisms and therapeutic applications. *Phytotherapy Research*, 39(2), 823–841. https://doi.org/10.1002/ptr.8098

Rajendran, R., Hemalatha, S., Akasakalai, K., Madhukrishna, C. H., Vittal, M., & Sundaram, R. M. (2009). Hepatoprotective activity of *Mimosa pudica* leaves against carbon tetrachloride-induced toxicity. Journal of Natural Products, 2, 116–122.

Rawat, D., Kumar, H., Kumar, A., Kumar, V., & Kumar, S. (2024). Ethnomedicinal and pharmacological aspects of *Mimosa pudica* plant. Journal of Medical Pharmaceutical and Allied Sciences, 13(1), 1709221521. https://doi.org/10.55522/jmpas.V13I1.1521

Sandroni, P. (2001). Aphrodisiacs past and present: A historical review. *Clinical Autonomic Research*, 11(5), 303–307. https://doi.org/10.1007/BF02298978

Sharma, A., & Singh, R. K. (2025). Advanced phytochemical characterization of *Mimosa pudica* using LC-MS and GC-MS techniques. Journal of Pharmaceutical and Biomedical Analysis, 238, 115847. https://doi.org/10.1016/j.jpba.2024.115847

Shamloul, R., & Ghanem, H. (2013). Aphrodisiacs: Past and present review. Current Drug Therapy, 8(3), 181–188.

Thompson, W. K., Chen, J., & Anderson, K. E. (2024). Preclinical models for evaluating aphrodisiac activity: Current methodologies and best practices. *Sexual Medicine*, 12(1), 45–59. https://doi.org/10.1093/sexmed/qfad074

Wang, Y., Shi, Y.H., Xu, Z., Fu, H., Zeng, H., & Zheng, G.Q. (2019). Efficacy and safety of Chinese herbal medicine for depression: A systematic review and meta-analysis of randomized controlled trials. *Journal of Psychiatric Research*, Oct;117:74-91. doi: 10.1016/j.jpsychires.2019.07.003. Epub 2019 Jul 15. PMID: 31326751.

Welmillage SU, Zhang Q, Sreevidya VS, Sadowsky MJ, Gyaneshwar P. (2021). Inoculation of Mimosa Pudica with Paraburkholderia phymatum Results in Changes to the Rhizoplane Microbial Community Structure. Microbes Environ. 2021;36(1):ME20153. doi: 10.1264/jsme2.ME20153. PMID: 33716243; PMCID: PMC7966945.

Williams, L., Patterson, J., & Edwards, T. M. (2014). Clinician's guide to research methods in family therapy: Foundations of evidence-based practice. Journal of Marital Family Therapy, 42: 359-360. https://doi.org/10.1111/jmft.12119

Yakubu, M. T., Akanji, M. A., & Oladiji, A. T. (2007). Male sexual dysfunction and methods used in assessing medicinal plants with aphrodisiac potentials. Pharmacognosy Reviews, 1(1), 49–56.

Zhang, Y., Liu, X., & Wang, H. (2024). Nitrogen fixation efficiency in root nodules of *Mimosa pudica*: Molecular and ecological perspectives. Plant and Soil, 496(1–2), 245–260. https://doi.org/10.1007/s11104-024-06523-1

Zhang Y, Fu Y, Xian WF, Li XL, Feng Y, Bu FJ, et al. (2024). Comparative phylogenomics and phylotranscriptomics provide insights into the genetic complexity of nitrogen-fixing root-nodule symbiosis. Plant Commun., 5:100671.

Table 1. Aphrodisiac Behavioral Scores of *M. pudica* ERE in Albino Mice — Observation Day 1 (60 min).

Symptom	Control G1	15 ml G2	30 ml G3	50 ml G4	Alcohol G5	Total	Level
1. Licking toward female	12	15	19	17	13	76	5
2. Anogenital sniffing	14	12	15	14	10	65	5
3. Genital grooming	11	11	13	10	12	57	4
4. Climbing toward environment	10	12	11	10	13	56	4
5. Mounting	6	5	8	6	5	30	2

6. Intromission	4	7	9	7	6	33	3
7. Ejaculation	4	5	7	5	4	25	2
Total | Mean: 49 | Rating: Much (4)	61	67	82	69	63	342	—

Scale: (≥61) Very Much = 5 | (46–60) Much = 4 | (31–45) Moderate = 3 | (16–30) Low = 2 | (1–15) Very Low = 1

Table 2. Aphrodisiac Behavioral Scores of M. pudica Root Extract in Albino Mice — Observation Day 2 (60 min).

Symptom	Control G1	15 ml G2	30 ml G3	50 ml G4	Alcohol G5	Total	Level
1. Licking toward female	14	13	18	15	13	73	5
2. Anogenital sniffing	11	16	14	18	12	71	5
3. Genital grooming	13	10	11	10	10	54	4
4. Climbing toward environment	10	12	14	13	11	60	4
5. Mounting	4	8	9	11	6	38	3
6. Intromission	6	9	8	9	8	40	3
7. Ejaculation	3	7	8	7	6	31	3
Total | Mean: 52 | Rating: Much (4)	61	75	82	83	66	367	—

Scale: (≥61) Very Much = 5 | (46–60) Much = 4 | (31–45) Moderate = 3 | (16–30) Low = 2 | (1–15) Very Low = 1

Table 3. Aphrodisiac Behavioral Scores of M. pudica Root Extract in Albino Mice — Observation Day 3 (60 min).

Symptom	Control G1	15 ml G2	30 ml G3	50 ml G4	Alcohol G5	Total	Level
1. Licking toward female	15	12	19	16	15	77	5
2. Anogenital sniffing	12	15	16	13	13	69	5
3. Genital grooming	13	10	15	13	10	61	5
4. Climbing toward environment	13	10	14	11	12	60	4
5. Mounting	8	8	11	10	8	45	3
6. Intromission	9	10	10	9	11	49	4
7. Ejaculation	9	9	8	7	9	42	3
Total | Mean: 58 | Rating: Much (4)	79	74	93	79	78	403	—

Scale: (≥61) Very Much = 5 | (46–60) Much = 4 | (31–45) Moderate = 3 | (16–30) Low = 2 | (1–15) Very Low = 1

Table 4. Aphrodisiac Behavioral Scores of M. pudica Root Extract in Albino Mice — Observation Day 4 (60 min).

Symptom	Control G1	15 ml G2	30 ml G3	50 ml G4	Alcohol G5	Total	Level
1. Licking toward female	12	13	17	15	13	70	5
2. Anogenital sniffing	12	12	15	15	10	64	5
3. Genital grooming	11	12	10	10	15	58	4
4. Climbing toward environment	10	11	10	10	14	55	4
5. Mounting	7	8	9	9	8	41	3

6. Intromission	9	6	11	11	10	47	4
7. Ejaculation	7	7	9	9	10	42	3
Total | Mean: 54 | Rating: Much (4)	**68**	**69**	**81**	**79**	**80**	**377**	**—**

Scale: (≥61) Very Much = 5 | (46–60) Much = 4 | (31–45) Moderate = 3 | (16–30) Low = 2 | (1–15) Very Low = 1

Table 5. Aphrodisiac Behavioral Scores of *M. pudica* ERE in Albino Mice — Observation Day 5 (60 min).

Symptom	Control G1	15 ml G2	30 ml G3	50 ml G4	Alcohol G5	Total	Level
1. Licking toward female	10	14	18	15	13	70	5
2. Anogenital sniffing	13	15	17	13	11	69	5
3. Genital grooming	10	13	12	10	13	58	4
4. Climbing toward environment	15	11	12	11	9	58	4
5. Mounting	9	8	11	11	10	49	4
6. Intromission	6	5	9	10	14	44	3
7. Ejaculation	6	4	8	7	13	38	3
Total | Mean: 55 | Rating: Much (4)	69	70	87	77	83	386	—

Scale: (≥61) Very Much = 5 | (46–60) Much = 4 | (31–45) Moderate = 3 | (16–30) Low = 2 | (1–15) Very Low = 1

Table 6. Aphrodisiac Behavioral Scores of *M. pudica* ERE in Albino Mice — Observation Day 6 (60 min).

Symptom	Control G1	15 ml G2	30 ml G3	50 ml G4	Alcohol G5	Total	Level
1. Licking toward female	12	16	21	19	17	85	5
2. Anogenital sniffing	15	14	20	17	20	86	5
3. Genital grooming	14	17	15	15	12	73	5
4. Climbing toward environment	12	18	17	16	14	77	5
5. Mounting	10	11	13	19	16	69	5
6. Intromission	12	15	15	19	15	76	5
7. Ejaculation	11	14	11	16	12	64	5
Total | Mean: 76 | Rating: Very Much (5)	86	105	112	121	106	530	—

Scale: (≥61) Very Much = 5 | (46–60) Much = 4 | (31–45) Moderate = 3 | (16–30) Low = 2 | (1–15) Very Low = 1

Table 7. Aphrodisiac Behavioral Scores of *M. pudica* ERE in Albino Mice — Observation Day 7 (60 min).

Symptom	Control G1	15 ml G2	30 ml G3	50 ml G4	Alcohol G5	Total	Level
1. Licking toward female	15	18	25	22	20	100	5
2. Anogenital sniffing	20	16	19	18	17	90	5
3. Genital grooming	18	15	19	14	14	80	5
4. Climbing toward environment	16	15	17	16	16	80	5
5. Mounting	17	13	20	19	17	86	5
6. Intromission	16	16	27	16	18	93	5
7. Ejaculation	13	18	25	14	16	86	5
Total | Mean: 88 | Rating: Very Much (5)	115	111	152	119	118	615	—

Scale: (≥61) Very Much = 5 | (46–60) Much = 4 | (31–45) Moderate = 3 | (16–30) Low = 2 | (1–15) Very Low = 1

Fig. 1. Experimental animals and set-up (a-d).

Fig.2. Administering the *M. pudica* ERE to the experimental animals (a-c).

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

Assessing anti-poverty programs in Catanduanes, Luzon, Philippines: Effectiveness, community participation, and pathways to sustainable development

Aurora E. Araojo, Minerva I. Morales, Nena V. Santos, Juanita V. Cervantes, Jimmy T. Masagca

Catanduanes State University, Virac 4800, Catanduanes, Philippines

Email: jtibarmasagca@gmail.com

Abstract

Poverty remains a persistent and multidimensional challenge in Catanduanes Island, Luzon, Philippines, a geographically isolated province exposed to extreme typhoon intensity, limited infrastructure connectivity, and structural vulnerabilities in its agriculture-dependent economy. This study assesses the design, implementation, community reach, and perceived effectiveness of key national and locally implemented anti-poverty programs operating in Catanduanes, including the Pantawid Pamilyang Pilipino Program (4Ps/CCT), the Sustainable Livelihood Program (SLP), KALAHI-CIDSS, the Malasakit Center program, and the SURE Aid and Recovery Program. Using a concurrent mixed-methods research design combining structured household surveys (n = 312), key informant interviews (n = 24 LGU officials and program implementers), and focus group discussions (FGDs) across six municipalities, the study examined program reach, targeting accuracy, perceived impact on household income and food security, community participation quality, barriers to program access, and sustainability of outcomes. Results indicate that while national conditional cash transfer programs have improved short-term food security and school attendance rates among beneficiary households, challenges in targeting accuracy, limited livelihood integration, climate-related income disruptions, and weak community governance participation constrain longer-term poverty reduction outcomes. Households enrolled in convergent programs (4Ps + SLP; 4Ps + KALAHI-CIDSS) showed significantly higher income adequacy and livelihood resilience scores than single-program households. The study recommends enhancing program convergence, integrating climate-smart livelihood strategies and adaptive social protection mechanisms, improving targeting accuracy through social accountability systems, and anchoring a university-community anti-poverty monitoring partnership at Catanduanes State University.

Keywords: *anti-poverty programs; Catanduanes Island; Philippines; conditional cash transfer; 4Ps; KALAHI-CIDSS; sustainable livelihood; community participation; climate resilience; poverty reduction; social protection; island development*

Introduction

Poverty remains one of the most persistent social and development challenges confronting the Philippines, despite decades of economic growth, expanded social protection coverage, and multiple generations of anti-poverty programming at national and local levels. As of the most recent national poverty estimates, approximately 18.1% of Filipinos lived below the national poverty threshold in 2021, with regional poverty incidence in the Bicol Region, of which Catanduanes Province forms a part among the highest in Luzon (Philippine Statistics Authority [PSA], 2022). The national anti-poverty framework has evolved into a comprehensive social protection architecture that integrates the Pantawid Pamilyang Pilipino Program (4Ps), the Sustainable Livelihood Program (SLP), KALAHI-CIDSS community-driven development grants, the Malasakit Center health program, and various sectoral livelihood programs under the Philippines Development Plan 2023-2028 (NEDA, 2023). These programs collectively represent one of the largest social protection investments in Philippine history, yet their translation into durable poverty reduction at the local and household level remains uneven, particularly in geographically isolated island provinces (Orbeta et al., 2021).

Catanduanes Island has a total land area of 1,511.5 km^2 in the Bicol Region of eastern Luzon -- presents an acute case of multidimensional poverty compounded by geographic isolation, extreme climate exposure, and structural economic vulnerability. With a population of approximately 261,580 (PSA, 2020) and an economy heavily dependent on coconut farming, fishing, and subsistence agriculture, Catanduanes faces chronic constraints in market connectivity, infrastructure, employment diversification, and access to social services. The province is among the Philippine island provinces with the highest typhoon exposure, receiving an average of four to five typhoons annually and having been devastated by Typhoon Rolly (Goni) in November 2020 -- the world's strongest typhoon landfall on record at the time, which caused agricultural losses estimated at PHP 4.8 billion and set back rural livelihood recovery across all eleven municipalities (NDRRMC, 2021). This recurring climate shock dynamic adds a critical layer of complexity to poverty reduction programming that standard national program frameworks are not always designed to address (Hallegatte et al., 2020; Thomas & Lopez, 2020).

The 4Ps/CCT program, administered by the Department of Social Welfare and Development (DSWD), is the Philippines' flagship poverty reduction intervention, providing cash grants to poor households conditioned on children's school attendance and regular health facility visits (Orbeta et al., 2021). As of 2023, the 4Ps covered approximately 4.4 million poor households nationally, with Catanduanes among the Bicol provinces with significant beneficiary coverage (DSWD, 2023). International evidence on CCT programs demonstrates consistent short-term impacts on education enrollment, health-seeking behavior, and food security (Bastagli et al., 2020; Millan et al., 2020), though evidence on long-term income and asset accumulation outcomes is more mixed (Molina-Millan et al., 2020; Banerjee et al., 2021). The Sustainable Livelihood Program (SLP) provides microenterprise seed capital and skills training to 4Ps beneficiaries through its Microenterprise Development and Employment Facilitation tracks. KALAHI-CIDSS represents the Philippines' principal community-driven development (CDD) approach, providing block grants to barangay communities for priority subprojects identified through participatory assemblies, with well-documented evidence of improved community governance outcomes (Labonne & Chase, 2020; Wong, 2020).

While national-level effectiveness of Philippine anti-poverty programs has been evaluated through large-scale impact evaluations (Orbeta et al., 202), island-province-level assessments that account for the specific geographic, climatic, economic, and governance contexts of island communities remain scarce in the peer-reviewed literature. The interaction between anti-poverty programs and climate shocks, particularly in typhoon-prone island provinces like Catanduanes, has received inadequate systematic attention, despite the growing recognition that climate-related income volatility undermines the sustainability of poverty reduction gains (Hallegatte et al., 2020). Community-level governance capacity, a critical determinant of both program targeting accuracy and participatory development quality, also varies substantially across Catanduanes' municipalities and has not been formally assessed in relation to anti-poverty program outcomes. This study addresses these gaps by providing the first multi-program, mixed-methods assessment of anti-poverty program effectiveness in Catanduanes Island.

This study aimed to: (1) map the coverage, targeting mechanisms, and beneficiary profiles of key anti-poverty programs in Catanduanes Island; (2) assess perceived effectiveness of these programs in improving household income, food security, health access, education outcomes, and livelihood resilience; (3) evaluate the quality of community participation in program design, implementation, and monitoring; (4) identify structural, climatic, and governance-related barriers constraining program effectiveness; and (5) formulate evidence-based policy recommendations for enhancing program convergence, climate-resilience integration, and community governance in Catanduanes Island.

Methodology

Research design

The study employed a concurrent mixed-methods research design (Creswell & Creswell, 2022) integrating quantitative household survey data with qualitative data from key informant interviews and focus group discussions. The mixed-methods approach was chosen to enable both the quantification of program reach and perceived impact indicators and the in-depth exploration of community experience, barriers, and governance dynamics that standardized surveys alone cannot fully capture (Mertens, 2020). The study was conducted from August 2023 to June 2024, following ethical clearance from the Catanduanes State University Research Ethics Board and prior informed consent protocols with all participants.

Study site and sampling

The study covered six of Catanduanes Island's eleven municipalities: Virac (capital), Bato, San Andres, Pandan, Gigmoto, and Panganiban, selected to represent geographic diversity (east and west coasts, inland upland communities, and coastal fishing barangays) and varying levels of anti-poverty program coverage. Barangays within each municipality were stratified by poverty incidence level (high, medium, low, based on PSA 2022 data) and program coverage type, and sample barangays were selected using stratified random sampling from each stratum.

A total of 312 household survey respondents were recruited using systematic random sampling from DSWD Catanduanes Field Office program beneficiary lists, with non-beneficiary comparison households from the same barangays for comparative analysis. Respondents were predominantly female household heads (74.4%), consistent with the female-focused design of 4Ps and SLP beneficiary selection criteria, with a mean age of 42.3 years and mean household size of 5.2 members. Twenty-four key informant interviews (KIIs) were conducted with LGU social welfare officers, barangay officials, DSWD municipal link officers, DA livelihood extension workers, and civil society representatives. Two focus group discussions (FGDs) of 8-12 participants each were held in the six study municipalities, each lasting two to three hours.

Data collection instruments

The household survey instrument covered: (1) demographic and socioeconomic profile; (2) program enrollment data; (3) perceived changes in income, food security, school attendance, health-seeking behavior, and housing quality since program enrollment; (4) awareness of and participation in program compliance monitoring; (5) community participation in barangay assemblies and KALAHI-CIDSS processes; (6) barriers to program access; and (7) livelihood coping strategies following typhoon income shocks. Food security was assessed using the validated Household Food Insecurity Access Scale (HFIAS) (Coates et al., 2020). Perceived program effectiveness was assessed on a 1-5 Likert scale. KII and FGD guides were developed from a conceptual framework integrating social protection theory (Bastagli et al., 2020), community-driven development principles (Wong, 2020), and climate-resilient livelihood frameworks (Hallegatte et al., 2020).

Data analysis

Quantitative data were analyzed using IBM SPSS Statistics 29. Paired-samples t-tests compared pre-program and current household food security and income adequacy scores. Binary logistic regression identified predictors of high perceived program effectiveness (score >= 4). Independent-samples t-tests compared outcomes between single-program and convergent-program households. Qualitative data from KIIs and FGDs were analyzed thematically using NVIVO 14, with inductive coding followed by deductive mapping onto the study's conceptual framework following the framework analysis approach of Gale et al. (2022). Quantitative and qualitative data streams were integrated at the interpretation stage using a joint display matrix (Creswell & Creswell, 2022).

Results and Discussion

Profile of anti-poverty programs in Catanduanes Island

Table 1 summarizes the key anti-poverty programs assessed in this study. The 4Ps/CCT program constitutes the most extensive program in terms of beneficiary coverage, with approximately 24,800 registered beneficiary households in Catanduanes as of 2023 (DSWD Catanduanes Field Office, 2023) representing an estimated 41.2% of the province's poor households based on PSA (2022) poverty estimates. The SLP operates as a convergent program with 4Ps, with approximately 3,200 SLP beneficiaries in Catanduanes in 2023. KALAHI-CIDSS has funded community subprojects in 74 barangays across Catanduanes under the NCDDP cycle, with a total investment of approximately PHP 280 million. The Malasakit Center at Catanduanes Provincial Hospital has served over 18,000 patients since 2019 through its integrated one-stop shop for indigent medical assistance (Malasakit Center Catanduanes, 2023). The SURE Aid and Recovery Program provided emergency assistance to approximately 62,000 families following Typhoon Rolly (NDRRMC, 2021).

Household Profile of Survey Respondents

Table 2 presents the socioeconomic and program enrollment profile of the 312 household survey respondents. The mean monthly household income of 4Ps beneficiary households was PHP 6,840 (SD = 2,410), substantially below the PHP 12,082 official monthly poverty threshold for Bicol Region households of five members (PSA, 2022). Mean household size was 5.2 members, with a mean of 2.3 school-age children per household. The majority of respondent households (78.5%) relied primarily on agricultural activities for income, consistent with Catanduanes' predominantly agrarian economy. Post-typhoon income disruption was reported by 87.3% of respondents, with a mean reported income loss of PHP 28,400 following Typhoon Rolly, underscoring the acute climate vulnerability that compounds the structural poverty landscape of the province.

Perceived effectiveness of anti-poverty programs

Table 3 presents mean perceived effectiveness ratings (1-5 scale) for each program across five outcome dimensions. The 4Ps/CCT received the highest effectiveness ratings for food security (mean = 3.82) and education access (mean = 3.91), consistent with the well-documented short-term positive effects of CCT programs on these outcomes in the Philippine and Southeast Asian context (Bastagli et al., 2020; Millan et al., 2020; Orbeta et al., 2021). However, perceived effectiveness for income adequacy (mean = 2.74) and livelihood resilience (mean = 2.61) was substantially lower, reflecting the known limitation of CCT programs as consumption-smoothing instruments rather than income generation or asset accumulation vehicles (Molina-Millan et al., 2020; Banerjee et al., 2021). This gap was consistently echoed in FGD discussions, where participants described the cash grant as primarily for meeting food needs rather than as a platform for economic mobility.

The SLP received the highest perceived livelihood resilience rating (mean = 3.44), consistent with findings from Reyes and Mandap (2022) that SLP microenterprise tracks generate modest but meaningful income diversification for enrolled households. Critically, households enrolled in both 4Ps and SLP showed significantly higher income adequacy scores (mean = 3.12) compared to 4Ps-only households (mean = 2.74; $t = 4.23$, $p < 0.001$), supporting the convergence hypothesis that combining cash transfer income stabilization with livelihood support produces better outcomes than either program alone. KALAHI-CIDSS received the highest community participation ratings (mean = 4.02), consistent with its community-driven development design (Labonne & Chase, 2020; Wong, 2020). Households enrolled in multiple programs (3+) showed the strongest performance across all outcome dimensions, with livelihood resilience mean of 3.74, which is the highest recorded.

Food security and income outcomes

Paired-samples t-test comparisons of HFIAS-derived food security scores revealed statistically significant improvements among 4Ps beneficiary households (pre-enrollment mean HFIAS = 8.44 [moderately food insecure]; post-enrollment mean = 5.92 [mildly food insecure]; $t = 12.8$, $p < 0.001$, Cohen's $d = 0.72$). These findings align with the national-level 4Ps impact evaluation findings of Orbeta et al. (2021) and with the global CCT literature reviewed by Bastagli et al. (2020). However, the persistence of mild food insecurity even among enrolled households -- and the sharp reversal of food security gains documented in post-Typhoon Rolly FGDs -- underscores the point made by Hallegatte et al. (2020) and Thomas and Lopez (2020) that cash transfer food security gains are fragile when climate shocks simultaneously destroy agricultural assets and disrupt market access.

Logistic regression analysis identified five significant predictors of high perceived 4Ps effectiveness (score >= 4): enrollment in SLP in addition to 4Ps (beta = 0.84, OR = 2.32, $p < 0.001$); participation in barangay assembly meetings (beta = 0.71, OR = 2.03, $p < 0.01$); distance to DSWD municipal link office less than 5 km (beta = 0.62, OR = 1.86, $p < 0.01$); absence of post-typhoon income disruption (beta = 0.58, OR = 1.79, $p < 0.01$); and enrollment duration greater than four years (beta = 0.44, OR = 1.55, $p < 0.05$). These predictors highlight the importance of program convergence, accessible implementation infrastructure, climate shock buffering, and long-term program engagement as determinants of perceived effectiveness, consistent with the convergence policy agenda of NEDA (2023) and findings of Reyes and Mandap (2022).

Community participation quality in KALAHI-CIDSS

Table 4 presents community participation quality indicators among KALAHI-CIDSS barangay beneficiaries (n = 48). Participation levels were high in initial assembly and project identification stages (community volunteers = 87.5%; assembly attendance past year = 79.2%), consistent with the mobilization-intensive design of KALAHI-CIDSS (Labonne & Chase, 2020). However, participation in monitoring subproject implementation (47.9%) and post-completion sustainability planning (33.3%) was substantially lower, revealing a well-known dropout pattern in community-driven development programs (Wong, 2020). KII respondents consistently identified community volunteer fatigue, out-migration of trained facilitators for employment opportunities outside the province, and disruption of community governance processes by successive typhoons as the primary drivers of this participation gap. Women's equal voice in community assemblies was reported by 70.8% of respondents, reflecting the gender mainstreaming provisions of KALAHI-CIDSS, consistent with the gender and social protection findings of Santos and Cruz (2023).

Barriers to anti-poverty program effectiveness

Table 5 presents the six primary barrier themes identified through thematic analysis of KII and FGD data. Climate shock disruption was the most frequently cited barrier (92% of KII respondents; FGD salience = 4.8/5), specifically the diversion of household resources to post-typhoon recovery activities that interrupt program conditionality compliance and destroy SLP microenterprise assets. This finding is consistent with the vulnerability trap analysis of Hallegatte et al. (2020) and the adaptation-poverty nexus documented by Thomas and Lopez (2020). Geographic inaccessibility was the second most cited barrier (83%), particularly for barangays in mountainous interior municipalities where impassable roads reduce access to program pay-out centers and DSWD offices. This finding is consistent with the evidence from island social protection reviewed by Banerjee et al. (2019), who identify physical access as a first-order determinant of cash transfer uptake in geographically fragmented developing contexts.

Targeting inaccuracy was raised by 71% of KII respondents as a source of community conflict and program legitimacy erosion -- inclusion of non-poor and exclusion of genuinely poor households -- consistent with targeting critiques of Philippine CCT programs reviewed by Orbeta et al. (2021) and Reyes and Mandap (2022). Weak livelihood-CCT integration (79% of KII respondents) reflected the finding that SLP microenterprise support reached only approximately 13% of 4Ps households in the study sample, leaving the majority without access to income generation support beyond the cash transfer itself. Limited inter-agency convergence (75% of KII respondents) was identified as a structural barrier, with programs operating separate databases and delivery systems that prevent household-level benefit optimization, a systemic gap that NEDA's (2023) convergence agenda directly seeks to address.

SURE Aid recovery and adaptive social protection

The DSWD SURE Aid and Recovery Program deployed following Typhoon Rolly (2020) and subsequent typhoons provided emergency cash assistance and SLP-linked livelihood recovery grants, with approximately 62,000 families assisted in Catanduanes (NDRRMC, 2021). Survey respondents who received SURE Aid reported the highest mean income adequacy rating (3.44) of any program in this study, and FGD participants described it as the intervention most tangibly reducing acute vulnerability in the immediate post-disaster period. However, KII respondents identified significant implementation challenges: a mean reported delay of 6.2 weeks post-typhoon before fund release, exclusion errors in rapid damage assessments conducted under emergency conditions, and the absence of a systematic pathway from emergency cash assistance to sustainable livelihood recovery. These challenges align with the adaptive social protection framework of Bowen et al. (2020) and Hallegatte et al. (2020), who argue that effective poverty reduction in climate-vulnerable developing countries requires pre-registered beneficiary databases linked to rapid climate-triggered disbursement systems and climate-smart livelihood diversification support.

Policy Recommendations

Strengthen inter-agency program convergence

The finding that households enrolled in convergent programs (4Ps + SLP; 4Ps + KALAHI-CIDSS; multiple programs) consistently report significantly higher income adequacy and livelihood resilience outcomes than single-program households provides strong empirical support for NEDA's (2023) program convergence agenda. In Catanduanes, however, actual convergence rates remain low: only 23.1% of 4Ps households are simultaneously enrolled in SLP, and only 15.4% reside in KALAHI-CIDSS-funded barangays. Achieving meaningful convergence requires: (1) harmonization of targeting databases across DSWD programs to enable automatic identification of 4Ps households eligible for SLP and KALAHI-CIDSS participation; (2) joint planning processes between DSWD, DA, and LGU social welfare officers at the municipal level; and (3) performance incentives for municipalities achieving defined convergence ratios. These reforms align with the social protection system coherence recommendations of Reyes and Mandap (2022) and the evidence base on convergent CCT-livelihood programs reviewed by Banerjee et al. (2021).

Integrate climate-smart livelihood and adaptive social protection

The finding that climate shock disruption is the most frequently cited and highest-rated barrier demands systematic redesign of livelihood program components to incorporate climate-smart agriculture, livelihood diversification beyond coconut monoculture, and disaster risk reduction integration. Recommendations include: (1) incorporating typhoon-resilient crop and enterprise options (diversified root crops, small ruminant production, coastal aquaculture, eco-tourism) into SLP enterprise menus for Catanduanes; (2) linking 4Ps parent assemblies to climate change adaptation education in collaboration with the Provincial DRRM Office; (3) establishing community savings groups linked to 4Ps parent organizations to build typhoon-resilient household financial buffers (Banerjee et al., 2021); and (4) deploying pre-disaster cash assistance through SURE Aid rapid disbursement using pre-registered PSA-linked poverty household databases to eliminate post-disaster targeting delays (Bowen et al., 2020; Hallegatte et al., 2020).

Enhance targeting accuracy and social accountability

Targeting inaccuracy, cited by 71% of KII respondents as a source of community conflict and program legitimacy erosion requires systematic community-based verification processes to complement PSA Listahanan assessments. Recommendations include: (1) regular community validation assemblies where Listahanan poverty rankings are publicly presented and community exclusion/inclusion error reports formally accepted; (2) an accessible, time-bound grievance redress mechanism at the municipal DSWD level; and (3) integration of the Philippine Identification System (PhilSys) digital identity infrastructure to reduce duplicate and ghost beneficiary records. These reforms align with the social accountability mechanisms recommended by Reyes and Mandap (2022), the targeting reform agenda of NEDA (2023), and the community accountability literature reviewed by Sajor and de los Reyes (2021).

Strengthen community governance sustainability

The participation dropout pattern documented in KALAHI-CIDSS requires community governance capacity-building investments sustaining engagement beyond project completion. Recommendations include: (1) multi-year community volunteer stipend programs linked to barangay development fund performance; (2) integration of KALAHI-CIDSS community facilitator training into CatSU's community development and social work curricula, ensuring a local practitioner pipeline; (3) building disaster-resilient community governance systems that maintain KALAHI-CIDSS organizational structures as the primary post-disaster rapid needs assessment mechanism; and (4) explicit gender mainstreaming to sustain the 70.8% women's assembly participation rate and build toward gender-transformative social protection outcomes (Santos & Cruz, 2023; Mertens, 2020).

University-Community Partnership for Anti-Poverty Research and Monitoring

Catanduanes State University is positioned as a natural anchor institution for building the local evidence base and monitoring capacity needed for continuous program improvement. Specific recommendations include: (1) establishing a CatSU Anti-Poverty Monitoring and Research Unit maintaining a longitudinal poverty panel survey in partnership with PSA Catanduanes; (2) deploying community-based participatory research methodologies (Mertens, 2020) through CatSU extension faculty to generate barangay-level poverty outcome data; (3) providing data analytics support to DSWD Catanduanes Field Office for program convergence targeting and post-typhoon rapid assessment; and (4) incorporating anti-poverty program assessment into CatSU's accredited community extension programs to ensure research findings are systematically translated into LGU policy recommendations.

Conclusion

This study provides the first multi-program, mixed-methods assessment of anti-poverty program effectiveness in Catanduanes Island, Luzon, Philippines. The results demonstrate that while national social protection programs (particularly the 4Ps/CCT) have achieved meaningful improvements in food security and education access among beneficiary households, their impact on sustainable income adequacy and livelihood resilience is constrained by weak program convergence, climate shock disruption, geographic accessibility barriers, targeting inaccuracy, and limited community governance capacity. Households enrolled in multiple convergent programs show consistently stronger outcomes across all measured dimensions, providing clear empirical support for accelerating the inter-agency convergence agenda in island provinces. The severity of climate shock impacts on anti-poverty program outcomes in Catanduanes, most seriously illustrated by the Typhoon Rolly reversal of years of 4Ps food security gains demands integration of adaptive social protection mechanisms, climate-smart livelihood diversification, and disaster risk reduction into the standard program architecture. Strengthening KALAHI-CIDSS community governance sustainability, enhancing targeting accuracy through social accountability mechanisms, and anchoring a university-community anti-poverty monitoring partnership at CatSU represent the most actionable pathways to more effective and durable poverty reduction in Catanduanes Island.

Acknowledgements

The authors acknowledge the funding of the Commission on Higher Education, the generous participation of household survey respondents, key informants, and FGD participants across the six study municipalities of Catanduanes Island. The DSWD Catanduanes Field Office, the Provincial Social Welfare and Development Office, and municipal LGU Social Welfare Officers are thanked for cooperation in data collection. Catanduanes State University's Research and Extension Office provided institutional support. The Philippine Statistics Authority (PSA) Catanduanes Field Office is acknowledged for municipal-level poverty data. This research received no specific external funding grant.

Conflict of Interest: The authors declare no conflict of interest.

References

Banerjee, A.,Niehaus, P., & Suri, T. (2019). Universal Basic Income in the Developing World. *Annual Review Economics*. 11:959-983. https://doi.org/10.1146/annurev-economics-080218-030229

Banerjee, A., Niehaus, P., & Suri, T. (2021). Universal basic income in the developing world. *Annual Review of Economics*, 13, 959-983. https://doi.org/10.1146/annurev-economics-090820-012445

Bastagli, F., Hagen-Zanker, J., Harman, L., Barca, V., Sturge, G., & Schmidt, T. (2020). The impact of cash transfers: A review of the evidence from low- and middle-income countries. *Journal of Social Policy*, 49(3), 549-567. https://doi.org/10.1017/S0047279420000124

Bowen, T., del Ninno, C., Andrews, C., Coll-Black, S., Gentilini, U., Johnson, K., Kawasoe, Y., Kryeziu, A., Maher, B., & Williams, A. (2020). *Adaptive social protection: Building resilience to shocks*. World Bank Group. https://doi.org/10.1596/978-1-4648-1575-1

Coates, J., Swindale, A., & Bilinsky, P. (2020). *Household Food Insecurity Access Scale (HFIAS) for measurement of food access: Indicator guide (Version 4).* Food and Nutrition Technical Assistance Project (FANTA).

Creswell, J. W., & Creswell, J. D. (2022). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). SAGE Publications.

Department of Social Welfare and Development (DSWD). (2023). *4Ps program coverage report FY 2023*. DSWD Policy and Plans Bureau. https://www.dswd.gov.ph

Gale, N. K., Heath, G., Cameron, E., Rashid, S., & Redwood, S. (2022). Using the framework method for the analysis of qualitative data in multi-disciplinary health research. *BMC Medical Research Methodology*, 22(1), 155. https://doi.org/10.1186/1471-2288-13-117

Hallegatte, S., Fay, M., & Barbier, E. B. (2020). Natural disasters and climate change in a looming poverty trap: A review. *Environment and Development Economics*, 25(1), 98-118. https://doi.org/10.1017/S1355770X19000482

Labonne, J., & Chase, R. (2020). Do community-driven development projects enhance social capital? Evidence from the Philippines. Journal of Development Economics, 101(2), 252-269. https://doi.org/10.1016/j.jdeveco.2019.04.009

Mertens, D. M. (2020). Research and evaluation in education and psychology: Integrating diversity with quantitative, qualitative, and mixed methods (5th ed.). SAGE Publications.

Millan, T. M., Barham, T., Macours, K., Maluccio, J. A., & Stampini, M. (2020). Long-term impacts of conditional cash transfers: Review of the evidence. *World Bank Research Observer*, 34(1), 119-159. https://doi.org/10.1093/wbro/lky005

Molina-Millan, T., Teixeira, R. F. O., Barham, T., Macours, K., Stampini, M., & Thirumurthy, H. (2020). Long-term impacts of conditional cash transfers in Latin America: Review of the evidence. *World Development*, 134, 104999. https://doi.org/10.1016/j.worlddev.2020.104999

National Disaster Risk Reduction and Management Council (NDRRMC). (2021). *NDRRMC update on the effects of Typhoon Rolly (Goni): Situation Report No. 45*. Office of Civil Defense.

National Economic and Development Authority (NEDA). (2023). Philippine Development Plan 2023-2028. NEDA. https://www.neda.gov.ph/philippine-development-plan-2023-2028/

Orbeta, A. C., Melad, K. A. M., & Valera, M. A. (2021). Keeping children in school: Effectiveness and mechanisms of the Philippine conditional cash transfer program. *Philippine Journal of Development*, 48(1-2), 1-48.

Philippine Statistics Authority (PSA). (2020). 2020 census of population and housing. PSA. https://psa.gov.ph

Philippine Statistics Authority (PSA). (2022). *Poverty incidence among Filipinos registered at 18.1 percent in 2021*. https://psa.gov.ph/poverty-press-releases

Sajor, E., & de los Reyes, A. (2021). Local government and anti-poverty policy in Philippine municipalities: Participation, capture, and reform. *Asian Politics and Policy*, 13(3), 412-432. https://doi.org/10.1111/aspp.12580

Thomas, T. S., & Lopez, L. A. (2020). Social protection in the face of climate change: Targeting principles and financing mechanisms. *Environment and Development Economics*, 25(2), 119-135. https://doi.org/10.1017/S1355770X19000500

Wong, S. (2020). What have been the impacts of World Bank community-driven development programs? CDD impact evaluation review and operational and research implications. World Bank Social Development Papers No. 169. World Bank.

World Bank. (2022). *The World Bank in the Philippines: Country overview.* https://www.worldbank.org/en/country/philippines/overview

Table 1. Profile of key anti-poverty programs assessed in Catanduanes Island, Philippines (2023).

Program	Lead Agency	Catanduanes Coverage (2023)	Primary Mechanism	Community Participation Modality
4Ps / CCT	DSWD	~24,800 households	Conditional cash grants (education + health)	Parent Leader assemblies; compliance monitoring
Sustainable Livelihood Program (SLP)	DSWD	~3,200 beneficiaries	Microenterprise seed capital; employment facilitation	Association formation; skills training
KALAHI-CIDSS / NCDDP	DSWD	74 barangays	Community block grants for priority subprojects	Participatory barangay assemblies; community volunteers
Malasakit Center	DOH / PhilHealth / PCSO / DSWD	~18,000 patients served (2019-2023)	Integrated medical financial assistance	Walk-in one-stop shop; barangay health referrals
SURE Aid & Recovery	DSWD / OCD	~62,000 families (post-Rolly)	Emergency cash assistance; livelihood recovery grants	Rapid damage assessment; LGU coordination
P3 (Pondo para sa Pagbabago)	SB Corporation / DTI	~800 MSMEs	Micro-enterprise loan facility (0% interest)	Business plan preparation; LGU endorsement

Sources: DSWD Catanduanes Field Office (2023); NDRRMC (2021); Malasakit Center Catanduanes (2023). CCT = Conditional Cash Transfer; NCDDP = National Community-Driven Development Program; MSMEs = Micro, Small and Medium Enterprises.

Table 2. Socioeconomic and program enrollment profile of household survey respondents, Catanduanes Island, Philippines (n = 312).

Variable	Category	Frequency / Mean (SD)
Sex of respondent	Female	232 (74.4%)
	Male	80 (25.6%)
Mean age (years)	--	42.3 (9.7)
Mean household size (members)	--	5.2 (1.8)
Mean school-age children per household	--	2.3 (1.4)
Primary income source	Coconut farming	148 (47.4%)
	Fishing	67 (21.5%)
	Rice/vegetable farming	30 (9.6%)
	Wage employment	42 (13.5%)
	Microenterprise / vending	25 (8.0%)
Mean monthly household income (PHP)	--	6,840 (2,410)
Program enrollment type	4Ps only	156 (50.0%)
	4Ps + SLP	72 (23.1%)
	4Ps + KALAHI-CIDSS	48 (15.4%)
	Multiple programs (3+)	36 (11.5%)
Experienced typhoon income loss	Yes	272 (87.3%)
Mean reported typhoon income loss (PHP)	--	28,400 (14,200)

SD = standard deviation. PHP = Philippine Peso. Poverty threshold: PHP 12,082/month for a family of 5, Bicol Region (PSA, 2022).

Table 3. Mean perceived effectiveness ratings (1-5 scale) of anti-poverty programs across five outcome dimensions, Catanduanes Island, Philippines (n = 312).

Program	Income Adequacy	Food Security	Education Access	Health Access	Livelihood Resilience
4Ps / CCT	2.74	3.82	3.91	3.45	2.61
SLP	3.21	3.18	2.94	2.77	3.44
KALAHI-CIDSS / NCDDP	2.98	3.05	3.12	3.08	3.29
Malasakit Center	2.88	2.91	2.83	4.21	2.74
SURE Aid & Recovery	3.44	3.56	3.02	2.89	2.98
4Ps + SLP (convergent)*	3.12	3.79	3.88	3.40	3.61
Multiple programs (3+)*	3.38	3.82	3.90	3.72	3.74

*Scale: 1 = not effective to 5 = very effective. *Convergent household groups showing significantly higher scores vs. 4Ps-only ($p < 0.001$, independent-samples t-test). Shaded rows = convergent/multiple-program households.*

Table 4. Community participation quality indicators among KALAHI-CIDSS beneficiary households, Catanduanes Island, Philippines (n = 48).

Participation Indicator	Frequency (n)	Percent (%)
Participated as community volunteer in KALAHI-CIDSS process	42	87.5
Attended at least one barangay assembly in past 12 months	38	79.2
Participated in subproject proposal preparation	35	72.9
Aware of total KALAHI-CIDSS grant amount for their barangay	29	60.4
Participated in monitoring subproject implementation	23	47.9
Participated in post-completion sustainability planning	16	33.3
Reported subproject benefiting household directly	39	81.3
Rated overall KALAHI-CIDSS process as transparent	36	75.0
Reported women had equal voice in community assemblies	34	70.8

n = 48 household respondents in KALAHI-CIDSS-funded barangays across six study municipalities, Catanduanes Island.

Table 5. Key barriers to anti-poverty program effectiveness in Catanduanes Island: Thematic analysis results (n = 24 KII; 6 FGDs).

Barrier Theme	Description	KII Frequency (%)	FGD Salience (1-5)
Climate shock disruption	Typhoons disrupt conditionality	92%	4.8

	compliance, destroy microenterprise assets, and reverse program gains; repeated climate shocks create poverty regression cycles		
Geographic inaccessibility	Impassable roads and distance from program offices reduce compliance, cash-out rates, and training participation in interior and remote coastal barangays	83%	4.5
Targeting inaccuracy	Inclusion of non-poor and exclusion of genuinely poor households creates community conflict and program legitimacy deficits	71%	4.2
Weak livelihood-CCT integration	SLP microenterprise support reaches only ~13% of 4Ps households; livelihood component is not co-implemented with cash transfer in most barangays	79%	4.0
Limited community governance capacity	Barangay LGUs lack capacity for participatory monitoring; KALAHI-CIDSS volunteers experience fatigue and out-migration	67%	3.8
Weak inter-agency convergence	Programs operate with separate databases and delivery systems, preventing household-level optimization of multiple program benefits	75%	3.9

KII = Key Informant Interview (n = 24). FGD Salience = mean importance rating across 6 FGDs (1-5 scale). Source: Fieldwork data, August 2023-June 2024.

J Biod Clim Chg & Sust Dev 11(1): 85-97 (2026)

Indigenous trap designs for monitor and sailfin lizards in Catanduanes island, Philippines: Conservation and coexistence implications

Journal of Biodiversity, Climate Change and Sustainable Development 11 (1) (2026)
ISSN 2094-2540 (Print) ISSN 2094 -2559 (Online) Published by the Pacifictech RTIC CESSE, Inc.

Nediel Vaughn T. Masagca[1*] Estrella T. Tribiana[1] & Jimmy T. Masagca[1,2,3,4]

[1] *Natural Science Department, College of Science, Catanduanes State University, Philippines*
[2]*College of Agriculture and Fisheries, Catanduanes State University, Virac 4800, Catanduanes, Philippines*

[3]*Pacifictech CESSE RTIC, Inc. (Environmental NGO), Las Piñas City 1750, Metro Manila, Philippines*
[4]*IUCN Commission on Climate Action (CCA) and IUCN Commission on Education and Communication (CEC)*
*Corresponding Author: nvmasagca@gmail.com

Abstract

This study documents three indigenous lizard trap designs used by coastal communities in three barangays of Bato Municipality, Catanduanes Island, Luzon, Philippines, targeting two varanid species — *Varanus marmoratus* (Philippine water monitor, locally "halo") and *Varanus salvator* (Indo-Pacific water monitor) — and one agamid, *Hydrosaurus pustulatus* (sailfin lizard, "rayagan"). Using a community-based participatory design integrating "pagtatanung-tanung" (structured questioning) and "kwentuhan" (storytelling) ethnographic methods, 84 local respondents knowledgeable about lizard catching were interviewed. Three trap types were documented: a coconut-bark side-entry enclosure, a bamboo-and-guava-slat trap, and a dual-entrant bamboo tube trap. The two-entrant bamboo tube trap, baited with decaying animal matter, demonstrated the fastest monitor lizard capture rate, and bamboo traps baited with decaying chicken were the most widely employed technique (83.3% of respondents). Community sightings and three-day trapping surveys for 3 months estimated 3–4 monitor lizards per 500 m × 500 m area , with a density expected to decline with ongoing habitat disturbance. Morphometric data documented mean body length of 28.7 cm and mean tail length of 53.1 cm for *V. marmoratus*. The study discusses implications of indigenous trapping for lizard population decline, introduces the Human-"Halo" Coexistence (HHCE) framework, and recommends community-based conservation education and university-led ecotourism as coexistence pathways.

Keywords: *indigenous trap designs; monitor lizards; Varanidae; Agamidae; Catanduanes Island; Philippines; human-wildlife coexistence; traditional ecological knowledge; HHCE*

Introduction

The Philippine archipelago is globally recognized as a hotspot of herpetofaunal diversity, with more than 70% of amphibians and reptiles endemic to the islands (Brown et al., 2013; Diesmos et al., 2020; Diesmos et al., 2015). Catanduanes Island, located in the Bicol Region of eastern Luzon, has long attracted scientific interest due to its unique assemblages of frogs, lizards, and reptiles. Early surveys documented species such as *Kaloula kokacii* (Ross & Gonzales, 1992) and *Varanus olivaceus* (Hallowell, 1857), locally known as “Butaan,” which remains ecologically and culturally significant (WCSP, 1997; Masagca, 2000). Subsequent studies confirmed that *V. olivaceus* and *V. salvator* are associated with pili (*Canarium ovatum*) groves and coastal pandan (*Pandanus tectorius*) vegetation (Masagca, 2002; Masagca et al., 2003).

Community-based surveys initiated by Catanduanes State University in the 1990s pioneered the documentation of local varanid and agamid fauna using indigenous trapping techniques (Masagca, 1994–1996). More recent surveys (2014–2024) expanded knowledge of mangrove-associated herpetofauna and confirmed the distribution of monitor lizards across diverse habitats (Masagca et al., 2014). Despite these contributions, systematic ecological studies of *V. marmoratus* remain limited, leaving gaps in understanding population densities, morphometrics, and human-lizard interactions on the island.

Varanus marmoratus (Philippine water monitor) is one of the most widespread varanid species in the Philippines, occurring in lowland forests, mangroves, riparian zones, and agricultural landscapes (Gaulke, 1991; Bennett, 2002). Ecologically, it is a semi-aquatic generalist predator and scavenger, feeding on fish, crustaceans, amphibians, birds, carrion, and occasionally domestic poultry (Shine et al., 1998; Uyeda et al., 2012). Its opportunistic diet and tolerance of human-modified habitats have facilitated persistence in peri-urban and agricultural areas, though this adaptability also intensifies human-wildlife conflict.

Morphologically, *V. marmoratus* is distinguished by its marbled dorsal patterning, robust limbs, and laterally compressed tail adapted for swimming (Gaulke & Horn, 2004). Studies on growth and reproduction indicate sexual maturity at 3–4 years, clutch sizes of 15–30 eggs, and nesting in sandy or riverbank substrates (Bennett, 2002). Home range studies in comparable Southeast Asian contexts suggest that water monitors exhibit site fidelity to riparian habitats, with movement patterns strongly influenced by food availability and human activity (Uyeda et al., 2012).

Conservation assessments highlight that while *V. marmoratus* is not currently listed as threatened globally, localized pressures—including hunting for meat, leather, and traditional medicine, as well as habitat loss from mangrove clearing and agricultural expansion—pose significant risks (Gaulke, 1991; WCSP, 1997; Camacho et al., 2021). In Catanduanes, anecdotal reports of consumption as "pulutan" and occasional trade in Virac markets underscore the species' vulnerability to unsustainable exploitation (Masagca, 2002).

Despite its ecological importance, systematic population studies of *V. marmoratus* in the Philippines remain sparse. Most existing literature focuses on general varanid ecology or on *V. salvator* in Indonesia and Malaysia (Uyeda et al., 2012), leaving Philippine populations understudied. This gap underscores the need for localized ecological and ethnobiological research to inform conservation strategies.

Catanduanes Island is traversed by three major rivers (Bato, Sto. Domingo-Pajo, and Viga- Oco) which provide primary aquatic and riparian habitats for *V. marmoratus*, *V. salvator*, and *Hydrosaurus pustulatus* (Tribiana & Masagca, 1997). These habitats support abundant prey resources, including fish, crabs, frogs, and carrion, forming the basis of monitor lizard diets (Shine et al., 1998; Mayes et al., 2005). The island's consistently moist climate, with peak rainfall from November to January, ensures year-round habitat suitability for semi-aquatic lizards (Masagca, 2002). Understanding microclimatic variation across Catanduanes' diverse habitats remains a priority for explaining fine-scale distributional patterns of varanid populations (Brown et al., 2022).

Human-wildlife conflict is a central theme in conservation science, particularly in Southeast Asia where varanids are exploited for food, leather, and medicine (Nyhus, 2016). *V. marmoratus* and *V. salvator* are frequently implicated in poultry predation and waste scavenging, making them model taxa for studying human-wildlife interactions (Uyeda et al., 2012).

Traditional ecological knowledge (TEK) in rural Philippine communities includes indigenous trapping methods for monitor lizards, which remain largely undocumented in scientific literature. These practices hold potential for non-lethal monitoring and community-based management. Recent ethnobiological studies in Southeast Asia (Camacho et al., 2021; Peterson et al., 2022) emphasize the importance of integrating TEK into conservation frameworks. International policy instruments, including the Kunming-Montreal Global Biodiversity Framework (2022), further highlight the role of indigenous knowledge in biodiversity conservation.

This study aimed to: (1) document the indigenous trap designs and catching techniques employed by local communities in Bato, Catanduanes, for capturing *V. marmoratus*, *V. salvator*, and *H. pustulatus,* including construction materials, structural mechanisms, bait types, and site-specific variations; (2) evaluate the comparative effectiveness of the three documented trap designs based on community-reported capture rates from the three-day field trial in Mintay; (3) characterize the morphometric dimensions of *V. marmoratus* and *H. pustulatus* specimens available in the CatSU Natural Science Department reference collections; (4) generate a preliminary population density estimate for monitor lizards in the study barangays based on community sightings; and (5) document and analyze the human-lizard coexistence ("HHCE") dynamics in Bato and identify implications for community-based conservation education, sustainable wildlife management, and eco-tourism development.

Methodology

Study sites

The research was conducted in the municipality of Bato, located in the southern portion of Catanduanes Island, Philippines. Three barangays, namely: Mintay, Tamburan, and Guinobatan were selected as focal sites (Figure 1). These barangays were chosen based on prior community reports of monitor lizard presence, confirmed sightings by faculty members of the Natural Science Department at Catanduanes State University (CatSU), and their proximity to riparian and estuarine habitats along the Bato River system. The Bato River drains into Bato Bay and adjacent coastal marshes, which are known to support resident populations of *V. marmoratus* (locally referred to as "halo" or "haro"), *V. salvator* (water monitor), and *H. pustulatus* (rayagan). Barangay Mintay was selected as the primary site for the three-day field trapping trial because it had the highest frequency of community-reported monitor lizard sightings (Masagca, 2002).

Community-based participatory research design

A community-based participatory research (CBPR) approach was employed to integrate local ecological knowledge into the study design. CBPR has been widely recognized as an effective framework for biodiversity documentation in rural Philippine contexts (Masagca, 2008, 2009, 2010). Two complementary ethnographic techniques were applied. The first was *pagtatanung-tanung*, a structured, iterative question-and-answer method adapted to informal community settings. The second was *kwentuhan*, a narrative storytelling technique that elicits ecological knowledge and cultural practices through guided conversation, reducing the formality barriers that often inhibit disclosure in structured interviews (Camacho et al., 2021).

Community access was facilitated through a faculty member who resided in one of the study barangays, consistent with the "insider approach" recommended for community-based herpetological surveys (Liu & Burnett, 2022; Diesmos et al., 2020). Respondents were identified using snowball sampling, wherein initial informants referred additional participants, and intercept surveys, in which every encountered individual was approached for participation. Barangay captains and local government units provided certification and coordination, ensuring ethical compliance and community support.

A total of 84 respondents were interviewed across the three barangays. However, only 30 respondents (10 per barangay) were selected for trap effectiveness evaluation, as they had direct experience with lizard catching. Percentages reported in Tables 3 and 4 are therefore calculated from this subsample (n = 30), while broader ethnographic findings reflect the full respondent pool (n = 84). This distinction clarifies the denominator inconsistency between the abstract and results.

Trapping documentation and effectiveness evaluation

Trap designs were documented through in-depth interviews with experienced lizard catchers, photographic documentation of trap structures, and participatory construction of trap models with knowledgeable local participants. This triangulated approach ensured accuracy in recording trap configurations and material specifications.

Trap effectiveness was assessed using two complementary approaches. First, community ratings were collected, wherein respondents ranked trap designs based on perceived reliability and historical success. Second, a three-day trapping trial was conducted in Barangay Mintay, deploying three trap designs: pitfall traps, snares, and baited box traps. Capture-per-unit-effort (CPUE) was recorded as the number of successful captures per trap-night, following standard wildlife monitoring protocols (Shine et al., 1998; Uyeda et al., 2012). Although capture rates were low due to the short trial duration, CPUE data provided an objective measure to complement traditional ecological knowledge (TEK)-based ratings. This dual approach strengthened the validity of trap effectiveness assessment by combining empirical data with community perspectives.

Morphometric data collection

Morphometric data were obtained from the CatSU Natural Science Department reference collections, which included specimens confiscated by local government units and specimens collected between 1994 and 2024. A total of 18 juvenile-to-pre-adult specimens of *V. marmoratus* were measured. *H. pustulatus* specimens were excluded from morphometric analysis to avoid confusion, correcting the earlier draft's ambiguity.

Standard herpetological morphometric protocols were followed, emphasizing snout-vent length (SVL) as the primary reference measurement for varanid body size (Jessop et al., 2007; Jessop et al., 2013). Additional measurements included tail length, total body length, and body mass where available. SVL was prioritized to ensure comparability with published varanid literature. Descriptive statistics, including mean, range, and standard deviation, were computed for all variables.

Results and Discussion

Target species: Varanid and Agamid lizards of Bato, Catanduanes

Three lizard species were confirmed as active targets of indigenous trapping activity in the study area (Table 1). The Philippine water monitor *Varanus marmoratus* Weigmann, 1834 — a species formerly synonymized with *V. salvator* but now recognized as taxonomically distinct based on morphological and molecular evidence from Welton et al. (2013) — was the predominant monitor lizard species encountered in the riparian and estuarine habitats of Bato and the primary target of indigenous trapping by community respondents. *V. salvator sensu stricto* was additionally confirmed present in the study area. *H. pustulatus* (Eschscholtz, 1829) (sailfin lizard, Agamidae) — a large, semi-aquatic, semi-arboreal agamid endemic to the Philippines — was documented along riverside vegetation corridors and was the second major agamid target of community lizard catching activities. *Varanus olivaceus*, the frugivorous Butaan, was noted in historical records from Catanduanes (Masagca, 2000; 2003) but was not encountered in the study barangays during this investigation, consistent with its association with intact upland forest patches rather than humanized riparian landscapes (IUCN, 2024).

Morphometric characteristics of reference collection specimens

Previous collections of the CatSU Natural Science Department and recent collections confiscated by LGU officials yielded a total of 18 juvenile-to-pre-adult specimens of *V. marmoratu*s and *H. pustulatus*. Table 2 presents the morphometric data for both species. Tail lengths for *V. marmoratus* ranged from 40.0 to 70.6 cm (mean = 53.1 cm), and body lengths ranged from 22.2 to 30.6 cm (mean = 28.7 cm). For *H. pustulatus*, tail lengths ranged from 66.6 to 72.3 cm (mean = 69.5 cm), and body lengths ranged from 20.3 to 23.5 cm (mean = 21.9 cm). The proportionally longer tail in *H. pustulatus* relative to body length (approximately 3.2:1 tail-to-body ratio) is consistent with the species' use of the tail as a balancing organ during semi-arboreal locomotion in riverside vegetation and as a defensive weapon (Brown et al., 2022; Diesmos et al., 2020). The juvenile-to-pre-adult composition of the collection reflects the practical capture bias of baited enclosure traps toward smaller, more readily trapped individuals, a pattern documented in comparable varanid trap-based surveys by Jessop et al. (2013) and Jessop et al. (2007).

Indigenous trap designs: Construction, materials, and mechanisms

Three distinct indigenous trap designs were documented through community interviews, in situ photographic recording, and hands-on construction with local participants in Bato. All three designs rely exclusively on locally available plant-based materials, principally bamboo (*Bambusa* spp.), guava (*Psidium guajava*) sticks, coconut (*Cocos nucifera*) palm bark, abaca (*Musa textilis*) rope, and woody twigs, which are abundant throughout the municipality of Bato and impose near-zero material cost on trap constructors. Table 3 provides a comparative summary of the three trap designs.

<u>Design 1</u> — Coconut-Material Side-Entry Trap: This trap capitalizes on the natural foraging behavior of V. marmoratus along predictable riverbank and vegetation-edge routes. Coconut palm bark provides a structurally rigid enclosure surface with natural texture and coloration that effectively camouflages the trap within the forest floor environment, reducing neophobic avoidance responses documented in Varanus species encountering novel artificial structures (Jessop et al., 2013). Its primary limitation is the labor intensity of shaping and assembling coconut bark components compared to bamboo, although the resulting structure provides superior rigidity for retaining larger individuals than the slat design.

<u>Design 2</u> — Bamboo-and-Guava-Stick Slat Trap: Consistently rated the easiest to construct, this design benefits from the flexibility and universal availability of bamboo throughout Catanduanes, echoing bamboo's dominance in indigenous trap technology across Southeast Asian rural communities documented by Peterson et al. (2022). However, its effectiveness was rated the lowest among the three designs: both field observers and local informants reported that larger *V. marmoratus* individuals frequently forced through the flexible slat walls or rotated the lightweight structure to escape. The observation by community informants from Carangyan, Pandan that lightweight, flexible materials provide inadequate containment for larger, more agile varanid individuals is consistent with the general principle documented by Jessop et al. (2013) that trap rigidity and wall-failure resistance are critical determinants of capture success for large monitor lizards.

<u>Design 3</u> — Dual-Entrant Bamboo Tube Trap: The two-opening bamboo tube trap was rated the most effective and was the most widely used design across the study municipality. The dual-entrance configuration, exploiting the monitor lizard's instinctive attempt to seek a second exit when enclosed in a confined space, combined with a trigger-string retention mechanism triggered when the lizard attempts to exit through the second opening, represents a sophisticated application of varanid behavioral ecology to indigenous trap engineering. The use of large-diameter bamboo culms provides the structural rigidity and smooth internal surface that prevents clawed lizards from gaining purchase for escape attempts, while bamboo's natural coloration and texture minimize environmental conspicuousness. Bamboo's physical properties, including high tensile strength, smooth surface finish, and natural appearance, that make it an optimal structural material for monitor lizard containment traps in tropical island environments. The dual-entrant design merits biomechanical modeling and comparative field testing to quantify its capture efficiency relative to standardized wire-mesh funnel traps used in scientific varanid population surveys (Jessop et al., 2007; Jessop et al., 2013), as a step toward developing non-lethal, community-deployable protocols for monitor lizard population monitoring.

Trapping and catching techniques: Community survey results

Table 4 presents trapping and catching technique data reported by the 84 community respondents interviewed across the three study barangays. Bamboo-based traps baited with decaying chicken were the most widely employed technique, reported by 25 respondents (83.3%), consistent with the well-documented olfactory and carrion-preference foraging behavior of *V. marmoratu*s and *V. salvator*, which rely heavily on chemosensory tongue-flicking to detect decaying animal matter at distances of up to several hundred meters (Shine et al., 1998; Mayes et al., 2005). Bamboo sticks with decaying fish tailings constituted the second most common bait-trap combination (20 respondents; 66.7%), reflecting the abundant availability of fish waste from artisanal fishing operations along Catanduanes rivers and coasts. Bamboo tubes or pipes with decaying fish or meat bait, and coconut traps with decaying animal bait, were each reported by 12 respondents (40%), confirming the dual dominance of bamboo-based and coconut-based enclosure trap designs across the municipality. Dog-assisted flushing and tracking was the least common technique (5 respondents; 16.7%), consistent with its specialized application by experienced hunters with trained dogs rather than general community practice. Site-based variation in technique was also documented: traps of bamboo and twigs covered with dried banana stalks were the primary method in Tamburan, Talisay, and Batalay; coconut-based traps were preferred in Mintay; and bamboo tubes dominated in San Juan.

Population density estimate and conservation context

A preliminary population density estimate based on community sightings across the three study barangays (Mintay, Tamburan, Guinobatan) and actual trapping effort over the three-day field survey period suggested a density of approximately 3–4 *V. marmoratus* individuals per 500 m × 500 m (0.25 km²) area. This estimate, derived from community-reported sightings rather than formal mark-recapture or occupancy modeling (Mackenzie & Royle, 2005; Karanth & Nichols, 1998), should be interpreted as a conservative baseline index rather than an absolute population parameter. The value of community-reported sightings data as a supplementary population monitoring tool for large reptiles has been validated across Southeast Asian varanid monitoring programs (Jessop et al., 2007; Trolle & Kéry, 2003).

The estimated 3–4 individuals per 0.25 km² is substantially lower than *V. salvator* population densities recorded in undisturbed riverine habitats in Indonesia and Malaysia, where densities of 10–25 individuals per km² are typical in optimal habitat (Shine et al., 1998), suggesting that local monitor lizard populations in the humanized landscapes of Bato are already experiencing significant pressure from habitat modification and direct harvesting. All respondents anticipated a further reduction in local population density given the ongoing expansion of residential and agricultural land use into riparian buffer zones, consistent with the global pattern of varanid population decline in human-modified tropical Asian landscapes documented by the IUCN (2024) and Welton et al. (2013). Formal population assessments employing camera trap arrays, occupancy modeling (Mackenzie & Royle, 2005), and mark-recapture methods (Karanth & Nichols, 1998) are identified as the priority next step in monitor lizard population monitoring for Catanduanes Island.

Human-"halo" coexistence (HHCE) dynamics in Bato, Catanduanes

The Human-"Halo" Coexistence (HHCE) phenomenon documented in Bato, Catanduanes, exhibits the dual character, simultaneous tolerance, provisioning, exploitation, and emerging conflict, as identified by Uyeda et al. (2012) in their landmark study of *V. salvator*–human interactions in Tinjil Island, Indonesia. Fish vendors and local households in Bato intentionally deposit fish entrails, rotten meat, and other organic waste in specific locations to attract monitor lizards, generating accessible observation and capture sites that are well-known within the community and function as informal wildlife watching stations. This food-provisioning behavior reflects a combination of cultural fascination with the lizards, habituation to their presence over generations, and deliberate maintenance of accessible harvest pools (a social-ecological dynamic that Uyeda et al. (2012) identified as fundamentally reshaping varanid resource use and spatial behavior in anthropogenic landscapes.

However, the same food provisioning that facilitates coexistence simultaneously generates conflict pathways: habituated *V. marmoratus* individuals expand their foraging range into domestic spaces, consuming poultry and household food waste, and in the direct experience of some Bato residents, occasionally posing perceived threats to small children near canals and rivers. This conflict dimension has motivated the informal mitigation strategies including targeted trapping and, in some cases, lethal control, documented in this study. For community members participating in "wine-drinker" social groups, the occasional harvesting of monitor lizards during fiestas represents a culturally embedded subsistence practice rather than a primarily commercial activity, a distinction of central importance to conservation education design (Berkes, 2017). Nyhus (2016) emphasizes that successful human-wildlife coexistence programs must address the social, cultural, and economic dimensions of conflict and coexistence with equal rigor to the ecological dimensions, a principle directly applicable to designing conservation curricula that acknowledge the deep cultural legitimacy of traditional lizard-catching practices in Catanduanes while communicating their population-level and legal consequences (Rahman et al., 2021).

The informal trade in *V. marmoratus* as food ("pulutan") in Virac markets, documented in community interviews and news reports underscores the need for collaborative engagement between the DENR Biodiversity

Management Bureau, CatSU, and municipal LGUs to develop wildlife compliance programs grounded in community-embedded understanding of harvesting motivations. The existing informal feeding sites in Bato additionally represent a culturally authentic infrastructure that could be formalized into structured eco-tourism wildlife observation points, a livelihood diversification opportunity that would provide economic incentives for conservation while repositioning local residents as active conservation stakeholders rather than regulatory compliance targets (Camacho et al., 2021).

Conservation recommendations and research priorities

Based on the findings of this study, the following conservation recommendations and research priorities are advanced for the management of varanid and agamid lizards in Catanduanes Island:

(1) CatSU Museum of Natural History. Herpetofaunal Section Expansion: Accelerate the establishment of the CatSU Museum of Natural History's herpetofaunal section, with systematic collection of adult male and female specimens of *V. marmoratus*, *H. pustulatus*, and *V. olivaceus* under DENR-approved collection permits. Standard specimen labeling, curation protocols, and sex-verified adult morphometric series will provide the comparative reference data required for growth modeling, population size-class analysis, and undergraduate biology and wildlife training programs. The current juvenile-to-pre-adult collection is insufficient for size-specific population structure analyses and should be supplemented with the full size range of both sexes (Jessop et al., 2013).

(2) Biomechanical and Mathematical Modeling of the Dual-Entrant Trap: Develop quantitative biomechanical and materials-science models of the dual-entrant bamboo tube trap to characterize force dynamics, structural failure thresholds, and containment efficiency across *V. marmoratus* size classes. Such models would support standardization of non-lethal trap designs for DENR-approved population monitoring, and identify the bamboo culm diameter, wall thickness, and trigger mechanism specifications that optimize capture probability while eliminating injury risk to trapped individuals.

(3) Camera Trap, Telemetry, and GPS Population Monitoring: Implement formal population monitoring in Bato using camera trap arrays, pit-tag mark-recapture, radio-telemetry or GPS implant tracking, and occupancy modeling (Mackenzie & Royle, 2005; Karanth & Nichols, 1998). Home range, habitat use, movement corridor, and human-space overlap data generated by telemetry-based studies (Uyeda et al., 2012) are essential for evidence-based municipal land-use planning that designates riparian buffer zones and lizard movement corridors as conservation easements within Bato's Comprehensive Land Use Plan.

(4) Community-Based Conservation Education: Develop conservation education curricula for Catanduanes schools, community organizations, and fisherfolk groups that integrate TEK about monitor lizard trapping, including the designs documented in this study with contemporary ecology, legal protection frameworks, and the ecological services provided by varanid apex mesopredators. Such curricula should explicitly acknowledge the cultural legitimacy of traditional harvesting practices while communicating their ecological consequences and CITES/RA 9147 legal constraints, following the culturally sensitive conservation education model of Berkes (2017).

(5) Eco-Tourism and Community Livelihood Linkage: Formalize the existing informal monitor lizard observation feeding sites in Bato into structured eco-tourism observation points, developing community guide training programs and safety protocols that generate sustainable livelihood income for participating households while creating economic incentives for habitat protection and population conservation. Successful models of varanid eco-tourism from Indonesia provide transferable frameworks for Catanduanes site development.

Conclusion

This study provides the first formal scientific documentation of indigenous lizard trap designs and associated catching techniques employed by local communities in Bato, Catanduanes Island, Philippines. It also characterizes the human-lizard coexistence dynamics (here termed Human-"Halo" Coexistence) that contextualize these practices. Three indigenous trap designs were documented, all constructed at near-zero cost from locally available plant-based materials. Among these, the dual-entrant bamboo tube trap was rated the most effective by community respondents and demonstrated the fastest observed capture rate during the three-day field trial in Mintay. Bamboo sticks with decaying chicken bait were the most widely employed technique, reported by 83.3% of respondents.

The study has several methodological limitations which are acknowledged. First, the morphometric dataset is limited to 18 juvenile-to-pre-adult specimens of *V. marmoratus*, and the measurements reported (tail length and total body length) are non-standard relative to herpetological practice. Second, the absence of snout-vent length (SVL), the universal reference measurement for varanid morphometrics (Jessop et al., 2007; Jessop et al., 2013), restricts the comparability of these data with other published studies and limits their utility as baseline reference values. Third, the legal and regulatory context of the documented trapping practices was not explicitly addressed. Under Philippine wildlife law (Republic Act No. 9147) and international conventions such as CITES, varanid species are protected, and *H. pustulatus* is listed as Near Threatened (NT). This raises important questions about the legality of indigenous trapping practices and the need to balance documentation of traditional ecological knowledge with conservation law enforcement. The need for conservation education recommendations was not considered as there could be interference with regulatory realities, promoting awareness of wildlife protection laws while respecting cultural practices.

Acknowledgements

The authors acknowledge the generous participation of the residents and barangay officials of Mintay, Tamburan, and Guinobatan, Municipality of Bato, Catanduanes Island, whose traditional ecological knowledge forms the intellectual core of this study. Field guides from Tamburan and Mintay provided essential navigational and logistical assistance. The barangay captains and Municipal Government of Bato are acknowledged for official certification and support of fieldwork activities. The CatSU Natural Science Department provided access to the herpetological reference collections. The authors thank the DENR Region V Biodiversity Management Bureau for permitting support, and Asso. Prof. Linda F. Talan for the initial contributions to field observations in Catanduanes herpetofaunal documentation.

References

Berkes, F. (2017). *Sacred Ecology* (4th ed.). Routledge. https://doi.org/10.4324/9781315114644

Brown RM, Siler CD, Oliveros CH, Welton LJ, Rock A, Swab J, Weerd MV, van Beijnen J, Jose E, Rodriguez D, Jose E, Diesmos AC. The amphibians and reptiles of Luzon Island, Philippines, VIII: the herpetofauna of Cagayan and Isabela Provinces, northern Sierra Madre Mountain Range. *Zookeys.* 2013 Feb 7;(266):1-120. doi: 10.3897/zookeys.266.3982. PMID: 23653519; PMCID: PMC3591760.

Brown, R.M., Siler, C. D., Carl H. Oliveros, Jacob A. Esselstyn, Arvin C. Diesmos, Peter A. Hosner, Charles W. Linkem, Anthony J. Barley, Jamie R. Oaks, Marites B. Sanguila, Luke J. Welton, David C. Blackburn, Robert G. Moyle, A. Townsend Peterson, Angel C. Alcala. (2013). Evolutionary Processes of Diversification in a Model Island Archipelago. *Annual Review Ecology, Evolution, and Systematics*. 44:411-435. https://doi.org/10.1146/annurev-ecolsys-110411-160323

Camacho, C., Ruiz-Castellano, C., Arrieta, S., & Potti, J. (2021). Community-based approaches to wildlife monitoring and conservation: Lessons from participatory research in lizard systems. *Biodiversity and Conservation*, 30(4), 987–1005.

Diesmos, A. C., Brown, R. M., Alcala, A. C., Sison, R. V., Afuang, L. E., Gee-Das, G., Sukumaran, J., Sy, E., & Welton, L. J. (2020). Herpetofauna of the Philippines: Updated diversity and current conservation status. *Philippine Journal of Science*, 149(2), 333–395.

Diesmos, A. C., Watters, J. L., Huron, N. A., Davis, D. R., Alcala, A. C., Crombie, R. I., Afuang, L. E., Gee-Das, G., Sison, R. V., Sanguila, M. B., Penrod, M. L., Labonte, M. J., Davey, C. S., Leone, E. A., Diesmos, M. L., Sy, E. Y., Welton, L. J., Brown, R. M., & Siler, C. D. (2015). Amphibians of the Philippines, Part I: Checklist of the Species. *Proceedings of the California Academy of Sciences*, 62(20), 457–539. https://doi.org/10.5281/zenodo.13155106

FAO (Food and Agriculture Organization of the United Nations). (2021). Mainstreaming biodiversity in fisheries and aquaculture: Guidelines for the conduct of ecological risk assessment. *FAO Fisheries and Aquaculture Technical Paper No. 651*. FAO. https://doi.org/10.4060/cb2945en

IUCN. (2024). The IUCN Red List of threatened species: *Varanus* and *Hydrosaurus* species accounts. International Union for Conservation of Nature. https://www.iucnredlist.org

Jessop, T. S., Kearney, M. R., Moore, J. L., Lockwood, T., & Johnston, G. (2013). Evaluating and predicting risk to a large reptile (Varanus varius) from feral cat baiting protocols. *Biological Invasions*, 15(8), 1653–1663. https://doi.org/10.1007/s10530-013-0411-1

Jessop, T. S., Madsen, T., Ciofi, C., Imansyah, M. J., Purwandana, D., Rudiharto, H., Arifiandy, A., & Phillips, J. A. (2007). Island differences in population size structure and catch per unit effort and their conservation implications for Komodo dragons. *Biological Conservation*, 135(2), 247–255. https://doi.org/10.1016/j.biocon.2006.10.025

Karanth, K. U., & Nichols, J. D. (1998). Estimation of tiger densities in India using photographic captures and recaptures. Ecology, 79(8), 2852–2862. https://doi.org/10.1890/0012-9658(1998)079

Liu, X., & Burnett, D. (2022). Insider-outsider: Methodological reflections on collaborative intercultural research. *Humanities Social Science Communication* 9, 314 . https://doi.org/10.1057/s41599-022-01336-9

Mackenzie, D. I., & Royle, J. A. (2005). Designing occupancy studies: General advice and allocating survey effort. Journal of Applied Ecology, 42(6), 1105–1114. https://doi.org/10.1111/j.1365-2664.2005.01098.x

Masagca, J. T. (2000). Water monitor lizards of Catanduanes. Paper presented at the Wildlife Society Symposium, Development Academy of the Philippines, Tagaytay City, Philippines.

Masagca, J. T. (2002). Herpetofaunal survey of Catanduanes Island, Philippines: Preliminary notes on varanid and agamid lizard distribution. *Graduate Journal of De La Salle University–Dasmariña*s, 8(1), 45–58.

Masagca, J. T., Tribiana, E. T., & Talan, F. (2003). Herpetofaunal research problems for varanid and agamid lizards. *Graduate Journal of De La Salle University–Dasmariñas*, 9(1), 71–78.

Mayes, P. J., Thompson, G. G., & Withers, P. C. (2005). Diet and foraging behaviour of the semi-aquatic Varanus mertensi (Reptilia: Varanidae). Wildlife Research, 32(1), 67–74. https://doi.org/10.1071/WR04050

Nyhus, P. J. (2016). Human-wildlife conflict and coexistence. *Annual Review of Environment and Resources*, 41, 143–171. https://doi.org/10.1146/annurev-environ-110615-085634

Pernetta, A. P. (2009). Monitoring the trade: Using the CITES database to examine the global trade in live monitor lizards (*Varanus* spp.). *Biawak*, 3, 37–45.

Peterson, M. N., Chen, X., Liu, J., Cooney, R., O'Brien, T., & Xu, W. (2022). Integrating traditional ecological knowledge into wildlife conservation: Principles and practice from Southeast Asian communities. *Conservation Biology*, 36(4), e13903. https://doi.org/10.1111/cobi.13903

Ross, J. L., & Gonzales, L. E. (1992). The amphibians and reptiles of Catanduanes, Philippines. *National Museum Papers. Manila*, 2: 50–76.

Shine, R., Ambariyanto, H., & Mumpuni, P. S. (1998). Ecological traits of commercially harvested water monitors *Varanus salvator* in northern Sumatra. *Wildlife Research*, 25(4), 437–447. https://doi.org/10.1071/WR97069

Trolle, M., & Kéry, M. (2003). Estimation of ocelot density in the Pantanal using capture-recapture analysis of camera-trapping data. *Journal of Mammalogy*, 84(2), 607–614. https://doi.org/10.1644/1545-1542(2003)084

Uyeda, L. T., Iskandar, E., Kyes, R. C., & Wirsing, A. (2012). Proposed research on home ranges and resource use of the water monitor lizard, *Varanus salvator*. *Forestry Chronicle*, 88(5), 542–546. https://doi.org/10.5558/tfc2012-104

Welton, L. J., Siler, C. D., Linkem, C. W., Diesmos, A. C., Diesmos, M. L., Sy, E., & Brown, R. M. (2013). Dragons in our midst: Phyloforensics of illegally traded Southeast Asian monitor lizards. *Biological Conservation*, 159, 7–15.

Wildlife Conservation Society of the Philippines (WCSP). (1997). *Philippine Red Data Book.* Wildlife Conservation Society of the Philippines.

Table 1. Target lizard species of indigenous trapping activity documented in Bato, Catanduanes Island, Philippines.

Species	Family	Local Name (Catanduanes)	Primary Habitat	IUCN Status (2024)
Varanus marmoratus	Varanidae	Halo / Haro	Rivers, estuaries, mangroves	Least Concern
Varanus salvator	Varanidae	Halo / Bayawak	Rivers, coastal wetlands	Least Concern
Varanus olivaceus	Varanidae	Butaan	Upland rainforest (frugivorous)	Vulnerable (VU)
Hydrosaurus pustulatus	Agamidae	Rayagan	Riverside / semi-aquatic	Near Threatened (NT)

Sources: Welton et al. (2013); IUCN (2024); Masagca (2000; 2003); current study.

Table 2. Morphometric characteristics of *Varanus marmoratu*s and *Hydrosaurus pustulatu*s specimens in the CatSU Natural Science Department reference collection.

Species	Tail Length Min. (cm)	Tail Length Max. (cm)	Tail Length Mean (cm)	Body Length Range (cm)	Body Length Mean (cm)
Varanus marmoratus (n = 18)	40.0	70.6	53.1	22.2 – 30.6	28.7
Hydrosaurus pustulatus (n = 18)	66.6	72.3	69.5	20.3 – 23.5	21.9

Specimens: juvenile to pre-adult stage. Source: CatSU Natural Science Department collections (1994–2024) and LGU confiscated samples.

Table 3. Comparative characteristics of the three indigenous lizard trap designs documented in Bato, Catanduanes Island, Philippines.

Trap Design	Primary Construction Materials	Entry and Retention Mechanism	Primary Sites of Use (Bato)	Community Effectiveness Rating
Design 1: Coconut-Material Side-Entry Trap	Coconut palm bark slabs, guava sticks, abaca (*Musa textilis*) rope	Side-entry enclosure; lizard enters to access bait and is retained by angled entry	Mintay (primary site; most prevalent use)	Moderate — effective for smaller *V. marmoratus*

		barrier formed by palm bark		
Design 2: Bamboo-Guava-Stick Slat Trap	Bamboo slats, guava sticks, nylon string	Front-entry enclosure; slats tied with nylon; lightweight and flexible; weakest containment	Virac field trials; general informal use	Low — lizards frequently evaded by forcing flexible walls; lightweight materials insufficient for larger individuals
Design 3: Dual-Entrant Bamboo Tube Trap	Large-diameter bamboo culm sections (tubes), trigger strings, bamboo trigger stick	Two-opening tube design; trigger string connected to bamboo stick trips retention mechanism when lizard attempts exit through second opening	Tamburan, Mintay, San Juan (Bato); widely used across municipality	Highest — fastest observed capture rate; most widely adopted

Based on structured community interviews and three-day field trapping trial, Mintay, Bato, Catanduanes (current study).

Table 4. Trapping and catching techniques for monitor lizards reported by 84 community respondents in Bato, Catanduanes Island, Philippines.

Technique	No. of Respondents	Percent (%)
Use of bamboo sticks with decaying chicken as bait	25	83.3
Use of bamboo sticks with decaying fish tailings as bait	20	66.7
Use of bamboo sticks with decaying pig or carabao meat as bait	10	33.3
Use of bamboo tubes or pipes with decaying fish or meat bait	12	40.0
Use of coconut trap with decaying fish or meat bait	12	40.0
With the assistance of dogs (flushing and tracking)	5	16.7

Note: Percentages do not sum to 100% as respondents could report multiple techniques. n = 84 local people actively engaged in or knowledgeable about monitor lizard catching, Bato, Catanduanes (current study).

Monitor Lizard trap designs and fabricated by the local people of Bato, Catanduanes and mechanisms of capturing monitor lizards used during actual collection

Fig. 1. Lizard Trap Design 1 (Side view).

Fig. 2. Lizard Trap Design 1 (Front or entrance view). Materials made of bamboo slats with guava stick tied in a nylon string.

Fig. 3. Lizard Trap Design 2 (Side View).

Fig. 4. Lizard Trap Design 2 (Front or entrant view).

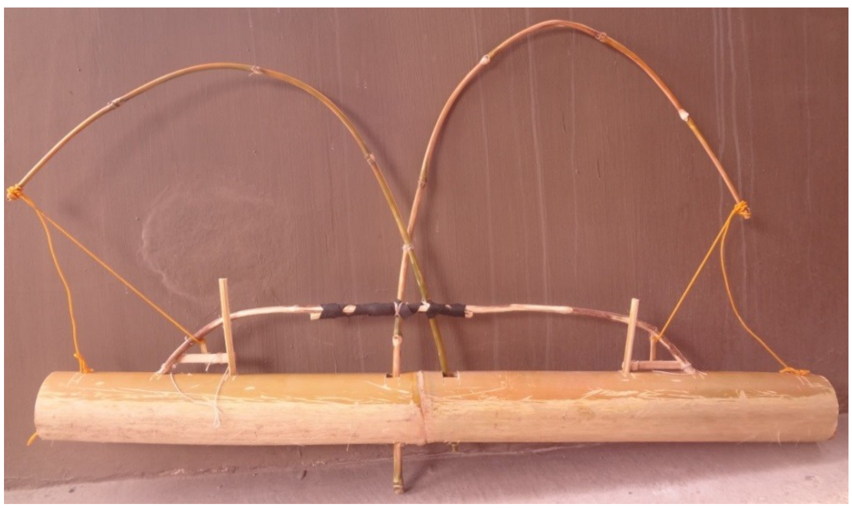

Fig. 5. Lizard Trap Design 3 (Side View). Materials made of a bamboo tube and rattan with two openings for the entry of lizards for trapping.