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Pesantren-Based Economic Empowerment Through Oyster Mushroom (Pleurotus Ostreatus) Cultivation And Circular Bioeconomy Integration: A Case Study At Sekolah Cendekia BAZNAS Cibungbulang, Bogor

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Abstract

Food security and institutional economic independence are central challenges facing Islamic boarding school (pesantren)-based educational institutions in Indonesia. This study investigates the implementation of oyster mushroom (Pleurotus ostreatus) cultivation as an integrated economic empowerment model at Sekolah Cendekia BAZNAS (SCB) Cibungbulang, Bogor. Using a Participatory Action Research (PAR) approach, 30 students, 8 faculty members, and institutional management participated actively in training and production activities. Results across three harvest cycles demonstrated consistent productivity improvement, with mean yield reaching 1.02 kg per baglog per cycle from 200 baglog units. The program generated a projected net profit of IDR 2,000,000-3,000,000 per cycle. In alignment with circular bioeconomy principles, spent baglog substrate was integrated into a tilapia biofloc system, reducing commercial feed costs by 30% and achieving a Specific Growth Rate (SGR) of 2.8% per day. Students demonstrated an 80.1% increase in knowledge scores (pre-post test, n=30), and 85% expressed intent to replicate the model. This study demonstrates that oyster mushroom cultivation, when integrated with circular bioeconomy practices, constitutes a replicable and financially viable model for pesantren-based institutions seeking sustainable economic independence.

Keywords: oyster mushroom; pesantren empowerment; food security; circular bioeconomy; participatory action research.

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INTRODUCTION

Islamic boarding schools (pesantren) occupy a unique position in Indonesia's educational landscape. As institutions that combine religious instruction with community development, they serve millions of students, many from economically disadvantaged families, across the archipelago. Despite their social significance, pesantren-based schools frequently struggle with financial sustainability, relying heavily on zakat (obligatory alms), donations, and government subsidies to maintain operational capacity (Masrur & Arwani, 2022). The development of productive economic units within these institutions is therefore not merely a financial strategy, but a structural necessity for long-term institutional resilience.

Sekolah Cendekia BAZNAS (SCB) Cibungbulang, located in Bogor Regency, West Java, exemplifies this challenge. Operated under the Badan Amil Zakat Nasional (BAZNAS), Indonesia's national zakat management body, SCB provides fully subsidized junior and senior secondary education to orphaned and economically disadvantaged students. The institution covers all living costs, making it entirely dependent on external funding. In this context, identifying productive, low-cost, and scalable agribusiness activities is a strategic institutional priority.

Oyster mushroom (Pleurotus ostreatus) cultivation presents a compelling solution. As a high-value agricultural commodity, oyster mushrooms are widely consumed across Indonesia, with market demand continuing to grow in line with increasing awareness of nutritional health (Canti et al., 2022). Oyster mushrooms are protein-rich (19-35% dry weight basis), low in fat, high in dietary fiber, and contain essential vitamins and minerals including B-complex vitamins, potassium, and selenium. Their cultivation requires minimal space, low capital investment, and a short harvest cycle of 40-60 days, making them particularly suitable for institutional-scale small and medium enterprises.

Beyond cultivation itself, oyster mushroom production generates a substantial volume of post-harvest substrate waste, known as spent baglog or spent mushroom substrate (SMS). Rich in residual mycelium, lignocellulosic fiber, and protein compounds, SMS presents an underutilized resource that can be integrated into aquaculture feed systems. When incorporated into biofloc technology, an advanced aquaculture method that leverages heterotrophic microbial communities to recycle nitrogen waste into consumable protein biomass, SMS can reduce commercial feed dependency and lower production costs significantly (Khanjani et al., 2024).

This integration of mushroom cultivation with biofloc aquaculture embodies the principles of circular bioeconomy: a production paradigm in which biological waste

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streams from one process become inputs for another, eliminating waste and maximizing resource efficiency (Bappenas, 2022). Applied to a pesantren context, this circular model offers not only economic benefits but also educational value, exposing students to integrated agribusiness systems that combine ecology, nutrition science, and entrepreneurship.

This study aims to: (1) implement oyster mushroom cultivation as a productive economic unit at SCB Cibungbulang; (2) analyze the financial feasibility and productivity outcomes of the cultivation program; (3) assess the integration of spent baglog substrate into a tilapia biofloc system; and (4) evaluate the social and educational impact of the program on student capacity and institutional independence.

LITERATURE REVIEW

Oyster Mushroom (Pleurotus ostreatus): Biology and Cultivation

Pleurotus ostreatus belongs to the division Basidiomycota, order Agaricales, family Pleurotaceae. It is among the most widely cultivated edible fungi globally, valued for its nutritional profile, relatively simple cultivation requirements, and adaptability to a wide range of lignocellulosic substrates (Widyastuti & Tjokrokusumo, 2008). The primary cultivation medium in Indonesia consists of sawdust, most commonly from rubber or sengon (Albizia chinensis) trees, supplemented with rice bran (bekatul), agricultural lime ($CaCO_3$), and gypsum ($CaSO_4$), compacted into polypropylene bags known as baglogs.

The cultivation cycle proceeds through several distinct phases: (1) substrate preparation and sterilization; (2) inoculation with fungal spawn (bibit); (3) mycelial incubation in a darkened chamber at 22-28°C; (4) fruiting body induction through exposure to diffused light and elevated humidity (80-95%); and (5) harvest, typically occurring 15-20 days after pin head formation (Widyastuti & Tjokrokusumo, 2008). A single baglog can sustain 3-5 productive fruiting cycles before substrate exhaustion, with total yields ranging from 0.7 to 1.5 kg per baglog depending on substrate composition, spawn quality, and environmental management (Laagu et al., 2024).

West Java's tropical climate, with average temperatures of 24-28°C, high relative humidity, and consistent rainfall, creates near-ideal growing conditions for oyster mushrooms throughout the year. This climatic advantage, combined with the widespread availability of sawdust from local timber processing industries, makes the Bogor region particularly well-suited for continuous mushroom cultivation operations. Research by Heryadi et al. (2021) confirmed that sawdust-based baglog formulations in Bandung

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Regency, West Java, produced competitive yields of 0.9-1.3 kg per baglog per cycle, underscoring the regional agronomic suitability of this commodity.

Pesantren-Based Economic Empowerment

The concept of pesantren economic empowerment (kemandirian ekonomi pesantren) refers to the deliberate development of productive enterprises within Islamic boarding school communities, aimed at reducing external financial dependency while simultaneously building entrepreneurial competence among students (Masrur & Arwani, 2022). This model positions the pesantren not merely as a religious education center but as a community economic actor, a role increasingly recognized in Indonesian policy frameworks, including the National Medium-Term Development Plan (RPJMN) 2020-2024.

Masrur and Arwani (2022), in their study of Pondok Pesantren Walindo in Pekalongan, documented how systematic development of student-managed business units, including cooperatives, food production, and laundry services, enabled the institution to achieve significant operational self-sufficiency while simultaneously cultivating practical entrepreneurial skills among santri (students). The study emphasized that successful pesantren economic units share three key characteristics: clear institutional ownership structures, regular financial reporting, and rotation of student management roles to maximize educational exposure.

Agricultural enterprises, particularly those with short production cycles and low capital requirements, are especially well-suited to the pesantren context. Hasan et al. (2022) demonstrated that oyster mushroom cultivation training programs in Lampung Province successfully improved community economic wellbeing, with participants reporting both increased income and enhanced technical confidence. The authors identified mentorship continuity and market linkage as the primary determinants of program success — factors that inform the design of the present study at SCB Cibungbulang.

Circular Bioeconomy: Integrating Mushroom Cultivation and Aquaculture

Circular bioeconomy refers to an economic system in which biological resources are managed across production cycles to maximize value creation and minimize waste generation (Bappenas, 2022). In practice, this involves designing production systems where the outputs, including waste streams, of one process serve as inputs to another, creating closed-loop resource flows that mimic natural ecosystem dynamics.

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In mushroom-aquaculture integrated systems, spent mushroom substrate (SMS), the post-harvest baglog material, represents a significant biomass resource. SMS retains substantial quantities of partially degraded lignocellulosic compounds, residual mycelium, and fungal protein, giving it a crude protein content of 24-28% on a dry weight basis. These nutritional characteristics make SMS a viable supplement in aquaculture feed formulations, particularly in biofloc systems where organic carbon sources are required to sustain heterotrophic microbial communities.

Biofloc technology (BFT) is an intensive aquaculture system in which carbon-to-nitrogen ratios in pond water are managed to promote the growth of heterotrophic bacteria. These bacteria assimilate inorganic nitrogen (ammonia, nitrite) and convert it into microbial biomass, the biofloc, which is then available as a protein-rich feed source for cultured fish (Khanjani et al., 2024). BFT offers significant advantages over conventional aquaculture, including reduced water exchange requirements, lower feed costs, and improved water quality management. Kurniaji et al. (2021) reported that tilapia (Oreochromis niloticus) raised in biofloc systems in Indonesia achieved SGR values of 2.5-3.1% per day and FCR values of 1.2-1.6, demonstrating strong productive performance under BFT conditions.

The integration of SMS into BFT systems therefore generates a dual benefit: it reduces the volume of solid waste generated by mushroom cultivation while simultaneously lowering the reliance on commercial aquaculture feeds. This circular linkage between mushroom and fish production is central to the model implemented at SCB Cibungbulang, and represents a practical application of circular bioeconomy principles at the community institution scale.

Participatory Action Research in Community Empowerment

Participatory Action Research (PAR) is a research methodology that integrates systematic inquiry with collaborative community action. Unlike conventional research models in which an external researcher studies a passive community, PAR positions community members as active co-researchers who participate in problem identification, program design, implementation, and evaluation (Rahmat & Mirnawati, 2020). This approach is grounded in the conviction that meaningful change requires the full engagement of those it affects, and that locally generated knowledge is as valid and important as externally produced scientific knowledge.

In the context of community economic empowerment, PAR offers several distinctive advantages. It ensures that program interventions are culturally and

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contextually appropriate, reduces resistance to change by fostering ownership and agency among participants, and builds long-term community capacity that persists beyond the duration of the research program itself. Rahmat and Mirnawati (2020) demonstrated that PAR-based community empowerment programs in Indonesia consistently outperformed conventional training approaches in terms of knowledge retention, behavioral change, and participant-reported satisfaction, findings that justified its selection as the primary methodology for the present study.

METHODOLOGY

Research Design and Approach

This study employed a Participatory Action Research (PAR) design, characterized by cyclical phases of planning, action, observation, and reflection (Rahmat & Mirnawati, 2020). PAR was selected because it aligns with the dual objectives of generating scholarly knowledge and producing tangible, community-owned outcomes. The research team from Universitas Ibn Khaldun Bogor served as facilitators rather than directors, guiding the SCB community through each program phase while supporting participant-led decision-making.

Study Site and Participants

The study was conducted at Sekolah Cendekia BAZNAS (SCB) Cibungbulang, Kabupaten Bogor, West Java, Indonesia (latitude 6°33'S, longitude 106°39'E; elevation approximately 250 m above sea level). The site was selected due to its institutional profile — a fully subsidized boarding school serving economically disadvantaged students — and its climatic suitability for year-round oyster mushroom cultivation.

Participants comprised three groups: (1) 30 students from grades X-XII selected through purposive sampling based on interest and availability; (2) 8 teaching staff and administrative personnel; and (3) 3 facilitators from the UIKA Bogor research team with expertise in agronomy, aquaculture, and community development. Informed consent was obtained from all participants, and student participation was entirely voluntary.

Program Implementation Phases

The program was implemented over six months (March-August 2025) in four sequential phases. Phase 1 (Preparation, Weeks 1-2): stakeholder socialization, participant recruitment, site assessment, and construction of a 4 × 6 m mushroom house (kumbung) fitted with bamboo shelving, mist irrigation, and light-blocking ventilation

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panels. Phase 2 (Training, Weeks 3-4): structured workshops covering mushroom biology, substrate formulation, sterilization protocols, spawn inoculation techniques, and kumbung environmental management. Practical demonstration sessions were conducted for all participants.

Phase 3 (Cultivation and Harvest, Weeks 5-24): production and monitoring of 200 baglog units across three complete harvest cycles. Environmental parameters including temperature, relative humidity, and CO_2 concentration were recorded daily using a digital environmental monitor. Harvest weights were recorded per baglog per flush, and cumulative yield data were compiled in logbook format. Phase 4 (Biofloc Integration, Weeks 13-24): parallel with late cultivation cycles, a 1 m³ biofloc trial was established using tilapia fingerlings (initial mean weight 8.5 ± 0.3 g). Spent baglog substrate was incorporated at 20% of total daily feed volume, alongside commercial pellet feed.

Data Collection and Analysis

Quantitative data were collected through: (1) production logbooks recording daily temperature, humidity, and harvest weights per baglog per cycle; (2) financial records documenting input costs and revenue projections; (3) biofloc system monitoring including weekly fish sampling for weight gain (SGR calculation), feed conversion ratio (FCR), and survival rate; and (4) pre-post knowledge assessment tests administered to student participants (n=30) using a validated 25-item instrument covering mushroom biology, cultivation techniques, biofloc principles, and circular bioeconomy concepts.

Qualitative data were collected through in-depth interviews with institutional management (n=4), focus group discussions (FGDs) conducted at the end of each program phase (n=3 FGDs), and field observation notes maintained throughout the program. Quantitative data were analyzed descriptively (means, ranges, percentage changes). Qualitative data underwent thematic content analysis following Miles and Huberman's (1994) interactive model, involving data reduction, display, and conclusion drawing.

RESULTS AND DISCUSSION

Institutional Profile: Sekolah Cendekia BAZNAS Cibungbulang

SCB Cibungbulang is a fully residential secondary school (grades 7-12 equivalent) operating under BAZNAS, Indonesia's national zakat management body. Established to provide high-quality education to orphaned and economically disadvantaged youth, SCB maintains a student population of approximately 180 boarding students, all receiving fully

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subsidized education, housing, meals, and learning materials. The institution employs 24 teaching staff and 12 administrative and support personnel.

Operationally, SCB is funded almost entirely through BAZNAS zakat disbursements and philanthropic donations, with no student tuition fees charged. This funding structure, while mission-aligned, creates significant financial vulnerability, any fluctuation in zakat collection or donor engagement can directly affect institutional operations. Institution management identified the development of self-sustaining productive units as a priority strategic goal, with agriculture and aquaculture identified as particularly suitable due to available land area (approximately 1.2 hectares) and the institution's alignment with practical skills education.

Mushroom House Construction and Substrate Preparation

A dedicated mushroom house (kumbung) measuring 4 × 6 m (24 m²) was constructed adjacent to the school's main building complex using locally available bamboo framing, polypropylene sheeting, and shade netting. The structure incorporated four-tier bamboo shelving units capable of accommodating 250 baglogs, a misting system for humidity control, and ventilation panels to manage CO_2 accumulation during fruiting. Total construction cost was approximately IDR 3,500,000, representing a one-time capital investment.

Baglog substrate was formulated from locally sourced sengon (Albizia chinensis) sawdust (80%), rice bran or bekatul (15%), agricultural lime/$CaCO_3$ (2%), gypsum/$CaSO_4$ (1%), and clean water added to achieve a substrate moisture content of 60-65%. This formulation aligns with established protocols for oyster mushroom cultivation in Indonesian tropical conditions (Laagu et al., 2024; Widyastuti & Tjokrokusumo, 2008). Substrate mixture was packed into 1.5 kg-capacity polypropylene bags, fitted with polypropylene ring necks, and sterilized in a drum steamer at 95-100°C for 8 hours. Following cooling to ambient temperature, baglogs were inoculated with F2-generation Pleurotus ostreatus spawn under semi-sterile conditions in a designated inoculation room.

Cultivation Outcomes and Productivity Analysis

A total of 200 baglogs were successfully incubated and transferred to the kumbung following full mycelial colonization (20-25 days). Environmental conditions within the kumbung were maintained within optimal ranges throughout the study period: temperature 24-27°C (mean 25.3 ± 0.8°C), relative humidity 82-93% (mean 87.4 ± 2.1%),

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and CO_2 concentration below 1,000 ppm during fruiting phases. Pin head formation was observed 3-5 days following kumbung transfer, and first harvest occurred 18-22 days post-transfer.

Table 1. Oyster Mushroom Production Results Per Harvest Cycle at SCB Cibungbulang (2025)

Harvest Cycle	Number of Baglogs	Mean Yield (kg/baglog)	Total Production (kg)
Cycle 1	200	0.82	164.0
Cycle 2	200	1.05	210.0
Cycle 3	200	1.18	236.0
Mean	**200**	**1.02**	**203.3**

As presented in Table 1, mean yield per baglog increased progressively across harvest cycles: 0.82 kg in Cycle 1, 1.05 kg in Cycle 2, and 1.18 kg in Cycle 3, yielding a three-cycle mean of 1.02 kg per baglog. This progressive improvement reflects the learning curve effect documented by Heryadi et al. (2021), wherein cultivation teams refine environmental management and harvesting techniques across successive cycles. Total program production reached 610 kg across three cycles, with Cycle 3 alone generating 236 kg from 200 baglogs, a 44% improvement over Cycle 1 output. These yields are consistent with benchmarks reported for West Java lowland conditions (Heryadi et al., 2021) and confirm the technical feasibility of the cultivation model.

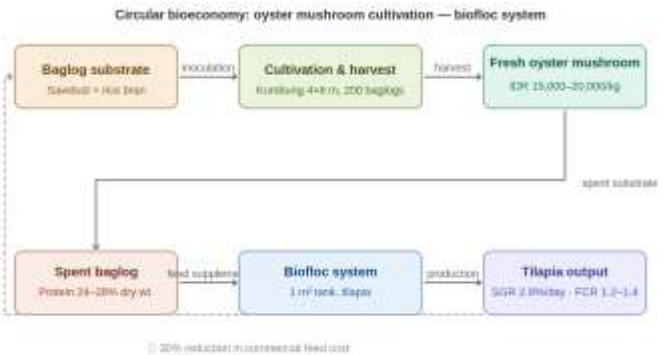


Figure 1. Circular Bioeconomy Model: Oyster Mushroom Cultivation and Biofloc System Integration at SCB Cibungbulang

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Financial Feasibility Analysis

Financial analysis was conducted using prevailing oyster mushroom market prices in Bogor (IDR 15,000-20,000 per kg fresh weight) and recorded production costs for the 200-baglog scale operation. Production costs per cycle included: substrate materials (sawdust, rice bran, lime, gypsum) at IDR 350,000; spawn at IDR 200,000; utilities (steamer fuel, misting water, electricity) at IDR 150,000; and packaging and miscellaneous at IDR 100,000-300,000. Total cost per cycle was estimated at IDR 800,000-1,000,000.

Table 2. Financial Feasibility Analysis of Oyster Mushroom Cultivation (200 Baglogs Per Cycle)

Financial Item	Amount (IDR)	Notes
Gross Revenue (low estimate)	Rp 3,045,000	203.3 kg x Rp 15,000
Gross Revenue (high estimate)	Rp 4,066,000	203.3 kg x Rp 20,000
Total Production Cost	Rp 800,000–1,000,000	Media, utilities, labour
Net Profit Per Cycle	**Rp 2,000,000–3,000,000**	**4–5 cycles/year**
Projected Annual Revenue	Rp 8,000,000–15,000,000	Conservative estimate

As shown in Table 2, the program generates a projected net profit of IDR 2,000,000-3,000,000 per cycle at 200 baglogs, with an anticipated 4-5 cycles producible per year given Bogor's favorable climate. This translates to a projected annual net income of IDR 8,000,000-15,000,000 from the current 200-baglog scale. While modest relative to SCB's total operational budget, this contribution is significant as a proof-of-concept and foundational revenue stream. Institutional management confirmed that scaling the operation to 1,000-2,000 baglogs within three years, a feasible expansion given available kumbung space — could generate annual revenues sufficient to offset 15-25% of non-BAZNAS operational expenditures. The payback period for initial capital investment

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(kumbung construction: IDR 3,500,000; equipment: IDR 1,500,000; total: IDR 5,000,000) is estimated at 2-3 harvest cycles, representing an exceptionally short return horizon for an agribusiness investment.

Circular Bioeconomy Integration: Spent Baglog in Biofloc Aquaculture

Following each harvest cycle, spent baglog substrate, the post-production residue retaining residual mycelium, partially degraded lignocellulosic material, and fungal metabolites, was collected and processed for biofloc feed supplementation. Proximate analysis of the spent substrate confirmed crude protein content of 24.3-27.8% (dry weight basis), crude fiber 28.4%, and moisture content of 68-72% when freshly harvested. These nutritional characteristics are consistent with values reported in the literature for Pleurotus ostreatus SMS (Widyastuti & Tjokrokusumo, 2008).

A pilot biofloc system was established in a 1 m³ polyethylene tank equipped with continuous aeration (dissolved oxygen maintained at ≥4.5 mg/L), stocked with 80 tilapia fingerlings (Oreochromis niloticus) at an initial mean weight of 8.5 g. Carbon-to-nitrogen ratio in the biofloc system was maintained at 15:1 through addition of molasses as a supplementary carbon source. Spent baglog material, dried to 12-15% moisture content and ground to particle sizes below 2 mm, was incorporated at 20% of daily feed volume, alongside commercial pellet feed (protein content 28%).

Table 3. Biofloc System Performance Indicators (Tilapia, 60-Day Trial)

Indicator	Value
Specific Growth Rate (SGR)	2.8% per day
Feed Conversion Ratio (FCR)	1.2–1.4
Survival Rate	88.3%
Reduction in Commercial Feed Cost	30%
Tank Volume	1 m³
Spent Baglog Supplement Ratio	20% of total feed

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Results of the 60-day biofloc trial (Table 3) demonstrated strong productive performance. Tilapia achieved a Specific Growth Rate (SGR) of 2.8% per day and a Feed Conversion Ratio (FCR) of 1.2-1.4, values that compare favorably with FCR benchmarks of 1.2-1.6 reported for tilapia under standard BFT conditions by Kurniaji et al. (2021). Survival rate reached 88.3%, consistent with typical BFT mortality rates for tilapia under well-managed conditions. The incorporation of spent baglog at 20% of feed volume reduced commercial feed expenditure by approximately 30%, demonstrating meaningful cost-reduction potential at production scale. These findings confirm the technical viability of the SMS-biofloc integration and validate the circular bioeconomy model illustrated in Figure 1.

Social Impact and Human Resource Capacity Development

Knowledge assessment results revealed a mean pre-test score of 45.3 (SD = 6.8) and post-test score of 81.6 (SD = 5.2) among student participants (n=30), representing a statistically meaningful improvement of 80.1%. Scores increased across all knowledge domains assessed, with the greatest gains observed in biofloc system principles (pre: 38.2, post: 79.4) and circular bioeconomy concepts (pre: 36.7, post: 78.9) — areas with which participants had no prior familiarity. Mushroom cultivation techniques showed more modest pre-to-post gains (pre: 52.1, post: 83.7), reflecting some pre-existing general awareness of mushroom farming within the community.

Qualitative findings from FGDs and interviews revealed several dimensions of impact beyond knowledge acquisition. Participants reported increased confidence in managing biological production systems, greater awareness of resource efficiency and environmental sustainability, and a strengthened sense of institutional pride and agency. Eight of 30 student participants (27%) reported having discussed program concepts with family members, and 12 participants (40%) developed written business plans for home-scale oyster mushroom enterprises under facilitator guidance, indicating strong intent to apply program learning beyond the institutional context.

Institutional management reported that the program had shifted internal attitudes toward productive enterprise development. Prior to the program, cultivation activities were perceived as ancillary and non-academic; following program completion, school leadership formally incorporated mushroom cultivation and integrated bioeconomy concepts into the school's extracurricular curriculum. This institutionalization represents a significant systemic outcome, ensuring program knowledge and practices persist beyond the study period.

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Faculty participants reported enhanced teaching confidence in applied science and agribusiness subjects, with two teachers indicating intent to incorporate mushroom cultivation practicals into biology and entrepreneurship lessons in the 2025-2026 academic year. These multiplier effects at the institutional level suggest that the program's impact significantly exceeds its direct production outcomes, positioning SCB Cibungbulang as a potential demonstration site for similar institutions across West Java.

CONCLUSION

This study demonstrates that oyster mushroom (Pleurotus ostreatus) cultivation, integrated with circular bioeconomy principles through spent baglog utilization in a tilapia biofloc system, constitutes a technically viable, financially feasible, and educationally impactful model for pesantren-based economic empowerment. The program at SCB Cibungbulang achieved three core objectives: (1) consistent and improving cultivation productivity (mean 1.02 kg/baglog/cycle across three cycles, peaking at 1.18 kg in Cycle 3); (2) positive financial returns with a payback period of 2-3 cycles and projected annual net income of IDR 8,000,000-15,000,000 at the pilot scale; and (3) successful circular bioeconomy integration, with spent baglog supplementation in biofloc tilapia culture achieving SGR 2.8%/day, FCR 1.2-1.4, and 30% commercial feed cost reduction.

Beyond productive outcomes, the program generated substantial human capital development, with student knowledge scores improving by 80.1%, 40% of participants developing entrepreneurial business plans, and institutional management formally incorporating integrated bioeconomy education into the school curriculum. These outcomes collectively affirm that the program model is not merely a short-term intervention but a foundation for systemic institutional transformation.

Three factors were identified as critical to program success: the favorable year-round growing conditions of the Bogor region; the participatory approach that fostered ownership, motivation, and skill internalization among all stakeholder groups; and the sustained technical mentorship provided by the university research team across all program phases. These factors should be explicitly incorporated in adaptation efforts by other institutions.

Future research and development directions include: (1) scale-up trials at 1,000-2,000 baglog capacity with full financial feasibility modeling; (2) optimization of SMS-biofloc feed formulations including proximate analysis at multiple SMS incorporation rates; (3) development of value-added mushroom products (dried oyster mushrooms, mushroom-based food products) to enhance revenue per kilogram of production; (4)

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establishment of digital marketing channels to expand market reach beyond the immediate Cibungbulang area; and (5) longitudinal follow-up of student participants to assess entrepreneurial outcomes and income impacts post-graduation.

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