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Empowering Whiteleg Shrimp Farmers through Rice Husk Biofertilizer Innovation

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ABSTRAK

Kegiatan pengabdian ini bertujuan meningkatkan kapasitas teknis pembudidaya udang vaname di Kabupaten Bombana, Provinsi Sulawesi Tenggara, melalui produksi biofertilizer berbasis sekam padi sebagai input pendukung budidaya. Kegiatan menggunakan pendekatan partisipatif-edukatif melalui identifikasi kebutuhan, pemetaan bahan lokal, sosialisasi, pelatihan, praktik fermentasi, pendampingan, dan evaluasi reflektif. Kebaruan model pemberdayaan ini terletak pada integrasi limbah pertanian lokal dengan kebutuhan operasional tambak, disertai alih keterampilan produksi, pengendalian mutu sederhana, penyusunan SOP, dan rencana replikasi berbasis komunitas. Hasil kegiatan menunjukkan peningkatan pemahaman terhadap pemanfaatan sekam padi sebagai bahan dasar biofertilizer, tahapan fermentasi, pengendalian mutu sederhana, serta peluang penerapannya dalam sistem usaha tambak berbasis ekonomi sirkular. Peningkatan kapasitas tersebut terlihat pada aspek pengetahuan, komitmen untuk menerapkan produksi biofertilizer secara mandiri pada aspek pengaturan kelembaban, bioaktivator, fermentasi, kematangan bahan, dan pemantauan mutu sederhana. Valorisasi sekam padi dengan model pemberdayaan ini berpotensi meningkatkan efisiensi pemanfaatan sumber daya lokal, mengurangi ketergantungan terhadap input eksternal, dan memperkuat kesiapan operasional budidaya udang yang lebih berkelanjutan.

ABSTRACT

This community engagement program aimed to enhance the technical capacity of whiteleg shrimp farmers in Bombana Regency, Southeast Sulawesi Province, through the production of rice husk-based biofertilizer as a supporting input for aquaculture practices. The program adopted a participatory-educational approach comprising needs assessment, local material mapping, socialization, training, fermentation practice, mentoring, and reflective evaluation. The novelty of this empowerment model lies in the integration of local agricultural residues with the operational needs of shrimp ponds, supported by production skill transfer, simple quality control, standard operating procedure development, and community-based replication planning. The results showed an improvement in farmers' understanding of rice husk utilization as a raw material for biofertilizer, fermentation stages, simple quality control, and its potential application within a circular economy-based pond farming system. This capacity improvement was reflected in the knowledge aspect and in farmers' commitment to independently apply biofertilizer production, particularly in moisture adjustment, bioactivator application, fermentation control, material maturity assessment, and simple quality monitoring. Rice husk valorization through this empowerment model has the potential to improve the efficiency of local resource utilization, reduce dependence on external inputs, and strengthen the operational readiness of more sustainable shrimp farming.

INTRODUCTION

Whiteleg shrimp (*Litopenaeus vannamei*) is a strategic aquaculture commodity due to its high economic value, relatively short production cycle, and continuously growing market demand. However, increased farming intensity often poses challenges related to water quality management, organic matter accumulation, production input requirements, and the declining carrying capacity of pond environments. These conditions require community engagement innovations that focus not only on production improvement but also on strengthening farmers' capacity to manage local resources efficiently and sustainably.

In coastal areas and rice-producing centers, rice husk is an abundant agricultural residue that is often underutilized. Rice husk can function as an organic amendment, microbial carrier, or biofertilizer component through controlled fermentation and composting processes. Recent studies have shown that agricultural residues can be converted into value-added biofertilizers and bioinputs that support circular economy practices, reduce waste burdens, and improve the functionality of organic matter in food production systems (Bibi et al., 2023; Kurniawan et al., 2025; Orlandella & Fiore, 2025; Rocha et al., 2024).

Meanwhile, at the farmer level, cultivation patterns generally remain focused on direct operational activities, such as pond preparation, feeding, water exchange, disease prevention, and the use of commercial inputs. Although these practices are important for maintaining production continuity, the utilization of local biomass resources has not yet been systematically integrated into shrimp-farming systems.

The use of rice husk as a biofertilizer material is highly relevant for empowering whiteleg shrimp farmers because it can facilitate the integration of agricultural and aquaculture sectors. This approach is aligned with the concept of a biocircular economy in aquaculture, in which waste streams and local organic materials are valorized into production inputs or environmental management resources. In whiteleg shrimp farming, effective organic matter and water quality management are essential because organic waste and stocking density can influence the stability of the rearing medium, shrimp health, and growth performance (Mohammadi et al., 2023; Paena et al., 2023).

This community engagement program was designed to address the needs of the partner group, particularly the need for practical technical knowledge in processing rice husk into a simple biofertilizer that can support more environmentally responsible aquaculture practices. The program also positioned the partner group as the main actor through a participatory-educational approach, enabling technology transfer through hands-on practice, discussion, and field mentoring. Accordingly, the intervention was not limited to information delivery but was directed toward building operational competence, strengthening commitment to sustainability, and creating opportunities for replication among other shrimp farmers in Bombana Regency.

The objective of this community engagement program was to improve the partner group's knowledge and skills in producing rice husk-based biofertilizer, develop a simple standard operating procedure, and introduce a model for utilizing agricultural residues as a supporting component of sustainable whiteleg shrimp farming. This article presents the implementation process, activity achievements, technical discussion, and future development directions for sustaining the empowerment model.

METHODS

This community engagement program was implemented with a partner group of whiteleg shrimp (*Litopenaeus vannamei*) farmers in Bombana Regency, Southeast Sulawesi, Indonesia. The main partner was a local shrimp-farming group that needed to strengthen its technical capacity in utilizing local organic materials as supporting inputs for aquaculture practices. This program adopted a participatory-educational approach designed to enhance the partner group's technical capacity through collaborative learning, hands-on practice, discussion, and field-based mentoring.

The participatory-educational approach was selected because the program was not merely intended to deliver information, but also to encourage the active involvement of the partner group in identifying needs, mapping the availability of rice husk, understanding the stages of biofertilizer production, and developing a follow-up plan suited to local pond-farming conditions. Thus, the partner group was positioned as the main actor in the learning process rather than merely as a recipient of technology.

The program was organized into five main stages. The first stage was preparation, which included identifying partner needs, mapping the availability of rice husk, preparing training materials, and arranging the tools and materials required for biofertilizer production. The second stage was socialization, which involved explaining the program objectives, introducing the benefits of rice husk utilization, and discussing opportunities to integrate agricultural residues with whiteleg shrimp farming systems. The third stage was technical training, which provided an understanding of material sorting, drying, simple chopping or grinding, moisture adjustment, bioactivator addition, fermentation techniques, material turning, maturity assessment, and appropriate packaging and storage methods.

The fourth stage focused on demonstration and production practice. At this stage, the partner group was directly involved in preparing mixtures of rice husk and supporting organic materials, adjusting moisture content, carrying out the fermentation process, and identifying material maturity indicators, such as changes in odor, color, temperature, and texture. The fifth stage consisted of mentoring and evaluation. Evaluation was conducted through participatory observation, reflective discussion, identification of constraints, and collaborative development of a follow-up plan to ensure that the partner group was prepared to apply the introduced technology independently.

Mentoring was conducted several days before the core activity, including the preparation stage, initial socialization, and preparation of the required tools and materials. The core activity focused on monitoring the biofertilizer production process, starting from material mixing, moisture adjustment, material turning, observation of physical changes during fermentation, and initial assessment of product maturity. When the activity duration did not cover the entire fermentation cycle, mentoring was directed toward strengthening procedural understanding and developing a follow-up plan so that the partner group could continue the production process independently after the community engagement program ended.

The improvement in the partner group's knowledge was evaluated based on their ability to explain the function of rice husk as a biofertilizer material, the role of bioactivators, the stages of fermentation, material maturity indicators, and the potential application of biofertilizer in a circular economy-based pond-farming system. Meanwhile, skill improvement was assessed based on the partner group's ability to select materials, adjust moisture content, mix organic materials and bioactivators, turn the materials, recognize physical maturity indicators, and understand the principles of product packaging and storage.

The evaluation instruments used in this program included participatory observation, reflective discussion, question-and-answer sessions during training, and a simple checklist to assess mastery of the production stages. The criteria for assessing the partner group's capacity were qualitatively categorized into three levels: not yet understanding, understanding with assistance, and being able to explain or practice independently. These categories were used to assess changes in the partner group's knowledge and skills after participating in socialization, training, and production practice.

Program success was determined based on several indicators, including the attendance and active participation of the partner group in each stage of the activity, their ability to explain the stages of biofertilizer production, their involvement in material mixing and fermentation practice, the development of a simple standard operating procedure, the formation of an initial product or prototype of rice husk-based biofertilizer, the identification of technical constraints during the production process, and the presence of a follow-up commitment for independent production and limited replication among shrimp-farming communities. The application of biofertilizer in shrimp ponds has not yet been quantitatively evaluated; therefore, program success in this activity was focused on improving technical capacity, strengthening operational readiness, and establishing an empowerment model based on the utilization of local agricultural residues.

Table 1. Implementation Stages of the Rice Husk-Based Biofertilizer Production

Stages	Main Activities	Process Outputs	Achievement Indicators
Preparation	Partner coordination, raw material mapping, and training material development	Inventory of tools, materials, and technical requirements	The partner group understood the activity plan and the roles of each party

Socialization	Introduction to the circular economy and the benefits of rice husk utilization	Shared understanding of the activity objectives and partner roles	The partner group accepted the program and actively participated in discussions
Training	Delivery of materials on formulation, fermentation, packaging, and simple quality control	Draft of a simple standard operating procedure for biofertilizer production	The partner group was able to explain the basic stages of biofertilizer production
Production Practice	Material mixing, bioactivator application, moisture adjustment, and initial fermentation	Initial product or prototype of rice husk-based biofertilizer	The partner group was directly involved in production practice and recognized the physical indicators of material maturity
Mentoring	Monitoring of the fermentation process and physical quality attributes	Notes on constraints and process improvements	The partner group was able to understand simple improvements related to moisture, aeration, odor, texture, color, and material temperature
Evaluation	Reflection on achievements, identification of constraints, and follow-up planning	Follow-up plan for independent production	The partner group demonstrated commitment to continuing production and limited replication

RESULTS AND DISCUSSION

Preparation Stage

The preparation stage was carried out through coordination between the implementation team and the whiteleg shrimp farming partner group in Bombana Regency, Southeast Sulawesi. At this stage, the team identified the needs of the partners, mapped the availability of rice husks, prepared training materials, and determined the equipment and materials required for biofertilizer production. The needs assessment revealed that the partners required a technology that is simple, easy to understand, low-cost, and applicable at the community level without dependence on complex laboratory equipment. These findings indicate that technological simplicity is a critical factor influencing the acceptance of innovation by the partners. In community empowerment programs, technologies that utilize locally available materials, require minimal investment, and can be easily replicated tend to have higher adoption potential than technologies requiring specialized facilities or intensive technical support. Rocha et al. (2024) demonstrated that bioinput development based on the fermentation of locally available organic materials is more readily implemented at the community level because the process is relatively simple and can be adapted to local conditions.

The availability of rice husks was a major supporting factor in this program. In areas where agricultural and coastal activities coexist, rice husks are relatively abundant as an agricultural residue. However, prior to the implementation of this activity, rice husks had not been systematically utilized as a supporting input in shrimp farming systems. Instead, they were generally regarded as low-value waste rather than as a biomass resource that could be converted into biofertilizer through controlled fermentation processes. This situation highlights a gap between the potential of local resources and the technical capacity of community members to transform them into value-added products. These findings suggest that the primary challenge lies not in the availability of raw materials but in the underutilization of local biomass resources. Similar observations were reported by Orlandella and Fiore (2025), who found that many agricultural residues remain underutilized despite their technical potential for conversion into biofertilizers and other value-added products. Therefore, the training activities in this program served as a bridge between the availability of local resources and the community's capacity to process them productively.

From a scientific perspective, the potential of rice husks as a biofertilizer component can be explained by their lightweight, porous structure and compatibility as both an organic support material and a microbial carrier medium. Previous studies have shown that rice husks, particularly when fermented or combined with microbial agents, can contribute to improved organic matter characteristics and humification processes. Li et al. (2024) demonstrated that the application of microbial agents to lignocellulosic biomass enhances nitrogen transformation and accelerates humification during fermentation. These findings were further supported by Zhai et al. (2025), who reported that the combination of decomposer microorganisms improves lignin degradation and humic substance formation in mixtures of rice husks and other organic materials. Sarin et al. (2024) also found that fermented rice husks have a greater capacity to support plant growth than untreated rice husks. Therefore, the utilization of rice husks in this activity should be viewed not only as a waste reduction strategy but also as a process of valorizing agricultural residues into materials that support more circular food production systems.

Figure 1. Preparation of activities and coordination between the implementing team and the shrimp-farming partner

Socialization Stage

The socialization stage was designed to build the partners' initial understanding of the program objectives, the benefits of rice husk utilization, and the potential integration of agricultural residues into whiteleg shrimp farming operations. During this stage, participants were introduced to the concept of the circular economy, which views organic waste as a resource that can be processed, reused, and assigned added value. This approach is important because changes in waste management behavior require not only technical knowledge but also a shift in perceptions toward materials that have traditionally been considered worthless. The socialization activities revealed that most participants began to view rice husks not as waste that should be discarded but as a resource with potential applications in aquaculture practices. This shift in perception is significant because it represents an early stage in the adoption of innovations based on local resources. Chen et al. (2024) explained that zero-waste and waste valorization approaches can transform waste management paradigms from disposal-oriented systems to resource recovery systems. Likewise, Kurniawan et al. (2025) emphasized that implementing bio-circular economy principles in the aquaculture sector requires a change in public perception regarding organic residues as potential raw materials for value-added products.

Discussions during the socialization sessions indicated that the partners preferred technologies that are practical, inexpensive, easy to replicate, and do not impose excessive operational burdens. This preference aligns with the characteristics of community-scale farmers, who are generally more likely to adopt innovations when the technologies match local resource availability, can be learned through hands-on practice, and do not require substantial investment. Accordingly, the socialization materials were delivered in simple technical language and included examples of challenges that may arise during fermentation, such as excessive moisture, unpleasant odors, uneven fermentation, unstable temperatures, and improper storage. These findings suggest that technology acceptance at the community level is strongly influenced by the compatibility between the proposed technology and the users' capabilities. Kurniawan et al. (2025) emphasized that the effective utilization of local resources and the enhancement of community capacity to transform residues into valuable products are key factors in the successful implementation of bio-circular economy principles in aquaculture. Therefore, the socialization approach adopted in this program not only conveyed information but also reduced technical barriers that could hinder technology adoption by the partners.

Field observations during the socialization stage indicated an increase in the partners' conceptual understanding of the relationship between rice husk utilization, organic waste management, and its potential application in circular-economy-based aquaculture systems. This improvement was assessed through question-and-answer sessions, reflective discussions, and the participants' ability to identify the benefits of rice husks as a biofertilizer material. Although not measured using quantitative instruments, participatory evaluations revealed that participants began to understand that successful biofertilizer production depends not only on raw material availability but also on balanced composition, moisture regulation, aeration, and fermentation duration. This understanding is scientifically supported because numerous studies have demonstrated that fermentation parameters are critical determinants of final product quality. Huang et al. (2023) showed that changes in composting conditions influence carbon and nitrogen dynamics, which contribute to the formation of more stable organic matter and determine the quality of the final product. Similar findings were reported by Zhang et al. (2024), who found that controlling fermentation conditions can accelerate organic matter maturation and improve compost quality. Consequently, the increased understanding of fermentation-related factors among the partners serves as an important indicator that the socialization activities not only enhanced general knowledge but also developed the technical understanding required to produce high-quality biofertilizers.

Training and Production Practice Stage

The training and production practice stage constituted the core component of the program because participants were not only provided with theoretical explanations but were also directly involved in the biofertilizer production process. The activities began with the selection of relatively clean rice husks, removal of coarse impurities, drying or conditioning of the materials, and mixing with supporting organic materials and bioactivators. Once the materials had been mixed, participants were introduced to the principles of moisture regulation, material turning, observation of physical changes during fermentation, and preliminary assessment of product maturity. Active involvement in every stage of production was essential because the fermentation process is strongly influenced by the initial characteristics of the substrate and the management practices applied throughout the process. Kalaiselvan et al. (2025) explained that the success of solid-state fermentation depends not only on the type of substrate used but also on moisture management, aeration, and the stability of the fermentation environment that supports microbial activity. Therefore, the training served not only as a means of transferring technical skills but also as a platform for introducing the scientific principles underlying biofertilizer production.

Figure 2. Practical Steps for Producing Biofertilizer from Rice Husk. No. 1 and 2: Mixing sliced banana stems with dry rice husk; No. 3: Mixing the bioactivator during the organic material fermentation process; No. 4: Applying the bioactivator to the organic material mixture.

The practical sessions demonstrated that participants were able to follow the basic production workflow, including material preparation, mixing, initial fermentation, packaging, and storage. This achievement was assessed through direct observation and simple checklists designed to evaluate participants' ability to perform each production step. Conceptually, the process introduced in this program is associated with solid-state fermentation, a bioconversion process in which solid organic materials are transformed into value-added products through microbial activity. The literature indicates that solid-state fermentation is widely used to convert agro-industrial waste into bioinputs, functional materials, and more stable organic products. Consequently, participation in the fermentation process provided not only practical experience but also an understanding that biofertilizer quality depends on process discipline rather than solely on the type of raw material used. These findings are scientifically supported because solid-state fermentation has been widely recognized as an efficient method for converting biomass into value-added products. Bibi et al. (2023) reported that solid-state fermentation technology can enhance the value of agro-industrial waste through microbial activity that induces physical, chemical, and biological transformations within the substrate. Furthermore, Mirsalami and Mirsalami (2024) demonstrated that rice husk fermentation using specific microorganisms can increase bioactive compound content and improve substrate characteristics compared with untreated materials. Therefore, the participants' ability to follow the fermentation procedures indicates that they began to understand that product quality is largely determined by process management rather than merely by the availability of raw materials.

Table 2. Achievements in Partner Capacity Aspects.

Capacity aspect	Baseline condition	Achievement after the activity	Evaluation method/ instrument	Assessment indicator/evidence
Raw-material knowledge	Rice husk was perceived as a low-value agricultural residue	The partner group understood the function of rice husk as a biofertilizer material and organic carrier	Question-and-answer session and reflective discussion	Participants were able to explain the function of rice husk as an organic carrier and biofertilizer material
Production skills	No simple production SOP was available	The partner group understood the workflow for production, turning, maturation	Participatory observation and production-stage checklist	Participants were able to follow the production workflow, including material selection, mixing, turning, and storage
Business sustainability	Agricultural residue utilization had not yet been connected to pond-farming activities	The partner group developed a follow-up plan for independent production and limited replication	Reflective discussion and follow-up planning	Participants expressed commitment to continue small-scale production and replicate the practice within the shrimp-farming community

Participants were also trained to recognize simple physical quality indicators, such as reduced unpleasant odors, darker coloration, a more friable texture, moderate moisture content, and relatively stable temperatures. These indicators were selected because they can be easily observed by farmers without laboratory equipment. The use of field-based indicators is particularly relevant in community empowerment programs because technologies that rely heavily on laboratory testing are often difficult to replicate among small-scale farming communities. Nevertheless, these physical indicators should be regarded as preliminary assessments rather than substitutes for laboratory analyses, especially if the product is to be further developed or applied on a wider scale in aquaculture systems. The use of these physical indicators has a scientific basis because changes in color, texture, temperature, and odor during fermentation reflect microbial activity and ongoing organic matter transformation. Huang et al. (2023) demonstrated that carbon and nitrogen dynamics during composting are closely associated with changes in physical characteristics, including odor reduction and increased material stability. Similar findings were reported by Temel (2023), who showed that the incorporation of rice husks into composting processes contributes to improved compost quality and accelerated material maturation. The study further indicated that improvements in compost quality during decomposition are generally accompanied by changes in physical characteristics that reflect increasing organic matter stability. Therefore, participants' ability to recognize these indicators represents an important achievement, as it enables them to conduct simple quality control independently before the product is used or further developed.

Table 2 shows that program achievements were linked to specific evaluation criteria and assessment methods. As a result, improvements in participant capacity could be tracked through clearly defined indicators, even though the results were not presented quantitatively. The use of question-and-answer sessions, practical observations, reflective discussions, and simple checklists enabled the implementation team to assess changes in participants' knowledge and skills in a more structured manner. This approach is appropriate for community-based empowerment programs because the primary focus is on enhancing capacity, operational readiness, and replication potential rather than experimentally testing product effectiveness. These findings indicate that practice-based learning effectively improved participants' technical understanding of biofertilizer production. Kalaiselvan et al. (2025) explained that successful fermentation processes depend heavily on users' understanding of production stages and their ability to control parameters that influence microbial activity during fermentation. Therefore, the observed increase in participant capacity serves as an important indicator that the empowerment model applied in this program has the potential to support the sustainable utilization of rice-husk-based biofertilizers at the community level.

Mentoring and Evaluation Stage

Mentoring was conducted to ensure that the partner group did not merely replicate procedures but also thoroughly comprehended the technical rationale underpinning each stage. During mentoring, the team underscored the paramount importance of maintaining simple yet informative records, including the date of mixing, turning frequency, odor condition, moisture condition, and visual observations. Such systematic records provide a robust basis for optimizing subsequent production cycles.

The evaluation results indicated that program success was supported by three main factors. First, the readily available raw material in the vicinity of the partner location rendered the technology highly feasible for sustained implementation. Second, the production process necessitated minimal investment in expensive equipment, thereby facilitating its adoption by small-scale farmers. Third, the activity's delivery through hands-on practice enabled the partner group to more clearly discern the intricate relationship among the fermentation process, product quality, and its potential application within shrimp farming systems.

The primary constraints identified included the time required to achieve material maturity, inherent variations in rice husk quality, and the necessity of establishing a new habit of diligent process recording. These constraints can be effectively addressed through continuous mentoring, the development of user-friendly control sheets, and repeated small-scale trials prior to broader application. Within the context of whiteleg shrimp farming, any application of biofertilizer must invariably be accompanied by rigorous water quality monitoring, particularly for parameters such as pH, dissolved oxygen, ammonia, and organic matter. This is crucial because shrimp performance is profoundly influenced by the stability of the rearing environment (Jing et al., 2025; Mohammadi et al., 2023; Paena et al., 2023).

Figure 3. Mentoring and Evaluation Activities for the Biofertilizer Production Process with Partners

Sustainability and Replication

Conceptually, this program demonstrates that shrimp farmer empowerment can be strengthened by integrating two local resources: agricultural residues and the technological needs supporting aquaculture. The utilization of rice husk as a biofertilizer material not only introduced novel knowledge to the partner group but also broadened the perspective that pond-farming sustainability can be robustly established through material efficiency, waste reduction, and locally based innovation. Studies on agricultural bioinputs consistently indicate that the fermentation and processing of organic residues can yield materials that effectively support sustainable agriculture and circular economy systems (Renganathan et al., 2024; Riddech et al., 2025; Rocha et al., 2024).

From the farmers' perspective, the primary benefit of the activity was the substantial improvement in technical capacity to independently produce supporting inputs. This enhanced autonomy is critically important because farmers frequently encounter fluctuations in input prices, limited access to technology, and the inherent risk of dependence on external products. With a simple standard operating procedure, the partner group can conduct repeated trials, adjust material composition, and develop production processes according to local conditions. Nevertheless, product development must continuously prioritize safety, ensure material maturity, and assess application suitability to prevent excessive organic loading in pond systems.

This activity also holds considerable potential for replication among other shrimp-farming communities situated in the coastal areas of Bombana Regency. Replication can be effectively facilitated through farmer-to-farmer training initiatives, small-scale demonstrations, and collaborative partnerships with universities for basic quality testing. Future activity enhancements should encompass comprehensive nutrient content analysis, rigorous microbiological testing, thorough application safety assessments, and pragmatic economic analysis to ascertain production cost efficiency. Through these strategic steps, rice husk-based biofertilizer can evolve beyond merely a training output to become a more structured supporting enterprise for sustainable shrimp farming.

Figure 4. Fermentation process of rice husk-based organic materials for biofertilizer production.

CONCLUSIONS

This community engagement program on rice husk-based biofertilizer production for whiteleg shrimp farmers in Bombana Regency enhanced the partner group's knowledge and skills in utilizing agricultural residues as supporting inputs for fostering more sustainable aquaculture practices. Structured across distinct stages of preparation, socialization, technical training, hands-on production, mentoring, and reflective evaluation, the activity fostered a systematic technical understanding of material formulation, fermentation processes, fundamental quality control, and strategic planning for independent production. This model demonstrates considerable potential as a circular-economy-based empowerment strategy, effectively bridging the local availability of rice husk with the imperative for innovation in whiteleg shrimp farming. To ensure the safe, measurable, and economically beneficial application of biofertilizer for farmers, the activity warrants continued efforts, including rigorous product quality testing, water quality monitoring, and facilitated replication. Given its reliance on locally available agricultural residues, low-cost production process, and community-based implementation approach, this model has strong potential for replication in other shrimp-farming communities with similar resource conditions. Furthermore, strengthening local production capacity and integrating biofertilizer utilization into routine farm management practices could support the long-term sustainability of the initiative while contributing to waste reduction, resource efficiency, and the broader transition toward a bio-circular aquaculture system.

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