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Community Empowerment of Alue Keurinyai Village Through Enhancing Economic Value of Rice Husk and Sawdust Waste Using Double-Fire Pipe Retort Kiln Technology

Kurniawan[1], Adi Setiawan[2], Asnawi[3], Shaki Saptiadi Putra[3], Rizka Mulyawan[4], Reza Putra[5], Muhammad[5], Nurul Islami[5*]

[1] Student of Mechanical Engineering Department, Malikussaleh University, Indonesia
[2] Master Program of Renewable Energy Egineering, Malikussaleh University, Indonesia
[3] Department of Mechanical Engineering, Malikussaleh University, Indonesia
[4] Department of Chemical Engineering, Malikussaleh University, Indonesia
[5] Department of Material Engineering, Malikussaleh University, Indonesia

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ABSTRACT

The utilization of retort kiln by Smart Minapadi program was implemented in Alue Keurinyai Village to address low agricultural productivity resulting from conventional cultivation practices, high pest infestations, dependence on chemical inputs, and the underutilization of biomass waste. The village also lacked modern agricultural technologies such as the Internet of Things (IoT) and pyrolysis technology, which meant sustainable agricultural innovation had not yet been effectively realized. This program was designed to introduce IoT-based pest control technology, and waste processing into biochar and liquid smoke as an environmentally friendly, efficient, and sustainability-oriented solution. The program aimed to achieve ecological and sustainable agriculture, enhance farmers' capacity and digital literacy, promote the use of renewable energy, and strengthen agricultural waste management through technological innovation. In addition, the program sought to introduce digital transformation within the village community so that residents could independently adopt modern agricultural practices. The implementation method comprised preparation, implementation, monitoring, and evaluation stages, carried out through a participatory approach. During the preparation stage, the team conducted a land survey, program socialization, and preparation of facilities, including IoT devices and a pyrolysis machine. The implementation stage included applying the minapadi system on a 400 m² pilot plot, using solar-powered IoT pest repellent devices, producing biochar and liquid smoke through pyrolysis, and providing intensive training to farmers, the Farmer Women's Group (KWT), youth, and village residents. Monitoring and evaluation were carried out through observation of plant growth, IoT effectiveness, biochar use, harvest yield analysis, and group discussions. This program provides a strong foundation for the sustainability of modern agriculture in Alue Keurinyai Village through the synergy of technology, community empowerment, and responsible environmental management.

1. Introduction

Indonesia is the most populous country in Southeast Asia and has one of the fastest growing economies among the G20 countries. Therefore, energy demand continues to increase in line with population growth, urbanization, and economic development. The main energy sources in Indonesia

**Corresponding author.*
E-mail address: nurulislami@unimal.ac.id
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are still dominated by fossil fuels, such as petroleum, natural gas, and coal. In an effort to support economic decarbonization, the Indonesian government is committed to reducing greenhouse gas (GHG) emissions by 29% compared to the business as usual scenario by 2030, as stated in its Nationally Determined Contribution (NDC) submitted to the UNFCCC in 2016 (Sharma et al., 2018).

The increasing scarcity of fossil fuel resources demands anticipatory efforts through the development of alternative energy sources, considering that global data shows that world fossil fuel consumption will reach a record high of 505 EJ in 2024, with oil consumption reaching 100 million barrels per day for the first time, while the world's proven oil reserves are estimated to only be sufficient for around 57 years based on current production rates, and fossil fuels still dominate 81.5% of total global primary energy, so that pressure on its availability in the future is becoming increasingly real (Worldometer, 2025).

One of the alternative energy sources that is being developed to anticipate this is biomass derived from agricultural waste, with potential energy reserves of 434,000 GW or the equivalent of 225 million barrels of petroleum, however, biomass from agricultural and forestry waste is generally still considered to have no use value and is often simply thrown away, thus potentially causing negative impacts on the environment (Wulandari, 2019).

Rice husk is a lignocellulosic biomass derived from agricultural byproducts; every 100 kg of unhusked rice produced produces approximately 20 kg of rice husk. Lignocellulosic biomass from the agricultural sector is composed of approximately 10-25% lignin, 20-30% hemicellulose, and 40-50% cellulose (Malik & Kumar, 2024). On the other hand, sawdust waste is a major by-product of the wood processing industry which is generally still burned directly or dumped into rivers without adequate recycling, even though it has a chemical composition rich in lignin, cellulose, and hemicellulose so it has the potential to be converted into valuable materials such as activated carbon (Suharti et al., 2021).

Several previous studies have examined the single pyrolysis of rice husks and sawdust waste separately to produce biochar and bio-oil (Suharti et al., 2021). However, studies that specifically examine the co-pyrolysis of a mixture of these two biomasses, especially with systematic variations in the mixture ratio and using a double-fire tube retort kiln reactor, are still limited. Co-pyrolysis of two raw materials allows for synergistic interactions between the materials, where the products produced by each material can react with each other so that the final product, both in terms of chemical composition, quantity, and quality, can be significantly different compared to the sum of the pyrolysis results of the two materials separately (Usino et al., 2021).

Based on the description, this study aims to analyze the effect of variations in the mixture ratio of rice husk and sawdust waste on the characteristics of co-pyrolysis products using a double-fire tube retort kiln, and to determine the optimal mixture ratio based on the evaluation of proximate analysis parameters, calorific value, and physical characteristics of bio-oil. The results of this study are expected to contribute to the development of sustainable biomass conversion technology and support the utilization of agricultural and wood industry waste as renewable energy sources in Indonesia (Basu, 2013).

2. Methodology

2.1 Materials and Equipment

The feedstock consisted of rice husk and sawdust mixed at a 50:50 mass ratio with a total initial mass of 5kg. The main equipment was a double-piping retort kiln equipped with a heating system, temperature measurement system, and condenser for recovering liquid products. Biochar characterization included moisture, ash, volatile matter, and fixed carbon. Rice husks and sawdust waste can be seen in figure 1.

(a) (b)

Fig. 1. (a) Rice husk (b) Saw dust

2.2 Experimental Procedure

The prepared rice husk and sawdust were mixed at a 50:50 ratio and placed into the retort. The reactor was heated until the operating temperature of 320°C was reached. Temperature was monitored throughout the process until the biomass decomposition process was completed. Vapors generated during co-pyrolysis were directed through the condenser to recover bio-oil, while the remaining gas was treated as the non-condensable fraction. The solid residue was collected as biochar. Each product was weighed to determine its yield.

2.3 Data Analysis

Product yield was determined from the ratio of product mass to initial biomass mass. Biochar quality was evaluated using proximate analysis consisting of moisture, ash, volatile matter, and fixed carbon. Fixed carbon was calculated as 100% minus the sum of moisture, ash, and volatile matter. Bio-oil density was determined using a pycnometer, while viscosity and specific gravity were obtained from the corresponding measurements.

2.4 Community Empowerment Steps

Location and Time. The community service activity was carried out in Alue Keurinyai Village, Banda Baro Subdistrict, North Aceh Regency, from July to November 2025.

Target Audience. The primary target audience comprised 10 members of the Alue Keurinyai Village farmer group aged 25–35 who were actively engaged in rice cultivation and willing to participate in the training and technology trials. In addition, village officials and agricultural extension workers from the Agricultural Extension Center (BPP) were involved as technical partners for implementation assistance and field-result validation.

Service Method. The activity employed a community-based participatory approach that emphasized the community's active involvement at every stage, from planning and implementation to evaluation. This approach was chosen because farmers' problems are not only technical but also involve social, institutional, and behavioral aspects; collaboration among the implementation team, farmer group, village government, and BPP was therefore needed to ensure program sustainability. Under this scheme, the community was positioned as a partner, as well as the implementer and guardian of the Smart Minapadi program's sustainability.

This service activity was designed using several complementary methods. Broadly, the series of activities focused on three main activities, namely:

1. Preparation and Institutional Strengthening Stage

The preparation stage began with a field survey and hearings with the Geuchik (village head), the Agriculture Office, the Agricultural Extension Center (BPP), and the farmer group. At this stage, problem mapping was carried out through field observation, initial interviews, and group discussions to identify the main issues, including declining productivity, plant pest organism (OPT) attacks, soil degradation, and agricultural waste management.

2. Technology Implementation

Stage Implementation was carried out on pilot plots belonging to partner farmers using a co-creation approach, in which the technology was designed and applied together with the farmers.

3. Results

3.1 Experimental Results

After the reactor reached the nominal operating temperature of 320°C, the temperature continued to fluctuate around the operating point. This indicates that the reactor operated close to the intended temperature during the co-pyrolysis process, although the temperature was not completely constant. The fluctuation is associated with heat transfer within the reactor, heating conditions, and the release of volatile compounds during biomass decomposition. The temperature profile image can be seen in Figure 2.

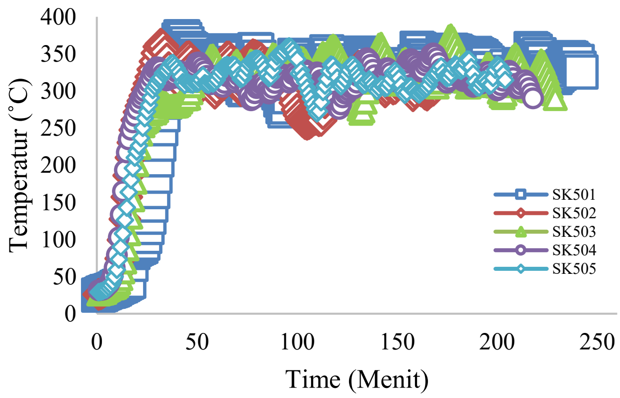

Fig. 2. temperature profile variation ratio 50:50

Because the ratio of rice husks to sawdust is equal, the interaction between these three components occurs proportionally. As a result, the resulting thermal decomposition temperature range is wider than the previous combination (Chen et al., 2026).

The biochar yield was 40.32%, indicating that a substantial fraction of the initial biomass remained as solid residue after thermal decomposition. The bio-oil yield was only 1.08%, whereas the non-condensable gas fraction reached 58.6%. The low liquid yield is consistent with the observation that the condensation process was not fully effective and that some vapor products remained in the gaseous phase. The high gas fraction therefore indicates that improvement of the condenser performance and system sealing may increase the recovery of condensable compounds. Product yield can be seen in table 1.

Table 1
Product distribution obtained from the 50:50 co-pyrolysis treatment

Product	Yield (%)
Biochar	40.32
Bio-oil	1.08
Non-condensable gas	58.60

According to Chandraratne & Asfaw G. Daful, (2021), the yield of biomass pyrolysis products is significantly influenced by operating conditions and the composition of the feedstock used. In slow pyrolysis processes with low heating rates and long residence times, the yields of biochar, bio-oil, and gas produced are typically 35%, 30%, and 35% of the feedstock weight, respectively.

Differences in yields produced from various types of biomass are also influenced by differences in lignin, hemicellulose, and cellulose content in each raw material, considering that these three components have different degradation kinetics (Tanger et al., 2013). Lignin, which has higher thermal resistance than hemicellulose and cellulose, contributes significantly to biochar formation, while hemicellulose and cellulose, which decompose at temperatures lower than 400°C, produce more liquid and gas fractions. Therefore, selecting the right pyrolysis temperature is a determining factor in optimizing the biochar yield produced from the lignocellulosic biomass pyrolysis process (Rambli et al., 2018).

The moisture content of the biochar was 1.99%, indicating that most of the moisture was removed during the thermal conversion process. The ash content was 17.31%. This value is influenced by the mineral fraction of the feedstock, particularly the relatively high mineral and silica content commonly associated with rice husk. The volatile matter was 19.55%, while fixed carbon reached 61.15%. The relatively high fixed-carbon fraction indicates that the resulting biochar retained a substantial carbon fraction after the release of volatile compounds during pyrolysis. Proximate analysis can be seen in table 2.

Table 2

Proximate analysis from the 50:50 co-pyrolysis treatment

Proximate Characteristics	Amount (%)
Moisture	1.99
Ash	17.31
Vollatile matter	19.55
Fixed carbon	61.15

Moisture content is one of the parameters in proximate analysis commonly applied to charcoal products. This parameter plays a crucial role in determining charcoal quality, as it directly affects the resulting calorific value, ease of ignition, combustion efficiency, and the volume of smoke produced during the combustion process (Rony. et al., 2025).

3.2 Community Empowerment Activities and Output

The preparation stage: which began with a field survey and hearings with the Geuchik (village head), the Agriculture Office, the BPP, and the farmer group, successfully mapped the main problems faced by farmers, namely declining productivity, high rates of plant pest organism (OPT) attacks, soil degradation, and agricultural waste management that was not yet environmentally friendly. This stage also involved institutional coordination to determine the pilot land and build commitment to participation. In addition, an initial questionnaire was designed and distributed to map farmers' knowledge, attitudes, and practices regarding fertilizer/pesticide use, minapadi (rice-fish farming), IoT utilization, and readiness to adopt the technology. To strengthen the program's sustainability, the local AgroTech institution was successfully established as a forum for coordination and learning.

Agricultural Waste Pyrolysis Technology Agricultural waste in the form of straw and rice husks was processed using simple pyrolysis technology to produce biochar and liquid smoke. Biochar was applied as a soil ameliorant to increase organic matter content and fertilization efficiency, while liquid smoke was used as a natural pesticide after undergoing a dilution process. This technology was directed at reducing open burning of agricultural waste and promoting the application of low-emission and zero-waste agricultural concepts.

Fig. 3. Location of Alue Keurinyai Village

Training and Knowledge Transfer Stage

Training activities were carried out through extension sessions and interactive discussions on sustainable agriculture, as the part of minapadi concept, the use of the Internet of Things (IoT), solar energy, and agricultural waste pyrolysis. This was followed by field demonstrations covering the application of the minapadi system on the pilot plot, the operation of IoT pest-repellent devices, and the process of producing and applying biochar and liquid smoke from pyrolysis. The training stage was then reinforced through hands-on practice by the farmers to ensure their mastery of operational skills, device maintenance, and the ability to apply the technology independently in cultivation activities.

Fig. 4. Implementation of retort kiln technology combined with IoT System.

Success Indicators.

Success indicators were developed for each activity component and were designed to be measurable to facilitate analysis. In the preparation and institutional strengthening stage, the success indicators included the completion of coordination with the Geuchik, BPP, and farmer group, evidenced by meeting minutes or attendance lists; the establishment of the local Agrotech community/institution as a forum for coordination and learning; and the development of a problem map and baseline of farmers' practices based on observation, interviews, and the initial questionnaire.

In the implementation of the minapadi system, the success indicators included the availability of a functioning minapadi pilot plot with a configuration of 80–85% of the area for rice and 15–20% for the trench/pond, as well as the documentation of basic cultivation parameters such as planting spacing, organic/biochar inputs, and operational records. In the implementation of the solar-powered IoT devices, the success indicators included the installation of devices at strategic points operating independently on solar energy, as well as recorded data on system activation frequency/OPT detection and maintenance logs kept by farmers.

In the waste pyrolysis and product utilization component, the success indicators included the completion of the straw/husk pyrolysis process and the resulting production of biochar and liquid smoke, as well as the application of biochar as a soil ameliorant and liquid smoke as a natural pesticide in accordance with dilution procedures. Furthermore, in the aspect of farmer capacity building, the success indicators included an increase in knowledge, attitude, and technology-adoption readiness scores based on a measurable comparison of pre-test and post-test results, as well as participants' active engagement in extension sessions, demonstrations, and practical exercises, measured through attendance lists and observation sheets.

Fig. 5. Preparation of Biomass Raw Materials in the Implementation of Retort Kiln Technology

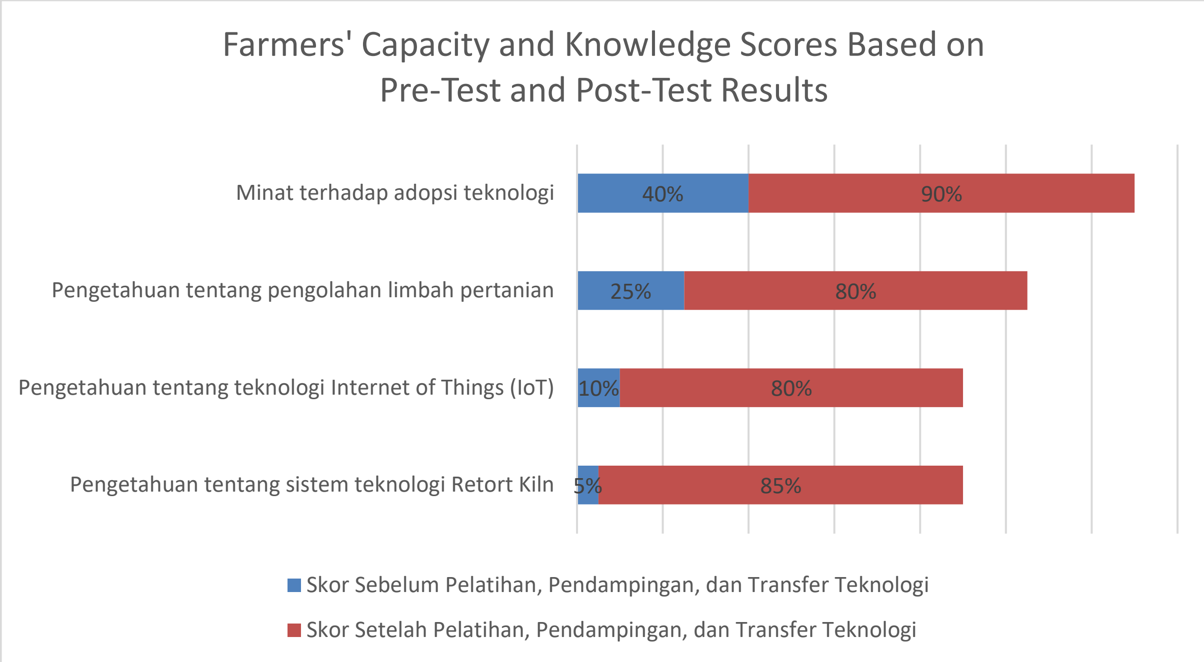

Fig. 6. Success indicator post program

4. Conclusions

The result of biochar from a mixture ratio of 50:50 showed quite good solid fuel characteristics and could be used as an alternative composition of a mixture of rice husk and sawdust waste in biochar production through the co-pyrolysis process. The product was used as a part of empowerment program for the farmer Community.

The community service program in Alue Keurinyai Village successfully translated its planning into concrete, measurable outcomes across all its stages. The preparation phase — grounded in field surveys, institutional coordination with the Geuchik, the Agriculture Office, and the BPP, and a baseline assessment of farmers' knowledge and practices — laid a solid foundation for the subsequent technical interventions and led to the establishment of the local Agrotech institution as a lasting coordination and learning platform. The integration of the minapadi system, solar-powered IoT pest-detection devices, and simple pyrolysis technology for converting agricultural waste (straw and rice husk) into biochar and liquid smoke demonstrated that ecological, low-emission, and zero-waste farming practices can be implemented at the community level using accessible, appropriately scaled technology. The training and knowledge-transfer activities, reinforced through field demonstrations and hands-on practice, ensured that farmers gained not only theoretical understanding but also the operational competence needed to sustain the technology independently. Overall, the program's success indicators such as spanning institutional coordination, functional pilot infrastructure, documented technical parameters, and measurable gains in farmers' knowledge, attitudes, and readiness to adopt technology were substantively achieved. This confirms that a participatory, technology-integrated approach combining minapadi, IoT, and pyrolysis-based waste processing is an effective and replicable model for advancing sustainable agriculture, strengthening farmer capacity, and promoting responsible environmental management in rural communities such as Alue Keurinyai.

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