

Optimizing Plantation Waste for Alternative Feed in Integrated Crop-Livestock System: A Case Study from Bulukumba, South Sulawesi

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ABSTRACT

Bulukumba Regency holds significant potential for developing an integrated crop-livestock system through the utilization of plantation waste such as copra meal, coconut husk, cocoa pod husk, and clove leaves as alternative feed for ruminant livestock. This research employed a case study approach using qualitative methods, supported by secondary data and laboratory analysis of the nutritional content of the waste materials. The study also assessed the level of utilization by farmers and livestock keepers, as well as the challenges encountered in its application. Data were collected through in-depth interviews, field observations, and documentation. The findings revealed that the use of plantation waste as animal feed remains low due to limited technical knowledge, inadequate processing technology such as fermentation, and weak institutional support and extension services. In fact, utilizing this waste could reduce feed costs by up to 40% without compromising livestock performance. This research proposes a zero-waste-based integration model consisting of several stages: mapping the potential of local waste resources, providing technical training, establishing farmer group enterprises, and conducting continuous monitoring. Regional policies and institutional support are necessary to strengthen the implementation of this model in order to create a sustainable and environmentally friendly crop-livestock system in Bulukumba.

Keywords: *Alternative feed, Crop-livestock system, Integrated farming, Plantation waste, Sustainability, zero waste*

INTRODUCTION

Bulukumba Regency, located at the southernmost tip of South Sulawesi Province, Indonesia, is endowed with abundant natural resources, particularly in the agricultural and plantation sectors. Its strategic geographic location and supportive tropical climate have made this region a key production center for important commodities such as coconut, cocoa, and cloves. Alongside these agricultural activities, the livestock sector, especially beef cattle farming, has also grown into an important economic activity. However, most of the livestock production is still managed traditionally by smallholder farmers.

According to data from ICRAF, Bulukumba is ranked among the five largest cocoa-producing regencies in South Sulawesi. The area of land cultivated for cocoa in Bulukumba covers approximately 7,456 hectares, with an annual production of around 4,626 tons (Khususiyah *et al.*, 2012). Coconut products are more commonly found in home gardens and mixed plantations. Meanwhile, cloves are cultivated on a total area of 44,524 hectares across the province, with Bulukumba contributing approximately 5.2% of South Sulawesi's total clove production, which amounts to around 16,385 tons (BPS Statistic of Bulukumba Regency, 2025).

Despite having abundant agricultural and plantation waste, such as copra meal and coconut husks, cocoa pod husks, and clove leaves, most of these waste materials remain underutilized. Commonly, these residues are either burned or discarded around the plantation areas, even though they have significant economic and ecological value. The practice of burning organic waste not only leads to the loss of economic potential but also causes various environmental problems, including air pollution from the smoke and the release of greenhouse gas emissions such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide

(N₂O). These emissions contribute significantly to global climate change and local environmental degradation (Zukwan *et al.*, 2025).

The burning of agricultural waste produces fine particles that can harm the respiratory system of nearby communities, especially when the burning is done openly and repeatedly (Lan *et al.*, 2022). In addition, this practice wastes organic materials that could actually be processed into valuable products such as compost, bioenergy, or animal feed. In the context of sustainable agriculture, letting this potential go to waste indicates a lack of efficiency in agricultural production systems, particularly in regions that heavily rely on the primary sector, such as Bulukumba. For instance, coconut meal waste contains up to 20% crude protein, while cocoa pod husks and clove leaves are rich in fiber and carbohydrates. These characteristics make them suitable as alternative raw materials in the formulation of ruminant animal feed. In the digestive system of ruminants like cattle, goats, and sheep, an adequate amount of crude fiber is necessary to maintain the balance of microbes in the rumen. If these materials are fermented properly, they not only become more digestible but can also improve the efficiency of nutrient utilization (Kazemi, 2025).

As the cost of commercial animal feed continues to rise, which often becomes a major challenge for smallholder livestock farming, integrating agricultural waste into livestock feeding systems emerges as an increasingly relevant solution. Therefore, substituting commercial feed with locally available materials such as plantation waste can significantly reduce farmers' operational costs. Furthermore, this approach aligns well with the framework of the circular economy and the zero-waste paradigm, both of which have become key pillars in sustainable development. The circular economy emphasizes the importance of reusing, recycling, and repurposing materials that were previously considered waste. This practice aims to extend the life cycle of products and reduce pressure on natural resources (Hom, 2024). In the context of livestock and agriculture, this approach not only helps to minimize the amount of waste that pollutes the environment but also fosters synergy between sectors that were previously managed separately.

The application of an integrated farming system enables the optimization of local resources within a unified production system. Waste from the plantation sector can be used as input for livestock farming, while animal waste such as manure can be processed into organic fertilizer to enrich agricultural land. This type of system has been proven to increase productivity, resource efficiency, and the economic resilience of small-scale farmers (Shanmugam *et al.*, 2024). However, the success of such integration greatly depends on the availability of appropriate waste-processing technologies that are practical and easy for farmers to adopt. Anaerobic fermentation technology using local or commercial microbes, such as EM4, has been proven effective in enhancing the quality of animal feed made from organic waste. The fermentation process not only reduces the levels of indigestible fiber but also increases the content of soluble protein and B-complex vitamins. According to Siw and Purwadaria (2017), fermenting coconut husks and cocoa pod husks can improve their digestibility value by up to 25% compared to their raw form.

The integration of plantation waste as livestock feed is supported by various research studies. Agricultural by-products have been successfully utilized in ruminant feed rations through treatments such as fermentation, which can enhance digestibility and nutrient availability (Kazemi, 2025). Reviews on agroforestry systems also reveal that silvopastoral practices play an important role in improving microclimate conditions (Satish *et al.*, 2024), enhancing soil fertility, and boosting livestock productivity, which makes farming systems more resilient to climate change (Brick *et al.*, 2022). In Southeast Sulawesi, a study demonstrated that plantation waste could be effectively converted into feed to optimize the carrying capacity of beef cattle, indicating that this approach is feasible at the local level (Munadi *et al.*, 2024). However, despite its high potential, the adoption of this approach in

Bulukumba remains very limited due to several constraints. These include technical barriers, such as farmers' lack of information on the nutritional content of waste and appropriate processing methods for local feed. Economic barriers also exist, as market incentives and business models for integrated farming-livestock systems are still underdeveloped. Additionally, social and cultural barriers persist, as farmers' awareness and acceptance of the benefits of inter-sectoral integration remain low (Moojen *et al.*, 2024).

In addition, the extension system in this region is still sectoral and has not yet integrated a curriculum oriented toward sustainability. Topics such as zero-waste management, agro-integration, and waste utilization are not yet main subjects in extension programs. The effective dissemination of innovations also requires close coordination between universities, research institutions, local governments, and business actors. Kasumaningrum *et al.* (2024), emphasize that cross-sector collaboration can accelerate innovation adoption through the synergy of knowledge, expertise, and resources, leading to creative solutions for complex problems faced by communities and businesses.

Considering this gap, a contextual and empirically-based study is needed. Such research should not only examine the biochemical potential of plantation waste but also explore the socio-cultural, economic, and policy dimensions that influence the adoption of waste as animal feed. A case study in Bulukumba Regency can provide insights into local challenges and best practices, and serve as an empirical basis for developing similar systems in other regions of Indonesia. Therefore, this study aims to explore the potentials and challenges of utilizing plantation waste as alternative feed for ruminant livestock within an integrated farming-livestock system in Bulukumba Regency. Specifically, the research seeks to assess the nutritional content and processing methods of coconut, cocoa, and clove waste; analyze the social-economic drivers and barriers affecting farmers' adoption; identify collaborative mechanisms that can be established between plantation and livestock sectors; and formulate strategies and policy recommendations aligned with zero-waste principles and sustainable development.

By using a case study approach, this research is expected to contribute both to the development of theories related to the integration of the agricultural and livestock sectors within the circular economy framework, and to the preparation of practical and applicable guidelines for local governments, extension agents, agribusiness actors, and farmer-livestock groups. Ultimately, the livestock farming system in Bulukumba is expected to evolve into a low-emission, community-based, efficient system that contributes to the sustainability of local food security.

MATERIAL AND METHODS

Location of The Research

This research was conducted in Bulukumba Regency, located in South Sulawesi Province. The location was selected purposively, meaning it was intentionally chosen based on several strategic considerations that make Bulukumba a representative site for studying the integration between the plantation and livestock sectors within the framework of the circular economy and sustainable development. Bulukumba Regency holds a strategic geographical position at the southern tip of South Sulawesi Province, with a total area of approximately 1,154.67 square kilometers. The region is well known as one of the main centers for important plantation commodities in South Sulawesi, including coconut, cocoa, and cloves. In addition to the plantation sector, livestock farming, especially beef and dairy cattle, also serves as a major contributor to the local economy.

The plantation potential in Bulukumba Regency is significant and has become an essential part of the livelihoods of local communities. Coconut is widely cultivated in home gardens and community plantations, with diverse varieties and abundant production. Similarly,

cocoa and cloves are prominent export commodities that contribute not only to the local economy but also to the national economy. The coconut industry in this region generates various by-products, such as coconut husks, shells, and copra meal, which have not yet been fully utilized. Likewise, cocoa pod husks and clove leaves often become waste after the harvesting and post-harvest processes. On the other hand, the cattle population in Bulukumba, both beef and dairy cattle, has experienced steady growth in recent years. Data from the Department of Livestock and Animal Health of Bulukumba Regency indicates that the cattle population numbers in the tens of thousands, distributed across several districts such as Gantarang, Ujung Loe, Bonto Bahari, and Kajang. This condition shows that the livestock sector plays a significant role in supporting the local economy and holds great potential for further development, particularly through integration with the plantation sector.

Choosing Bulukumba as the research location was also based on the consideration that this region combines a high production potential of plantation waste with the need to strengthen the livestock sector through the provision of alternative feed sources. In the context of waste management and the development of livestock feed based on local resources, Bulukumba possesses unique characteristics since the majority of its population still depends on agriculture and plantations. Unfortunately, the utilization of plantation waste such as copra meal, cocoa husks, and clove leaves as animal feed remains very limited, mainly due to a lack of technical knowledge, inadequate processing infrastructure, and minimal policy interventions that encourage systematic waste utilization.

Moreover, selecting this location aligns with the sustainable development agenda promoted by both the national and local governments. Bulukumba Regency is committed to fostering environmentally friendly economic growth by strengthening productive sectors based on local potentials. In this context, the integration between the plantation and livestock sectors becomes a highly relevant approach to develop. Utilizing plantation waste as animal feed not only helps reduce production costs in livestock farming but also contributes to decreasing the volume of organic waste that could potentially pollute the environment. From a socio-cultural perspective, the people of Bulukumba are known for their long-standing traditions of farming and livestock raising, which have been passed down through generations. However, the current systems of agriculture and livestock management are still dominated by traditional practices that have not fully adopted principles of efficiency and sustainability. Therefore, this research is also expected to provide new insights for the local community regarding the importance of integrating these two sectors through a more scientific approach supported by appropriate technologies.

Academically, Bulukumba is an interesting location for research because of the limited studies that specifically explore the potential integration of plantation waste as animal feed in this region. Most research on waste management and livestock feed development is concentrated in other regions such as West Java, Yogyakarta, or North Sumatra, while such studies in Eastern Indonesia, including South Sulawesi, remain scarce. Thus, conducting research in Bulukumba Regency is expected to make a significant contribution to enriching the national body of research in the field of integrated agriculture and livestock systems. Another factor that influenced the selection of this research location is the support from local government and relevant institutions such as the Livestock Department and the Plantation Department. The synergy between researchers, local government, and communities is essential to ensure that the research findings can be practically implemented in the field. Therefore, this research aims not only to contribute academically but also to deliver practical impacts for local economic development and the enhancement of community welfare in Bulukumba.

Considering all these aspects, this study was conducted in Bulukumba Regency as a representative area with great potential for implementing an integrated farming-livestock

system based on the circular economy. This research is expected to result in an efficient and applicable model for managing plantation waste as an alternative feed source for ruminant animals such as cattle, goats, and sheep. Additionally, the findings are anticipated to provide policy recommendations for local governments in designing programs that support waste management and livestock development based on sustainable local resources.

By selecting Bulukumba Regency as the study site, this research also seeks to contribute to addressing global challenges related to waste management, carbon emission reduction, and enhancing local food security. Through an integrative and participatory approach, this study aims not only to produce comprehensive data and information but also to build collective awareness at the local level about the importance of managing resources wisely and sustainably for future generations.

Research Approach and Type

This research employs a descriptive qualitative approach using a case study method. This approach was chosen to gain an in-depth understanding of the dynamics involved in utilizing plantation waste for the development of sustainable livestock farming in Bulukumba Regency. The case study method allows the researcher to comprehensively explore the local context, the interactions between various actors, and the integrative practices that have developed in the field.

Informants

The informants in this research were selected purposively by considering their involvement and knowledge in activities related to the utilization of plantation waste and livestock farming. The categories of informants include:

- a. Plantation farmers
- b. Cattle farmers
- c. Agricultural and livestock extension officers
- d. The Agriculture and Livestock Service of Bulukumba Regency

The number of informants was determined based on the principle of data saturation, meaning data collection continued until no new or significant information emerged.

Data Collection

Data collection was conducted using the following main techniques:

- a. In-depth interviews

This technique was used to explore the views, experiences, and perceptions of informants regarding the utilization of plantation waste, technical challenges, and opportunities for integrating the plantation and livestock sectors.

- b. Participatory observation

The researcher conducted direct observations of the activities of farmers and livestock keepers, including waste management practices, feed provision, and socio-economic interactions among the stakeholders.

- c. Documentation study

This involved collecting official documents from relevant government departments, statistical data, local policies, program reports, and records from farmer or livestock groups to support the primary data.

- d. Focus Group Discussions (FGD)

FGD were conducted with farmers and livestock keepers to gain a collective understanding of the potentials and challenges in developing an integrative system based on the zero-waste approach.

Data Analysis

The data collected in this study were analyzed using the thematic analysis method. This method involves systematically identifying, organizing, and interpreting patterns of meaning (themes) within qualitative data. To enhance the validity of the results, the

researcher applied a triangulation strategy. This included triangulation of informants, triangulation of data collection and triangulation of time (data collected at different times). This approach ensures that the findings are credible, consistent, and reflective of the actual conditions in the field. The analysis process was carried out through the following steps:

Data Transcription

The data obtained from interviews and observations were transcribed verbatim to ensure the completeness and accuracy of the information.

Data Coding

The transcribed data were coded based on key themes relevant to the study, including the types of waste utilized, methods of processing, feed efficiency, farmers' perceptions, technical constraints, and institutional support. Coding was conducted to categorize meaningful information that reflects the focus of the research.

Categorization

The codes generated were grouped into broader categories and sub-themes to identify relationships and patterns among different pieces of information.

Conclusion Drawing and Narrative Development

Conclusions were drawn by interpreting the categorized data in the context of local conditions and sustainable livestock farming theories. An interpretative narrative was then developed to provide a comprehensive understanding of the research findings.

RESULT AND DISCUSSION

Regional Profile and Informant Characteristics

Bulukumba Regency is predominantly composed of plantation areas covering approximately 7,364 hectares and grazing land of about 57 hectares (BPS Statistic of Bulukumba Regency, 2025). This land composition positions Bulukumba as a region with high potential for developing an integrated system between the plantation and livestock sectors. This potential is further supported by a relatively stable agro-climatic condition throughout the year and strong social integration between farming and livestock communities, which has been preserved across generations.

The findings from field observations and interviews indicate that most informants are small-scale farmer-livestock keepers, managing land plots ranging from 0.5 to 2 hectares. These lands are mainly cultivated with coconut, cocoa, and clove commodities. In addition to farming, these households rear local cattle in small numbers (2-5 heads) using a semi-intensive system. Typically, these livestock keepers are aged between 45 and 60 years and have been engaged in agricultural activities for a long period. In their daily practices, farmers are still highly dependent on natural forages and crop residues, such as rice straw, as the primary feed sources. However, the utilization of plantation waste as livestock feed remains very limited. Among the various types of plantation waste, cocoa husks have begun to be used on a limited scale. Farmers mix cocoa husks into the feed because they are known to contain relatively high protein content after undergoing a fermentation process (Suariani *et al.*, 2024). On the other hand, other types of waste such as copra meal, coconut coir, and clove leaves have not yet received sufficient attention for feed utilization. This condition indicates that the opportunity to optimize the use of plantation waste as an alternative feed source remains underutilized. The primary obstacles include the lack of technical knowledge and limited access to processing technologies at the farmer level. As a result, the potential economic and nutritional benefits of these abundant agricultural by-products have not yet been fully harnessed in Bulukumba's rural farming systems.

Another significant challenge is the absence of structured training or extension programs that specifically address the processing of agricultural waste into safe and nutritious animal feed. Some farmers who attempted to use cocoa husks directly without any form of

processing reported cases of livestock health problems, such as diarrhea and reduced appetite. These health issues are primarily caused by the presence of theobromine, an alkaloid compound found in cocoa husks that is toxic to ruminants if its active concentration is not sufficiently reduced (Klein *et al.*, 2021). Theobromine can also disrupt rumen microbial activity due to the high fat content and the presence of unstable natural fermentation residues in the husks. As a consequence of these adverse effects, farmers tend to revert to traditional feeding patterns based on rice straw, which, although safer, are less efficient both nutritionally and economically. This situation highlights the importance of understanding the detoxification processes, fermentation techniques, and nutritional formulation when utilizing agricultural waste for feed. Without this essential knowledge, the use of such waste can pose serious risks to animal health. Conversely, if simple technologies such as fermentation are applied correctly, the potential to improve feeding efficiency and reduce costs is considerable.

Farmers who have participated in fermentation training reported that the use of fermented agricultural waste could reduce feed costs by 30-40% per season, while simultaneously decreasing the volume of organic waste that would otherwise be discarded or burned. Unfortunately, the number of farmers adopting these methods remains limited, and no widespread movement or replicable model has yet been established to promote this practice. In terms of raw material availability, Bulukumba Regency holds substantial potential. Every year, thousands of tons of plantation waste are generated from the harvest of coconuts, cocoa, and cloves (Table 1). However, there is no systematic mapping or cross-sectoral program from the local government aimed at integrating the utilization of these wastes into value-added commodities. This gap presents a significant barrier to optimizing the circular use of plantation residues within the region's agricultural systems.

The results of the focus group discussion (FGD) also revealed that the majority of farmers and livestock keepers have not yet recognized the economic value of plantation waste. Most participants still perceive waste as useless residue. However, after the potential benefits of waste utilization were explained, some participants expressed interest in integrating waste into their livestock feeding systems. The main barriers identified include the lack of processing equipment, insufficient technical training, and the weak institutional capacity of farmer groups (Utomo *et al.*, 2023).

Institutional capacity plays a crucial role in the success of an integrated farming system. Putsenteilo *et al.* (2020), emphasized that both formal institutional structures (such as regulations, policies, and organizations) and informal institutions (such as local norms and cooperation) are key factors in improving the efficiency of agricultural sector transformation. Institutional support is essential for the adoption of technology, market access, and the sustainability of agriculture in developing countries. Unfortunately, in Bulukumba, many farmer groups function only as administrative entities, primarily active during the distribution of government assistance. There are no consistent programs for technological training or annual innovation initiatives. Meanwhile, agricultural and livestock extension officers have not yet been effective in promoting sectoral integration. The extension materials provided are still conventional and do not address sustainability aspects or the integration of waste across commodities.

This study also underscores that the success of integration requires both technical and social approaches. It is important to consider local values, farmers' mindsets, and active participation from the planning stage to the implementation phase. The direct involvement of farmers and livestock keepers fosters a sense of ownership, which is a foundational element for system sustainability. The concept of integrated farming emphasizes the importance of combining technical and social elements: adapting to local values, empowering farmers, and fostering community ownership are essential foundations for a sustainable system (Atapattu *et al.*, 2025). From an environmental perspective, utilizing waste as animal feed can reduce

waste burning practices, lower greenhouse gas emissions, and decrease reliance on imported feed. Ghotra (2025), noted that agricultural or production waste can be converted into animal feed, biofertilizers, and even energy, all of which contribute directly to reducing greenhouse gas emissions and supporting local and circular economies. Therefore, an integrated farming system not only strengthens the local economy but also contributes to achieving the Sustainable Development.

Table 1. Production of Smallholder by Type of cCrops in Bulukumba Regency (ton), 2022-2024

Type of crops	2022	2023	2024
Hybrid coconut	3.356,43	1.681,54	1.622,76
Cocoa	2.560,98	1.130,74	1.557,38
Clover	486,68	435,57	1.665,54

Source: BPS Statistic of Bulukumba Regency, 2025.

Types of Available and Potential Plantation Waste

Field observations revealed that various types of plantation waste are abundantly available in Bulukumba Regency. Among the most common are coconut waste, which includes copra meal, coconut coir, and coconut shells. These types of waste are generated from the process of converting coconuts into copra. In addition to coconuts, the cocoa commodity also produces significant amounts of waste, particularly in the form of cocoa fruit husks, which are available both fresh and dried, as well as cocoa leaves that naturally fall during the harvest season. On the other hand, the clove commodity generates waste in the form of twigs and leaves, which are typically pruned after the harvesting process. These three types of plantation waste are seasonally available and are widely distributed across almost all sub-districts in Bulukumba, especially those that serve as plantation centers.

Various studies and laboratory analyses have demonstrated that these plantation wastes possess high potential as nutritional sources for livestock. According to scientific references, copra meal contains approximately 16 to 20 percent crude protein, making it a good protein source, particularly for beef cattle. A review by Punzalan and Rosentrater (2024), indicated that fermented copra meal can effectively replace soybean-based feeds in ruminant diets without compromising growth performance. Meanwhile, coconut coir and coconut shells have higher fiber content, which makes them suitable as raw materials for high-fiber feeds. However, to enhance their nutritional value, these materials typically require specific fermentation processes to break down their complex fibers. Through proper processing, the fibrous waste can become a valuable feed component, contributing not only to feed efficiency but also to the reduction of waste accumulation in plantation areas.

Cocoa husk is also recognized as one of the most promising types of plantation waste. Research findings indicate that cocoa husk contains up to 25% crude fiber and approximately 40-45% carbohydrates (Mael, 2024). Although cocoa husk naturally contains anti-nutritional compounds, such as theobromine, this component can be reduced through fermentation, making the husk safer and more suitable for use as an alternative livestock feed (Sriherwanto *et al.*, 2016). Research by Rakhmani and Puastuti (2022), further demonstrated that the fermentation of cocoa pod husk (CPH) using *Aspergillus oryzae* can increase the crude protein content from 6.7% to 15.9%, while also enhancing fiber digestibility (neutral detergent fiber or NDF) up to 67% in sheep.

Clove twigs and leaves, although not yet widely used directly in feed formulations, still possess potential, particularly due to their essential oil content. Clove essential oil (CEO) is rich in eugenol (70-90%), a compound with strong antimicrobial properties against pathogenic

bacteria and fungi (Cui *et al.*, 2018). However, the use of clove essential oil in large quantities must be approached cautiously, as its potential toxicity to livestock remains under-researched. Essential oil components, including eugenol and humulene, have been shown to cause toxic and irritating effects at high doses (Pandey *et al.*, 2022).

Although existing data confirms that plantation waste contains valuable nutritional components, in practice, farmers in Bulukumba still make very limited use of these wastes. One of the main reasons for this is the absence of accessible processing units or simple technologies at the farmer level. Processing methods such as fermentation, drying, grinding, or silage production are still unfamiliar to most smallholder farmers. As a result, such wastes are often left to accumulate, burned, or discarded without further utilization. Additionally, there is a lack of access to training, information, and business capital, which further constrains the situation. Small-scale farmers, who generally operate using traditional methods, lack sufficient knowledge on how to efficiently convert agricultural waste into livestock feed. In fact, in some cases, farmers are not even aware that wastes like copra meal or cocoa husk possess high nutritional value. This knowledge gap underscores the urgent need for technology dissemination, farmer education, and support programs to unlock the full potential of plantation waste for sustainable livestock feeding systems in rural areas.

To address these problems, it is necessary to apply appropriate and practical technologies that can be directly implemented by farmers. One of the key technologies is fermentation, which can improve the nutritional quality of agricultural waste while reducing the content of antinutritional factors. For example, the fermentation of cocoa husks using the fungus *Rhizopus oryzae* has been proven effective in reducing theobromine levels. This process can be carried out at a low cost, requires relatively short processing time, and does not need complex equipment. According to Saeed *et al.* (2021), clove essential oil (CEO) and clove extract can also modulate rumen fermentation by reducing methane production and increasing propionate levels, thereby offering ecological benefits and enhancing livestock productivity. In addition to fermentation, other applicable methods include sun drying, grinding, and silage production. Sun drying helps preserve wastes such as leaves and cocoa husks, making them last longer before use. Grinding converts the materials into powder form, which can be easily mixed into livestock feed rations. Meanwhile, producing silage by combining plantation waste with other forage materials allows for long term storage without significant nutrient losses.

Several studies have been conducted to examine the effectiveness of plantation waste as livestock feed. The results indicate that feeding fermented copra meal can significantly increase the daily weight gain of beef cattle. These findings are consistent with other studies that suggest replacing commercial feed with agricultural and plantation waste can reduce production costs by up to 30%. However, in Bulukumba Regency, this potential has not been fully utilized because there has not yet been a systematic field study that integrates waste availability, processing technologies, and farmer adoption. Therefore, it is important to encourage the involvement of academics, the local livestock services department, and agricultural extension institutions to introduce integrated models that have already proven successful in other regions. This collaborative approach is essential to ensure that innovations can be effectively applied and adapted to local conditions, benefiting both farmers and the environment.

Level of Utilization and Farmers' Perception

The use of plantation waste as livestock feed is considered a strategic alternative to address the challenges of feed supply, especially in rural areas that are rich in agricultural and plantation by-products. However, based on in-depth interviews conducted with 20 farmers, most of them have not yet systematically utilized plantation waste as part of their livestock feed formulation. The practice of using plantation waste remains sporadic, limited

in scope, and has not become part of a well-planned feed management routine. From the data collected, only 3 out of the 20 farmers stated that they routinely mix copra meal (coconut residue) into their livestock feed rations. These three farmers explained that they obtain the copra meal from coconut oil processing factories located near their residential areas. They directly acknowledged that using coconut residue helps reduce the need for fresh forage, especially during the dry season, and lowers the costs of purchasing concentrate feed. One of the farmers also mentioned that..

"I usually mix dried coconut residue with rice bran; it is more economical and the cattle still eat it eagerly."

This statement reflects that such practices are based on direct experience and a personal belief in the economic benefits of utilizing local agricultural waste. However, the majority of farmers still have a low perception regarding other types of plantation waste, such as cocoa husks, clove leaves, coconut coir, and coconut residue. When asked about the possibility of using these materials as livestock feed, most informants expressed negative opinions. They stated that such waste is not suitable for feeding animals because it is perceived to have little nutritional value or may even be harmful to animal health.

One farmer stated:

"I wouldn't dare to give cocoa husks to my cattle; I'm afraid they might be poisonous."

Another farmer added:

"Clove leaves have a strong smell, and I worry that the cattle won't eat them or might get stomach problems."

These statements reflect concerns that arise from limited information and empirical experiences that have not been scientifically tested. Further investigation revealed that one of the main reasons for the low utilization of plantation waste is the farmers' lack of knowledge about the nutritional content and proper processing methods of these materials. Farmers do not yet have adequate access to information on how to process agricultural waste into safe and nutritious livestock feed. This condition is worsened by the absence of training programs or extension services that specifically focus on this topic. An agricultural extension officer who was actively interviewed explained this situation, stating that...

"We mostly provide information about forage feeding and how to make silage from corn or elephant grass. We have never specifically discussed plantation waste."

In other words, agricultural extension institutions have not yet made this topic a priority in their farmer education programs. In fact, various studies have shown that plantation waste such as cocoa husks, clove leaves, coconut coir, and coconut residue has great potential as alternative feed ingredients. Cocoa husks contain high levels of crude fiber and carbohydrates, and they can be included in feed formulations after undergoing fermentation to reduce tannin content, which can be harmful if consumed in large amounts. Clove leaves, which contain bioactive compounds such as eugenol, can also be used as feed additives in limited quantities due to their antimicrobial and antioxidant properties. However, the use of these materials requires sufficient understanding and simple processing technologies to ensure that they do not cause negative side effects on livestock health. Therefore, promoting the knowledge and application of such technologies is essential to help farmers safely and effectively utilize these local resources.

This condition highlights the importance of strengthening farmers' capacities through educational approaches that are relevant to the local context. Ragasa *et al.* (2022), emphasized that being a member of farmer groups and participating in field demonstrations significantly increases farmers' confidence and adoption of new technologies. Experimental demonstrations can enhance farmers' technical knowledge about the productivity of livestock fed with agricultural waste-based feeds. It is also recommended that farmers with more resources and those who are members of farmer groups share their knowledge about farming

systems with others (Okello *et al.*, 2021). When asked about the sources of information they usually rely on for managing livestock feed, most farmers answered that they depend more on personal experience or by copying the practices of other farmers in their community. Farmers tend to trust and adopt information more readily when it comes from peers who have already tried and succeeded, rather than from theoretical explanations or written sources that are difficult to access. Therefore, strategies that involve model farmers or the use of demonstration plots become crucial to accelerate the adoption of technologies for utilizing plantation waste as livestock feed.

In the interview, one of the senior farmers enthusiastically stated..“I started using copra meal because I saw my neighbor succeed. His cattle looked fat and healthy.”

This statement illustrates that the success of an individual in adopting an innovation can serve as a trigger for collective attitude change within the farming community. When farmers witness tangible benefits experienced by their peers, they are more likely to develop trust and interest in trying the same practices. This peer influence plays a significant role in promoting the adoption of new technologies in rural settings.

Potensial for integration and production cost efficiency

Meeting the feed requirements for livestock is one of the main challenges in smallholder or community-based livestock farming, especially in rural areas where access to commercial feeds is limited and farmers' purchasing power is relatively low. Feed costs often represent about 60% to 75% of the total production costs in global livestock farming. This condition means that any fluctuation in feed prices can significantly threaten the sustainability of livestock businesses, particularly for small-scale farmers who already operate with minimal capital. Due to the limited supply of high-quality feed, smallholder farmers are often compelled to seek alternative feeding strategies based on locally available and more affordable resources. One such strategy is the utilization of plantation waste. By-products like copra meal (also called coconut meal) and cocoa pod husks are common residues from coconut and cocoa industries, especially in tropical countries where these commodities are produced in large quantities. These by-products, when processed properly, can serve as potential feed materials for livestock. Coconut meal, for example, contains between 18% and 25% crude protein on a dry matter basis. It is also known for its high by-pass protein quality, which means that a significant portion of the protein can pass through the rumen and be absorbed directly in the intestine of ruminants like cattle and goats (Mat *et al.*, 2022). Although coconut meal is low in essential amino acids such as lysine and methionine, which are critical for monogastric animals like poultry and pigs, its protein content is highly beneficial for ruminants. Similarly, cocoa pod husks are initially rich in fiber and tannins, compounds that can hinder nutrient absorption and digestibility. However, after undergoing fermentation or chemical treatments, the digestibility of protein and fiber in cocoa pod husks can increase significantly, reaching levels of 60% to 67% (Mael, 2024). This improvement makes cocoa pod husks more suitable for livestock feed, particularly for ruminants. One of the strategies discussed during focus group discussions (FGD) with farmers and agricultural extension workers was the utilization of plantation waste as an affordable and locally accessible alternative feed source. The findings of the FGD revealed that when the use of plantation waste is managed in an organized and collective manner through farmer groups, it has the potential to reduce feed production costs by approximately 25% to 40%. This cost reduction reflects significant efficiency gains and opens up considerable opportunities for developing a livestock farming system based on local resources. Such a system can contribute to the sustainability of rural livestock production while reducing dependency on costly commercial feeds.

During the FGD, some farmers actively shared their experiences, stating that the use of coconut pulp (copra meal residue) and fermented cocoa husks had helped them reduce their expenses on commercial concentrate feeds, which were previously a major component

of their operational costs. One experienced farmer, who has been raising livestock for over 10 years, explained, *“Since we started using coconut pulp and fermented cocoa husks, our feed costs have decreased by almost half. Yet, the cattle’s weight gain remains stable, not much different compared to when we used purchased feed.”* This statement illustrates how empirical experiences and innovative practices can serve as valuable learning resources for other farmers within the community. Moreover, several farmers reported that the use of these alternative feed materials did not significantly decrease livestock performance. The average daily weight gain of their cattle remained between 0.6 to 0.8 kilograms per day, which is consistent with the growth standards for beef cattle. This evidence supports the potential of plantation waste as a viable substitute for conventional feeds, contributing to more sustainable and cost-effective livestock production in rural areas.

Field observations and informants’ statements have strengthened the findings that certain types of agricultural waste, such as coconut cake (copra meal), contain high levels of crude protein, ranging from 16 to 20%. This high protein content makes copra meal suitable as a substitute for commercial concentrate feeds. On the other hand, fermented cocoa husks have been found effective in reducing tannin content, which is known to interfere with nutrient absorption, while also improving fiber and energy digestibility in livestock feed.

During the focus group discussion (FGD), the local livestock extension officer actively reported that they had initiated training sessions on the fermentation of cocoa husks in two pilot villages. The officer explained, *“We started teaching farmers how to ferment cocoa husks using EM4 (Effective Microorganisms) and rice bran. The results are quite good, and the livestock are willing to eat the feed.”* This information illustrates the important role that extension officers can play in bridging technological innovations with practical applications in the field, especially when supported by village-level policies and enthusiastic participation from farmers.

Furthermore, the FGD discussions identified three key elements that determine the success of this farming system model. First, there must be a continuous and reliable supply of waste materials as raw feed ingredients. Second, farmer groups need to possess sufficient capacity to manage the collective enterprise effectively. Third, support from extension agents and village regulations is crucial to facilitate the distribution channels and marketing of processed feed products. In this context, a participatory extension strategy, which integrates technical, social, and institutional approaches, is considered an appropriate solution. This model has already demonstrated success in the development of integrated farming systems in several regions of Indonesia.

Nevertheless, challenges remain. One of the main obstacles highlighted by FGD participants is the limited availability of equipment and fermentation facilities, alongside the lack of advanced training on feed safety. Some farmers expressed concerns about the potential growth of molds or the production of toxins if fermentation is not conducted properly. In this regard, the role of research institutions and universities is highly significant in providing technical assistance and conducting quality assessments of the processed feeds. Further research is needed to develop standardized processing protocols that are safe, low-cost, and easily applicable by smallholder farmers. Establishing these protocols would ensure that waste-based feeds are both nutritionally beneficial and free from harmful contaminants, thereby supporting sustainable and resilient livestock production in rural communities.

Development Model Based on Zero Waste

The issue of feed shortage is a critical problem frequently faced by smallholder farmers in many rural areas of Indonesia. These farmers often depend on seasonal forage and commercial concentrate feeds, whose prices fluctuate significantly. This dependence places smallholder farmers in a vulnerable position, especially during the dry season when natural forage becomes scarce (Gayatri *et al.*, 2016), (Hilmiati *et al.*, 2024). In this context, the use

of plantation waste as an alternative feed source emerges as a strategic option. This strategy not only reduces production costs but also contributes to the broader goals of economic, ecological, and social sustainability at the local level (Wikinson, 2011) .

Based on field findings obtained through interviews, direct observations, and focus group discussions (FGD), an integrative model has been formulated. This model consists of four key components and is designed to address practical challenges encountered by farmers while promoting the transformation of livestock systems that rely on local resources. The first step in this model is the mapping of plantation waste resources available in each village. Every region typically has certain key commodities, such as coconut, cocoa, and clove, which generate substantial amounts of organic waste. These wastes, including copra meal, coconut husks, cocoa pod husks, and clove leaves, contain fiber, crude protein, and energy content that can be utilized as raw materials for livestock feed after undergoing appropriate processing.

The identification of these resources is carried out through collaboration between village governments, farmer-livestock groups, and field extension officers. Data collection is conducted using rapid surveys, seasonal observations, and the documentation of post-harvest waste volumes. For example, in villages known for coconut production, the amount of copra meal and coconut husks produced can reach hundreds of kilograms per week. Unfortunately, much of this potential has not been optimally utilized. Understanding this resource potential is crucial as it serves as the foundation for determining the processing unit's capacity and designing a systematic distribution channel for the processed feed materials.

The second step in the development model focuses on empowering human resources by providing technical training on how to process agricultural waste into livestock feed. This training aims to equip farmers with practical skills to convert waste materials into safe and nutritious feed for their animals. The training modules cover several important topics, including simple fermentation techniques, feed formulation, and proper handling of materials to ensure safety and hygiene standards are met. In the pilot training sessions conducted in several trial locations, farmers were taught how to use locally available fermentation agents such as EM4 (Effective Microorganisms), molasses, and rice bran. These materials are applied to enhance the nutritional value of organic waste, making it more suitable and beneficial for livestock consumption.

A field extension officer actively shared his experience, stating, *"When we taught farmers how to process cocoa pod husks, they were very enthusiastic because the results were visible right away cattle remained healthy and fat even though the feed was cheaper."* This statement illustrates that simple and context-relevant technology transfer can be quickly accepted and applied by farmers when they see tangible benefits.

The third step in this model is the establishment of micro-enterprise units managed by farmer-livestock groups. These units are responsible for the collection, processing, storage, and distribution of processed feed made from agricultural waste. This business initiative not only adds economic value to waste materials but also creates new employment opportunities, increases group income, and strengthens the independence and resilience of smallholder farmers.

The management of these micro-enterprises is conducted through a mutual cooperation system, where profits are shared among members based on agreed-upon arrangements. Village governments can provide initial support by allocating village funds specifically for community economic empowerment. Additionally, this model can utilize unused village assets, such as community halls or vacant warehouses, to serve as production sites. By implementing an integrated farming system based on collective groups, the model

fosters greater social resilience, as it is built on community participation and a shared sense of ownership.

The fourth step involves conducting regular monitoring and evaluation of the integrated model's performance. Monev is essential for assessing the effectiveness of activities, identifying technical challenges, measuring farmers' acceptance, and exploring potential areas for improvement in the model. This evaluation process engages a technical team composed of extension officers, university researchers, and representatives from the farmer groups. Key indicators of success in the monev process include increased livestock production, improved feed cost efficiency, sustainability of the processing enterprise, and social impacts on the beneficiary groups.

Notably, farmers who have adopted waste-based processed feed have reported production cost savings of up to 35%, while maintaining stable average daily weight gains in their livestock. These outcomes demonstrate that with proper monitoring, guidance, and community involvement, the model can enhance both the economic and social well-being of rural farming communities.

CONCLUSION

Bulukumba Regency has significant potential to develop an integrated agriculture-livestock system by utilizing plantation waste such as coconut meal, coconut husks, cocoa pod husks, and clove leaves as alternative feed for ruminant livestock. However, this potential has not yet been fully optimized due to several constraints. These include the limited technical knowledge of farmers, lack of access to processing technologies like fermentation, and weak institutional support and extension services, which are not yet integrated with the zero waste concept and the circular economy approach. Proper use of plantation waste can help reduce livestock feed production costs by 30-40% and improve the efficiency of livestock production without compromising the growth performance of the animals. To address these challenges, an integrative model has been proposed, which consists of four key stages mapping the potential waste resources at the village level, providing technical training on waste processing for animal feed, establishing micro-enterprise units based on farmer-livestock groups, and conducting regular monitoring and evaluation to ensure the effectiveness of the model's implementation. In addition to technical aspects, institutional support is essential. This includes the development of local government regulations, collaboration with research institutions and universities, and the capacity building of agricultural and livestock extension agents. Strengthening the role of extension agents is important so they can effectively educate and assist farmers and livestock keepers in the sustainable utilization of plantation waste. Such capacity building efforts are necessary to enhance the awareness, knowledge, and skills of farmers, enabling them to move beyond traditional practices and adopt innovations that make better use of local resources. By doing so, farmers will not only improve their economic outcomes but also contribute to environmental sustainability. Overall, implementing the zero waste model in the agriculture-livestock sector of Bulukumba holds great potential not only to increase productivity and economic efficiency but also to reduce environmental pollution, lower greenhouse gas emissions, and strengthen local food security in a sustainable manner. These findings suggest the need for cross-sectoral policies that support the integration of agriculture and livestock. Moreover, the development of continuous education and extension programs is recommended to encourage widespread adoption of waste processing technologies among farmers and livestock producers.

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