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Exploration and Valorization of Agri-Food Waste in A Circular Economy Ecosystem: Systematic Literature Review

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Abstract

The exponential increase in global population triggers a surge in food demand that has a direct impact on the accumulation of waste in the agricultural and food industry sector (agri-food waste). Conventional disposal methods such as landfill and incineration have been shown to cause significant environmental degradation. This study used the Systematic Literature Review (SLR) method to integrate scientific evidence related to organic waste treatment strategies into high-value-added products (valorization) to support the transition to a zero-waste circular economy. Based on a comparative analysis of national and international literature, three main lines of valorization were found: (1) the transformation of agro-industrial waste (such as tofu pulp, straw, bran, and palm oil meal) and manufacturing defective food products into alternative feed for ruminant livestock, poultry, and fishery cultivation; (2) waste bioconversion using Black Soldier Fly (BSF) larval agents to produce animal proteins; and (3) thermochemical conversion through slow pyrolysis to produce high-performance active biochar for environmental remediation. The implementation of this technology in Indonesia still faces challenges in the form of regulatory ambiguity, variability in nutrient content, and contamination risk, which requires cross-sectoral policy synchronization to achieve the Sustainable Development Goals.

INTRODUCTION

The world's population is currently growing exponentially and is projected to reach nearly 9 billion people by 2050. This condition puts massive pressure on natural resources, especially the availability of land, water, and food (Alotaibi et al., 2023; Mir et al., 2025; Mishra, 2023; Xiong et al., 2023). To meet these food needs, the production of the agricultural sector and the global food processing industry must be increased by up to 70%. However, the escalation of this production activity has a negative impact in the form of the generation of agro-food waste (*agri-food waste*) in massive quantities, which is estimated to reach 150 billion metric tons per year with an annual growth rate of 7.5%. Globally, about one-third of the total food produced for human consumption is lost (*Food Loss*) or wasted (*Food Waste*) along the supply and processing chain (Pandey et al., 2025). Wasting food is also a waste of valuable resources, water, energy, fuel, and manpower. The researchers state that maintaining sustainable food production, smart management, and proper food distribution are key factors that must be addressed if we hope to meet the food needs of the world's population (Asri & Handoyo, 2024). Improving the efficiency of natural resources and a more environmentally friendly approach to nutraceutical extraction is an important paradigm for sustainability (Hasan et al., 2025).

In Indonesia, this problem is a crucial issue because the composition of domestic waste

is dominated by organic waste and food waste (Kusumawardani et al., 2023; Mandasari, 2025; Martianto et al., 2024; Waluyo & Kharisma, 2023). In fact, Indonesia is reported to be one of the largest food waste disposal countries in the world. Conventional waste management practices in Indonesia have so far relied on landfill (*landfill*) and open incineration. This linear "take-use-throw" method has been shown to release high greenhouse gas emissions, pollute soil and groundwater through leached, and trigger substantial economic losses (Farahdiba et al., 2023).

Indonesia faces serious challenges in waste management, especially food waste and agroindustry. Indonesia is one of the largest waste-producing countries in the world and still faces obstacles in an effective waste management system (Waluyo & Kharisma, 2023). On the other hand, the livestock sector faces the problem of high feed costs which can reach 70% of the total production cost (Muwakhid et al., 2024). The use of agribusiness by-products is a promising approach to advance sustainable agriculture while contributing to climate stability efforts. The agricultural sector faces significant challenges due to the need to produce enough food for the growing global population amid the potential for climate change. (Zambela et al., 2025). Agricultural waste is also often disposed of by burning or stockpiled in landfills, posing a significant threat to ecosystems (Chellamboli et al., 2025).

As a solution, the concept of a circular economy (*circular economy*) is present to replace the conventional linear model by prioritizing resource preservation through recovery (*Recovery*) and raw material regeneration. Agro-food industry waste is actually rich in organic compounds such as carbohydrates, proteins, dietary fiber, as well as bioactive components (phenolics, flavonoids, and carotenoids). Therefore, the waste holds great potential for reuse (*upcycling/valorization*) into the economic supply chain (Sieradzka et al., 2025). The circular economy concept offers a closed system approach that emphasizes resource efficiency, waste reduction, and material reuse (Waluyo & Kharisma, 2023). In this context, agro-industrial waste and food waste have great potential to be used as alternative feed and cultivation media for Black Soldier Fly maggot (Shah et al., 2024).

The novelty of this study lies in its integrative approach, systematically synthesizing three distinct valorization pathways alternative animal feed production, BSF bioconversion, and thermochemical biochar conversion within a unified circular economy framework tailored to the Indonesian context. Unlike previous studies that examined these pathways in isolation (Kinanti et al., 2021; Muwakhid et al., 2024; Syah et al., 2024; Sieradzka et al., 2025), this research provides a comprehensive mapping of technological innovations while simultaneously analyzing the regulatory and policy barriers that hinder large-scale implementation in Indonesia. This research aims to conduct a systematic literature review (Systematic Literature Review) to map, review, and integrate various technological innovations in the use of agro-food waste that are developing in the latest scientific discourse. The main focus of the analysis was directed at the unconventional feed valorization pathway, insect-based bioconversion, as well as thermochemical conversion for environmental applications. The findings are expected to provide both theoretical contributions to the circular economy literature and practical recommendations for policymakers and industry stakeholders in Indonesia.

Although various studies have discussed this aspect separately, there have not been many studies that integrate the *perspective of circular economy* policies with waste utilization

innovations in the food and livestock sectors. This research aims to conduct a systematic literature review (*Systematic Literature Review*) to map, review, and integrate various technological innovations in the use of agro-food waste that are developing in the latest scientific discourse. The main focus of the analysis was directed at the unconventional feed valorization pathway, insect-based bioconversion, as well as thermochemical conversion for environmental applications.

METHOD

This study applied the *Systematic Literature Review (SLR)* by adapting standard guidelines to identify, screen, and evaluate the scientific literature in a transparent and accountable manner(Scott, 2019).

Literature Search Stage

Article searches are conducted on reputable scientific databases, including *Google Scholar*, *ScienceDirect*, *Scopus*, and *Nature Scientific Reports*. The keywords used include a combination of terms: "Agro-industrial Waste", "Alternative Feed", "Circular Economy", "*Agri-Food Waste Valorization*", and "*Black Soldier Fly*".

Inclusion and Exclusion Criteria

Selected articles must meet the inclusion criteria, namely:

1. Published in the period of 2021 to 2025.
2. Focus on processing food waste sourced from agricultural commodities, plantations, and livestock.

Meanwhile, the exclusion criteria include articles that do not provide *full-text* or focus on non-organic industrial waste (such as plastics or metals). Based on the screening process, 6 main articles were selected as the basis for the data synthesis in this SLR and 3 other articles as supporting studies, as follows:

Table 1. List of Article Sources

No.	References	Article Source
1	Title: Study of Layer Chicken Growth and Productivity by Using Agricultural and Plantation Waste as Unconventional Feed Author: Ratri Nur Kinanti, Nadiyatul Husna and Achmad Efendi Wijaya Year 2021	Proceedings of the 2021 National Webinar on Veterinary Medicine
2	Title: Literature Review: Agro-industrial Waste as an Alternative Feed Source for Increasing Lamb Production Author: Badat Muwakhid, Umi Kalsum, Usman Ali and Camal Adi Maskur Year 2024	Indonesian Research Journal on Education, Vol. 4, No. 3
3	Title: Utilization of Organic Waste in the Food Industry as Food Ingredient for Maggot Cultivation at PT Siklus Mutiara Nusantara Author: Fikri Nur Rahman Syah, Wilma Nurrul Adzillah	INFOMATEK: Journal of Informatics, Management and Technology, Vol. 26, No.1

No.	References	Article Source
	and Prasetyo Harisandi Year 2024	
4	Title: Poultry industry waste and its benefits as a source of protein for ruminants: a brief review Author: Yanuartono, Indarjulianto Soedarmanto and Alsi Dara Paryuni Year 2024	Journal of Animal Husbandry, Vol. 21 No.2
5	Title: Exploration of Organic Waste and its Processing as Fish Feed Ingredients: A Literature Review Author: Yuli Andriani, M. Galuh Nurdaya, Rusky Intan Pratama, Iskandar and M. Fatah Wiyatna Year 2024	Journal of Fisheries and Marine Vol. 14 No. 2
6	Title: Valorisation Of Food Industry Waste Into High-Performance Biochar for Environmental Applications Author: Małgorzata Sieradzka, Wojciech Jerzak, Agata Mlonka-Mędrala, Anna Marszałek, Mariusz Dudziak, Izabela Kalemba-Rec, Aleksandra Błoniarz, Markus Reinmöller, Agnieszka Kopia, Wojciech Nowak and Aneta Magdziarz. Year 2024	Scientific Reports - Nature Portfolio Vol.15

Source: Research Primary Data, 2026.

RESULTS AND DISCUSSION

Waluyo and Kharisma in their study emphasized that Indonesia is still in the stage of developing regulations *circular economy*. Unlike Germany and the Netherlands which already have a strong Circular Economy Act, Indonesia still relies on sectoral regulations. The lack of comprehensive regulation is an obstacle in optimizing food waste reduction (Waluyo & Kharisma, 2023). Aulia Ulfah Farahdiba et al highlighted that food waste management regulations in Indonesia have not explicitly regulated the direct use of food waste in waste-to-energy schemes. This shows the need for policy harmonization to encourage a food-based circular economy (Farahdiba et al., 2023).

Based on a systematic analysis of the articles studied, it can be explained that the discussion of agro-food waste valorization strategies can be grouped into three main technology clusters, as follows:

Utilization of Agro-Food Waste as Alternative Animal Feed

Feed absorbs the largest operating costs in the livestock and fisheries industry, so its consistent availability must be guaranteed(Kinanti et al., 2021). Through the use of unconventional waste, commodity utilization competition between human consumption and animal feed can be minimized (Yanuartono et al., 2024).

In the poultry sector, specifically for layer chickens, agricultural and plantation waste such as rice straw, soybean straw, pineapple, elephant grass, reeds, and field grass has been proven to be used as unconventional feed for laying hens (layer). The use of this alternative feed ingredient, if formulated correctly, is able to maintain the stability of chicken growth and

productivity without reducing the quality of egg production(Kinanti et al., 2021).

In the ruminant livestock sector, particularly sheep and cattle, the agro-industrial sector produces abundant by-products such as tofu pulp, peanut shells, coconut fiber, and rice bran, which offer high nutritional value for sheep (Muwakhid et al., 2024). In addition, by-products from the poultry industry including feather meal, hatchery waste, offal meal, blood meal, bone meal, and manure (litter) can be reprocessed into alternative protein sources for ruminants following physical, chemical, or biological treatments to eliminate pathogenic microbes (Yanuartono et al., 2024).

In the fisheries sector, where intensive farming is challenged by escalating commercial pellet costs, organic waste offers a practical solution. Waste materials such as vegetable residues (cabbage and mustard greens) and food waste from restaurants have been successfully utilized as alternative feed components for tilapia (*Oreochromis niloticus*) and catfish, particularly when fermented to enhance nutrient digestibility and overall feed quality (Andriani et al., 2024).

Waste Bioconversion Using Black Soldier Fly (BSF) Larvae

One of the innovative technological leaps in organic waste management in Indonesia is the use of black soldier fly larvae (*Black Soldier Fly/BSF - Hermetia illucens*). This technology is recognized nationally through the Waste to Energy policy because of its ability to degrade organic matter quickly and hygienically(Farahdiba et al., 2023).

The food production process in the beverage and food industry sector often leaves defective products (*Defective Products*) that are not fit for human consumption. For example, non-B3 waste processing companies have successfully utilized these manufacturing defective food products as a medium for BSF maggot enlargement. The use of food industry waste provides an advantage in the form of a more stable and homogeneous nutrient composition compared to household mixed organic waste. The harvested BSF larvae have high levels of crude protein and fat, so they are ideal for processing into maggot flour as a substitute for raw materials for fish and poultry feed that have high economic value(Shah et al., 2024).

Thermochemical Conversion to Biochar for Environmental Applications

In addition to being used as feed, lignocellulouric waste from the food processing industry can be valorized through thermochemical conversion pathways in the form of slow pyrolysis (*Slow pyrolysis*) at high temperatures (about 600°C) in conditions without oxygen (Sieradzka et al., 2025).

Food residues such as oil palm meal, rapeseed cake, maize cobs, and walnut shells have a fixed carbon content of around 45%. The pyrolysis process converts the residue into a highly porous product called biochar. The intrinsic fiber and lignin content in each biomass affects the physical characteristics of the resulting biochar(Sieradzka et al., 2025).

Sieradzka et al (2025) It also explains in detail that to improve its performance, raw biochar can be activated physically (using water vapor at 850°C) or chemically (using phosphoric acid *H3PO4* or zinc chloride *ZnCl2).* Chemical activation has been shown to be more effective in increasing the specific surface area (reaching more than 300 m^2/g) as well as the oxidative stability of biochar. This engineered active biochar product has an outstanding adsorption ability in filtering the environment, being able to absorb 100% of heavy metal inorganic pollutants such as lead (*Pb2+)* and 82% of organic toxic compounds such as phenols from liquid waste. This engineering contributes directly to the achievement of several

Sustainable Development Goals (SDGs) targets, namely clean water (SDG 6), responsible consumption (SDG 12), climate action (SDG 13), and life on land (SDG 15).

Policy Challenges and Recommendations in Indonesia

Although the technical potential of agro-food waste valorization is promising, its massive implementation in Indonesia is still faced with multidimensional obstacles. Primarily, raw materials derived from agro-industrial waste exhibit high nutritional variability dictated by seasonality and handling practices. To address these fluctuations, processing methods such as drying and biotechnological interventions including fermentation using microorganisms like *Aspergillus niger* are crucial to enhance crude fiber digestibility, degrade antinutrients, and eliminate hazardous toxins or pathogens before the waste can be safely utilized as animal feed (Muwakhid et al., 2024).

A major obstacle to scaling circular practices in Indonesia lies in the existing regulatory and policy gaps. Although the Indonesian government enacted a National Policy and Strategy (Jakstranas) under Presidential Regulation Number 97 of 2017 aiming for a 30% waste reduction and 70% waste management rate by 2025 (Presidential Decree of the Republic of Indonesia No. 97, 2017) specific legal instruments governing the standardization of waste-derived products remain overlapping and lack national integration. This creates regulatory ambiguity for derivative applications such as maggot-based feeds or the use of biochar for fertilizers and water filtration. To resolve these friction points, Indonesia needs to adapt regulatory models from circularity pioneers like Germany, the Netherlands, and China, which provide legal certainty, offer economic incentives for the waste treatment industry, and enforce strict environmental legislation (Waluyo & Kharisma, 2023).

Compounding these institutional challenges, Indonesia faces a complex web of constraints within its waste separation system, spanning public behavioral patterns as well as structural and financial hurdles. Public awareness and literacy remain critically low, as many residents do not yet recognize the necessity of separating organic and inorganic waste (Farahdiba et al., 2023). Community engagement remains minimal due to a limited understanding of the circular economy's role in environmental sustainability, which is further exacerbated by gaps in information literacy and inadequate public education regarding policy monitoring and evaluation (Waluyo & Kharisma, 2023). This behavioral bottleneck is worsened by severe infrastructure deficits; households and communities frequently lack designated sorting receptacles, and both urban and rural areas suffer from a shortage of hygienic separation procedures. Consequently, collecting clean organic streams for bioconversion initiatives such as black soldier fly (maggot) cultivation remains exceptionally difficult (Farahdiba et al., 2023).

Furthermore, food waste collection poses major technical and hygienic challenges due to rapid bacterial proliferation on wet organic matter, which generates foul odors and risks contamination during transit to processing facilities (Farahdiba et al., 2023). From a fiscal standpoint, waste management receives minimal backing. In 2022, the average national budget allocation for waste management accounted for a mere 0.51% of total expenditures, while state and regional budgets lacked explicit regulatory provisions mandating dedicated funding for circular economy initiatives (Waluyo & Kharisma, 2023).

Systemically, Indonesia lacks an integrated national legislative instrument such as a dedicated Circular Economy Act resulting in regulatory overlaps, bureaucratic complexities,

and poor cross-sector coordination between government agencies and the business community (Waluyo & Kharisma, 2023). Operational capacity is further strained by a shortage of proficient operators, technicians, and skilled labor needed to manage waste treatment facilities effectively (Farahdiba et al., 2023). Finally, data monitoring remains a major vulnerability; unlike the European Union's Eurostat, Indonesia lacks a dedicated statistical agency to oversee sectoral policy implementation, accurately track waste flows, and enforce extended producer responsibility (Farahdiba et al., 2023). This issue is compounded by the National Waste Management Information System (SIPSN), whose reported data often lacks comprehensive coverage across all municipalities (Waluyo & Kharisma, 2023). Overall, these challenges make the 30% waste reduction target by 2025 still difficult to achieve (Farahdiba et al., 2023).

CONCLUSION

The valorization of agro-food industrial waste is a strategic pillar in realizing a circular economy ecosystem and overcoming the environmental crisis due to organic waste hoarding in Indonesia. Through the *Systematic Literature Review method*, this study proves that agricultural waste, plantations, and failed products of the food industry can be degraded and transformed into nutritious unconventional animal feed, BSF maggot bioconversion media, and active biochar functional materials for water pollutant purification. The main recommendation for the future is the need to standardize the feed technology processing process (fermentation) to ensure biosecurity, accompanied by strengthening integrative circularity regulations from the government to support national feed independence and environmental sustainability.

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