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Turning losses into opportunities: waste valorization and its potential application in the production of Philippine commodities

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Abstract

This paper systematically reviewed the current technological advancements in the valorization of different wastes and by-products as raw materials for major industries in the Philippines. Such innovations mitigated environmental concerns, enhanced the value and sustainable utilization of by-products, and addressed issues of resource depletion. All articles that were considered in this review were thoroughly investigated, passed the exclusion criteria, and were divided according to the application of the product in the following industries: agriculture, food, and biofuel. The paper identified food wastes, organic industrial wastes, agricultural by-products, municipal wastes, and pharmaceutical by-products as the key sources for valorization. Processes including microbial fermentation, enzymatic digestion, dehydration, enzyme extraction, and homogenization had been explored to convert agricultural commodities, including growth media, substrates, fertilizers, and foodstuffs. In the food industry, valorization focused on the utilization of the nutritional value of by-products and the extraction of bioactive compounds. Emerging valorization methods to obtain these desired compounds included microwave-assisted extraction, microbe-assisted bioconversion of bio-based compounds, drying and milling, and fermentation, among others. For bioethanol production, the integration of alkali/acid and autohydrolysis pretreatments was combined with microwave or ultrasonic assistance techniques as well as simultaneous saccharification and co-fermentation. In biodiesel production, a synergistic approach involving acid pretreatments, bio-, nano-, or alkaline catalysts, and assisted transesterification methods had been adopted. In conclusion, the wide range of applications of advanced valorization techniques to diverse waste and by-product streams was being rigorously explored. This approach drove the sustainable production of high-value products and opened new avenues for industrial applications, paving the way to a more sustainable and resource-efficient future. Ultimately, future research focusing on optimized valorization techniques to enhance the efficiency and scalability of waste by-product utilization in the Philippines was recommended.

Keywords: agriculture, biofuel, food, industry, renewable resource

1. Introduction

Waste has always been a part of the human life cycle, even before the existence of modern civilization, and has now reached a point where the accumulated amalgamation of waste poses another problem to human society and the world at large. Since the start of the age of industrialization to the present day, waste materials have progressed from organic materials to electronic waste, where the once-considered luxury items have now shifted to common everyday goods. This consumerist lifestyle generates billions of tons of waste, causing the current waste management system scrambling to keep, up which leads to inefficient waste management, leaching in the environment, and other hazardous changes to various ecosystems and human health. Now, the rising awareness and consciousness of the undesirable effects the current lifestyle has wrought have awakened societies, and more importantly, the world government's interest in sustainability, not only in terms of the environment but also in terms of societal and economic development (Zaman, 2015; Bogusz *et al*., 2018; Coracero *et al*., 2021). This is also a pressing issue in the Philippines, as the country is now generating 14.66 million tons of waste annually and has become the third largest generator of waste in Southeast Asia (Coracero *et al*., 2021).

Better waste management and, consequently, waste reduction were some of the measures brought up when talks of sustainable development first gained global traction in the 1970s. In 1973, Paul Palmer introduced the term 'Zero Waste' in consortia with his business involving the recovery of resources from used chemicals (Zaman, 2022). Over the years, this term would be adapted into a visionary concept in waste management that is currently universally defined by the Zero Waste International Alliance (2018) (as cited in Bogusz 2018): *"The conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning and with no discharges to land, water, or air that threaten the environment or human health.*" (Fig.1).

Many countries have implemented various systems in response to this paradigm since its introduction, from the various coalitions and associations adopting the paradigm and working towards alternatives to inefficient waste management systems to the various bills and legislations on zero waste developments. One notable milestone in this movement was the recent zero-waste-to-landfill achievement of ABB Smart Power's manufacturing in Italy in 2021 (Zaman, 2022). The Philippines also implemented many zero-waste programs, like the "Bayan ko, Linis ko Program" and the "Zero Waste Project", which strengthens the implementation of the Republic Act 9003, also known as the Ecological Solid Waste Management Act of 2000. With the waste segregation drive and the proper waste disposal, recovery, and processing, coupled with the rising awareness and initiative of the citizens, the country is slowly realizing the goal of having a trash-free country (Coracero, 2021).

Still, one other solution to the country's waste management problems, apart from the implementation of bills and programs, is through waste valorization. This aims not only to address waste management problems globally but also problems with resource depletion. Waste valorization, a value-adding process in which waste materials are converted into more useful products like chemicals, fuels, and so on, is one of the hottest topics in zero-waste research

(Coracero, 2021). Waste valorizations will not only reduce the 61 million metric tons of generated daily waste in the country, but it also addresses not only the 12th sustainable development goal (SDG) of 'responsible consumption and production'. It also could provide alternative ways to promote and achieve the rest of the SDGs, including food security and energy security (Lui *et al.*, 2018; Katigbak and Villaruel, 2023). This review paper collated and analyzed recent research on valorizing the wastes and by-products for their potential application in the production of major commodities in the Philippines. The paper also identified trends in the raw material and commodities, as well as the various valorization techniques used in the recent studies.

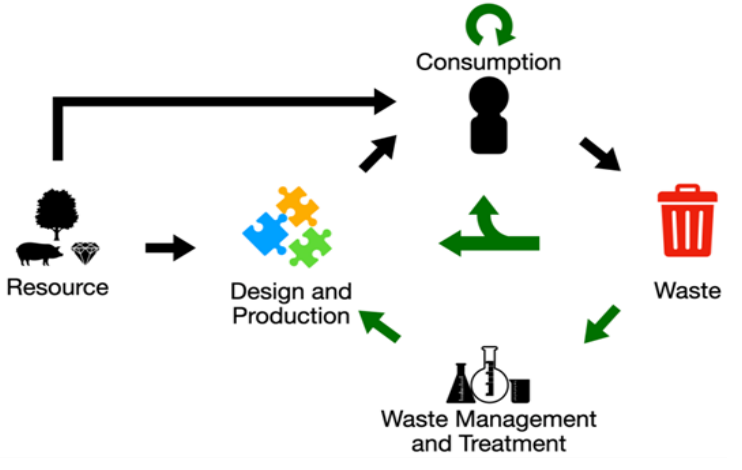

Figure 1. Zero Waste Concept showing the shift towards sustainable movement of resources from the linear and consumeristic management of resources (adapted from Zaman, 2015)

2. Materials and Methods

2.1 Literature search

The background data utilized in this study pertained to recent advancements in the valorization of wastes and by-products. This information was obtained from relevant online literature published from 2018 to 2023. The compilation of these sources involved extracting preliminary and initial research findings from a range of search engines, including ScienceDirect, Food Science and Technology, Journal Storage (JSTOR), National Center for Biotechnology Information (NCBI), Multidisciplinary Digital Publishing Institute (MDPI), and ScienceDirect. Nature, Frontier, and Emerald Insight were also included. Utilizing specific key terms such as "valorization," "by-product," "waste," "raw material," "agriculture," "food," and "biofuel" yielded a high number of related publications. The authors conducted an extensive evaluation of both the title and abstract to ensure that only studies pertinent to this review paper's topic were incorporated. For this evaluation, Mendeley Reference Manager was utilized to organize and expedite the referencing process. Figure 2 shows the process of literature search for this review.

2.2 Eligibility criteria

The selection process for articles was restricted to those that were published between 2018 and 2023 and focused on recent advancements in the valorization of waste and by-products.

Journals from the following academic databases were considered: ScienceDirect, Nature, Frontier, Emerald Insight, Food Science and Technology, Journal Storage (JSTOR), the National Center for Biotechnology Information (NCBI), the Multidisciplinary Digital Publishing Institute (MDPI), and the Institute of Food Science and Technology. These were consequently evaluated to arrive at an updated conclusion based on the data that the authors have gathered. Nevertheless, the subsequent exclusion criteria were implemented: (1) reviews or mini-reviews, (2) non-English text, (3) inaccessible or no full text, (4) non-waste sources, and (5) must be applicable in the Philippines.

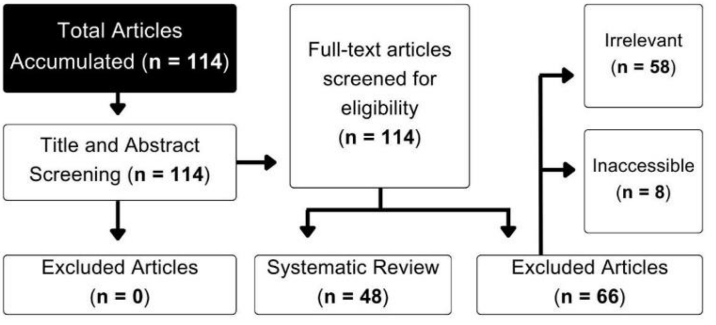

Figure 2. Workflow diagram for literature search.

2.3 Data selection and strategy

The accumulated data were extracted to examine what products could be obtained through various valorization approaches derived from the waste and by-products included in this review. To safeguard the relevance and integrity of each article assessed, the papers were classified into three categories and scrutinized using inclusion and exclusion criteria. The industries were divided into three categories: agriculture, food, and others. The third category includes biofuels and manufacturing. A full assessment of each article's title, abstract, materials, techniques, and results was then conducted, with particular attention to the source, by-product used, valorization process, product obtained and/or application, publication date, and author's name. Consequently, raw data were encoded using Microsoft Excel spreadsheets for future reference. In total, 89 articles were retrieved from search engines using the key terms.

3. Results and Discussion

3.1 Valorization of wastes and by-products as raw materials in the agriculture industry

Sustainable farming has been an ongoing priority not only in the Philippines but also in the world due to the rapid environmental changes and high production costs caused by conventional farming methods. As such, novel and practical ways to address these concerns, like the valorization of the various recoverable waste materials and by-products, are needed to achieve the goal of a circular economy (Adegbeye *et al.*, 2020). A total of 20 articles have been highlighted in this review to feature some of the recent advances in waste valorization for agricultural commodities like growth media, biofertilizers, water, and feeds (Table 1).

Table 1. Recent research on agricultural commodities and raw materials from valorized wastes and by-products.

By-product / Waste Used	Valorization Process			Application/ Product	References
	Method	Reactor/Fermenter	Organisms Associated		
Alternative growth media for microbial inoculants for biofertilizer and pesticide production					
corn cobs	HT, SSF	20L earthen vessel	*Trichoderma viridae*	Biofungicide and biostimulants	Narwade *et al.* (2023)
penicillin fermentation waste matter	AkT, BF	500L fermenter flasks	*Bacillus thuringiensis*	bioinsecticide	Choe *et al.* (2022)
grass and pruning waste	HT, SSF	0.5L packed reactor	*T. harzianum*	biostimulant and biopesticides	Ghoreishi *et al.* (2023)
municipal solid waste (o)	H, AD, EH, SSF	packed-bed bioreactor	*B. thuringiensis* var israelensis	bioinsecticide, and hydrolysate	Molina-Peñate *et al.* (2023)
Soil amendments and fertilizers from valorized wastes					
poultry litter	P	N/A	-	biochar	Sikder and Joardar (2018)
chicken feathers & poultry litter	HTT	250L pilot setup with reactor	-	liquid feather protein hydrolysates	Nurdiawati *et al*. (2019)
chicken feather	S, Pl, Da, C	-	*Streptomyces enissocaesilis* AM1	compost	Khalel *et al*. (2020)
pig slurry (l)	Ak, Cf, LLC	-	-	dry sediment, $(NH_4)_2SO_4$	Rodríguez-Alegre *et al.* (2023)
	Ac, Cf, M, O	-	-	fertilizer (l)	Rodríguez-Alegre *et al.* (2023)
swine wastewater	BFED	20m3bio-flocculation tank	*Acidithiobacillus ferrooxidans*	potassium and NH_3-N ion recovery	Wang *et al.* (2023)
molasses, sugarcane leaves, & distillery slop	LF	plastic cans	bacterial consortia	fertilizer (l)	Phibunwatthanawong and Riddech (2019)
banana peel	P	N/A	-	biochar	Islam *et al*. (2019)
food waste	AD, HT	1000L digester	bacterial consortia	digestate fertilizer	Cheong *et al.* (2020)
municipal solid waste, cow dung	C	passive aerobic bin	*B. subtilis, B. tequilensis, B. venezuelans, B. amyloliquefaciens*	compost	Ratsogi *et al.* (2019)
municipal solid waste (o)	C	*Hermetia illucens*	*H. illucens*	compost	Sarpong *et al.* (2019)

sewage sludge	AD, P, CT			ash & bio-char	Kopp *et al.* (2023)
Treated wastewater as alternative irrigation water sources					
wastewater	Vf	unspecified ver-miworms	unspecified ver-miworms	vermiaqua	Kumar and Ghosh (2019)
pig slurry (l)	Ak, Cf, P, MS	-	-	irrigation wa-ter	Rodríguez-Alegre *et al.* (2023)
Potential feeds or feedstuff for different livestock production					
fruit & veg-eta-ble waste	H	N/A	*H. illucens*	fish & animal feed	Giannetto *et al.* (2020)
fresh sardine waste	F	anaerobic tank	*Lactobacillus plantarum, Asper-gillus orayzae*	chicken feed	Shabani *et al.* (2021)
tofu wastewater	F	-	*Lactobacillus sp., Acetobacter*	feed supple-ment (l)	Shen *et al.* (2022)
corn cob	SF, BF, H	150/500mL con-ical flask	*Enerococcus fae-cium, L. planta-rum,L. acidophi-lus*	feed additive	Wang *et al.* (2023)

Note: HT: heat treatment, SSF: solid state fermentation, AkT: alkaline treatment, BF: batch fermentation, AD: anaerobic digestion, EH: enzymatic hydrolysis, P: pyrolysis, S: sulfitolysis, Pl: proteolysis, Da: deamination, C: composting, Cf: centrifugation, LLC: liquid-liquid contractor, AcT: acidic treatment, M: microfiltration, O: forward osmosis, BFED: bio-flocculation with electrodialysis, LF: liquid fermentation, Vf: vermifiltration, MS: stripping of membrane, Pa: pasteurization, H: homogenization, F: fermentation, SF:simultaneous saccharification fermentation, (o): organic, (l): liquid

3.1.1 Alternative growth media for microbial inoculants for biofertilizer and pesticide production

Two of the most used organisms for biopesticide production are *Trichoderma spp.* and *Bacillus thuringiensis*. These two have been proven to have effective pesticidal properties against common pests in the field (Choe *et al.*, 2022; Narwade *et al.*, 2023). Apart from pesticidal properties, *Trichoderma* species are also capable of producing bio-stimulants, as shown in the studies of Narwade *et al.* (2023) and Ghoreishi *et al.* (2023). The use of *Trichoderma* as bio-stimulants and pesticide has already been adapted in the country and is commonly used as a biocon microbial inoculant for various crops like palm, banana, papaya, rice, and vegetables in the Philippines. *Bacillus* species have also been used as inoculants, fertilizers, and pesticides (Brown, et al., 2016; FPA, 2024). *B. thuringiensis,* in particular, is the main microbial inoculant of Bactrolep, which is an insecticide for corn borers and the diamondback moth (Brown *et al.*, 2016). However, the production of these biopesticides and microbial inoculants often involves expensive substrates, which also increases their market price (Narwade *et al.*, 2023).

In the study of Narwade *et al.* (2023), they addressed this issue by using corn cobs as an alternate growth media in an earthen vessel under natural aeration. They note that the moisture, particle size, and temperature affected the growth of the fungi during their experimental setup. A similar observation is also noted in the study of Molina-Peñate *et al.* (2023) with *B. thuringiensis* and the valorization of municipal organic waste (MOW). However, unlike in Narwade *et al.* (2023) study, where the temperature effects on the yield are seen during the heat treatment pre-fermentation, the temperature considerations they note in Molina-Peñate *et al.* (2023) study are due to the microbial activity during the fermentation. Narwade *et al.* (2023) study notes that for small-scale setups using earthen vessels, heat treatment at 90°C for

15 mins after sterilization for fungi growth yields higher spores. For upscaled setups for bacteria, it is important to carefully monitor the increasing temperatures in a packed bed reactor, particularly when considering the production of secondary metabolites with pesticidal activity. Additionally, they also note that pre-treating the MOW through enzyme hydrolysis increased spore yield. In their study on the valorization of green waste (grass clippings and pruning waste) as alternate substrates for *T. harzianum,* Ghoreishi *et al.* (2023) observed that higher temperature is required by *T. harzianum* to produce more indole-3-acetic acid (IAA), a plant growth stimulant, compared to its spore production. They also noted the need for further studies on the optimization of fermentation time for maximum conidia and IAA yield. Their team also emphasizes that the pre-treatment (addition of a phosphate buffer) of the substrate helps in addressing the homogeneity of the nutrients in their chosen alternate substrate. This buffer addition promotes the growth of the fungi by preventing high pH fluctuations during fermentation. On the other hand, pH fluctuations in Molina-Peñate *et al.* (2023) study are addressed using alkaline cosubstrates since additions of buffers are seen to be useful during the beginning process of solid-state fermentation only. In the study of Choe et al. (2023), two pretreatment variables were induced in between drying and grinding processing of the penicillin fermentation waste—acid (acetic acid) and alkali treatment (Na_2CO_3). Of the two, the alkali treatment was observed to create a better environment for *B. thuringiensis,* as the addition of Na_2CO_3 disrupted the cell membrane of the penicillium mold cells, allowing the release of the proteins.

It was also notable that of the five articles highlighted, only Narwade *et al.* (2023). used an alternative fermenting vessel to establish a simple, cost-effective, and sustainable method for biopesticide production. This method could easily be translated to a technology that could be disseminated to small-scale farmers. The remaining studies used bioreactors for solid-state fermentations, which, as mentioned in Molina-Peñate *et al.* (2023) study, could cause issues with the heat transfer in scaled-up fermentation.

3.1.2 Valorization of bio-agricultural wastes for fertilizer and soil amendments production

There are three usual valorization methods used to produce biofertilizers from waste, namely, waste stabilization, thermal treatments, and waste conditioning. Waste stabilization includes composting and fermentation. Thermal treatments include biochar and ash production, while the last method includes acidic or alkaline hydrolysis period. (Chojnacka *et al.*, 2022). Under waste stabilization, the most common method observed during the screening process for this review was composting. The composting process itself was usually simple, inexpensive, and often promoted in the Philippines to promote the use of organic farming practices, especially since many agricultural residues (i.e., straw, stover, and manure) are used as alternatives to synthetic fertilizers (BSWM, 2020). Two of the three highlighted articles on composting concentrate on reducing the humification time which expedites the compost maturation. The researchers achieved this by adding *Streptomyces eissocaesillis,* which has keratinase activity, on a feather compost (Khalel *et al.*, 2020) and a consortia of *Bacillus* species mixed with cow dung to a municipal waste compost (Ratsogi *et al.*, 2019). The last composting method is the use of *Hermetia illucens* (black soldier fly). This study observed that the larva can reduce the heavy metal accumulation in the compost (Sarpong *et al.*, 2019). The black soldier fly composting has been adapted and reported to be successful in (DA Region 10, 2022) Cagayan de Oro. Valorization through microbial fermentation is employed in the study of Cheong *et al.* (2020). In this study, food waste is anaerobically digested to produce liquid fertilizer that contains high ammonia-nitrogen, phosphorus, and potassium. Their group also observes that anaerobic digestate fertilizers were able to sustain quick nutrient releases. Phibunwatthanawong and Riddech (2019) conducted another study that also uses microbial fermentation to produce liquid fertilizer with IAA valorizes sugarcane by-products, and distillery slop. Their results show that the valorized argi-industry by-products are free of phytotoxic substances, which could be unsafe for fertilizer use. They are also able to compete with commercial hydroponic fertilizers in promoting growth and increasing the chlorophyll content of Green Cos Lettuce (Phibunwatthanawong and Riddech, 2019).

There are four articles under the thermal valorization treatment of waste. Both Sikder and Joardar (2018) and Nurdiawati's (2019) studies valorize poultry litter (PL) using different methods. Sikder and Joardar (2018) observed that pyrolyzing PL into biochar enhances its resistance to microbial decay and its capacity for long-term nutrient provision. However, unlike the other studies, they did not study performance of the biochar compared to commercial fertilizers. Nurdiawati *et al.* (2019) produce liquid feather hydrolysate through hydrothermal treatment using a combined reactor and boiler unit. The hydrolysate is seen to not be able to produce the same results compared to a commercial synthetic liquid fertilizer by itself during field trials. However, the best plant growth is observed from a mixed application of hydrolysate and commercial fertilizer. The last two studies report similar results when compared to commercial fertilizers. In Kopp's group (2023), their observations note that despite the acidification and alkalinization pretreatment of the sewage sludge biochar to enhance the phosphorus content, it still fails to match or exceed the performance of current synthetic phosphorus inputs. Though the acidification pretreatment is observed to be more promising in enhancing the phosphorus content, it still requires further testing. Likewise, though banana peel biochar has the potential to be an alternative potassium source, during the field trial, the biochar is not able to produce noteworthy results (Islam *et al.*, 2019). For the conditioning valorization treatment, Rodríguez-Alegre *et al.* (2023) compared the use of alkaline and acidic treatment to recover nitrogen, phosphorus, and potassium nutrients from pig slurry waste. Liquid fertilizer is produced using the acid treatments while dry sediment, ammonium sulfate, and water are recovered from the alkaline treatment. It is also observed that the liquid fertilizers are of a better quality in comparison to the fertilizers from the alkaline treatment. While the performance of the fertilizers is not tested in the field or against commercial fertilizers, they note that the alkaline treatment-derived fertilizers could potentially be impractical as organic fertilizers.

3.1.3 Treated wastewater as alternative irrigation water sources

Several research avenues on wastewater valorization have been explored by various industries and scientists, from nutrient recovery to biotreatments and wastewater reuse. One such study involves the fabrication of a low-cost biofiltration unit that used earthworms to filter and clean wastewater before its discharge to various bodies of water or farms (Kumar and Ghosh, 2019). The authors report that earthworms act as bioreactors as they not only physically but also chemically degrade pollutants in the wastewater. The gut microbes present in the earthworms also stabilize volatile compounds. They are also capable of degrading unwanted and harmful microbes present in the wastewater. Kumar and Ghosh (2019) also noted that the population density of the earthworms and biomass in the vermifiltration unit varied every two months as expected due to the worm's reproductive and life cycle. They also specified that the wastewater must remain in contact with the earthworms for one to two hours. As of 2021, this biotreatment process had already been established in India, Ghana, Australia, New Zealand, Scotland, Chile, Peru, Bolivia, Ecuador, the USA, France, and Mexico (Tompkins, 2021). This could also be easily adapted in the Philippines, as vermicomposting has been a major agribusiness since 1970 (Guerrero, 2008). By-products of biofiltration treatment like vermicompost, vermicast, and vermiworms could also add to the value of this technology. The product, vermiaqua, was also noted to possess nutrients like ammonia (NH_3) and nitrate (NO_3), which made it more useful as an alternative irrigation source (Kumar and Ghosh, 2019). The other highlighted study under this section can recover 75.1% of irrigation water from the liquid fraction of the pig slurry via alkaline treatment and ammonium stripping. The effluent is also observed to contain potassium (K_2O). The amount is negligible by fertilizer standards but still useful as irrigation water (Rodríguez-Alegre *et al.*, 2023).

3.1.4 Potential feeds or feedstuff for different livestock production

The food service industry, which is one of the largest profitable sectors of the country, contributes 26% to the generated food waste, 40% of which happens in restaurants and supermarkets. Coupled with the food waste generated by agriculture and fisheries, especially during calamities like the ₱4.66 billion worth of losses during the Taal Volcano eruption back in January 2020, it is important to find ways to turn these losses into opportunities (Barrion et al., 2023). This review observes that many feeds are often valorized from food wastes and by-products through fermentation with *Lactobacillus* inoculants in consortia with other microbes. Both highlighted studies by Shen *et al.* (2022) and Shabani *et al.* (2021) are tested on chickens. Shen *et al.* (2022) valorized fish sardine waste (FSW) into chicken feed through anaerobic fermentation, which promotes the growth of *Aspergillus oryzae* and *L. plantarum.* The increased population of these microbes lowers the pH and fat content of the feed and increases the production of lactic acid bacteria and crude protein. The FSW feed is observed to increase weight gain and improve the gut health of the chickens by promoting the growth of beneficial microflora in the intestine, especially when added as a supplement to other probiotics given to the chicken. Similarly, the liquid feed additive from tofu wastewater is also noted to have the same effects on the chicken and is even observed to enhance the broilers' resistance to *Salmonella.* However, unlike in Shen and co-workers' (2022) study, Shabani *et al.* (2021) reported an increase in the kidney index instead of the liver. In the study of Wang *et al.* (2023), feed additives are extracted from *Lactobacillus* species grown on corn cobs through an optimized fermentation and pre-fermentation treatment (liquid hot water treatment) after testing various fermentation methods. This lowers the production costs of L-lactic acid and xylo-oligosaccharides (Wang *et al.*, 2023). Another potential feed is the pupae and larvae of *H. illucens* which are good alternate sources of protein, fat, and other nutrients. Giannetto *et al.* (2020) noted the different nutritive qualities of *H. illucens,* larva and pupae and emphasizes the presence of taurine and the possibility of being able to select their nutritional profile. On another note, *H. illucens* reared on MSW had high levels of cadmium, which is detrimental for its use as a feed (Sarpong *et al.*, 2019).

3.2 Valorization of wastes and by-products as raw materials in the food industry

High-value products such as vanillin, pectin, and other bioactive compounds can be obtained from different waste and by-product sources through recent valorization methods (Table 2). These bioactive compounds can serve as raw materials and/or as functional ingredients in the production of food products because of their functional capabilities, which include antioxidant, anti-inflammatory, anticarcinogenic, and antibacterial activities (Mann *et al.* 2019). To feature some of the recent valorization methods for the production of raw materials in the food industry, a total of 14 articles were highlighted. All valorized sources are from food processing and agricultural by-products. Valorization measures discussed may be adopted in the Philippines.

Table 2. Valorized wastes and by-products as raw materials in the food industry.

Source	By-product Used	Valorization Method	Product Obtained / Application	Reference
Coffee By-products	Coffee Pulp	Microwave-Assisted Extraction and Pulse Electric Field (MAE-PEF)	Bioactive Food Ingredient	Macías-Garbett *et al.* (2022)
Soy By-products	*Okara*	Solid-state Fermentation	Functional Food Ingredient	Chan *et al.* (2019)
Mango By-products	Mango Peels	Drying and Milling	Peel Flours as Functional Ingredient in Yogurt	Pérez-Chabela *et al.* (2021)
	Mango Peels	Drying and Milling	Peel Powder as Fat Repacler in Chicken Patties	Chappalwar *et al.* (2020)
	Mango Peels	Fermentation	Novel Probiotic Milk	Vicenssuto and de Castro (2020)
	Mango Peels	Microwave-Assisted Extraction	Mango Peel Pectin as Fat Replacer in Chinese Sausage	Wongkaew *et al.* (2020)
	Mango Seed Kernel	Drying and Milling	Mango Kernel Flour Based Composite Cakes	Das *et al.* (2019)
Corn By-products	Corn Cob	Ferulic Acid Adsorption, and Biotechnological Production of Vanillin by *Amycolatopsis sp. ATCC 39116*	Bio-vanillin	Valerio et al. (2022)
Rice By-products	Rice Bran	Hydrolysis and Recrystallization	Bio-vanillin	Hasanvand and Rafe (2019)
	Rice Straw	Bioconversion to Bio-based Compounds by *Serpula lacrymans*	Bio-vanillin	Nurika *et al.* (2020)
Papaya By-products	Unripe Papaya	Drying and Milling followed by Compressed Fluid Extraction Techniques	Pectin	Pedraza-Guevara *et al.* (2021)
Watermelon By-products	Watermelon Rind	Citric Acid Extraction Method	Pectin	Pérez *et al.* (2022)
Banana By-products	*Saba* Banana Peel	Microwave-Assisted Extraction	Pectin	Rivadeneira *et al.* (2020)
Chicken By-product	Mechanically Deboned Chicken Meat (MDCM) by-product	Purification, Conditioning, and Extraction	Gelatin	Mokrejš *et al.* (2021)

3.2.1 Food ingredients from valorized by-products of coffee and soybean production

Among the various by-products produced by the coffee industry (i.e., coffee husk, pulp, parchment, and silverskin), coffee pulp (CP) valorization has been less explored despite it being a natural and cheaper source of many essential food components and bioactive compounds (Klingel *et al*., 2020). Though these compounds can be extracted from the CP, extraction procedures are often costly, time-consuming, inefficient, and involve high energy and chemical consumption (Mediani *et al.*, 2022). Recent innovations in these procedures include assisted emerging techniques that promote cell wall weakening for solvent exposure. Macias-Garbett *et al.* (2022) demonstrate one such method using pulsed electric field (PEF) and microwave-assisted extraction (MAE) for polyphenol recovery from coffee parchment and pulp. This green extraction process involves titration, PEF pretreatment, microwave treatment, centrifugation, and precipitation. Not only is this method faster, but it also lessens the chemical usage because water is used as the only solvent during the extraction. The Tukey Test (at a 95% significance level) conducted on the combined MAE+PEF process also showed a significant improvement of the phenolic recovery for the studied substrates. This yield improvement is attributed to the cytolytic effect of the MAE+PEF process on the vegetal matrixes. Free or coupled forms of monophenols, flavonoids, catechols, and tannins are included in the extracted bioactive compounds from the CP.

Another by-product valorized into a food ingredient is the *okara*, a non-soluble component of soybeans. It is the yellowish-white component that remains in the filter sack during the production of soy milk, soybean curd, and tofu. The widespread availability of *okara* has emerged as an issue of concern for the soybean processing industry. Each 1000 grams of soybean used to make tofu or soy milk yields 1200 grams of wet (fresh) *okara* (Santos *et al.*, 2019). Despite being a nutritious source of nourishment, humans seldom consume them since they are perishable and difficult to digest. Polyunsaturated fatty acids, aldehyde compounds, and insoluble dietary fibers cause fishy and beany odors, rendering them unsuitable for expanding the food sector (Vong and Liu, 2019). Currently, food manufacturers are increasingly examining the nutritional composition of *okara*. Some tried to identify its potential as a raw material in various food formulations. By employing *Eurotium cristatum* CGMCC3.7934, Chan *et al.* (2019) created an innovative *okara*-based component that has the potential to serve as a dietary intervention for diabetes. This was accomplished via *okara* solid-state fermentation. Also, studies using activity assays (*i.e.*, *in vitro* α-glucosidase and in vivo studies) have implicated that fermented *okara* (ECO) from *E. cristatum* could decrease the sugar level of the blood after a meal by blocking α-glucosidase enzyme activity. The underlying mechanism behind α-glucosidase is believed to have something to do with the breaking down of 1,4-linked polysaccharides, which synthesizes glucose—a key metabolic product. Hence, the hypothesis that ECO's potential as an innovative food ingredient for diabetic management is amplified.

The mentioned innovations in the valorization of coffee pulp and *okara* into food ingredients can also be applied in the Philippines, given that coffee is recognized as one of the major industrial crops in the country (Philippine Statistics Authority, 2024), and soybean is considered a high-value crop by the Department of Agriculture (2011). The growing local demand for coffee, particularly for Excelsa and Liberica beans (Arcalas, 2024) and for soybeans (Philippine Statistics Authority, 2022), indicates an increasing amount of by-products from processing, which can be mitigated by adopting the recent valorization measures discussed in this section.

3.2.2 Valorization of different mango by-products for formulating of novel food products

Valorization measures of mango processing by-products are relevant to the Philippines, being one of the top producers of mango in the world (DOST-PCAARRD, 2024). Aside from cultivating mangoes, local growers are involved as well in the processing of mangoes into dried fruit, puree, juice, jam, juice concentrates, and chutney. This practice aims to reduce postharvest losses, boost their income, and make the seasonal fruit available all year round (ATI, 2006). Local growers may further increase their profit through the valuable compounds that can be extracted from mango by-products like vitamins, minerals, essential fatty acids, carotenoids, antioxidants, phytosterol, and fiber. These bioactive compounds (BACs) have captured the interest of researchers for their antioxidant, anti-inflammatory, anticarcinogenic, and antibacterial activities (Mann *et al*., 2019). Thus, several recent studies on the valorization of mango by-products for their BACs have been done. Mango peel flour is investigated by Pérez-Chabela *et al.* (2021) as a functional food ingredient in yogurt. It is found to promote probiotic colonization of the gastrointestinal tract because of its prebiotic activity. Mango peels are also used as a fat replacer in chicken patties (Chappalwar *et al.*, 2020) and in Chinese sausage (Wongkaew *et al*., 2020). Chappalwar *et al.* (2020) develop low-fat chicken patties by incorporating mango peel powder as a fat replacer without affecting the quality of the patties. Wongkaew *et al*. (2020), on the other hand, extract pectin from mango peels and use it in the formulation of low-fat dried Chinese sausage. The mango peel pectin successfully replaces fat in Chinese sausage while improving the color. Production of novel probiotic milk using mango peel as a fermentation substrate is investigated by Vicenssuto and de Castro (2020). Results show an increase in the antioxidant qualities as well as a possible probiotic activity of the novel probiotic milk. Lastly, Das *et al*. (2019) developed mango kernel flour-based composite cakes that can be kept for 7–10 days without any preservatives.

3.2.3 Valorization of different agro-waste residues into bio-vanillin

One of the most crucial flavoring ingredients in the food sector is vanillin (Gomathi and Rameshpathy, 2023). Vanillin can be naturally produced from refined ferulic acid synthesized from food and agro-industrial wastes and by-products generated in the Philippines, such as corn fiber, rice bran, and rice straw. Valerio *et al.* (2022) demonstrate that it is possible to purify ferulic acid extracted from corn fiber and subsequently use the extracted purified ferulic acid (10 g/L) and a biological agent, *Amycolatopsis* sp. ATCC 39116 to produce biotechnological vanillin. Ferulic acid can also be sourced from ϒ-oryzanol, a compound found in rice bran pitch (Hasanvand and Rafe, 2019). Pure ferulic acid can be obtained from ϒ-Oryzanol through hydrolysis followed by recrystallization. Rice straw can also be converted to vanillin. Nurika *et al*. (2020) assess the feasibility of utilizing rice straw inoculated with *Serpula lacrymans* fungi for the synthesis of bio-based compounds, including vanillin. They confirmed that the process of fungal conversion of rice straw to vanillin has the potential to serve as a cost-effective alternative to existing procedures.

3.2.4 Valorization of food processing by-products for pectin extraction

The Philippines has yet to commercially produce pectin locally. Because of the unavailability of local production, the country relies on imported pectin for various applications, but there are potential sources of pectin in the country. Food processing by-products such as peels, seeds, shells, pods, and pomace can be valorized into valuable products like pectin instead of disposing or incinerating them in landfills (Marić *et al*., 2018). Pérez *et al.* (2022) investigated the use of watermelon rind waste for pectin extraction with citric acid as the extracting solvent. The study revealed that wastes from watermelon rind can be a low-cost source for the synthesis of highly purified pectin with excellent quality. Pedraza-Guevara *et al*. (2021) established a green protocol for pectin extraction from unripe papaya flour. High-quality pectin similar to commercial products is obtained from unripe papaya through the Enhanced Solvent Extraction (ESE) technique. Through microwave-assisted extraction, pectin can also be obtained from Saba banana peels as investigated by Rivadeneira *et al.* (2020). Based on the results, optimized microwave-assisted extraction is a promising technology for the production of pectin-based thickeners which can be used in various food applications. Other industrial applications for pectin include gelling agents, food stabilizers, emulsifiers, and as fiber sources in diet.

3.2.5 Valorization of mechanically deboned chicken meat by-product into gelatins
Chicken processing in the Philippines generates a variety of by-products. The increasing production of chicken meat since 2020, wherein approximately 1.25 billion chickens were slaughtered for meat production (Statisca, 2024), signifies a growing amount of by-products generated. A study on the valorization of mechanically deboned chicken meat (MDCM) by-products into gelatins investigated by Mokrejš *et al.* (2021) may be considered to minimize processing waste. The collagen rich MDCM by-product undergoes purification with water, NaCl, and NaOH, followed by conditioning with a proteolytic enzyme, which is an ecology-friendly method, and lastly by gelatin extraction. The study revealed that the gelatin produced from MDCM as a by-product can be a suitable ingredient for confectioneries. The gelatins in the study were characterized to have a gel strength and viscosity with low-medium strength at 140 Bloom and 2.5 mPa.s, respectively. These are properties known to have invaluable food applications.

3.3 Valorization of animal-derived wastes and lignocellulosic biomass in the production of biofuel
The growing energy demands, along with increasing global concerns for fossil fuel use, encourage the search for renewable and clean energy sources. Across decades of research, biofuel emerged as a promising sustainable alternative fuel to petroleum-based sources, largely due to its biodegradability, high bioavailability, and low carbon emissions, making it an attractive green energy source (Ambaye *et al*., 2021). In Southeast Asia, the Philippines is the first country to enact legislation on biofuels (Montefrio and Sonnenfeld, 2011). One of its initiatives, in response to the ongoing energy and global warming crisis, was the implementation of the Republic Act 9367, or the Biofuels Act of 2006, in 2007, mandating the blending of 10% bioethanol and 20% biodiesel with gasoline and diesel, respectively (Acda, 2021). Biofuel in the Philippines is produced mainly from renewable organic sources that are mostly derived from various food-based feedstocks rich in sugar, starch or oil. Recently, however, due to concerns over availability and food security, there has been a shift in interest in the use of second-generation biofuel (non-edible feedstocks) derived from lignocellulosic biomass and animal wastes. Non-edible feedstocks, which are more abundant, sustainable, and economically available than other fuels, present a more viable option as a biofuel resource (Melendez *et al*., 2022). Valorization of animal-derived wastes and lignocellulosic biomass–obtained from plant residues, by-products, and biomass components of agricultural, food, and organic industrial wastes–presents promising opportunities for biofuel production.

As a primarily agricultural country, the Philippines produces an abundance of bioavailable agricultural biomass and residues, which can be harnessed as a sustainable source of biofuel (Go *et al.*, 2019). When paired with efficient and cost-effective valorization techniques, biofuel production can increase significantly, further narrowing the gap with petroleum-based fuels. Two major types of biofuels have been widely used in the Philippines: bioethanol and biodiesel (Acda *et al.*, 2022). In this review, recent treatment strategies are presented along with potential sources of substrates for biofuel production.

3.3.1 Production of bioethanol

In the Philippines, the major feedstocks used in bioethanol production are sugarcane and molasses (Go, 2020). However, due to the competing value of these feedstocks, especially in the food sector, there is now a problem with the insufficient supply of the feedstocks for bioethanol production (Gatdula *et al.*, 2020). Thus, research and developments should explore more feedstock alternatives that balance availability and high ethanol yield. Lignocellulosic biomasses (second-generation feedstocks) are non-edible feedstocks generated as wastes or by-products of the agricultural industry in the Philippines. Rather than leaving these resources underutilized, these wastes can be repurposed through valorization into bioethanol. The high bioavailability of these resources makes them a desirable candidate as an alternative to edible feedstocks.

Bioethanol production of lignocellulosic biomass generally involves the following processes: (1) pretreatment, (2) enzymatic hydrolysis, and (3) microbial fermentation. Pretreatment is a requisite step for the removal of highly recalcitrant hemicellulose and lignin structures present in the lignocellulosic feedstock sources (Ayodele *et al.*, 2020). These structures are highly resistant to microbial and enzymatic transformation (Melendez *et al.*, 2022); thus, they must be removed in pretreatments to allow accessibility of deeply embedded substrates (mostly cellulose) for enzymatic hydrolysis and subsequent microbial fermentation (Ayodele *et al.*, 2020). Research advancements in bioethanol production use different combinations of novel pretreatment and fermentation strategies that reduce cost and energy requirements, reduce toxic chemical wastes and by-products, and increase overall ethanol recovery (Table 3). These novel strategies may be used in the Philippine context to accelerate and improve bioethanol production in the country.

Table 3. Different combination of pretreatment and fermentation strategies in the valorization of lignocellulosic biomass to bioethanol.

Waste Source	Pretreatment	Treatment		Ethanol Yield	Reference
		Fermentation	Associated microbe/s		
Wheat straw	Subcritical water	Ethanolic fermentation	*Saccharomyces cerevisiae* NX11424	93.34 - 96.18%	Chen *et al.* (2021)
	Alkaline pre-extraction and alkaline hydroxide peroxide	SSCF	*Saccharomyce cerevisiae* SR8u	-	Yuan *et al.* (2018)
Brewer's spent grain	Dilute sulfuric and phosphoric acid	Co-fermentation	*Escherichia coli* SL100	-	Rojas-Chamorro *et al.* (2020)
	Autohydrolysis	Hybrid saccharification and fermentation	*Saccharomyces cerevisiae* (BLG11 1762, PE-2)	94%	Pinhero *et al.* (2019)
Sugarcane bagasse (SB)	Hydrodynamic cavitation-assisted alkaline hydrogen peroxide	Ethanolic fermentation	*Scheffersomyces stipites* NRRL-Y7124	>95%	Hilares *et al.* (2018)
	Two-stage ultrasound assisted sulfuric acid	SSCF	*Saccharomyces cerevisiae* SHY07-1	93.37%	Chen *et al.* (2022)
OFMSW	Hydrothermal treatment	Ethanolic fermentation	*Mucor indicus* CCUG 22424	-	Mahmoodi *et al.* (2018)

Note: SSCF (Simultaneous Saccharification and Fermentation); OFMSW (Organic Fraction of Municipal Solid Waste)

Acid pretreatment and simultaneous saccharification and co-fermentation (SSCF)
The use of two-stage ultrasound dilute acid pretreatment (TUDA) using sugar cane bagasse (SCB) as feedstock is a novel approach for bioethanol production (Chen *et al.*, 2022). Sugarcane is one of the most highly valued crops in the country, and its industry constitutes a significant part of the economy. SCB is the major waste product generated in the sugarcane industry, which contains a favorable amount of cellulose of about 30-40% of its composition, making for a promising and attractive sustainable feedstock source for bioethanol production (Bu *et al.*, 2019; Gatdula *et al.*, 2020). However, since 20-30% of SCB's composition is hemicellulose, it therefore necessitates pretreatment methods. Dilute acid pretreatment is commonly used because of its efficient capacity to break down hemicellulose from lignocellulosic biomasses. This pretreatment, unfortunately, is highly corrosive to equipment and generates toxic inhibitory compounds, such as hydroxymethylfurfural (HMF), in strong acidic and high-temperature systems (Ayodele *et al.*, 2020). These can ultimately hamper bioethanol production by inhibiting enzyme activity during hydrolysis and microbial growth and metabolism during fermentation. Moreover, additional steps are necessary to remove these inhibitors, which can contribute to increased energy and cost of production. Chen *et al.* (2022) circumvent this issue by modifying pretreatment under optimized milder acid conditions (2% H_2SO_4) and reduced temperature (90°C). Two-stage ultrasound is also harnessed during pretreatment by transmitting high-energy mechanical-acoustic waves (760 w for 20 min. and 190 w for 60 min.) to the SCB. Subsequently, the hydrolysates extracted from pretreatment are then subjected to simultaneous saccharification and co-fermentation (SSCF) which uses SHY07-1 yeast to ferment glucose and xylose to ethanol. SSCF allows mixed culture of yeasts and simultaneous fermentation of both hexose and pentose substrates in a single reactor (Sharma *et al.*, 2020). It is more advantageous than the conventional separate hydrolysis and fermentation (SHF) as it can effectively reduce enzyme requirements and shorten operational times. In the reduced temperature approach, Chen *et al.* (2022) were able to lower concentrations of furfural and acetic acid inhibitors while the ultrasonic application successfully disrupts lignocellulosic structures by inducing pores in cellulosic fibers and increasing lignin solubility. TUDA is able to successfully degrade hemicelluloses by 92.40% and remove lignin by 57.41% and recover 95.72% cellulose. This ethanol production generates 93.73% efficiency.

Alkaline pretreatment and simultaneous saccharification and co-fermentation (SSCF)
Other pretreatment methods are employed using different compounds than dilute acid. Yuan *et al.* (2018) are able to produce bioethanol from wheat straw (a low-cost and sustainable feedstock source) with combined alkaline/alkaline hydrogen peroxide treatment (AHP). One advantage of AHP is its operation under low temperature and atmospheric pressure, which reduces concentrations of inhibitors in the hydrolysates. Moreover, AHP treatment utilizes hydrogen peroxide (H_2O_2) as the chemical solvent, which is easily available in commercial markets. Yuan *et al.* (2018) recognized that this method is not economically favorable, as single-stage AHP requires high chemical inputs of the solvent; therefore, another pre-treatment step is required to reduce these inputs. In their study, alkali pre-extraction is conducted prior to AHP in order to reduce H_2O_2 charge and extract high-purity lignin. SSCF is established in the study with the use of the *S. cerevisiae* SR8u strain for the fermentation of xylose and hexoses. Yuan *et al.* (2018) reported improved delignification (91.4% lignin yield) and hemicellulose removal with increasing AHP (H_2O_2 charge), which results in improved cellulose content. High cellulose recovery means decreasing operational time and costs by reducing the needed enzyme loads for hydrolysis in the proceeding step. Additionally, AHP yields undetectable levels of inhibitory HMF and furfurals and has no impact on enzymatic hydrolysis. This study reports a remarkable sugar conversion of 92.4% from SSCF with a consequent ethanol production of 31.1 g/L. This yield is higher than just the single-stage enzymatic

hydrolysis. In the Philippines, wheat cannot be normally grown and cultivated; thus, they are primarily imported from other countries like the United States (Australian Export Grains Innovation Centre, 2021). Rice straws could be an alternative to wheat straw, as rice is one of the major agricultural commodities in the country. It has already been demonstrated that bioethanol can be successfully extracted from rice straws with a maximum potential yield of 158 (L/ton) (Gatdula *et al.*, 2020), and it may be further improved through the novel use of valorization techniques.

Aside from acid pretreatment, SCB feedstocks can also be pretreated with AHP with the integration of assisted technology such as the novel hydrodynamic cavitation (HC) method (Hilares *et al.*, 2018). While AHP is a known efficient technique in improving ethanol productivity through improved lignocellulosic disruptions, it is held back by longer operational times under mild conditions and the requirement of high H_2O_2 concentrations (Yuan *et al.*, 2018). As such, Hilares *et al.* (2018) integrated HC, a mechanical pretreatment, to work around these setbacks. In HC, cavitation bubbles are formed and exploded into the feedstock, which generates tremendous pressure and temperature, resulting in the dissociation of water into strong oxidants and superoxide radicals that can attack and degrade lignin. The force from the cavitation can also contribute to the collapsing of lignocellulosic structures and the increase in pore volume, making cellulose more bioavailable for enzymatic hydrolysis. Moreover, H_2O_2 can be further generated under alkaline conditions, which minimizes the requirement for high doses of H_2O_2. The percolate column reactor is additionally investigated in the study to determine the operability of high solid loading of 20% in the enzymatic hydrolysis step. SSCF utilized *Scheffersomyces stipitis* NRRL-Y7124 in a bubble column reactor for ethanol production. In the study, Hilares *et al.* (2018) pointed out that cellulose hydrolysis yield is higher (74.7%) with high solid loading in a packed bed flow-through column reactor (PBFTCR) compared to when done similarly in an Erlenmeyer flask. This demonstrates the potential of PBFTCR in improving hydrolysate yield when using high solid loadings. Structural characteristics of HC-pretreated SCB reveal expected enlarged pore volume and surface loosening as a result of shock waves generated from the water cavitation. These structural changes can be attributed to the high hydrolysis yield resulting from enhanced accessibility of the hydrolytic enzymes to the cellulose.

Autohydrolysis pretreatment and separate hydrolysis and fermentation (SHF)
Different water-based pretreatments have emerged as substitutes for dilute acid or alkali due to their low cost and eco-friendly nature, as they do not use chemicals and, most importantly, reduce the production of toxic or inhibitory compounds. Chen *et al.* (2021) integrated subcritical water (SW) pretreatment for the ethanolic production from wheat straw (WS). This strategy only uses water, which is maintained in a liquid state at a critical pressure (22 MPa) and heated above 100°C but below 374°C (Zhang *et al.*, 2020). Elevated temperature and pressure can reduce the pH level, leading to an increase in acid reactions. Additionally, SW solubilizes organic substances in lignocellulosic biomass due to the lowering of the dielectric constant (Zhang *et al.*, 2020). In the study, Chen *et al.* (2021) also incorporated high solid loadings in the enzymatic hydrolysis process to ensure the production of highly concentrated of sugar hydrolysates for ethanolic fermentation using the simultaneous saccharification and fermentation (SSF) method. Enzymatic hydrolysis generates high sugar yields of 77.85-89.59%, which can be attributed to high hemicellulose removal and structural degradation. However, unlike other pretreatments, Chen *et al.* (2021) pointed out that SW may only affect the structural interaction between lignin and cellulose but cannot remove lignin from the lignocellulosic biomass. With the use of high solid loading hydrolysis of 15%, the study generated a good bioethanol concentration of 37 g/L (3.34 - 96.18%), an amount that almost meets international standards for industrial distillation.

3.3.2 Production of biodiesel

Biodiesel is generated from the transesterification of feedstocks rich in vegetable oil or animal fats (Rajendran *et al.*, 2022). In the Philippines, coconut oil serves as the primary feedstock for biodiesel production as the country is among the leading producers of coconuts worldwide (Landoy *et al.*, 2022). However, similar to the edible feedstocks used in bioethanol production, biodiesel derived from first-generation sources faces challenges such as food security concerns, competition with other uses, low yield, and limited availability. Consequently, non-food feedstocks- such as waste cooking oil and fats derived from animal wastes- offer a more cost-effective and sustainable alternative.

Basic biodiesel production involves the transformation of feedstocks through transesterification. The incorporation of pretreatment techniques, transesterification-assisted methods, and the addition of efficient, low-cost, and reusable catalysts represents the current trend that aims to enhance biodiesel yield while considering the cost, energy requirement, environmental impact, and overall efficiency. Below are some of the techniques that can be applied in the Philippine setting. These techniques employ different cost-effective approaches while promoting high biodiesel yield (Table 4).

Table 4. Different combination of conventional pretreatment and fermentation strategies with novel catalysts in the valorization of vegetable oil and animal fat to biodiesel.

Waste Source	Pretreatment	Catalyst	Transesterification	FAME Yield	Reference
Soy bean oil	-	Calcined pineapple leaves waste	Transesterification	98%	De S Barros *et al.* (2020)
Waste cooking oil	-	Zinc doped CaO nano catalyst from waste egg shells	Direct transesterification	96.74%	Borah *et al.* (2019)
	Acid esterification (H_2SO_4)	TiO2/RGO nanocomposite	Basic Transesterification	98%	Borah *et al.* (2018)
Dairy waste scum	-	CaO from eggshell waste	Transesterification	96%	Kavitha *et al.* (2018)
Animal waste fats	Thermal pretreatment	H_2SO_4	Microwave assisted esterification	93%	Idowu *et al.* (2019)
Chicken skin waste	Cooking + acid esterification (H_2SO_4)	NaOH	Basic transesterification	97.5%	Abid *et al.* (2019)
Solid Food waste	Acid esterification	-	Ultrasound-assisted -alkali-transesterification	93.23%	Carmona-Cabello *et al.* (2019)
Note: FAME: Fatty acid methyl esters: generic chemical name for biodiesel					

Valorization using homogeneous catalyst

Conventional transesterification employs homogeneous catalysts as accelerants for biodiesel production. These catalysts are soluble in the solution with the reactants which contributes to their high catalytic activities. The most commonly used homogenous basic catalysts are sodium hydroxide (NaOH) and potassium hydroxide (KOH) due to their rapid rate of reaction and lower molar concentrations (Rajendran *et al.*, 2022). Several modified techniques incorporating pretreatment and assisted technologies are detailed below.

In a study conducted by Abid *et al.* (2019), they investigated the addition of acid esterification as a pretreatment to chicken skin wastes prior to the transesterification with base catalysts. Valorization of the chicken skin remains into biodiesel is a beneficial avenue for poultry waste reduction and generation of green energy. However, chicken wastes contain high amounts of free fatty acids (FFA), which can lead to saponification. Thus, in cases where there are insufficient amounts of base catalysts, soap formation may occur and reduce biodiesel yield (Aboelazayem *et al.*, 2018). Abid *et al.* (2019) applied fat extraction using a pressure cooker and acidic esterification with sulfuric acid as a solvent to reduce FFA to acceptable concentrations. This process is followed by basic transesterification using NaOH as a catalyst. The study showed a significant reduction in FFA to less than 1%, which is the required concentration for transesterification. Moreover, they also reported a biodiesel (FAME) yield of 97.5%, which was higher compared to several studies.

Carmona-Cabello *et al.* (2019) employed a similar acid esterification pretreatment strategy for solid food wastes (SFW), which are also rich in FFA. However, during the biodiesel production stage, ultrasound (US) was used to assist in the transesterification process. Transesterification typically requires continuous stirring under heated conditions to accelerate reaction rates, but these processes are often slow and consume significant amounts of energy. In their study, Carmona-Cabello *et al.* (2019) utilized the US as a mechanical assistance method to accelerate reactions and reduce the molar ratio of alcohol to oil. This process induces microbubble formation and subsequent implosion, generating high local temperatures and resulting in rapid emulsion formation. The study generated a promising FAME conversion yield of 93.23%. When compared to the conventional transesterification, US-assisted transesterification yielded similar conversion but outperformed in terms of shorter reaction times and higher energy efficiency. These results highlight the energy-saving capability of US-assisted transesterification.

Several studies have also utilized acid transesterification. In the study of Idowu *et al.* (2019), a new combination of techniques for biodiesel production from animal waste fats (AWF) utilized thermal pretreatment and microwave-assisted acidic esterification. AWF feedstocks are characterized by very high FFA (>20 wt%) and water content, necessitating pretreatment for efficient biodiesel conversion. Feedstocks are preheated at 88°C, resulting in lower viscosity and a reduced water content of 0.55 wt%. This was followed by microwave treatment at 70W, which significantly reduced FFA in a short amount of time. Since basic catalysts are ineffective for feedstocks with high FFA content, acid-catalyzed esterification was employed instead. Microwave assistance was incorporated into the process to expedite chemical reactions by increasing thermal conditions. Using these methods, Idowu *et al.* (2019) were able to generate a promising FAME conversion of 93 wt%.

Valorization using heterogeneous catalysts

A few studies have recently explored the use of heterogeneous catalysts. While homogeneous catalysts have higher catalytic activity, their major disadvantages include corrosiveness and high production costs, particularly during biodiesel purification, which often requires large amounts of water (Kavitha *et al.*, 2019). Heterogeneous solid catalysts are gaining attention because they are not only economically available but also simple to separate and recover for reuse, thereby lowering production costs (Rajendran *et al.*, 2022).

Borah *et al.* (2018) investigated an emerging technique using nanoparticles as catalysts for FAME conversion from waste cooking oil. In their study, nanoparticles were composited with titanium dioxide and reduced graphene oxide to form a stable TiO_2/RGO nanocomposite. Prior to the study, acid esterification was performed to reduce the high FFA levels in waste cooking oil. Basic transesterification with TiO_2/RGO nanocomposite resulted in a FAME conversion of 98%, attributed to the high surface-to-volume ratio and reduced particle size of nanoparticles, which catalyzed a faster reaction rate. Furthermore, the catalyst could be reused for over three cycles, eliminating additional treatment costs.

In another study, Borah *et al.* (2019) utilized waste eggshells to synthesize a low-cost catalyst for biodiesel production. Eggshells contain considerable amounts of calcium carbonate ($CaCO_3$), which can be calcined to form calcium oxide (CaO). CaO is a widely recognized, efficient solid catalyst that is not only inexpensive but also noncorrosive and highly reusable. The catalyst was impregnated into nanoparticles by doping it into a solution of zinc acetate dihydrate. The Zn-doped-CaO nanocatalyst generated a biodiesel conversion of 96.74%, exhibiting high catalytic activity and reusability.

Other low-cost and highly bioavailable catalysts can also be synthesized from agro-industrial wastes. For example, De S Barros *et al.* (2020) synthesized a bio-based catalyst from the calcination of pineapple leaf waste (CPL). Alkaline transesterification with CPL catalyst generated a remarkable biodiesel conversion rate of 98%. Additionally, CPL also demonstrated high catalytic activity for up to four recycling cycles and required low activation energy for transesterification. This study highlighted the high efficiency of CPL as a sustainable heterogeneous catalyst.

4. Conclusions

A diverse array of waste and by-product sources, including food waste, organic industrial waste, agricultural by-products, municipal waste, and pharmaceutical by-products, has been explored using innovative and advanced valorization techniques to generate high-value products with significant industrial applications. Key agricultural commodities such as growth media, fertilizers, water, and feedstuff have been successfully produced through processes like microbial fermentation, enzymatic digestion, dehydration, enzyme extraction, and homogenization. Moreover, cutting-edge valorization approaches, such as microwave-assisted extraction, microbial bioconversion, drying and milling, and fermentation, have enabled the extraction of valuable compounds like vanillin, pectin, gelatin, and other functional food ingredients for the food industry. For biofuel production, strategies incorporating advancements in pretreatment methods, microbial fermentation, and transesterification using novel catalysts have shown great promise in enhancing the efficiency and sustainability of bioethanol and biodiesel synthesis.

Future research and development in the Philippines is recommended to focus on scaling up these valorization technologies to address the country's specific waste management challenges, harnessing the vast availability of agricultural by-products and organic wastes to produce economically viable and environmentally sustainable solutions. Policies should prioritize integrating valorization technologies into national and local waste management systems by establishing funding programs for research and pilot projects, fostering collaborations between academia and industry, and ensuring the implementation of tax benefits or subsidies for companies that invest in sustainable waste valorization. Additionally, the formulation of national strategies to integrate valorization into waste management policies would not only mitigate environmental impacts but also stimulate economic growth through the creation of new markets and job opportunities.

These advancements underscore the pivotal role of valorization technologies in transforming waste into valuable resources, contributing to a circular economy, and fostering sustainable development.

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