Review Article

**A Review on the Valorization of Agricultural Biomass Wastes in Nigeria with Focus on Banana Pseudo-Stem, Empty Palm Bunch, and Rice Husk Applications**

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ABSTRACT

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| Biomass wastes (BW) have gained significant attention recently for their potential use in various industrial applications. This review reports the varieties of biomass wastes, ranging from agricultural and forest residues. The wastes are in abundance and poses environmental and health risks despite their positive potentials. However, innovative approaches such as composting, anaerobic digestion, and thermochemical conversion have emerged to transform the wastes into valuable products such as organic fertilizers, biofuels, biochemical and feedstuff for animals. Focusing on Nigeria, a major producer of biomass wastes such as bananas, oil palm, and rice, this paper reports the great quantities of these local biomass wastes generated their underutilization. This review also reports the potential of these biomass wastes including animal feed production, bioenergy generation, and soil enrichment. **Conclusion:** By promoting sustainable management practices and exploring innovative utilization pathways, biomass wastes can play a crucial role in mitigating environmental pollution, enhancing agricultural productivity, and fostering economic development. |

*Keywords: Biomass waste, Empty palm bunch, Banana pseudo-stem, Rice hull, Feedstuff*

1. INTRODUCTION

Biomass wastes (BW) have in recent times become the target of different scientific research all over the world, for their transformation into value added products for various industrial applications. Recent studies have particularly shown that various biomass wastes in the form of agricultural and forest residues could be processed into animal feedstuff and additives (Obasi, 2017; Okoli, 2020a; Ohanaka, 2022; Nwogu, 2022). The excessive cost of conventional feedstuffs, due to competition with human food and seasonal scarcity and shrinking pasture lands due to anthropogenic activities and the resultant conflicts between pastoralists and crop farmers have made livestock farmers and researchers to increasingly depend on alternative feedstuffs which are mostly biomass residues as potential sources of nutrients for livestock (Okoli et al., 2014; Ohanaka et al., 2017; Uchegbu et al., 2017). The term biomass has been defined as organic substances of non-fossil origin such as natural living organisms (flora and fauna), the resultant residues (e.g. animal excrements), dead (but not fossilized) phytomass, and organic matter, and substances generated through their transformation by means of technological applications and/or use of the materials or substances that result from the transformation (e.g. abattoir and organic household wastes). Biomass wastes therefore refer to organic materials of plant or animal origins that are no longer valued after the original product has been extracted. They commonly consist of forestry residues, agricultural wastes, animal wastes, industrial wastes, municipal solid wastes, food processing wastes etc. (Iwuaze et al., 2014; Hakeem et al., 2015; Jekayinfa et al., 2020).

Most crops are subjected to further processing that usually generates secondary and tertiary waste streams in addition to the primary biomass wastes generated in the field during harvest (Shah et al., 2018; Bhuvaneshvari et al., 2019). These wastes encompass various organic matter or carbon-containing compounds derived from living things such as plants and animals. Agricultural residues comprise remnants of crops such as stalks, husks, hulls, and stems left in the field after harvest, whereas forest residues consist of branches, treetops, bark, wood shavings and sawdust resulting from logging activities (Jekayinfo et al., 2020). Food wastes include discarded food, trimmings, and peels generated during food processing, distribution, and consumption, while animal manure refers to the waste produced by livestock farming, such as cow dung, poultry litter, and pig manure (Bonechi et al., 2017). Energy crops involve specifically cultivated plants like switchgrass, miscanthus, or fast-growing trees for biomass energy production (Unal and Alibas 2007), while aquatic biomass encompasses organic material sourced from aquatic environments, such as seaweed and algae (Bonechi et al., 2017). Energy crops involve specially cultivated plants like switch grass, miscanthus, or fast-growing trees for biomass energy production (Unal and Alibas, 2007), while aquatic biomass encompasses organic material sourced from aquatic environments such as seaweed and algae (Bonechi et al., 2017).

2. VOLUMES OF BIOMASS WASTES GENERATED IN NIGERIA

UNEP (2015) reported that about 140 Gt of agricultural residues are generated each year, while about 517 million tons of this remains unexploited each year. Jekayinfa et al. (2020) reported more recently that 2.8 Gt of cereal crops, 3.1Gt of 17 major kinds of cereals and legume and 3.8 Gt of 27 common food crop residues are produced globally. More than 60% of these agricultural residues have been estimated to come from the developing low-income countries like Nigeria (Duque-Aovede et al., 2020). UNEP (2016) have therefore projected the global production of agricultural residue to continue to increase with the global population, especially as intensification approaches are increasingly adopted for increased crop yield. Akorode et al. (2017) estimated that more than 94 million tons of agricultural biomass residues are produced in Nigeria and are distributed as shown in table.1, with cassava, yam, millet and plantain wastes being the major ones. Limited quantities of these agricultural residues applied to various traditional uses as animal feed, fertilizer, biofuel, building materials and artisanal crafts, while most of them are disposed inappropriately, resulting in environmental degradation, pollution, and nuisance (Subagyo and Chafide, 2020; Okoli, 2020a). Bos and Hamelink (2014) report that these agricultural wastes are usually discarded through incineration, landfills and wastes dump site and usually results in human health risk and dirty environments (Fapohunda and Oluwasegunota, 2019; Fapohunda, et al., 2021). Inappropriate disposal of crop wastes has been specifically reported by researchers to have negative influence on both human and animal health as well as environmental pollution, greenhouse gas (GHG) emission, and climate change (Bos and Hamelinck, 2014; Bharathiraja et al., 2017; Sadh et al., 2018). Excessive accumulation of agricultural wastes due to inappropriate disposal over large areas of land has particularly been reported to pollute the land and lead to eutrophication due to nitrogen and phosphorus accumulation and may result in phyto-toxicity (Yang et al., 2017). Such mineral accumulation may also contaminate surface and sub-terranean water sources, thereby compromising the quality of water meant for human and animal consumption (Liu et al., 2019).

Although these biomass wastes have been highly exploited in some part of the world for varied purposes, their utilization in Nigeria remains very low and almost negligible. They have however traditionally been converted to organic fertilizer through composting or anaerobic digestion, thereby enriching soil fertility and structure (Bhardwaj et al., 2014; Chew et al., 2019). Recently, they have been used as substrate for the production of mushrooms, livestock feeds, industrial chemicals and fiber production (Obasi, 2017; Uchegbu et al., 2017; Subagyo and Chafidz, 2018; Okoli, 2020a). They have also been converted into energy, through processes like combustion, anaerobic digestion, fermentation, pyrolysis, and gasification (Qiao et al., 2011; Gumisiriza et al., 2017). Biomass wastes can also serve as raw materials for other industrial processes, including the production of biofuels, biochemicals, bioplastics, and other bio-based materials.

In recent times, several innovative methods such as production of feed-grade ash, biochar and activated charcoal (Nwogu, 2022; Ohanaka, 2022), production of biogas, biofuel and briquettes (Edo, 2023) and processing into cost effective animal feedstuffs (Obasi, 2017; Uchegbu et al., 2017) have been tried in our station to enhance the value of locally available biomass wastes. Generally, the physicochemical characteristics of these biomass wastes make them potential feed raw materials, although more for ruminant livestock than monogastrics. The conversion of biomass wastes to value added products has therefore several environmental benefits, such as reducing greenhouse gas emissions, diverting waste from landfills, and promoting the use of renewable resources. It is however essential to implement sustainable management practices that prioritize responsible sourcing, efficient conversion technologies, and the consideration of the overall life cycle impacts associated with biomass utilization (Yu et al., 2022).

Table 1: Estimate of some crop residue production in Nigeria for 2014

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| Crop | Crop residue production (million metric tonnes) |
| Cassava | 29,000,000 |
| Yam | 22,000,000 |
| Millet | 11,000,000 |
| Maize | 3,000,000 |
| Rice | 1,800,000 |
| Potato | 600,000 |
| Cowpea | 4,050,000 |
| Groundnut | 6,000,000 |
| Oil palm | 400,000 |
| Sugar cane | 300,000 |
| Sweet potato | 2,000,000 |
| Cocoyam | 1,500,000 |
| Coffee | 400,000 |
| Cashew | 300.000 |
| Plantain | 9,450,000 |
| Sorghum | 2,500,000 |

**Source:** Akorode *et al.* (2017)

**2.1 Common Biomass Wastes in Nigeria**

Nigeria, like many tropical countries, generates various types of biomass wastes from agricultural, forestry, industrial, and municipal activities (Olorunnisola, 2007). Jekayinfa *et al.* (2020) listed forest residues, crop stalks, leaves, roots, fruit peels, seeds/nut shells and animal wastes as the predominant biomass wastes/residues produced in the country. Akorode *et al.* (2017) reported that about 94.4 million tons of crop residues are produced in the country, with cassava, yam, millet, plantain and groundnut residues being the abundant. About 0.78 million tons of animal waste has also been estimated for the country, they also estimated that about 0.4 and 1.8 million tons of oil palm and rice wastes respectively are produced in the country.

Since Nigeria is a major producer of bananas, palm oil and rice, the quantity of wastes produced from these crops will be high, indicating the need for their conversion into beneficial products. The major biomass wastes derived from banana, oil palm and rice, which could be processed into animal feeds, using different technological approaches include the banana pseudo-stem; empty palm fruit bunch, and rice hulls respectively (Anyanwu *et al.*, 2013; Iwuaze *et al.*, 2014; Ishola *et al.*, 2019; Jekayinfa *et al.*, 2020).

**2.1.1 Banana pseudo-stem (BPS)**

The banana plant, also known as a banana tree (though it is technically a herbaceous plant), is a large perennial plant that belongs to the family Musacea and genus Musa and native to the Malasia, Indonesian region of Southeast Asia (Aziz *et al.*, 2011; Ma, 2015). Bananas are widely produced in the tropical and sub-tropical countries of the world with Nigeria being the 2nd and 8th largest producer of banana and plantain respectively in Africa (FAOSTAT, 2018). The banana is a remarkable plant with a rich cultural, economic, and agricultural significance in the regions where it is cultivated. It provides not only nutritious fruits but also various materials and resources that are utilized in different ways. For example, after the harvest of the banana fruit bunch, the trunk or pseudo-stem and leaves are discarded as wastes. For each of banana fruit harvested about 4 tons of such wastes are produced, indicating four times more biomass wastes than fruits. The banana plant is characterized by its tall, sturdy stem, called a pseudo-stem, which is not actually made of wood like a tree trunk (Ma, 2015). The pseudo-stem consists of tightly overlapping leaf sheaths that provide support for the plant (Oladiji *et al.*, 2010). The leaves are large, elongated, and arranged spirally at the top of the pseudo-stem. The plant produces clusters of fruits known as hands, which typically contains several individual banana fruits. After the flowering, the fruit develops facing down-wards in a process that can take several months (Kirchoff, 2017). There are numerous banana varieties, but the most widely cultivated and consumed is the Cavendish banana, partly because of its high productive capability, and tenacity, even in adverse climatic conditions (Okoli, 2020c; FAO, 2023). Banana plants are propagated through their rhizomes, which are underground stems. When a banana plant matures and bears fruit, it sends up a new shoot from the rhizome called a sucker which can be separated from the parent plant and replanted to grow a new banana plant (Mustaffa and Kumar, 2012; Madison, 2023). Bananas require warm temperatures, adequate rainfall, or irrigation, plenty of sunlight, and well-drained soil while they are sensitive to frost and cannot tolerate extreme cold, thus making the tropical environment ideal for their growth (Mustaffa and Kumar, 2012; Chand *et al.*, 2021)

The pseudo-stem of a banana plant is not a true stem, but a collection of tightly packed leaf sheaths that form a strong and sturdy structure (Ma, 2015). Jayaprabha *et al.* (2011) reported that the number of pseudo-stem sheaths differ among varieties of the same type of banana species and further observed a minimum of 13 layers of sheath found in the pseudo-stem of all Nendran varieties. The banana plant grows vertically from the ground and can reach heights of up to 5 – 7.6 meters in some banana varieties (Nelson *et al.*, 2006). The stem provides structural support to the banana plant and therefore helps the plant to withstand strong winds, while supporting the weight of the leaves, flowers, and fruit clusters (Ma, 2015). It also contains an inner tender core which is located in the middle of the stem and carries the immature inflorescence until eventually it emerges at the top (Subagyo and Chafidz, 2020). It is the most nutritious part of the stem and surrounded by the delicate emerging leaves (Lakshman *et al.*, 2015). It also acts as a reservoir, for storing water and nutrients which can be used by the plant during periods of drought or unfavorable conditions (Ali, 2022). After harvesting the fruit, the pseudo-stem is usually cut down to make way for new suckers that will grow into mature plants and produce fruit in the future. The structure of the banana tree and pseudo-stem are shown in plate 1. Several studies have revealed the potential values of the various parts of banana such as the peels which could be converted to edible ash for cooking and as additive in livestock feed (Duruanyim, 2017; Hikal *et al.*, 2022). The leaves are used as packaging material, for cooking, as feedstuff for livestock and for arts and crafts (Kamira *et al.*, 2015; Thiet *et al.*, 2022).

The pseudo-stem has been processed for its fiber which is being used in textile, paper, pulp ropes and arts and crafts production while they has been used to make confectionaries and liquid fertilizer (Subagyo and Chafidz, 2020, Arafat *et al.*, 2018; Matos *et al.*, 2019). The pseudo-stem is also traditionally fed to ruminants and pigs in many Asian countries and has recently received research attention as a potential cheap alternative feed raw material (Thiet *et al.*, 2022; Wanga *et al.*, 2016; Arjin *et al.*, 2020).

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| Banana trees | Banana pseudo-stem |
| Milled banana pseudo-stem | |

**Plate 1**: The pictures of banana trees, banana pseudo-stem, and milled banana pseudo-stem (Picture series: Giwa, 2023)

**2.1.2 Empty palm fruit bunch (EPFB)**

Oil palm (*Elaeis guineensis*) is the most commercial perennial tree cultivated in the world as a source of oil. The oil palm tree being a tropical plant originated from West and Central Africa but has now spread extensively to diverse tropical locations worldwide, especially Asian countries such as Malaysia and Indonesia. The oil palm tree is known for its tall and slender trunk and grows up to 20 m in height. Their leaves are characterized by multiple leaflets arranged on both sides of the central leaf stem known as pinnate. These leaves can reach lengths of up to 5 meters and are arranged in a spiral pattern at the top of the trunk. In Africa, the oil palm is the source of a local fermented drink (palm wine) produced by tapping the male inflorescence or the trunk of the oil palm tree for its sap and fermenting the resulting sap to form palm wine (Mynepalli & Adeoluwa, 2009**).** Beneath the leaves of the oil palm tree are the palm bunches in which the oil palm fruits are produced.

Palm oil is the most widely used vegetable oil in the world, with 73.80 million tonnes being produced globally in 2021/2022, increasing from approximately 73.00 million tons in the 2020/2021 marketing year (Shahbandeh, 2023). Statista (2023) also report Nigeria is the 5th largest producer of palm oil in the world (1.40 million tons) and the largest producer in Africa. Palm oil production and processing are therefore major economic ventures in Nigeria, especially in the southern states where the palm trees grow in the wild and in plantations (Okoli, 2020f). The oil is highly versatile and widely used as edible oil for domestic cooking, food processing, cosmetics production, and a range of other industrial applications, such as biofuel production and manufacturing (Pande *et al.*, 2012; Norhaizon *et al.*, 2013). The palm nut extracted from the palm kernel also contains a lot of oil which is also extracted and used for cooking and several industrial applications (Bong *et al.*, 2020). The oils account for only 10% of the oil palm’s biomass (Bauer and Kauffman, 2020), implying that about 90% of the oil palm biomass eventually becomes residues. These residues include the empty palm fruit bunch, palm kernel shells, trunk of the plant, press fibre, leaves, liquid effluents and others (Mynepalli and Adeoluwa, 2009**).** Specifically, about 70% of the fresh oil palm fruit bunch is turned into waste in the form of empty fruit bunch, fiber, shell and liguid fluent after palm oil extraction (Okoli, 2020b). Plate 2 shows the palm tree, its fruit bunch and the empty bunch after the extraction of the nuts.

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| Palm plantation  (Source: Okoli 2020f) | We Buy Any Quantity Of Palm Fruits Bunches.. - Business - Nigeria  Heap of Palm fruit bunches  source: Google |
| Heap of Empty palm bunches (EPB)  (Source: Giwa, 2023) | Milled empty palm bunch  **(**Source: Giwa, 2023) |

**Plate 2:** Pictures of palm plantation, palm fruit bunches, empty palm bunches and milled empty palm bunch

The empty palm fruit bunch (EPFB) is the leftover or discarded portion of the oil palm fruit bunch after the palm nuts have been removed during the palm oil extraction process. EPFB is a major waste product produced in oil palm plantations, accounting for about 20 – 23% of the oil mill residue. Abdullah and Sulaiman (2013) specifically reported that the EPFB represents about 22 % of the fresh fruit bunch on wet basis and 14.6 % on dry weight basis. Noah (2022) reported that more than 22.4 million tons of EPFB are produced worldwide, thus posing disposal challenge. As a result, several approaches have been employed to reduce the volumes generated in local palm oil mills, through burning in open air or in a burner to generate energy. The ash produced from the burning of EPFB is rich in potassium and other minerals and have been utilized in soil enrichment, soap making and as edible bioash (Duruanyim, 2017; Afiana *et al.*, 2021; Okoli, 2020g). Ujile and Okwakwam (2018) reported the use of the ash as absorbent to remove heavy metals in water while, Fapohunda *et al.* (2021) reported its use in attaining sustainability in structural concrete production and practice.

Empty palm fruit bunch has been combusted to produce feed-grade ash, biochar, and activated charcoal (Promraksa and Rakmak, 2020; Nwogu, 2022; Edo, 2023) and edible ash (Duruanyim, 2016). It has equally been used in the production of biogas, biofuel, and briquettes (Srisong *et al.*, 2017; Suksong *et al.*, 2020) to enhance the value of the material. Januari and Agustina (2022) reported that composting and anaerobic digestion are the alternative treatments that can be implemented by palm oil mills since both can reduce the EPFB waste and produce products that can be sold or reused.Mynepalli & Adeoluwa (2009) in their review also reported the valorization of EPFB in weeds and erosion control, the maintenance of soil moisture around young palm trees and also its use in the production of paper. Majesty and Herdiansyah (2019) reported the use of EPFB in the production of furfural, a bio-based chemical derived from the cellulose found in the empty palm fruit bunch. This bio-based substance serves as a foundational component for creating various valuable products such as the fuel additive methyltetrahydrofuran (MTHF), an eco-friendlier substitute for lead as an anti-knocking agent (Eseyin and steele, 2015). Zakaria *et al.* (2018) also reported the utilization of EPFB in the production of bio-phenolic resin, an alternative way to reduce the dependency of petroleum-based phenol. Okoli (2020f) revealed that the cellulose and hemicellulose derived from the empty palm fruit bunch can be hydrolyzed to sugars which could further be fermented to produce biofuels, organic acids, and enzymes among other products through thermo-chemical transformation.

Furthermore, EPFB has been reportedly used as a potential substrate for the production of feed-grade bio-proteins through solid-state fermentation, employing fungal organisms (Suksong *et al.*, 2020). Such approach has also been used to improve the nutritional quality of EPFB for use as feedstuff for livestock (Nur-Nazratul *et al.*, 2021). Studies by Tabi *et al.* (2008); Kavitha *et al.* (2013) and Lin *et al.* (2015) have also reported the efficient utilization of EPFB as substrate for the cultivation of mushrooms such as the oyster mushroom (*Pleurotus ostreatus*). Despite all these innovative uses of empty palm fruit bunch, the biomass material remains very much underutilized in many African countries where it constitutes environmental problems, ranging from fouling, attraction of pests, greenhouse gas emissions to soil acidification, and human health challenges.

**2.1.3 Rice hulls/husks**

Rice, scientifically known as *Oryza sativa*, is a type of nourishing starchy cereal grain that grows as a grass plant, belonging to the Poaceae family. The cultivated rice plant is an annual grass and grows to about 1.2 metres (4 feet) in height, has long and flattened leaves borne on hollow stems, broad fibrous root system and panicle, or inflorescence (flower cluster), made up of spikelets bearing flowers that produce the fruit, or grain. The major rice-producing countries in the world include China, India, Indonesia, and Bangladesh, while Nigeria is the largest producer in Africa and 14th in the world (FAOSTAT, 2018). The majority, or 95% of the rice harvest worldwide is consumed by humans (Bouman *et al.*, 2007), particularly in Asia and Africa. Only three agricultural crops, namely rice, maize, and wheat, contribute almost 66% of the world's total energy intake from food (Jones & Ejeta, 2016). Of the overall 24.6 billion metric tons of rice produced in Africa in the 2020/2021 (Kamer, 2023), Nigeria accounted for 55%, while Egypt accounted for 30% of the total volume. Although rice majorly rice is majorly cultivated in the northern part of Nigeria, its production cuts across many zones in the country with Kano, Jigawa, Niger, Kwara, Kebbi, Ebonyi, Anambra, Ekiti Nasarawa, Ogun, Kaduna and cross river states being the major producers (Maduawuchi, 2020; Mba *et al.*, 2021). These states are therefore the major locations where rice and its by-products could be found in abundance.

The production of rice generates many by-products starting at the field during harvest and during processing. At the field during harvest, the paddy rice is threshed out of the straw thereby leaving the straw as the waste, whereas during rice processing (milling), the by-products are majorly rice hulls and rice bran (James *et al.*, 2017). Notably, the processing of paddy rice results in 68 - 72% production of the rice grain (endosperm) as the major product, while rice hull/husk (20%), rice bran (8-12%) and rice germ (2%) are the by-products (Esa *et al.*, 2013; Samaddar *et al.*, 2017). The annual worldwide production of rice hull is very substantial, approximating 100 million tons with 90% of this being produced in the developing countries (Glushankova *et al.*, 2018). Plate 3 shows a paddy rice field, the rice straw generated after harvest and a mountain of rice hull at a rice processing location in Nigeria.

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| Why we want government to invest more in rice farming' | The Guardian  Nigeria News - Nigeria and World News — Features — The Guardian Nigeria  News – Nigeria and World News  Rice field | Keeping composting simple - Ileia  Heap of rice straw |
| 107 Rice Hulk Images, Stock Photos, 3D objects, & Vectors | Shutterstock  Heap of rice hull/husk | |

**Plate 3**: Rice field, a heap of rice straw in the field and heap of rice hull at a rice mill

(Pictures series: Google )

Rice hulls are the outer protective layer of the rice grains and are removed during the milling process. They are lightweight, voluminous, and often considered as waste by the rice farmers and most millers in Africa. Nigeria produces about one million tons of rice by-products annually (Ubara *et al.*, 2014), which pose disposal challenges and environmental concerns, necessitating innovative solutions for their management (Ejiofor *et al.*, 2020). These husks are fibrous and have limited nutritive value for livestock, which restricts their use as animal feed. Consequently, rice hulls often accumulate at the rice-processing sites, leading to disposal challenges. Improper disposal methods, such as open burning or dumping in water bodies, not only contribute to environmental pollution but also pose health hazards due to the release of harmful gases and pollutants (Njoku *et al.*, 2021). Despite the disposal challenges, rice hulls offer promising potential for various applications in agriculture, industry, and environmental management (Das *et al.*, 2022).

For example, the ash produced from rice hulls has many applications in road construction (Patil *et al.*, 2014) and cement production (Petal, 2019; Zaid *et al.*, 2021; Liu *et al.*, 2021). The hulls have been processed and mixed with other materials to create composites suitable for construction purposes. These composites can be used to make lightweight and eco-friendly building materials such as boards, panels, and insulators (Hasan *et al.*, 2015). Through controlled pyrolysis, rice hulls can be converted into biochar (Herrera *et al.*, 2022), a stable form of carbon that can improve soil quality, carbon sequestration, and nutrient retention in agricultural soils due to its absorptive properties (Singh *et al.*, 2022). Rice hulls can also be used directly to enhance soil properties, such as water retention and aeration, when used as a soil amendment. They can be incorporated into soil to improve its structure and fertility, especially in regions with sandy soils (Singh *et al.*, 2022). Darmawan *et al.* (2018) and Salisu *et al.* (2021) reported the use of rice hulls as source of biomass fuel to generate energy for heating, and electricity production, thus, contributing to rural electrification, and reducing the reliance on fossil fuels. This can be achieved by either gasification or direct combustion methods in order to efficiently utilize the rice hulls for energy production. Rice hulls can serve as bedding material for livestock, because as a good absorbent it can help in the management of odors and can therefore improve the overall hygiene of animal housing facilities. For example, carbonized rice husk has been employed by Shah *et al.* (2022) as an effective bedding material for broilers to reduce the burden of *E. coli* and ammonia production in the litter. Rice hulls have also been used as substrate for mushroom cultivation, providing a suitable medium for the growth of edible and medicinal mushrooms (Frimpong-Manso *et al.*, 2011; Hanai *et al.*, 2005; Okigbo *et al.*, 2021).

3. CONCLUsion

This review highlights the immense potential of biomass wastes as valuable resources that can be harnessed for various industrial applications, particularly in animal feed production industries. The abundance of biomass wastes, including agricultural residues, forestry residues, and food wastes, presents an opportunity for their transformation into high-value products, thereby mitigating environmental pollution and addressing challenges in livestock feed supplementation. However, despite their potential, biomass wastes are often underutilized, leading to environmental and health hazards.

Furthermore, by exploring innovative approaches such as composting, anaerobic digestion, and thermochemical conversion, biomass wastes can be effectively converted into organic fertilizers, biofuels, and biochemicals, thus contributing to sustainable agriculture and energy security. Lastly, leveraging the potential of biomass wastes and implementing sustainable management practices, we can not only address environmental challenges but also create economic opportunities and enhance resilience in the face of global resource constraints. The continued exploration and development of biomass waste utilization pathways hold promise for achieving a more sustainable and prosperous future.

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