Biodegradation of Agro-Industrial Wastes by Fungi in Nigeria: A Review

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ABSTRACT

Managing agro-industrial waste is a significant environmental and economic issue in Nigeria, where agriculture plays a vital role in the economy. These wastes, largely made up of lignocellulosic materials which offer opportunities for value addition through fungal biodegradation. This review examines the potential of fungi in transforming agro-industrial residues such as groundnut shells, rice husks, plantain peels, yam peels, and palm oil mill effluents. Case studies demonstrate the effectiveness of fungal species like *Aspergillus niger*, *Trichoderma viride*, and *Pleurotus* spp. in improving the nutritional quality of these materials, reducing environmental pollution, and enabling the creation of valuable products. Fungal biodegradation also helps to lower greenhouse gas emissions which supports environmental cleanup to produces affordable raw materials for other uses.. The review emphasizes the need for more research and the broader implementation of fungal-based waste management approaches to foster sustainable agro-industrial practices in Nigeria.

Keywords: Agriculture, fungi, lignocellulose, sustainable, pollution

INTRODUCTION

Nigeria, Africa's most populous country with over 150 million people (Taiwo *et al.*, 2012), has a primarily agrarian economy. Agriculture is the main source of food, raw materials, and income for a large portion of the population. Key food crops grown in Nigeria include sorghum, millet, rice, maize, wheat, yam, cassava, cowpea, groundnut, vegetables, and fruits (Akande, 2015). Agro-industrial wastes are by-products from agricultural and agro-industrial processes that are not used for food. These wastes include crop residues, animal manure, slaughterhouse waste, and by-products from food processing and consumption (Jonathan,2019, Ogbu and Okey, 2023). The agro-industrial sector, especially the food industry, significantly contributes to solid waste production, mainly from processing activities. These wastes consist of stalks, straws, leaves, husks, shells, peels, seeds, and pulps from fruits, legumes, and cereals like rice and maize, as well as bagasse from sugarcane processing (Ayo *et al.*, 2015). The rapid population growth in Nigeria has led to an increase in food and agricultural production, thereby worsening agro-industrial waste accumulation (Kolawole *et al.*, 2024). Improper disposal of agricultural waste causes environmental pollution and creates breeding grounds for vectors like flies, mosquitoes, and harmful microorganisms, which present serious public health risks. Additionally, open burning of agricultural residues in Nigeria emits carbon dioxide (CO_2) and other greenhouse gases, contributing further to environmental concerns (Kolawole *et al.*, 2024).

The existing approaches to agro-waste disposal in Nigeria are ineffective and pose significant risks to both the environment and public health (Eneji *et al.*, 2016). In alignment with the United Nations Sustainable Development Goals (UNDP, 2022), which emphasize environmental conservation and improved public health, there is an urgent need to explore sustainable and eco-friendly alternatives for managing agro-industrial waste. In contrast, developed nations efficiently repurpose agricultural residues into biodegradable and cost-effective products, including textiles, footwear, reinforcement fibers, and other bio-based materials (Abdallah *et al.*, 2021).

Recent advancements in biotechnology, especially enzyme and fermentation technology, have shown that microorganisms can effectively degrade agro-industrial waste. Biodegradation reduces the environmental impact of agro-waste by breaking it down into less harmful substances or converting it into raw materials for industrial use (Stahl). Agro-industrial wastes mainly consist of sugars, fibers, proteins, and minerals of industrial value (Ayo *et al.,* 2016). However, many of these wastes contain phenolic acids and other toxic compounds, which can harm the environment if not properly treated. Much of agro-industrial waste is lignocellulosic biomass, composed of cellulose, hemicellulose, and lignin (Ayo *et al.,* 2016). The transformation of lignocellulosic materials into industrial products through biological processes relies on cellulolytic and hemicellulolytic enzymes (Akinyele *et al.*, 2020).

Fungi have an efficient hydrolytic system, secreting enzymes like cellulases and hemicellulases that break down lignocellulosic biomass into valuable metabolites (Soliman *et al.*, 2013). Due to their enzymatic potential, fungi offer promising biotechnological applications for agro-industrial waste management. This review explores the role of fungal biodegradation in Nigeria's sustainable management of agro-industrial waste, focusing on its challenges, opportunities, and prospects.

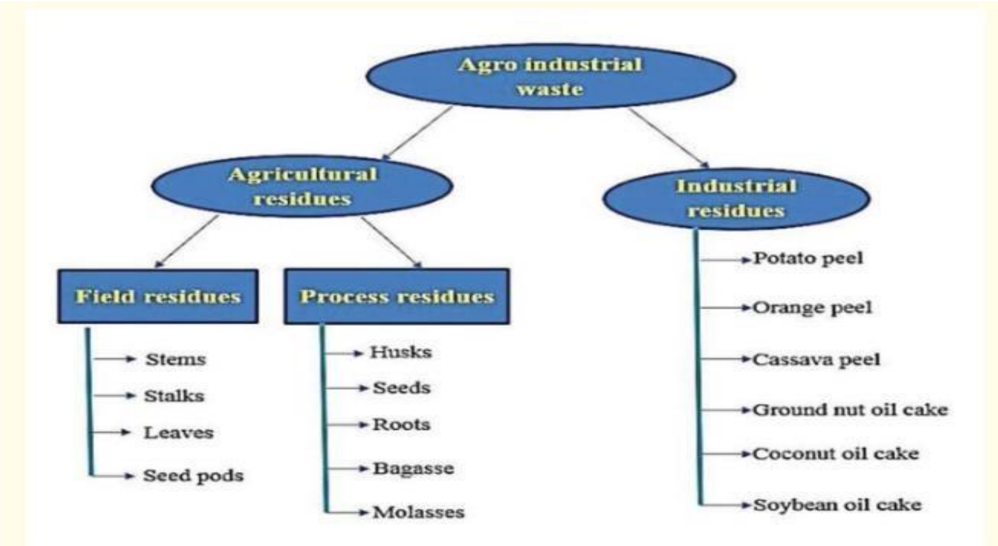
Agro-industrial wastes in Nigeria

Types and sources of agro-industrial waste

Agriculture plays a vital role in Nigeria's economy, contributing about 19.17% to the nation's Gross Domestic Product (GDP) (Isiwu *et al.*, 2023). Beyond providing food, raw materials, and a primary source of income for many people, agricultural activities generate large amounts of waste annually, especially from food industry processing operations. Agro-industrial waste, which originates from various agricultural processes, includes a wide range of organic by-products such as shells, peels, straws, stems, seeds, stalks, lint, and stubble from fruits, legumes, and cereals. Other significant waste materials include by-products from sorghum milling, spent coffee grounds, brewer's spent grains, and sugarcane bagasse (Ayo *et al.*, 2015). In addition, fruit marc or pomace from oil or juice extraction, and residues from meat processing industries like animal fats, chicken skin, eggshells, and slaughterhouse waste, contribute notably to agro-industrial waste. Further sources include starch residues from starch production, de-oiled seed cakes from edible oil production, and molasses from sugar production industries (Afolalu *et al.*, 2020). Non-edible oil plants such as *Pongamia pinnata* and *Jatropha curcas* also generate de-oiled seed cakes, which are classified as agro-industrial waste (Maiti *et al.*, 2016).

The growing accumulation of these waste materials presents significant environmental challenges. Therefore, effective waste management approaches, including recycling, composting, and biotechnological conversion, are crucial for sustainable agricultural and industrial practices. Agro-industrial waste can be divided into three main categories: (i) recyclable and compostable waste, (ii) non-recyclable and non-compostable waste, and (iii) hazardous waste. Recyclable and compostable waste, commonly referred to as naturally occurring agricultural and agro-industrial waste, can be repurposed on farms or processed in recycling facilities. This category comprises primary residues generated directly from crop and livestock activities, including straw, leaves, stover, stalks, bagasse, cobs, and animal manure. Additionally, secondary residues, such as pits, shells, peels, husks, and slaughterhouse waste, emerge as by-products of agro-industrial processing (Chikezie *et al.*, 2023).

Non-recyclable and non-compostable agro-industrial waste arises from activities like farm construction, mechanization, transportation, and livestock facility management. These materials are often large and difficult to manage due to their limited potential for reuse or recycling. Examples include plastic sheets, containers, tires, metal structures for fencing, and irrigation equipment. Hazardous agro-industrial waste presents serious environmental and health risks if not properly managed. This category includes phytosanitary products, chemical containers, acids, fertilizers, wastewater, chemically contaminated water, food waste, and various industrial by-products such as medicines, agrochemicals, and detergents (Chikezie *et al.*, 2023). Implementing effective waste management strategies is essential to reduce the environmental impact of these materials and promote sustainable agricultural and industrial practices.



Classification of recyclable agro-industrial waste (Sadh et al.,2023)

Environmental and Economic Impact

The improper disposal of waste from agro-based industries presents a major environmental risk, leading to pollution that negatively impacts both human and animal health (Afolalu *et al.*, 2020). The continuous buildup of agricultural waste in Nigeria and worldwide has resulted in environmental degradation, evident in land, air, and water pollution. This accumulation encourages microbial growth, harms environmental aesthetics, and releases harmful gases into the air (Ogundele *et al.*, 2018). However, waste materials that were once considered economically insignificant are now being recognized as valuable resources. By-products from agro-industrial processing, forestry, and animal production are increasingly being used as raw materials with considerable economic potential (Chikezie *et al.*, 2023).

Current Waste Management Practices

In Nigeria, untreated agricultural waste is often disposed of through unregulated practices such as landfilling and burning, which contribute to climate change by increasing the emission of greenhouse gases (Afolalu *et al.*, 2020). In urban areas, food waste is usually placed in bins, collected by waste management services, and taken to landfills. In contrast, rural areas often see food waste being discarded in the bush, on roadsides, or burned, leading to CO2 emissions and pollution (Abdurrahman et al., 2020). Moreover, agricultural solid waste is frequently mismanaged due to a lack of awareness, as many farmers lack the knowledge to adopt effective waste management strategies. This waste is often disposed of carelessly, either dumped or burned in open areas, producing harmful gases, smoke, and dust, which contribute to contamination of the soil, water, and air (Oluseun and Adebukola, 2020).

Fungal Bio-degradation Processes

Fungi are crucial for lignin degradation through the coordinated action of ligninolytic enzymes, organic acids, mediators, and accessory enzymes (Mehdi Dashtban *et al.*, 2010). They have a highly efficient hydrolytic system that facilitates the conversion of lignocellulosic materials into essential metabolites for growth. Key enzymes released by fungi, such as cellulases, hemicellulases, and β-glycosidases, help break down lignocellulose. Notably, engineered mutant strains of *Trichoderma reesei* can produce high levels of extracellular cellulases, reaching up to 35 g/L. Increasing enzyme activity is essential for improving lignocellulose hydrolysis efficiency. Lignocellulose, primarily composed of lignin, hemicellulose, and cellulose, is a major component of agricultural and industrial waste. The large-scale accumulation of lignocellulosic waste presents a significant environmental threat. However, converting this waste into valuable products like biofuels, chemicals, and animal feed offers a sustainable waste management solution while generating economic benefits. Utilizing low-cost lignocellulosic materials for enzyme production can significantly lower processing costs. Biological degradation, especially fungal-mediated degradation, is an efficient method for managing agricultural and industrial waste (Soliman *et al.,* 2013). Several fungal species have been extensively studied for their potential in degrading agro-industrial waste.

Lignocellulolytic enzyme-producing fungi

Fungi that produce lignocellulolytic enzymes are found across a range of taxonomic groups, including ascomycetes like *Trichoderma reesei* and basidiomycetes such as white-rot fungi (*Phanerochaete chrysosporium*) and brown-rot fungi (*Fomitopsis palustris*). Furthermore, some anaerobic fungal species, such as *Orpinomyces sp.*, have been recognized for their role in cellulose degradation within the digestive systems of ruminant animals (Mehdi Dashtban *et al.,* 2010).

White rot fungi

Ligninolytic basidiomycetes, a unique group of saprophytic fungi, are responsible for the white-rot decay of wood and are commonly known as white-rot fungi (Nadeem *et al.,* 2015). These fungi play a vital role in the degradation and natural breakdown of lignocellulosic materials, such as decaying wood and plant residues. White-rot fungi secrete extracellular enzymes that break down lignin, including lignin peroxidase, manganese peroxidase, and laccase (Latif *et al.,* 2023). These enzymes promote the oxidation and depolymerization of lignin, which increases the availability of hemicellulose and cellulose for nutrient absorption and energy production by the fungi.

Jonathan *et al* (2008) investigated the biodegradation of sawdusts wastes from four Nigerian economic trees namely, *Holoptelia grandis, Mansonia altissima, Milicia excels*a and Terminalia superba by macrofungus named Pleurotus tuber-regium.They observed that the pH of the fermented woodwastes dropped to 4.0 after 90 days of incubation. Conversely amino nitrogen content were found to increase.

The highest lignin reduction were observed in H. grandis wastes followed in order by T. superba, M. altissima and M. excelsa. Invitrol digestibility of the spent substrates by these ruminants were also found to increase during the solid state during fermentation: M. excelsa > M. altissima > T. superba >H. grandis.

Jonathan et al,2008 observed that all the fresh wood wastes investigated were found to stimulate the mycelial extention of the studied fungus..The ability of Pleurotus tuber-regium to grow on different wood wastes could be attributed to the ability of this organism i to produce hydrolyzing and oxidizing enzymes, which could promote the decomposition of biodegradable compounds in the woodwastes to digestible compounds (Gbolagade etal.,2006,Akinfemi *et al*.,2009,Jonathan et al.,2010 & 2013)..Agricultural wastes of *H. grandis, M. excelsa, M. altissima* and *T. superba*, which could constitute nuisance to our environment, can be adequately used as substrates for propagation of P. tuber-regium and other Nigerian edible fungi(Jonathan *et al*.,2013, Otunla *et al*.,2018)

Brown Rot Fungi

Brown-rot fungi are highly effective in breaking down cellulose and hemicellulose, leaving behind the characteristic brown coloration of decayed wood due to the incomplete degradation of lignin. This selective decomposition of polysaccharides while largely preserving lignin distinguishes them from white-rot fungi. Notable examples of brown-rot fungi include *Serpula lacrymans, Laetiporus sulphureus,* and *Gloeophyllum trabeum* (Nadeem *et al.,* 2015).

Soft Rot Fungi

Soft-rot fungi are categorized into two types based on their degradation patterns. Type I soft-rot fungi create biconical or cylindrical cavities within the secondary cell walls, whereas Type II soft-rot fungi exhibit an erosion-like degradation, leading to rapid bio-delignification of biomass (Nadeem *et al.,* 2015).

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Enzymes Involved in Lignin Degradation

Lignin is the most abundant aromatic biopolymer on Earth and is highly resistant to degradation. As the most structurally intricate and insoluble component of the plant cell wall, it contributes to both its mechanical strength and recalcitrance (Nadeem *et al.*, 2015). By establishing covalent bonds with hemicellulose and cellulose, lignin forms a protective physical and chemical barrier that limits the access of lignocellulolytic enzymes to the inner structure, thereby hindering enzymatic breakdown (Mehdi Dashtban *et al.,* 2010).

Lignin Peroxidase (LiP)

Lignin peroxidase is a heme-based enzyme that facilitates the oxidation of both aromatic and non-aromatic compounds. It plays a crucial role in lignin degradation by cleaving C–C and C–O bonds within its complex structure. Due to its high redox potential, lignin peroxidase efficiently enhances the natural decomposition and oxidation of various persistent pollutants (Latif *et al.,* 2023).

Manganese Peroxidase (MnP)

Manganese peroxidase is a heme-based enzyme produced by white-rot fungi. It catalyzes the oxidation of manganese (II) to manganese (III), which subsequently aids in the decomposition of various phenolic and non-phenolic compounds. This oxidation process allows manganese (III) to play an indirect role in lignin degradation (Rubilar *et al.*, 2008).

Laccase (Lac)

-Laccase is an extracellular multicopper oxidase enzyme that is produced by White rot fungi. Laccase speeds up oxidation in phenolic and non-phenolic compounds while reducing molecular oxygen to water (Unuofin *et al.*,2019).

Versatile Peroxidase (VP)

Versatile peroxidases have a wide-ranging oxidative ability, allowing them to break down various aromatic compounds, whereas manganese peroxidases are specialized in degrading lignin and other persistent pollutants. Importantly, versatile peroxidases demonstrate substrate specificity, enabling the oxidation of both high- and low-redox potential compounds. Furthermore, they exhibit lignin peroxidase (LiP)-like activity, aiding in the oxidation of veratrylglycerol-β-guaiacyl ether and phenolic compounds (Nadeem *et al.*, 2015).

Cellobiose Dehydrogenases (CFH)

White-rot fungi also produce non-lignin degrading enzymes, such as cellobiose dehydrogenases, which play a crucial role in breaking down various pollutants (Latif *et al.*, 2023). These enzymes facilitate the degradation of cellulose and lignocellulosic biomass by generating reactive oxygen species, oxidizing cellobiose and other cello-oligosaccharides, and releasing electrons that can be transferred to different electron acceptors, including pollutants, thereby enhancing their breakdown. Additionally, hydrolases contribute to the hydrolysis of pollutant compounds such as esters, amides, glycosides, phosphates, and sulfates (Zinjarde & Ghosh, 2010).

Factors Influencing Fungi Degradation

There are a variety of factors that affect degradation by fungi. These factors include pH, temperature, oxygen, nutrient availability, moisture, and microbial community composition (Shallu Sihang *et al*,2014)

Table 1: Factors affecting microbial degradation

Limiting factors	**Effects**
Weathering	Aggregation, spreading, dispersion, adsorption.

Water potential	Evaporations, photo-oxidation
Temperature	Osmotic and matrix forces, exclusion of water from hydrophobic aggregates.
Oxidant	Influence on evaporation and degradation rates
Mineral nutrients	Oxygen required to initiate oxidation.
Reaction	Low pH may be limiting
Microorganisms	Degraders may be absent or low in numbers

Microbial growth relies on optimal temperature and pH conditions, which enhance enzymatic activity (Eyalira *et al.*, 2023). Generally, lower pH levels stimulate fungal activity, whereas higher pH levels tend to suppress it (Safari Sinegani *et al.*, 2005). Furthermore, fungi require essential nutrients, including carbon and nitrogen, to support their growth and facilitate the breakdown of waste and contaminants (Geeyanjali Rajhans *et al.*, 2021). Proper moisture levels and adequate oxygen availability are also vital, as they influence fungal proliferation, enzyme function, and substrate degradation rates. During the biodegradation process, CO_2 is released as a by-product, and excessive accumulation can hinder fungal metabolism, especially in liquid media or submerged environments. In the fungal biodegradation of plastics, an overabundance of oxygen and glucose can inhibit fungal activity. This occurs due to the adverse effects of high oxygen pressure and the buildup of carbon catabolites from excess glucose, which suppress respiratory enzyme function (Eyalira *et al.*, 2023).

Studies on Fungi Bio-degradation of Agro-industrial Waste in Nigeria

In Nigeria, fungi have been utilized to break down various agro-industrial wastes, such as groundnut shells, rice husks, plantain peels, and cassava peels (Mohamed *et al.*,2021). Through fungal degradation, these waste materials are converted into valuable products.

Bio-degradation of Groundnut shells

Ngene *et al.* (2021) conducted a study using *Aspergillus niger* and *Trichoderma viride* to biodegrade groundnut shells. This process increased crude protein and fat content while decreasing crude fiber, tannins, cyanogenic glycosides, and oxalates. By enhancing the nutritive value of the groundnut shells, the biodegradation process improved their suitability for use as animal feed or dietary supplements.

Bio-degradation of Rice Husks

A study by Akinfemi *et al*. (2018) examined the chemical composition and in vitro digestibility of rice husks after inoculation with different fungi, including *Pleurotus pulmonarius*, *Pleurotus sajor-caju*, and *Pleurotus florida*. Sterilized rice husks were inoculated and incubated for 21 days, leading to a significant decrease in neutral detergent fiber, acid detergent fiber, and acid detergent lignin content, while crude protein levels increased considerably. These results emphasize the potential of converting rice husks into value-added feed for ruminants.

Fungal Bio-degradation of Plantain Peel

Lawal *et al.* (2011) investigated the fungal biodegradation of plantain peel using *Aspergillus niger* to evaluate its suitability for broiler finisher feed. The study assessed the in vitro dry matter digestibility of the biodegraded plantain peel, revealing improvements in crude protein, ash, and gross energy content. These enhancements contributed to better nutrient digestibility and increased body weight gain in broiler finisher birds. Hematological and serum biochemical analyses further demonstrated superior performance in birds fed the degraded plantain peel compared to those consuming the undegraded form. Additionally, *Itelima et al.* (2013) reported that saccharification and fermentation of plantain peels using a co-culture of *Aspergillus niger* and *Saccharomyces cerevisiae* led to ethanol production, highlighting its potential as an alternative energy source.

Solid-State Fermentation of Yam Peels

A study on the solid-state fermentation of yam peels using *Saccharomyces cerevisiae* revealed a significant increase in crude protein, true protein, fat, and ash content, particularly when ammonium sulfate was added. The findings demonstrated that fermenting white yam peels with *S. cerevisiae*, both with and without inorganic nitrogen supplementation, facilitated protein production. The highest protein yield was observed with ammonium sulfate supplementation, effectively enhancing the initially low protein content of yam peels, making them a promising protein supplement for animal feed (Tawakalitu *et al.*, 2016).

Banana and Pineapple peels

A study on the simultaneous saccharification and fermentation of waste materials from banana, plantain, and pineapple, utilizing a co-culture of *Aspergillus niger* and *Saccharomyces cerevisiae*, led to the production of ethanol, which can be used as an alternative energy source (Itelima *et al.*, 2013). Ethanol produced from renewable sources for use as fuel or fuel additives is referred to as bioethanol.

Bio-degradation of Palm Oil mill Effluents

A study on the biodegradation of palm oil mill effluents (POME) using *Candida rugosa* and *Geotrichum candidum* showed high efficiency in removing oil, grease, and organic matter. The findings suggest that pre-treating POME before discharge can significantly minimize the risk of waterway pollution (Ibegbulam-Njoku and Achi, 2014).

Fungi Fermentation of Cocoa pod husks

A case study on the fermentation of cocoa pod husks using *Rhizopus stolonifer* aimed to reduce theobromine and fiber levels, which could hinder the use of pod meal in poultry feed. The results indicated an improvement in the nutritional value of the fermented cocoa pod husk meal, with increased crude protein and a reduction in crude fiber and anti-nutrient content (Olugosi *et al.*, 2019).

Fungal Fermentation of mango kernel cake

Kayode (2010) investigated the impact of mono-culture fungal fermentation on the mineral composition and amino acid profile of mango kernel cake. The study involved the isolation of *Rhizopus oligosporus,Aspergillus niger, Rhizopus stolonifer, and Penicillium chrysogenum* from decomposed mango kernels, which were subsequently utilized for fermentation. The findings indicated a significant increase in calcium and iron levels, thereby enhancing the mineral nutritional value of the mango kernel cake. The study suggests that when supplemented with essential amino acids, mono-culture fungal-fermented mango kernel cake has the potential to serve as an alternative, non-conventional feed ingredient to partially or fully replace maize in poultry diets.

Benefits of Fungi Degradation and Potential Applications

Fungal biodegradation presents significant economic and environmental benefits. By eliminating disposal costs, it reduces overall waste management expenses for industries and governments. Additionally, this process generates valuable bioproducts, including biofuels, enzymes, and organic acids, contributing to industrial and biotechnological advancements. Fungal biodegradation also improves soil fertility, thereby lowering fertilizer costs and promoting sustainable agricultural practices. Furthermore, it facilitates job creation across multiple sectors, such as waste management, recycling, bioremediation, sustainable agriculture, and biofuel production.

Beyond economic advantages, fungal biodegradation plays a critical role in environmental conservation by mitigating pollution, preserving biodiversity, and conserving natural resources, ultimately contributing to a reduction in greenhouse gas emissions. The process enhances soil health by decomposing organic pollutants, releasing essential nutrients, supporting beneficial microbial communities, and improving water retention. Moreover, this technology provides a cost-effective and sustainable approach to waste management, fostering new business opportunities in green industries and driving innovation while maintaining ecological balance (Fapohunda *et al.,* 2021; Senthilkumar *et al.,* 2020).

The Applications of fungal bio-degradation include:

Fungal biodegradation plays a crucial role in environmental sustainability and efficient resource utilization (Thirumalaivasan *et al.,* 2024). It facilitates bioremediation by decontaminating polluted soil, water, and air while simultaneously reducing waste volume and toxicity. Additionally, fungi contribute to soil enrichment by converting organic waste into nutrient-rich fertilizers, thereby supporting sustainable agricultural practices.

Fungal processes also play a significant role in biofuel production by transforming waste materials into bioethanol and biodiesel, providing a renewable energy source (Raven *et al.,* 2019). In the agricultural sector, fungi aid in the production of protein-rich animal feed, enhancing livestock nutrition. Moreover, fungal-derived enzymes are widely applied across various industries, improving efficiency in biotechnological processes.

Furthermore, fungal biodegradation enables the synthesis of high-value bio-products, including bioplastics, biopesticides, biocides, and biofertilizers, fostering innovation in sustainable industries and contributing to the development of environmentally friendly alternatives.

Future directions for fungal bio-degradation research:

Advancing fungal biodegradation involves scaling up and optimizing its processes to enhance efficiency and applicability (Garg, *et al.,*2024) . Genetic engineering of fungi offers potential improvements in their biodegradation capabilities, making them more effective in breaking down complex pollutants. Integrating fungal biodegradation with emerging technologies such as nanotechnology and artificial intelligence can further refine its applications and monitoring systems. Exploring its potential in space and planetary environments could expand its role in extraterrestrial sustainability efforts. Additionally, the development of fungal-based biosensors for pollution monitoring provides a promising approach to environmental assessment and control (Sarsen *et al.,*2022). These advancements will deepen our understanding of fungal biodegradation, fostering innovation and promoting sustainable solutions.

CONCLUSION

Fungi serve as valuable sources of enzymes essential for numerous industrial applications. Their ability to break down agro-industrial wastes presents a promising solution to feed scarcity while helping to lower the cost of feed ingredients, as some degraded materials can be repurposed for animal nutrition. Incorporating fungal biodegradation into waste management strategies marks a significant step toward environmental sustainability, fostering the expansion of bio-based industries and promoting circular economies.

REFERENCES

1. Abdurrahman, M. I., Chaki, S., & Saini, G. (2020). Stubble burning: Effects on health & environment, regulations, and management practices. Environmental Advances, 2, 100011.
2. Adejumo, I. O., & Adebiyi, O. A. (2020a). Agricultural solid wastes: causes, effects, and effective management. Strategies of sustainable solid waste management, 8(10.5772).
3. Adejumo, I. O., & Adebiyi, O. A. (2020b). Agricultural solid wastes: causes, effects, and effective management. Strategies of sustainable solid waste management, 8(10.5772).
4. Afolalu, S. A., Salawu, E. Y., Ogedengbe, T. S., Joseph, O. O., Okwilagwe, O., Emetere, M. E., ... & Akinlabi, S. A. (2021, April). Bio-agro waste valorization and its sustainability in the industry: a review. In IOP conference series: materials science and engineering (Vol. 1107, No. 1, p. 012140). IOP Maiti, S.,
5. Sarma, S. J., Brar, S. K., Le Bihan, Y., Drogui, P., Buelna, G., & Verma, M. (2016). Agro-industrial wastes as feedstock for sustainable bio-production of butanol by Clostridium beijerinckii. Food and Bioproducts Processing, 98, 217-226.

6. Afolalu, S. A., Samuel, O. D., & Ikumapayi, O. M. (2020). Development and characterization of nano-flux welding powder from calcined coconut shell ash admixture with FeO particles. Journal of Materials Research and Technology, 9(4), 9232-9241.
7. Akande, T. (2002). An overview of the Nigerian rice economy. Nigerian Institute of Social and Economic Research (NISER), Ibadan, Nigeria, 1-11.
8. Akinfemi A,Babayemi OJ and Jonathan SG(2009). Bioconversion of maize husk into value added ruminant feed by using white-rot fungus. Revista Cientifica UDO Agricola 9 No. 4 972-978
9. Akhtar, N., Goyal, D., & Goyal, A. (2015). Biodegradation of cellulose and agricultural waste material. Advances in biodegradation and bioremediation of industrial waste. CRC Press, USA, 211-234.
10. Akinyele, H. A., Taliat, A. A. T., Enwerem, G. C., Dawodu, O. G., & Owojuyigbe, O. S. (2020). Lignocellulosic waste degradation potential of some cellulolytic fungal strains isolated from putrid fruits. J Pure Appl Microbiol, 14(3), 2585-2593.
11. Ayo, J. A., Adedeji, O. E., & Olaoye, T. F. (2015). The untapped potential of agro-industrial wastes in developing countries: A case study in Nigeria. American Research Journal of Agriculture, 1(4), 1-14.
12. Dashtban, M., Schraft, H., Syed, T. A., & Qin, W. (2010). Fungal biodegradation and enzymatic modification of lignin. International journal of biochemistry and molecular biology, 1(1), 36.
13. Eneji, C. V. O., Eneji, J. E. O., & Ngoka, V. N. (2016). Attitude towards waste management and disposal methods and the health status of cross river state, Nigeria SCIREA Journal of Agriculture, 1(2), 231- 247
14. Fapohunda, C. A., & Oluwasegun, O. B. (2019). Evaluation of the structural performance of concrete with OPC fraction partly replaced by empty palm oil bunch ash (EPO-FBA). FUW Trends in Science & Technology Journal, 4(1), 202-208.
15. Gbolagade J.S,(2006). Bacteria associated with compost used for cultivation of Nigerian edible Mushrooms: Pleurotus tuber-regium (Fr.) Singer, and Lentinus squarrosulus (Berk.).African Journal of Biotechnology.5 (4) :338-342
16. Garg, S., Kim, M., & Romero-Suarez, D. (2024). Current advancements in fungal engineering technologies for Sustainable Development Goals. Trends in Microbiology.
17. Ibegbulam-Njoku, P. N., & Achi, O. K. (2014). Biodegradation of Palm Oil Mill Effluent. British Microbiology Research Journal, 4(12), 1440-1450.
18. Itelima, J., Onwuliri, F., Onwuliri, E., Onyimba, I., & Oforji, S. (2013). Bio-ethanol production from banana, plantain, and pineapple peels by simultaneous saccharification and fermentation process.
19. Jonathan,S.G;Fasidi,I.O:Ajayi,A.O and Adegeye,A(2008).Biodegradation of Nigerian wood wastes by Pleurotus tuber-regium (Fries) Singer. Bioresource Technology 99:807-811
20. Jonathan, S.G;Akinfemi,A and Adenipekun, C.O(2010).Biodegradation and invitro digestibility of maize husks treated with edible fungi (Pleurotus tuber-regium and Lentinus subnudus) from Nigeria. Electronic Journal of Environmental, Agricultural and Food Chemistry(EJEAFche) 9(4):742-750
21. Jonathan SG, Nwokolo VM, Ekpo EN(2013). Yield performance of Pleurotus pulmonarius (Fries.) quelet, cultivated on different agro-forest wastes in Nigeria. World Rural Observations ;5(1):22-30
22. Jonathan SG (2019).Fungi Here, Fungi There, Fungi Everywhere: Unique And Unparalleled Contributions Of Fungi To Environment, Food Production And Medicine-. Inaugural lecture. University of Ibadan.Ibadan .Nigeria .ISBN978-978-8529-88-0. (91 Pages).
23. Kolawole, I. D., Kolawole, G. O., Sanni-manuel, B. A., Kolawole, S. K., Ewansiha, J. U., Kolawole, V. A., & Kolawole, F. O. (2024). Economic impact of waste from food, water, and agriculture in Nigeria: challenges, implications, and applications—a review. Discover Environment, 2(1).
24. Latif, W., Ciniglia, C., Iovinella, M., Shafiq, M., & Papa, S. (2023). Role of white rot fungi in industrial wastewater treatment: a review. Applied Sciences, 13(14), 8318.
25. Lawal, T. E., Alabi, O. M., Oguntunji, A. O., Alagbe, I. A., & Adebiyi, O. A. (2021). Fungal biodegradation of plantain peel for broiler finisher feeding: In vitro digestibility, effects on performance, haematological and serum parameters. Nigerian Journal of Animal Production, 38(2), 82-89.
26. Mohamed, H., Shah, A. M., & Song, Y. (2021). Conversion of agro-industrial wastes into value-added products. In Conversion of Renewable Biomass into Bioproducts (pp. 197-217). American Chemical Society.
27. Ngene, A., Onyimba, I., Dashen, M., Dasok, W. A., Njoku, A., Amapu, T. Y., Job, M., Ogbonna, A., Isaac, D., & Isaac, I. (2024). Biodegradation of Groundnut Shells by Aspergillus niger and Trichoderma viride for Feed Potential Enhancement, 8, 214-228.

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28. Ogbu, C. C., & Okey, S. N. (2023). Agro-industrial waste management: the circular and bioeconomic perspective. Agricultural Waste-New Insights.
29. Ogbu, C. C., & Okey, S. N. (2023). Agro-industrial waste management: the circular and bioeconomic perspective. Agricultural Waste-New Insights.
30. Okal, E. J., Heng, G., Magige, E. A., Khan, S., Wu, S., Ge, Z., ... & Xu, J. (2023). Insights into the mechanisms involved in the fungal degradation of plastics. Ecotoxicology and Environmental Safety, 262, 115202.
31. Okal, E. J., Heng, G., Magige, E. A., Khan, S., Wu, S., Ge, Z., ... & Xu, J. (2023). Insights into the mechanisms involved in the fungal degradation of plastics. Ecotoxicology and Environmental Safety, 262, 115202.
32. Olugosi, O. A., Agbede, J. O., Adebayo, I. A., Onibi, G. E., & Ayeni, O. A. (2019). Nutritional enhancement of cocoa pod husk meal through fermentation using Rhizopus stolonifer. African Journal of Biotechnology, 18(30), 901-908.
33. Otunla, C.A., Jonathan, S. G., Idowu, O.O. and Olawuyi, O. J. (2018). Mycelial growth and sclerotia production of Pleurotus tuber-regium (Fries) singer on four sawdust types at three composting intervals. Agronomski 80 (2): 79-90.
34. Rajhans, G., Barik, A., Sen, S. K., & Raut, S. (2021). Degradation of dyes by fungi: an insight into mycoremediation. Biotechnologia, 102(4), 445.
35. Raven, S., Francis, A., Srivastava, C., Kezo, S., & Tiwari, A. (2019). Fungal biofuels: innovative approaches. Recent Advancement in White Biotechnology Through Fungi: Volume 2: Perspective for Value-Added Products and Environments, 385-405.
36. Rubilar, O., Diez, M. C., & Gianfreda, L. (2008). Transformation of chlorinated phenolic compounds by white rot fungi. Critical Reviews in Environmental Science and Technology, 38(4), 227-268.
37. Sadh, P. K., Duhan, S., & Duhan, J. S. (2018). Agro-industrial wastes and their utilization using solid-state fermentation: a review. Bioresources and bioprocessing, 5(1), 1-15.
38. Senthilkumar, K., Naveen Kumar, M., Chitra Devi, V., Saravanan, K., & Easwaramoorthi, S. (2020). Agro-industrial waste valorization to energy and value-added products for environmental sustainability. Biomass valorization to bioenergy, 1-9.
39. Soares, D. M., Procópio, D. P., Zamuner, C. K., Nóbrega, B. B., Bettim, M. R., de Rezende, G., ... & Stevani, C. V. (2022). Fungal bioassays for environmental monitoring. Frontiers in Bioengineering and Biotechnology, 10, 954579.
40. Soliman, S. A., El-Zawahry, Y. A., & El-Mougith, A. A. (2013). Fungal biodegradation of agro-industrial waste. Cellulose-Biomass Conversion, 75-100.
41. Taiwo, A. M., Olujimi, O. O., Bamgbose, O., & Arowolo, T. A. (2012). Surface water quality monitoring in Nigeria: Situational analysis and future management strategy. Water quality monitoring and assessment, 13, 301-320.
42. Tawakalitu, E. A., Aworh, O. C., Raji, A. O., & Olagunju, A. L. (2017). Protein enrichment of yam peels by fermentation with Saccharomyces cerevisiae. Annals of Agricultural Science, 62, 33-37.
43. Thirumalaivasan, N., Gnanasekaran, L., Kumar, S., Durvasulu, R., Sundaram, T., Rajendran, S., ... & Kanagaraj, K. (2024). Utilization of fungal and bacterial bioremediation techniques for the treatment of toxic waste and biowaste. Frontiers in Materials, 11, 1416445.
44. UNDP. (2022). Sustainable Development Goals. United Nations Development Programme.https://www.undp.org/sustainabledevelopmentgoals.
45. Unuofin, J. O., Okoh, A. I., & Nwodo, U. U. (2019). Aptitude of oxidative enzymes for treatment of wastewater pollutants: a laccase perspective. Molecules, 24(11), 2064.
46. Zinjarde, S. S., & Ghosh, M. (2010). Production of surface-active compounds by biocatalyst technology. Biosurfactants, 289-303.