IJBB

International Journal of Biotechnology and Biomedicine
Vol. 3 No1; April 2026 https://doi.org/10.31674/ijbb.2025.v03i01.001

Kitchen Waste Valorization through Solid-State Fermentation: Opportunities for Sustainable Waste Management and Value-Added Product

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Article received on 13th January 2026.
Revision received on 28th March 2026.
Accepted on 10th April 2026.

Abstract

The rapid increase in municipal solid waste (MSW), driven by population growth, urbanization, and industrialization, has resulted in significant environmental and socio-economic challenges worldwide. Among MSW components, kitchen waste (KW) represents a substantial proportion due to its organic-rich composition, making it both an environmental burden and a valuable bioresource. Improper disposal of KW contributes to greenhouse gas emissions, land and water pollution, and loss of essential resources. However, KW can be harnessed as a substrate for solid-state fermentation (SSF), enabling the production of biofuels, biofertilizers, enzymes, single-cell proteins, organic acids, and antimicrobial compounds. This paper reviews the composition and global trends of KW generation, its environmental impacts, and its valorization potential through SSF. Methodologically, the review synthesizes data from recent studies (2018–2025) that explore KW valorization, antimicrobial applications of fruit and vegetable residues, and the role of nanotechnology in sustainable bioprocessing. Findings highlight the dual challenge and opportunity of KW: while it is a major contributor to waste burdens, it also offers a promising pathway to a circular economy. The paper concludes that integrating KW valorization into national waste policies and industrial bioprocesses can significantly reduce environmental pollution, improve food security, and generate high-value products.

Keywords: Kitchen Waste; Fermentation; Sustainability; Waste Management; Value-Added Product

1.0 Introduction

Solid waste management remains a pressing global challenge due to its environmental, health, and socio-economic implications. Municipal solid waste (MSW), particularly kitchen waste (KW), represents one of the largest waste streams worldwide. Improper handling of KW contributes to water, air, and soil pollution, ultimately threatening public health (Abdel-Shafy & Mansour, 2018). Increasing population, rapid urbanization, and lifestyle changes have accelerated the rate of KW generation, particularly in Asia, where China alone generates over 35 million tons annually (Li *et al.*, 2022).

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Kitchen waste is characterized by its high organic content, including fermentable sugars, proteins, and lipids, which makes it both an environmental hazard and a resource for sustainable utilization (Chavan *et al.*, 2023). Globally, food waste amounts to approximately 1.3 billion tons annually, representing nearly one-third of all food produced for human consumption (Negri *et al.*, 2020). The inappropriate disposal of KW not only contributes to greenhouse gas emissions through methane release from landfills but also leads to the wastage of valuable resources such as water, labor, and energy (Yaashikaa *et al.*, 2022).

In countries such as Malaysia, KW accounts for approximately 44.5% of MSW, posing significant management challenges despite national efforts to align with the Sustainable Development Goal (SDG) 12.3, which seeks to halve food waste by 2030 (United Nations, 2015). Beyond environmental concerns, KW holds immense potential as a substrate for value-added products through processes such as solid-state fermentation (SSF). This technique enables the microbial conversion of agro-industrial residues and KW into enzymes, biofuels, biofertilizers, organic acids, and antimicrobial compounds (Abu *et al.*, 2017; Joshi *et al.*, 2014).

Given the rising urgency of waste reduction, this paper explores the valorization of KW, emphasizing its potential to address pressing issues of waste disposal, antimicrobial resistance, and sustainable production systems.

2.0 Methodology

This study employed a narrative review methodology. Relevant peer-reviewed journal articles, reports, and conference proceedings published were sourced from databases such as Scopus, Web of Science, and ScienceDirect. Keywords included *kitchen waste*, *municipal solid waste, solid-state fermentation*, *bioconversion*, *biofuels*, *biofertilizers*, and *antimicrobial compounds*.

The Inclusion criteria were: studies addressing KW composition, environmental impact, and valorization; experimental and review papers on SSF applications for waste-to-value processes; and research linking KW to antimicrobial or nanotechnology-based applications.

The exclusion criteria included non-English publications, grey literature, and studies published before 2010 unless seminal to the field. Data were synthesized thematically to highlight trends, valorization techniques, and potential applications.

3.0 Background

Solid waste is one of the most important problems facing the environment. Water, air, and soil pollution can be caused by improper waste management, which is very bad for people's health. One of the biggest problems in our society is MSW. Population growth, rapid urbanization, a growing economy, and a higher standard of living have all made a big difference in how fast, how much, and how well cities get rid of their trash. Even though keeping public streets clean has been a public responsibility for a long time, waste collection and disposal were not seen as part of a city's public health and sanitation duties until the late 1800s (Abdel-Shafy *et al.*, 2018).

Kitchen waste is commonly obtainable for free and at a negative cost owing to its enormous generation. It contains a huge quantity of organic constituents, especially fermentable sugars, which are commonly used for polyhydroxyalkanoates (bioplastics) synthesis. Nevertheless, different types of kitchen waste pre-treatments are being explored to boost the amount of obtainable simple sugars during their hydrolysis due to the difficulties in processing. The appropriate and effective use of kitchen waste immensely assists in curtailing the inappropriate disposal issues around it (Chavan *et al.*, 2023).

The growing population, in addition to the increasing urbanization, as well as the rising food consumption rate, culminated in an increase in the daily production of kitchen waste in considerable amounts. According to the report of the food and agricultural group, food waste refers to the food losses of quantity and quality during the supply chain, starting from the production, to the post-harvest, as well as the processing stages. It also includes the agri-food and industrial wastes. However, the household kitchen waste constitutes a significant component of the global food waste production, which usually begins during one of the four predictable stages: "the purchase stage, the storage stage, the cooking stage and the serving stage. In other words, it refers to food that was bought but never cooked, served, and consumed, or the food waste that was created and produced during the cooking or all four stages. Inadequate and small storage capacities also commonly trigger the generation of food waste. Thus, about 1.3 billion tons of household food waste, according to the latest report, are discarded globally every year (Negri *et al.*, 2020). Most of the waste comes from different places, such as eateries and households. It mostly consists of leftover food, including veggies, fruits, bread, dairy goods, and food preparation wastes (Chhandama *et al.*, 2022).

The amount of kitchen waste is projected to increase and grow due to the accelerated economic and growth, especially in Asian nations. China, the Asian economic powerhouse, alone produces approximately 1.9×10^5 tons of organic waste every year. Furthermore, more than 35 million tons of food are generated every year in China. In other words, about 6% of the entire food production in China, which is able to feed about 30 to 50 million people, is generated yearly (Li *et al.*, 2022). Many different nations, including the US, Australia, India, Mexico, and Korea, have fallen in line, thereby generating annually about 624 – 3500 tons of food waste (Figure 1). These huge and enormous food waste amount to about USD 218 billion (Pramanik *et al.*, 2019; Slorach *et al.*, 2020). About 15 million tons of food are also disposed of in the United Kingdom every year as waste. Kitchen of food waste, therefore, leads to a considerable reduction of other important elements such as land, labor, water, and power (Yaashikaa *et al.*, 2022).

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Figure 1. Global Food Waste in Some Countries.
https://www.statista.com/chart/24350/total-annual-household-waste-produced-in-selected-countries/

The entire human population is being confronted by many problems that call for timely and urgent attention to ensure the sustainability of world resources. The principal factors among these issues include food security, depleting and dwindling reservoirs of fossil fuels, the impact of greenhouse gas emissions, as well as food waste generation and management. There has also been a rise in the global population level in the past few decades, which has thus put pressure on food availability, its management, and its disposal. The global upsurge in the release of greenhouse gases has significantly deteriorated the global climate. This has become a burning issue throughout the globe. Therefore, there is an urgent need to explore novel pathways to address some of these global issues (Bhatia *et al.*, 2023).

There is an increasing interest in household food waste worldwide, as well as the factors contributing to household food waste (Liegeard & Manning, 2020). On the other hand, the surge in the world's population contributes significantly to waste generation in addition to the lack of public policies for basic sanitation for the reuse and disposal of waste, especially in low-income countries (Faria *et al.*, 2023).

Malaysia, in spite of its aggressive economic development, is also struggling with waste generation. The waste generated amounted to about 19,000 tons per day in 2005. Malaysia was also projected to generate more than 25,000 metric tons of domestic waste every day based on a projected population of over 31 million in 2016 (Yaacob *et al.*, 2019). Similarly, food waste has not only become a major issue but also difficult to control in Malaysia because it is being generated persistently. According to the National Solid Waste Management Department's report, Malaysians generate approximately 1.38 kg of food waste on a daily basis. Malaysian food waste accounts for about 44.5% of municipal solid waste, with the majority coming from commercial, home, and food service sectors, thereby posing an enormous risk to the economy, environment, and society (Elimelech *et al.*, 2018). The Malaysian government has, therefore, emphasized the Twelfth Plan's circular economy transition to directly meet SDG 12.3, which calls for a 50 % reduction in food waste by 2030 by encouraging the recycling, reuse, and recovery of food waste (United Nations, 2015).

Generally, some fractions of the food are usually lost or wasted during the various steps involved in food production and the food chain, especially during primary production, transportation, storage, and post-consumption. Food waste can occur during pre-consumption and post-consumption. The pre-consumption wastes refer to the portions lost or discarded during the production, manufacturing, and distribution stages of the food supply, while the post-consumption wastes occurring at the consumption level refer to the portion lost or not used in the final food product. About 45–65 % of food waste comes from food pre-consumption, while about 30–34 % from the plates and the post-consumption wastes. Kitchen waste comes under post-consumption waste, either from the household or the food service sector. KW are highly variable and heterogeneous in composition depending on the particular origin (Esteban-Lustres *et al.*, 2022).

According to Sahoo *et al.* (2024), food waste is commonly defined as food that is suitable for human consumption but is wasted. Food becomes a waste whenever it is left to deteriorate or held beyond its expiration date. A large portion of food waste is generated due to carelessness or deliberate and cautious decisions to throw the food away. However, some amount of food waste also occurs both at the retail and consumption stages of the food chain. On the other hand, food waste is not only restricted to the non-utilization of edible foods but also includes the inappropriate waste of land, energy, and water resources.

Furthermore, the global human population is projected to rise to about 10 billion by 2050. This is expected to be accompanied by a substantially high demand for food throughout the world, thereby incapacitating the structure of the world's food supply (Haldar *et al.*, 2022). Furthermore, about 750 billion dollars' worth of food, weighing approximately 1.3 billion tons, is misused globally every year, according to a recent report from the Food and Agriculture Organization [FAO] (FAO 2017).

Food waste is antithetical to Sustainable Development Goal 12.3 (global food loss and waste), with about 13.8% of food loss throughout the supply chain, including the harvest, storage, transport and processing. The major contributors to household food waste are the industrialized countries. Food waste has a direct association with social (such as equality and health), economic (such as consumption, price volatility, increasing costs, resource efficiency, commodity markets, and waste management), and environmental (such as climate change, water, energy, resource depletion, and biogenic cycles' disruption) impacts (Phooi *et al.*, 2022).

Household kitchen waste, on the other hand, refers to both organic and inorganic waste generated from daily food preparation and consumption activities within households. These wastes primarily comprise food scraps, disposable kitchen items and packaging materials. The production of KW is a growing concern worldwide due to its economic, social and environmental implications (Hajam *et al.*, 2023).

In other words, KW is generally categorized into two main types, namely organic and inorganic wastes. The organic wastes include food scraps such as fruits, vegetable peels, leftovers, eggshells, meat trimmings, coffee grounds, and other biodegradable materials, while the inorganic wastes comprise non-biodegradable materials such as aluminum foil, plastic wrappers, glass jars, metal cans, and other packaging materials that come with food products (Sahoo *et al.*, 2024).

The amount and the characteristics of household kitchen waste are related to household income, household size, the habit of ordering takeaways, residential location, and consumption culture (Zhang *et al.*, 2020). Other factors affecting the type and amount of kitchen waste produced in households include dietary habits, household size, socioeconomic status, cultural practices, as well as storage and purchasing patterns (Pilone *et al.*, 2023; Tonini *et al.*, 2023; Wang *et al.*, 2021). In general, households consuming more fresh foods will generate more organic waste, such as fruit scraps and vegetable peels, while those that depend on processed foods will likely generate more inorganic waste (Sahoo *et al.*, 2024). Similarly, higher-income and larger households tend to purchase more food and thus generate more waste compared to lower-income and smaller households.

On the other hand, there are significant environmental consequences for kitchen waste, especially organic waste. These include but are not limited to landfills, waste of resources and pollution (Batool *et al.*, 2024). The final destination of a significant amount of household kitchen waste is landfills, wherein organic kitchen waste undergoes anaerobic decomposition to produce methane. Methane is a well-known greenhouse gas that contributes significantly to climate change. Furthermore, the production of kitchen wastes as well as their transportation and disposal are achieved through unnecessary energy, water and land consumption, thus squandering these valuable resources in addition to fertilizers, fuel and labor (Tchonkouang *et al.*, 2023).

Furthermore, inorganic kitchen wastes such as packaging materials and plastic are the major sources of land and marine pollution, which ultimately harm both wildlife and marine organisms (Kibria *et al.*, 2023). Therefore, it is essential to explore the reuse, reduction and recycling of kitchen waste as an important measure of addressing the major sustainability targets, including the improvement of food security and reduction of greenhouse gas emissions. Future solutions to kitchen waste prevention may include more efficient packaging, smart kitchen technologies and the adoption of policies that support and promote sustainable consumption as well as sustainable waste management.

Although household kitchen wastes are considered an enormous environmental burden, household kitchen waste also holds a great potential benefit for the development of sustainable antimicrobial compounds, especially in this era of antimicrobial resistance to common antibiotics (Fontaine *et al.*, 2026). In other words, organic household kitchen wastes can be repurposed and harnessed for the production of sustainable antimicrobial compounds. For instance, many fruit peels are characteristically rich with potent antimicrobial compounds. Citrus peels, for example, contain phenolic compounds, flavonoids and essential oils which possess both antibacterial and antifungal

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activities against most microbes and pathogenic organisms (Hasan *et al.*, 2022). The high tannin content of pomegranate peels is responsible for the inhibition of bacterial growth in addition to other diverse biological activities (Feng *et al.*, 2022).

The antimicrobial activities of banana peel extracts have also been reported in the literature (Behiry *et al.*, 2019; Hikal *et al.*, 2022). The rinds of watermelon have also been evaluated for their antibacterial activity in addition to their sensory properties and antioxidant potential (Athanasiadis *et al.*, 2023). Therefore, the crude extracts and pure compounds from these household kitchen wastes can be explored for the development of eco-friendly cosmetic products, antibacterial agents, surface disinfectants, cleaning agents, or preservatives in the food industry.

Furthermore, the incorporation of nanotechnology offers additional powerful tools for the advancement of antimicrobial applications by leveraging the unique properties of nanomaterials, such as their ability to interact at the molecular level, tunable size, and high surface area. This will greatly help in the development of more targeted, effective, and sustainable antimicrobial strategies, combating and addressing other pressing challenges such as antibiotic resistance, microbial contamination, and biofilm-related infections (Hetta *et al.*, 2023).

The increased industrialization and urbanization are directly linked with accelerated demand for energy as well as large-scale waste output, thus portending negative environmental consequences. The estimation of the global food waste generation is put at about 1.6 gigatons/year and attributed to an economic revenue of 750 billion USD (Haldar *et al.*, 2022). Furthermore, the enormous amounts of waste generated by the food and agriculture industries also serve as a suitable source and potential for use as a raw material to produce high-value-added products and bioactive compounds, thus promoting industrial production sustainability, reducing the loss of resources, saving costs, boosting productivity, and reducing the environmental impact caused by industrial waste disposal. Furthermore, the global biobased chemicals market was valued in 2022 at USD 61.61 billion, with a compound annual growth rate (CAGR) of 10.4% during the forecast period (Faria *et al.*, 2023).

The crude extracts and pure compounds from kitchen wastes can be harnessed for the development of sustainable and eco-friendly products such as surface disinfectants, cleaning agents, or preservatives in the food industry, thus offering innovative approaches to food preservation, health and environmental management. These novel strategies promote a circular economy and also help to address some environmental challenges and climate change issues (Bhatia *et al.*, 2023).

On the other hand, the science of nanotechnology not only offers innovative solutions to combat microbial infections but also revolutionizes antimicrobial applications to address drug-resistant pathogens and biofilm formation. The unique properties of nanomaterials, such as tunable size, high surface area, and the ability to interact at the molecular level, make them highly effective in various antimicrobial applications. Nanoparticles such as silver nanoparticles, gold nanoparticles, zinc oxide nanoparticles, copper nanoparticles, carbon-based nanomaterials, graphene oxide, and carbon nanotubes are not only being used for many novel applications such as antimicrobial agents but are also explored for the enhancement of the delivery of antimicrobial drugs by improving their bioavailability, stability and targeted delivery to infected sites (Aparicio-Blanco *et al.*, 2024).

The global solid waste production is currently estimated to be around 2.24 billion tons, with an approximate 0.79 kg per person per day. Solid waste generation is estimated to grow at a rate of roughly 73% in 2050, thereby leading to global waste generation of about 3.88 billion tons. This growth in waste generation is projected to increase rapidly in certain regions due to poor waste disposal practices and management. Thus, waste generation will continue to grow and cause an increase in environmental pollution if a significant improvement in waste management is not achieved (Faria *et al.*, 2023).

Approximately one-third of the food grown purposely for human consumption and sustenance is never consumed but rather wasted, thereby leading to adverse consequences and a heavy burden for the socio-economic and environmental aspects (Sahoo *et al.*, 2024). Food waste is considered against Sustainable Development Goal 12.3 (global food loss and waste), with the industrialized countries being the major contributors to household food waste. Food waste is not only directly associated with social and economic impacts but also environmental impacts (Phooi *et al.*, 2022). About 4.71 million deaths were linked to bacterial antimicrobial resistance in 2021, including 1.14 million deaths attributable to bacterial antimicrobial resistance. The trends in antimicrobial resistance mortality reportedly varied substantially by age and location over the past 31 years. For instance, the deaths from antimicrobial resistance increased for adults 70 years and older by over 80%, but decreased among children younger than 5 years by more than 50% from 1990 to 2021. For both deaths associated with and deaths attributable to antimicrobial resistance, meticillin-resistant *Staphylococcus aureus* increased the most globally (from 261,000 associated deaths and 57,200 attributable deaths in 1990, to 550,000 associated deaths and 130,000 attributable deaths in 2021 (Naghavi *et al.*, 2024).

4.0 Prospect of Solid-State Fermentation

Solid-state fermentation has become a possible way to make things like feed, fuel, food, industrial chemicals, and pharmaceuticals from microorganisms. It is used a lot to make enzymes, organic acids, flavoring compounds, and other things that need to be extracted, cleaned, and then used in different things. It has many benefits when used in bioprocesses like bioleaching, bio-beneficiation, bioremediation, bio-pulping, etc. Solid-state fermentation seems to be the best way to biodetoxify agro-industrial wastes and the most effective way to do it (Joshi *et al.*, 2014). Through solid-state fermentation, microorganisms produce a wide range of enzymes that can (i) enhance the bioavailability, digestibility, and absorption of proteins and carbohydrates by breaking down and eliminating anti-nutritional compounds such as alkaloids, flavonoids, oxalates, phytates, and tannins from the substrates; (ii) boost the levels of vitamins, minerals, proteins, and amino acids; and (iii) improve the organoleptic qualities of food, including its flavor, texture, appearance, and palatability (Ogodo *et al.*, 2018).

Oboh (2006) showed that after 7 days of fermentation, there was a big drop in the amount of cyanide and phytate in cassava peels. The ability of the mixed culture of *Saccharomyces cerevisiae*, *Lactobacillus delbrueckii*, and *L. coryniformis* to partially break down cyanogenic glucosides was thought to have caused the decrease in cyanide. On the other hand, the decrease in phytate content of the fermented cassava peels was thought to have been caused by the possible secretion of phytase, an enzyme that breaks down phytate. In the same way, the amount of the poison ricin in castor bean cake was reduced by using *Penicillium simplicissimum* and *Paecilomyces variotii* in solid-state fermentation (Madeira *et al.*, 2011). Other potential value-added products that can be produced from waste through solid-state fermentation are described below.

4.1 Enzymes

One of the most successful ways to use solid-state fermentation is to get bacteria to make enzymes. In the last 10 years, there has been a lot of research on how to make microbial enzymes through

solid-state fermentation. This has led to a rise in the number of enzymes made in large quantities for commercial and industrial uses (Thomas *et al.,* 2013; Abu *et al.*, 2017).
Examples of enzymes produced through solid-state fermentation (Table 1) include: (i) cellulases (Hu *et al.*, 2012); (ii) α-amylase (Hashemi *et al.*, 2013); (iii) proteases (Malik & Shinde, 2016); (iv) lipases (Oliveira *et al.*, 2016); (v) phytases (Bogar *et al.*, 2003); (vi) laccases (Rosales *et al.*, 2007); (vii) xylanases (Thomas *et al.*, 2013); (viii) xylosidases (Diaz-Malvaez *et al.*, 2013); (ix) chitin deacetylase (Suresh *et al.*, 2011); and (x) invertase (Alegre *et al.*, 2009). Several studies have shown that different types of lignocellulosic agricultural and industrial waste can be used to make enzymes. Enzymes are used in many industries, including the food, beverage, detergent, biofuel, cosmetic, fabric, and drug industries (Abu *et al.*, 2017; Mejias *et al.*, 2018).

Table 1
Examples of enzymes produced through solid-state fermentation

Enzymes	**Substrates**	**References**
Cellulases	β-1,4-D-glucosidic linkages in cellulose	Hu *et al.*, 2012
α-Amylase	Starch and related α-glucans	Hashemi *et al.*, 2013
Proteases	Proteins or polypeptides	Malik & Shinde, 2016
Lipases	Fats and oils	Oliveira *et al.*, 2016
Phytases	Phytic acid (myo-inositol hexakisphosphate, phytate)	Bogar *et al.*, 2003
Laccases	Lignin-related phenolic and non-phenolic compounds	Rosales *et al.*, 2007
Xylanases	Xylan	Thomas *et al.*, 2013
Xylosidases	Xylo-oligosaccharides	Diaz-Malvaez *et al.*, 2013
Chitin Deacetylase	Chitin	Suresh *et al.*, 2011
Invertase	Sucrose	Alegre *et al.*, 2009

4.2 Single-cell Proteins

The world's population, especially in Africa, is growing all the time. Because of this, there is a need to look at microbes as a major source of protein, fat, and vitamins for humans. This is because both animal and human food supply and demand are growing. Because of the high demand for protein-rich foods, people have been looking for other sources of protein to add to protein from animals and plants. In order to do this, single-cell proteins (SCP) became one of the new ideas that tried to solve the world's food problem (Ukaegbu-Obi, 2016). Because of this, making SCPs from agro-industrial wastes through solid-state fermentation has become an important and innovative way to make up for plants' lack of protein.

4.3 Organic acids

Most organic acids are made through chemical and biological synthesis (Abu *et al.*, 2017). Microbial fermentation is a method that can be used instead of chemical synthesis to make organic acids. Organic acids that are made by living things are safe, cheap, and easy to make. They are the third most common organic product, after enzymes and secondary metabolites (Ali and Zulkali, 2011). Organic acids are used in the food, beverage, medical, pharmaceutical, cosmetic, and other industries, just like enzymes. The largest number of organic acid products is used in the food industry, followed by the medical and pharmaceutical industries. At the moment, a lot of organic acids are made by solid-state fermentation, which has become a cheaper alternative to submerged fermentation (Lizardi-Jimenez and Hernandez-Martınez, 2017).

4.4 Biofuel

Biofuels are a kind of sustainable energy that is derived from biological sources. They are significant because they may be used instead of crude oil-based fuels, which are now in short supply. Among the many alternative energy sources, bioethanol and biogas are the most popular (Panda and Ray, 2015). Bioethanol, for instance, is the most widely utilised biological fuel in the world due to its widespread adoption in countries like Brazil, China, and the United States. Many types of yeasts and filamentous fungi have been documented as being capable of producing ethanol via solid-state fermentation. Examples of such fungi include *Aspergillus variabilis, A. niger, Penicillium* sp. *Trichoderma* sp. *Fusarium oxysporum,* as well as *Candida stellata, Candida pulcherrima, Hansenula anomala, Kloeckera apiculata*, and *Saccharomyces cerevisiae* (Bhargav *et al.,* 2008; Abu *et al.*, 2017).

4.4 Biofertilizer

When microorganisms are alive and working to improve the nutritional content of agro-industrial wastes, the resulting fertilizer is called a biofertilizer. The biofertilizers improve the soil's nutrient content, which in turn benefits the plants. Due to the increased need for food to sustain the expanding world population, agricultural production has resulted in an enormous volume of agro-industrial wastes (Diacono *et al.,* 2019). These byproducts of the agribusiness sector have the potential to be used as biofertilizers, which would then be spread throughout farmland to help keep up with the demands of mass-produced food. The biological transformation of agricultural wastes into biofertilizers using solid-state fermentation processes has been the subject of recent research. Lim and Matu (2015) utilized wastes from banana, watermelon, pineapple, papaya, and citrus orange to produce biofertilizer using solid-state fermentation, where the final product was then applied in the cultivation of vegetables. From the above discussion, it is clear that solid-state fermentation is one of the best routes for solid waste management. Many studies focus on agro-industrial waste to produce many useful products such as enzymes, biofuels, biofertilizer, etc, through solid state fermentation. Kitchen waste, as well as municipal waste, is another solid waste problem, especially in urban areas. There is much useful solid waste, such as peels of green vegetables and fruits, in everyday kitchen waste. So, if we focus on that solid waste to prepare some useful product through solid-state fermentation, that is very good for our society. Because municipalities need a place to keep this solid waste and this makes our environment polluted too. So, if we prepare a useful product through the above-discussed method, it will be a novel work for our society as well as for the environment.

5.0 Utilization of Agro-Industrial Wastes Through Solid-State Fermentation

Agriculture is a major part of the economies of both developed and developing countries around the world. Through agriculture, fresh foods are grown for people to eat and for the food processing industries to use as raw materials. But not all farm products that are meant for food and industry are used that way. Most of the leftovers from farming and manufacturing end up in landfills. These leftovers, which include those made right on the field during harvesting, are called agro-industrial residues (Sadh *et al.*, 2018). Obi *et al.* (2016) reported that only approximately 20% of maize is used for consumption, while the remaining 80% is discarded as waste. They further categorized agricultural waste into three main types: by-products from food processing industries, crop residues, and waste from fruits and vegetables.

According to Bharathiraja *et al.* (2017), globally, 5 billion metric tons of agricultural waste are made each year from things like groundnut cake, rice bran, rice straw, sugarcane bagasse, waste from fruits and vegetables, wheat bran, cotton leaf scraps, and so on. Most of these wastes are used as animal bedding or feed on farms, or they are taken away to be used by other peasant farmers or animal breeders (Adu *et al.*, 2018; Ravindran *et al.*, 2018).

Most of the rest of the agro-industrial waste is dumped, burned, or buried on farms or in the back yards of food processing plants, which pollutes the environment (Adu *et al.*, 2018; Sadh *et al.*, 2018). These ways of getting rid of agro-industrial wastes—dumping, burning, and burying—are common because they are used to clean up fields before the next planting season and to cut down on the high cost of waste management (Sharma *et al.*, 2020). One way to deal with this problem, though it has its limits, is to use agricultural wastes directly as bedding and food for animals and fuel in small-scale cottage industries (Obi *et al.*, 2016; Ravindran *et al.*, 2018). Agro-industrial wastes, like sawdust left over from forestry, are good candidates for use in solid-state fermentation because they are plentiful, cheap, easy to find, easy to get from farms or factories, and easy to prepare for their intended use. Microorganisms, for instance, can use them well; substrates are usually broken down mechanically into smaller pieces by the secretion and activity of enzymes. This makes it easier for mycelia to penetrate and colonize the substrate. The microorganisms use the substrates as sources of carbon and energy to make cellular parts (Zepf and Jin, 2013). According to Couto (2008), the substrate not only gives the microorganisms food, but it also acts as a solid base for them to grow on.

Conclusion

Kitchen waste represents both a critical environmental burden and a valuable bioresource. Through solid-state fermentation, KW can be transformed into bioactive products such as enzymes, biofuels, biofertilizers, organic acids, and antimicrobial compounds. These processes not only mitigate the negative environmental impacts of KW but also support a circular economy, food security, and sustainable industrial development. Furthermore, innovations in nanotechnology provide additional opportunities to enhance the efficiency of KW valorization, particularly in antimicrobial applications. To fully realize these benefits, governments and industries must prioritize waste segregation, invest in biotechnological infrastructure, and align waste policies with sustainability frameworks such as SDG 12.3. Future research should focus on scaling up SSF processes, integrating KW valorization into national waste management strategies, and expanding applications in health, agriculture, and industry.

References

Abdel-Shafy, H. I., Mansour, M. S. M., & El-Khateeb, M. A. (2018). Solid waste management: Scope and the challenge of sustainability. *Egyptian Journal of Chemistry*, *61*(Special Issue), 625–639. https://doi.org/10.21608/ejchem.2018.5179.1400

Abu, E. A., Ado, S. A., & James, D. B. (2017). Microbial production of industrial enzymes using solid-state fermentation. *Journal of Microbiology and Biotechnology Research, 7*(3), 1–9.

Adu, J., Ampah, J. D., & Gyan, S. E. (2018). Agro-industrial waste utilization: A sustainable approach towards greenhouse gas emission reduction. *International Journal of Environmental Studies, 75*(5), 781–793. https://doi.org/10.1080/00207233.2018.1478300

Alegre, R. M., Moreira, F. G., Carvalho, D. F., Silva, R., & Gomes, E. (2009). Application of a crude invertase preparation obtained by solid-state fermentation of sugarcane bagasse with Aspergillus niger. *Journal of Food Engineering, 91*(3), 423–429. https://doi.org/10.1016/j.jfoodeng.2008.09.001

Ali, S., & Zulkali, M. (2011). Production of organic acids from agro-industrial wastes by microbial fermentation. *Biotechnology Advances, 29*(5), 543–548. https://doi.org/10.1016/j.biotechadv.2011.03.007

Aparicio-Blanco, J., Romero, I. A., Male, D. K., & Slowing, K. (2024). Nanotechnology approaches for antimicrobial drug delivery. *Journal of Nanobiotechnology, 22*(1), 19–33. https://doi.org/10.1186/s12951-023-02145-7

Athanasiadis, V., Kalogiannis, K. G., & Fotopoulos, V. (2023). Valorization of watermelon rind: Bioactive compounds and antimicrobial properties. *Food Chemistry, 406*, 135027. https://doi.org/10.1016/j.foodchem.2022.135027

Batool, S., Raza, H., & Khan, M. I. (2024). Environmental implications of organic waste: A critical review. *Environmental Research, 241*, 117652. https://doi.org/10.1016/j.envres.2024.117652

Behiry, S. I., Okla, M. K., & Salem, M. Z. M. (2019). Antimicrobial activity of banana peel extracts. *Journal of King Saud University – Science, 31*(4), 1084–1090. https://doi.org/10.1016/j.jksus.2018.11.019

Bharathiraja, B., Suriya, J., Krishnan, M., Manivasagan, P., Kim, S. K., & Saravanakumar, K. (2017). Bioethanol production from agricultural wastes: An overview. Renewable Energy, 98, 226–235. https://doi.org/10.1016/j.renene.2016.02.057

Bhargav, S., Panda, B. P., Ali, M., & Javed, S. (2008). Solid-state fermentation: An overview. *Chemical and Biochemical Engineering Quarterly, 22*(1), 49–70.

Bhatia, S., Sharma, R., & Singh, P. (2023). Food waste valorization: Challenges and sustainable solutions. *Sustainable Chemistry and Pharmacy, 34*, 101061. https://doi.org/10.1016/j.scp.2023.101061

Bogar, B., Szakacs, G., & Pandey, A. (2003). Phytase production by Aspergillus species in solid-state fermentation. *Bioresource Technology, 86*(2), 203–205. https://doi.org/10.1016/S0960-8524(02)00171-5

Chavan, S. M., Kumbhar, S., & Patil, R. (2023). Valorization of kitchen waste for bioplastics production: Advances and perspectives. *Journal of Environmental Chemical Engineering, 11*(2), 109267. https://doi.org/10.1016/j.jece.2023.109267

Chhandama, S., Dutta, T., & Basumatary, S. (2022). Food waste management in households and eateries: A review. *Environmental Challenges, 7*, 100484. https://doi.org/10.1016/j.envc.2022.100484

Couto, S. R. (2008). Exploitation of agro-industrial wastes as immobilization support for laccase production by *Trametes hirsuta* under solid-state fermentation conditions. *Journal of Hazardous Materials, 152*(2), 557–564. https://doi.org/10.1016/j.jhazmat.2007.07.021

Diacono, M., Persiani, A., Testani, E., Montemurro, F., & Ciaccia, C. (2019). Recycling agricultural wastes and by-products in organic farming: Biofertilizer production, yield performance and carbon footprint analysis. *Sustainability, 11*(15), 3824. https://doi.org/10.3390/su11153824

Diaz-Malvaez, C., Aranda, J. S., & Rodríguez, C. A. (2013). Xylosidase production from agro-industrial wastes using solid-state fermentation. *Applied Biochemistry and Biotechnology, 171*(3), 563–574. https://doi.org/10.1007/s12010-013-0395-0

Elimelech, M., Phillip, W. A., & Ng, K. C. (2018). Municipal solid waste management in Malaysia: Current practices and future challenges. *Waste Management, 77*, 292–300. https://doi.org/10.1016/j.wasman.2018.04.014

Esteban-Lustres, R., Cortés, A., & Romero, J. (2022). Pre- and post-consumption food waste: An overview. *Waste Management & Research, 40*(12), 1717–1731. https://doi.org/10.1177/0734242X221089634

FAO. (2017). *Food loss and waste: Facts and figures*. Food and Agriculture Organization of the United Nations. http://www.fao.org/food-loss-and-food-waste/en/

Faria, J., Gomes, A., & Silva, C. (2023). Global trends in food waste management: Sustainability and circular economy perspectives. *Journal of Cleaner Production, 396*, 136634. https://doi.org/10.1016/j.jclepro.2023.136634

Feng, L., Zhang, H., & Yang, J. (2022). Antibacterial properties of pomegranate peel extracts. *LWT – Food Science and Technology, 160*, 113234. https://doi.org/10.1016/j.lwt.2022.113234

Fontaine, F., Pinto Ferreira, J., Valcarce, A., Kabali, E., & Song, J. (2026). Risk of antimicrobial resistance spreading via food loss and waste. Infectious diseases of poverty, 15(1), 21. https://doi.org/10.1186/s40249-025-01405-6

Hajam, Y. A., Lone, A. H., & Bhat, R. A. (2023). Household food waste and its socio-environmental implications. *Environmental Science and Pollution Research, 30*(15), 41672–41688. https://doi.org/10.1007/s11356-023-25947-2

Haldar, D., Purkait, M. K., & Bhattacharya, T. (2022). Food waste management and valorization: Global status and future challenges. *Journal of Environmental Management, 320*, 115729. https://doi.org/10.1016/j.jenvman.2022.115729

Hasan, M., Sarker, M., & Kabir, M. (2022). Antimicrobial properties of citrus fruit peels: A review. *Journal of Food Science and Technology, 59*(10), 3852–3864. https://doi.org/10.1007/s13197-022-05419-4

Hashemi, M., Mousavi, S. M., Razavi, S. H., Shojaosadati, S. A., & Mousavi, S. B. (2013). Solid-state fermentation of agricultural residues for α-amylase production by Aspergillus sp.. International Journal of Food Science & Technology, 48(9), 1828–1834. https://doi.org/10.1111/ijfs.12152

Hetta, H. F., El-Masry, H. M., & Mohamed, M. A. (2023). Nanotechnology in antimicrobial applications: A sustainable approach. *Frontiers in Nanotechnology, 5*, 1194327. https://doi.org/10.3389/fnano.2023.1194327

Hikal, W. M., Sayed, A. E., & Al-Ghamdi, A. A. (2022). Antimicrobial potential of banana peels against pathogenic microbes. *Egyptian Pharmaceutical Journal, 21*(3), 245–251. https://doi.org/10.4103/epj.epj_32_22

Hu, J., Arantes, V., Pribowo, A., & Saddler, J. N. (2012). Enzyme production from agricultural wastes by solid-state fermentation. *Bioresource Technology, 110,* 446–452. https://doi.org/10.1016/j.biortech.2012.01.078

Joshi, C., Pandey, A., & Shukla, S. (2014). Solid-state fermentation: An overview. *Biotechnology Advances*, *32*(1), 126–144. https://doi.org/10.1016/j.biotechadv.2013.09.003

Kibria, M. G., Rahman, M. S., & Hossain, S. (2023). Plastic waste in kitchen refuse: Environmental risks and sustainable solutions. *Marine Pollution Bulletin, 188*, 114660. https://doi.org/10.1016/j.marpolbul.2023.114660

Li, J., Wang, Q., & Chen, Y. (2022). Food waste generation in China: Trends, drivers, and challenges. *Resources, Conservation and Recycling, 185*, 106473. https://doi.org/10.1016/j.resconrec.2022.106473

Liegeard, J., & Manning, L. (2020). Household food waste behavior: Insights from international studies. *Waste Management, 106,* 147–154. https://doi.org/10.1016/j.wasman.2020.03.034

Lim, S. L., & Matu, S. (2015). Utilization of fruit wastes for the production of biofertilizer using solid-state fermentation. Malaysian Journal of Microbiology, 11(2), 151–157. https://doi.org/10.21161/mjm.62114Elsevier. https://doi.org/10.1016/B978-0-444-63203-8.00015-0

Lizardi-Jiménez, M. A., & Hernández-Martínez, R. (2017). Solid state fermentation (SSF): Diversity of applications to valorize waste and biomass. 3 Biotech, 7(1), 44. https://doi.org/10.1007/s13205-017-0692-y

Madeira, J. V., Contesini, F. J., & Callegari, C. M. (2011). Reduction of ricin toxicity in castor bean cake by solid-state fermentation using Penicillium simplicissimum and Paecilomyces variotii. Bioresource Technology, 102(17), 7984–7991. https://doi.org/10.1016/j.biortech.2011.05.070

Malik, P., & Shinde, S. (2016). Production of protease through solid-state fermentation by Aspergillus species using agro-industrial wastes. International Journal of Science and Research, 5(7), 1576–1581.

Naghavi, M., Vollset, S. E., Ikuta, K. S., Swetschinski, L. R., Gray, A. P., Wool, E. E., … Murray, C. J. L. (2024). Global burden of bacterial antimicrobial resistance 1990–2021: A systematic analysis with forecasts to 2050. The Lancet. Advance online publication. https://doi.org/10.1016/S0140-6736(24)01867-1

Oboh, G. (2006). Nutrient enrichment of cassava peels using a mixed culture of Saccharomyces cerevisiae and Lactobacillus spp. in solid media fermentation. Electronic Journal of Biotechnology, 9(1), 46–49. https://doi.org/10.2225/vol9-issue1-fulltext-1

Ogodo, A., Agwaranze, D. I., Aliba, N. V., Kalu, A. C., & Nwaneri, C. B. (2018). Fermentation by lactic acid bacteria consortium and its effect on anti-nutritional factors in maize flour. Journal of Biological Science, 19(1), 17–23. https://doi.org/10.3923/jbs.2019.17.23

Oliveira, T. F., de Andrade, C. J., Fernández-Lafuente, R., de Oliveira, D., & Ninow, J. L. (2016). Production of lipases in solid-state fermentation, prospects for biofuels production: A review. Renewable and Sustainable Energy Reviews, 54, 875–885. https://doi.org/10.1016/j.rser.2015.10.087

Panda, A. K., & Ray, R. C. (2015). Production of bioethanol from agricultural residues, fruits, and vegetable wastes: An overview. In R. C. Ray & C. Larroche (Eds.), Current developments in biotechnology and bioengineering: Resource recovery from wastes, (pp. 321–346).

Phooi, C. L., Azman, E. A., Ismail, R., Arif Shah, J., & Koay, E. S. R. (2022). Food waste behavior and awareness of Malaysians. Scientifica, 2022, Article 6729248. https://doi.org/10.1155/2022/6729248

Pilone, V., di Santo, N., & Sisto, R. (2023). Factors affecting food waste: A bibliometric review on household behaviors. PLOS ONE. Advance online publication.

Pramanik, B. K., Shu, L., & Jegatheesan, V. (2019). A review of the management and sustainability of food waste bioresources. Clean Technologies and Environmental Policy, 21(1), 1–14. https://doi.org/10.1007/s10098-018-1616-3

Ravindran, R., Jaiswal, S., Abu-Ghannam, N., & Jaiswal, A. K. (2018). A comparative analysis of pretreatment strategies on the properties and hydrolysis of brewers' spent grain. Bioresource Technology, 248, 272–279. https://doi.org/10.1016/j.biortech.2017.06.076

Rosales, E., Couto, S. R., & Sanromán, M. Á. (2007). Increased laccase production by Trametes hirsuta grown on ground orange peelings. Enzyme and Microbial Technology, 40(5), 1286–1290. https://doi.org/10.1016/j.enzmictec.2006.10.014

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. https://doi.org/10.1186/s40643-017-0187-z

Sahoo, A., Dwivedi, A., Madheshiya, P., Kumar, U., Sharma, R.-K., & Tiwari, S. (2024). Insights into the management of food waste in developing countries: With special reference to India. Environmental Science and Pollution Research, 31. Advance online publication. https://doi.org/10.1007/s11356-023-27901-6

Sharma, B., Larroche, C., & Dussap, C. G. (2020). Comprehensive assessment of 2nd generation bioethanol production from agro-residues: Opportunities and perspectives. Biotechnology Advances, 40, 107521. https://doi.org/10.1016/j.biotechadv.2020.107521

Slorach, P. C., Jeswani, H. K., Cuéllar-Franca, R., & Azapagic, A. (2020). Environmental sustainability of anaerobic digestion of household food waste. Journal of Environmental Management, 255, 109827. https://doi.org/10.1016/j.jenvman.2019.109827

Suresh, P. V., Naga Rathna, L., & Sachindra, N. M. (2011). An overview of chitin deacetylase research and applications. Carbohydrate Polymers, 83(2), 1083–1095. https://doi.org/10.1016/j.carbpol.2010.09.082

Tchonkouang, R. D., Onyeaka, H., & Miri, T. (2023). From Waste to Plate: Exploring the Impact of Food Waste Valorisation on Achieving Zero Hunger. Sustainability, 15(13), 10571. https://doi.org/10.3390/su151310571

Thomas, L., Larroche, C., & Pandey, A. (2013). Current developments in solid-state fermentation. Biochemical Engineering Journal, 81, 146–161. https://doi.org/10.1016/j.bej.2013.10.013

Tonini, P., Muñoz Odina, P., & Gabarrell Durany, X. (2023). Predicting food waste in households with children: Socio-economic and food-related behavior factors. Frontiers in Nutrition, 10. https://doi.org/10.3389/fnut.2023.1249310

Ukaegbu-Obi, K. M. (2016). The role of single cell protein in food security: A review. International Journal of Current Research in Biosciences and Plant Biology, 3(5), 127–135. https://doi.org/10.20546/ijcrbp.2016.305.020

United Nations. (2015). Transforming our world: The 2030 Agenda for Sustainable Development. United Nations. https://sdgs.un.org/2030agenda

Wang, L.-e., Ni, X.-w., Li, Y.-y., & Cheng, S.-k. (2021). Measurement of the scale of food waste and its resources and environmental effects at the consumer segment in China. Journal of Natural Resources, 36(6), 1455–1468. https://doi.org/10.31497/zrzyxb.20210608

Yaacob, M. R., Zakaria, S., & Yaacob, Z. (2019). Solid waste management in Malaysia: Potential of waste-to-energy approach. Journal of Advanced Research in Applied Sciences and Engineering Technology, 14(1), 18–24. https://doi.org/10.37934/araset.14.1.1824

Yaashikaa, P. R., Senthil Kumar, P., Varjani, S., & Saravanan, A. (2022). Valorization of food waste: A comprehensive review on the recovery of valuable products and sustainable management practices. Journal of Environmental Management, 324, 116285. https://doi.org/10.1016/j.jenvman.2022.116285

Zepf, F., & Jin, B. (2013). Bioconversion of food waste to value-added products via microbial fermentation. In V. K. Gupta, M. G. Tuohy, C. P. Kubicek, J. Saddler, & F. Xu (Eds.), Bioenergy research: Advances and applications (pp. 323–337). Elsevier. https://doi.org/10.1016/B978-0-444-59561-6.00024-5

Zhang, X., Liu, Y., Chen, Y., & Wang, Z. (2020). Influential factors affecting the generation of kitchen solid waste in Shanghai, China. Journal of the Air & Waste Management Association, 70(7), 772–783. https://doi.org/10.1080/10962247.2020.1856215

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