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Environmentally sustainable approaches for the utilization of agricultural wastes for ensuring global food security: A review

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Abstract

Increasing population and urbanization have significantly enhanced the global demand for food. Hence, with intensified farming, it has been estimated that the global waste will increase by 70% in 2050, and the contribution of agricultural waste to the total waste matter would be significant. Presently, the annual global agricultural waste generation is 998 million tons and if not treated and properly managed it would be challenging to maintain environmental sustainability. Therefore, it's timely to investigate agricultural waste management techniques that will ensure food security and environmental sustainability. Hence, this study was conducted based on a comprehensive literature review on strategies for agricultural waste utilization, its novel technologies, and its environmental concerns and potentials in safeguarding global food security with the aim of presenting potential approaches for utilizing agricultural wastes to enhance food security and environmental sustainability and its future perspectives. Improper waste disposal, lack of awareness, and government policies are the main reasons for the unprecedented waste generation globally. On-farm compost production, use for animal feeding, production of energy was identified as conventional approaches for agricultural waste utilization, while bioremediation, extraction of phytochemicals, and smart-waste management technologies were identified as novel approaches for the farmers to diversify their agriculture activities. However, many of the novel technologies are lack in practice due to several limitations. Hence, this study identified the importance of future research on novel approaches and expanding knowledge on existing technologies as promising moves to enhance sustainable agricultural waste utilization in the future.

Keywords: *Agricultural wastes, Environment, Food security, Sustainability*

1. Introduction

Agricultural waste can be defined as the waste generated during the production and processing of agricultural products, including crop waste, animal waste, processing waste, and hazardous waste (Obi et al., 2016). In recent years agricultural wastes have become an increasing concern with their excessive generation. Rapid population growth and urbanization have increased the demand for food, which produces large quantities of agricultural wastes (Harshwardhana & Upadhyay, 2017). Expanding agricultural production to meet the increasing food demand naturally has resulted in large quantities of livestock waste, agricultural crop residues, and agro-industrial by-products (Agamuthu, 2009). Besides, improper methods of waste disposal, irrational application of intensive farming methods, and abuse of chemicals in farming due to lack of awareness, poor government policies, and insufficient resource utilization also can be considered as major reasons for the excessive agricultural waste generation in the global scale (Rout & Sahoo, 2017). Even though the world has technologically developed, most agricultural operations still use conventional waste disposal practices such as open dumping, burning, and directing to septic ponds without having proper management (Sindhu et al., 2015). As a result, to the 2 billion tons of total waste-producing annually around the world, agricultural waste contributes by 998 million tonnes and, it causes significant negative impacts on the environment and sustainable development (Rout & Sahoo, 2017. Millati et al., 2019). According to Food and Agricultural Organization (FAO), food waste accounts for a large amount of agricultural waste generating around the world each year, and food waste and loss contribute to the global hunger crisis, with close to 800 million food-insecure people. The carbon footprint of food produced and not eaten is estimated as 4.4 gigatons (billion tons) of CO_2 equivalent (FAO, 2013). However, the waste generating from agricultural activities has a good potential to utilize as a source of energy (Harshwardhana & Upadhyay, 2017). Therefore, this paper compares and evaluates different agricultural waste management methods while highlighting the potentials for effective agricultural waste management and utilization to enhance global food security and environmental sustainability.

2. Methodology

The study was conducted based on a comprehensive review of the existing literature on strategies for agricultural waste utilization, its novel technologies, and its environmental concerns and potentials in safeguarding global food security.

3. Results and Discussion

Classification of agricultural wastes and their generation

Agricultural wastes can be mainly classified into two major categories called non-biodegradable wastes and biodegradable wastes. Accordingly, the non-biodegradable agricultural wastes include discarded pesticide containers, plastics, bags and sheets, tires, batteries, clinical waste, old machinery, oil, packaging waste, etc. Biodegradable agricultural wastes include crop residues, slurries, and manure (CIWM, 2020).

Even though numerous individuals suffer from hunger, the quantity of world waste products increases day by day. It's been predicted that the number of waste products created has double the potential to feed those suffering populations. It has been calculated that about 30 percent of the world's food is wasted during production and processing, and about 16 percent of food is wasted by retailers and consumers (Statista Research Department, 2016). The main reasons for the food loss in many developing countries are <u>inadequate storage facilities, lack of smart transportation systems, or refrigeration</u>, while in developed nations, food is often thrown away due to oversupply from retailers or expiring due to not consuming on time (FAO, 2017). Further, with the increasing global food demand, agricultural development has coupled with the irrational application of intensive farming methods and intense utilization of chemicals (fertilizers, pesticides, herbicides, etc.) in cultivations (Dien & Vong, 2006). However, when persistently applied, it accumulates in the soil causing harm to beneficial organisms. Due to the higher water solubility of pesticides and fertilizers, they may also leach and enter into the sources of water and food products. This will lead to serious health risks in humans, including cancer, Parkinson's disease, Alzheimer's disease, congenital disabilities, and reproductive disorders (Mostafalou & Abdollahi, 2013).

Animal wastes incorporated with dairy shed gushing (pee, fertilizer, wash water, lingering milk, and wasted feed), dairy excrement, poultry litter (a blend of manure, water, spilled feed, plumes, and bedding material), renderings, and different squander from animals' operations is the other principle wellspring of farming waste that is needed to oversee appropriately (Balaman, 2019). The amount and the nature of the animal waste vary with the kind of animal species. In any case, the expanding demand that requires a higher measure of animal production has prompted numerous ecological and biosecurity issues

(Ogbuewu et al., 2012). Furthermore, harvesting and processing of aquacultural produce generate huge volumes of waste, and it has been estimated as 35-80% of the total animal waste. Aquacultural wastes include catch and rejects from fish harvesting, and processing waste generated from de-heading, deskinning, deboning, evisceration, washing, trimming, peeling, and filleting operations (Ghaly et al*.,* 2013). The non-natural agricultural wastes like agricultural plastics, tires and other hazardous substances generating from agricultural activities have caused huge environmental issues due to improper waste disposal methods (Cavanagh et al*.,* 2014). Consequently, the expanding quantities of agricultural waste result in several environmental problems, including air pollution, water pollution, soil pollution, loss of biodiversity, etc. (Sharma et al., 2019a).

In each year, billions of agricultural wastes are generated in developed and developing countries in the world (Yevich & Logan, 2003). The largest quantities of agricultural waste are generated from China among the Asian and Pacific region countries. In China, rice, corn, and wheat production generate 587 million tons of residues annually, and India is considered the second most agricultural waste generating country in Asia (Prasad et al., 2020). In Malaysia, agricultural wastes mainly generate rice, palm oil, rubber, coconut, and forest products, and it accounts for disposing of 1.2 million tons of agricultural waste into landfills annually (Agamuthu, 2009., Koopmans & Koppejan, 1997). In Sri Lanka, agricultural waste is mainly comprised of waste from paddy cultivation (paddy husk and straw), animal waste, coir fiber, and coir dust from coconut cultivation and bagasse from sugarcane cultivation, etc. and contributes to 6.4% of the total municipal solid waste (Premachandra, 2006). Table 1 summarizes the agricultural waste generation rate in Asian countries.

Table 1: Agricultural waste generation rate in Asia (modified from Agamuthu, 2009).

Country	**Agricultural Waste Generation Rate (kg/cap/day)**
Sri Lanka	**0.3-0.14**
Japan	0.17
Singapore	0.165
Korea	0.15
Malaysia	0.122
China	0.12
Indonesia	0.114
Thailand	0.096
Vietnam	0.092
Myanmar	0.068
Nepal	0.060
Bangladesh	0.04

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Rice straw, Sugarcane, Wheat, and Corn are the four major crops cultivated in the world that account for a high level of global agricultural production (Saini et al., 2015). Therefore, these four crops are responsible for generating the majority of agricultural waste in the world. Asia accounts for the highest global production of rice straw and wheat straw, while America produced the highest quantities of corn stover and sugarcane bagasse (Ali et al., 2019). Figure 1 illustrates the global availability of the above four major agricultural wastes

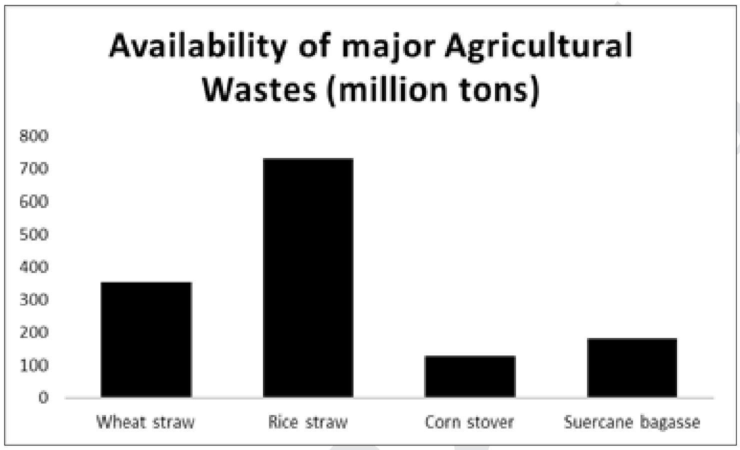

Figure 1: Globally Available major agricultural wastes (modified from Saini et al., 2015).

Agricultural wastes and the environment

The same as the other facets of development activities agriculture has become a major source of environmental pollution and waste generation. Therefore, it is important to draw our concern towards the minimization of waste generation and proper management of agricultural waste to achieve environmental sustainability (Nagendran, 2011). The impact of agricultural waste on the environment depends on two factors: the amount of agricultural waste generated and the method of disposing of the agricultural wastes. Generally, agricultural wastes are generated from several sources, notably from cultivation, livestock, and aquaculture (Loehr, 2012). Improper agricultural waste management practices such as open dumping, residue burning, and directing of wastes to natural waterways can be considered primary reasons for the environmental pollution associated with the agricultural waste (Rout & Sahoo, 2017). Agricultural waste burning releases pollutants such as carbon monoxide, nitrous oxide, nitrogen dioxide, and particles (smoke carbon) which are considered greenhouse gases. Emission of greenhouse gases and global warming, climate change, and destruction of aquatic ecosystems due to conditions like eutrophication caused by improper agricultural waste management has become a barrier towards the development of environmental sustainability (Levine, 1994). However, reducing, reusing, and recovering agricultural wastes enhance environmental sustainability by avoiding the addition of burden to the environment through the production of unnecessary materials that could be reused, conserving valuable natural resources while reducing the pollution and creating less waste, and extending the life of existing landfills (Rathi, 2006).

Livestock production is considered a major contributor to global warming, and it causes 35-40% of global anthropogenic methane and 9% of global anthropogenic CO_2 emissions. Further, livestock farming contributes to 65% of global nitrous oxide anthropogenic emissions which is considered as the most potent of the three major greenhouse gases. Enteric fermentation and manure constitute 80% of the methane emission while manure and urine cause 64% of global anthropogenic ammonia emissions. Hence, livestock waste is a major agricultural waste that creates adverse impacts on the environment (Abbasi & Abbasi, 2016). Besides, landfills are the largest man-made contributors of methane emissions to the atmosphere. When organic waste is disposed of without composting, it ends up in a landfill, producing large quantities of methane under anaerobic conditions (Gollapalli & Kota, 2018). Methane is considered a greenhouse gas that is 72 times more potent than CO_2 (Nyman, 2014). However, it has been predicted that the proper manure handling, biogas plants, crop burning ban, and reduction of aquatic contamination from agricultural wastes together can reduce 28% of global greenhouse gas emissions (Cooper et al., 2013).

Biogas production refers to the process of digesting organic waste anaerobically to produce an excellent fertilizer and combustible gas by disposing of agricultural residues, aquatic weeds, animal and human excrement, and other organic matter is considered a good source of clean, renewable energy. Biogas is a combination of methane (60-70%) and CO_2 (30-40%), which, if released in a non-combustible form, is harmful to the environment (Usman & Ekwenchi, 2013). Therefore, in addition to the production of renewable energy, controlled anaerobic digestion of animal manures reduces greenhouse gas emissions, nitrogen, and odor from manure management and intensifies the recycling of nutrients within agriculture (Zafar, 2018). Further, composting is also considered a sustainable approach for producing an organic fertilizer while reducing the quantity of waste generation and the potential pollutants. However, it has been revealed that composting has some pollution-associated problems despite these positive impacts (Shephered et al., 2000). The main pollution problems of composting include the emission of gases or volatile compounds into the air and the leaching of pollutants into groundwater. Therefore, to avoid these unfavorable impacts on the environment, it is needed to facilitate optimum conditions for the process of composting while ensuring the proper raw material selection, which determines the C/N ratio, optimum moisture condition and porosity, management of the compost heap, and the pile including the water addition, covering and the frequency of turning. Moreover, maintaining optimum maturation time is also very important to control the gas emissions and leaching problems (Schenk et al., 1996).

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However, the main goal of agriculture is to meet the existing global food demand with the surplus amount of food production for exporting and future purposes. Therefore, with the increase of the agricultural output, chemical fertilizers, pesticides usage have also increased. Although the application of chemical inputs serves as a boon by increasing agricultural yields, it creates long-term negative impacts on the environment and human health (Abhilash & Singh, 2008). Higher levels of these contaminants from agricultural waste in soil and consequent plant uptake may affect public health, causing diseases like skin allergies, cancer, disorders of the central nervous system, etc. (Sharma et al.,2019b). The Chronic Kidney Disease of undetermined cause (CKDu) is affecting agricultural communities in Central America, South Asia, and possibly other parts of the world can be denoted as one of the severe health issues of agricultural wastes (Weaver et al*.,* 2015). Various possible causes have been suggested for CKDu, including pesticides and fertilizers mainly TSP, which contain a high amount of arsenic like potentially toxic trace elements (Jayasumana et al*.,* 2015). Annually a large amount of chemicals is adding to the agricultural soils in terms of fertilizers and pesticides like herbicides, insecticides, and fungicides weedicides and the residues of these applications may increase the levels of heavy metals while polluting almost every part of the environment including soil, water, land, and air (Atafar et al., 2010). The fertilizers and manure used in agriculture may cause detrimental effects on the environment. For example, fertilizers and manure used in agriculture contain a high amount of nitrate and phosphates, these nutrients can be washed into nearby water bodies (Savci, 2012). High levels of nitrogen and phosphorus in water bodies can cause eutrophication. This may result in hypoxia (“dead zones”), causing fish kills and decreased aquatic life. Excess nutrients can cause Harmful Algal Blooms (HABs) in freshwater systems, which disrupt wildlife and produce toxins harmful to humans (Le et al., 2010). Thus, every year millions of fertile soils are lost due to synthetic fertilizers, pesticides, and herbicides combined with other farm practices. The chemicals contained in pesticides can cause long-lasting damage to the soil. This can gradually alter the soil microbial activities, soil chemistry and finally deplete the soil fertility (Joko et al*.,* 2010).

Hence, organic agriculture can be considered a holistic production and management approach that supports the environment, health, and sustainability (Dubey, 2013). Organic farming is mainly based on minimizing the use of external inputs like synthetic fertilizers, pesticides, and on-farm resources efficiently for sustainable food production (Van Grinsven et al., 2015). There, agricultural waste can be used as an on-farm resource. Compost produced from agricultural wastes and sewage sludge, agro-industrial sludge, slaughterhouse sludge, and pig slurry digestate is some of the on-farm agricultural wastes that mainly use in organic farming. (Sharma et al., 2019b).

Rapid urbanization and industrialization have led to the increasing disposal of potentially toxic trace metals into the environment (Wong et al., 2006). According to various researchers,

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low-cost agricultural waste such as rice husk, sawdust, sugarcane bagasse, coconut husk, oil palm shell, neem bark, etc., can be used in the elimination of most hazardous potentially toxic trace metals (Cr, Ni, Cu, Zn, Cd, Pb, Hg, and As) (Obi et al., 2016). Furthermore, bioremediation techniques that utilize the biological mechanisms of fungi, bacteria, and plants to degrade, transform, accumulate, or mineralize a pollutant to a nontoxic state can be effectively utilized to treat agricultural wastes at the farm level or in locations of accumulation (Evans, 2018).

Agricultural wastes for enhancing food security

Global food security can be achieved when all people at all times have adequate physical and economic access to enough safe and nutritious food to meet their needs for a healthy and active life (Clapp, 2014). Feeding 9 billion people globally is a great challenge and requires changes in agricultural production and management practices (Stefanis, 2014). Further, in 2050 the projected world population is 9.7 billion and it will enhance the global food demand by 71% than today (Cole et al., 2018). Therefore, as a strategic solution to this issue, it is necessary to take appropriate steps to convert agricultural wastes into a resource that could be utilized effectively without being discarded. Agricultural waste can enhance food security by converting waste to biofertilizer and organic substrates, energy, and through use as animal feeds (Amoding, 2007).

Production of bio-compost by utilizing agricultural wastes, including food wastes from fields to market, can be regarded as a much effective way to supply precious nutrients back into the soil while reducing the agricultural wastes in landfills (FAO, 2013). Crop residues, animal excreta, fruits and vegetable waste, grains, cereals, eggshells, dairy waste, etc. can be used for the process of composting. When drawing concern on the role of composting towards enhancing global food security, it improves the soil properties associated with plant growth and improves the nutritional content and the productivity of the crops grown in compost-rich soils while ensuring food security. Besides, composting replaces the application of chemical fertilizers, pesticides, and herbicides and it is essential for the production of quality agricultural products for the food industry (Shilev et al., 2007).

The utilization of agricultural wastes like straw, sugar cane by-products, and fruits and vegetable by-products for animal feeding is another best practice to enhance food security especially through increasing dairy animal productivity (Sruamsiri, 2007). Dairy farmers most commonly use rice straw to feed animals during the dry season when no green forage is available. During this period, farmers will have to supplement more concentrates to animals to get higher milk yields. However, urea or ammonia-treated rice straw is considered as a low-cost and effective solution to increase animal production during this season (Promma et al., 1993). Furthermore, it has been predicted that when the animals were fed with soya bean

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pod husk, a by-product of soya bean oil and meal industry, it has significantly increased the milk fat production of dairy animals (Sanitwong et al., 1997). Besides, pineapple wastes which consist of a crown, core, peel, leaves, and waste from flesh trimming can be used for cattle feeding due to its high palatability. It has been reported that the dried pineapple waste and ensiled pineapple waste can be used as supplemental roughage and can be replaced 50% of roughage in the total mixed ration for dairy cattle without adversely affecting the animal production (Jitramano, 2005). The by-products of the sugar cane industry, including sugarcane tops, sugarcane leaves, bagasse, and molasses, can also be used effectively for animal feeding due to their high nutrient contents. Especially, the sugarcane silage can be effectively used as a roughage source in cattle fattening diets and as a winter supplement for producing brood cows (Pate et al., 2002).

Production of energy from agricultural residues enhances food security by providing a valuable by-product, good quality fertilizer which improves the crop yields while providing additional revenue (Usman & Ekwenchi, 2013). Besides, agricultural wastes can be used as substrates for fruit, vegetable, and mushroom production. Cultivation of fruit and vegetable crops such as strawberry, pepper, tomato, cucumber, and okra on compacted rice straw bales in open fields or under greenhouses is a promising method to utilize rice straw residues towards enhancing food security. Further, the application of rice straw for the plantation of mushrooms is a well-known technique that has become increasingly popular in recent years (Abou Hussein & Sawan, 2010). Furthermore, spent mushroom substrate, which is a residue generating during the production process of mushrooms, can also be used as compost, as a substrate for other mushroom-forming fungi, as an animal feed, to promote the health of animals, and to produce biofuels and enzymes (Grimm & Wösten, 2018).

Recently, researchers have paved their attention towards the potentials for utilizing agricultural wastes for food value addition. Accordingly, they have identified the extraction of phytochemicals from agro wastes as a sustainable means of agricultural waste utilization. In that regard, dried mango (*Mangifera indica*) leaves have been used for the extraction of the phytochemical mangiferin that acts as a valuable biomolecule in the food and pharmaceutical industry (Rao and Rathod, 2018). Furthermore, recent studies have extracted and identified phenolic compounds such as flavonoids, amino acids, tannins, ascorbic acids from tomato leaf waste, underutilized crops like *Ficus racemose,* etc. Accordingly, it was proved that the extraction of phytochemicals from agricultural wastes, as a sustainable approach for utilizing agricultural wastes for food value addition (Sharma et al., 2020; Arab et al., 2019).

Smart agriculture and waste management

The agricultural sector is currently facing a wide range of challenges, while its role in human existence grows more vital with the increasing global population. Growing populations increase the demand for food, while at the same time, arable landscapes are shrinking due to urbanization (Campbell et al., 2014). However, it is essential to optimize agricultural productivity to meet the rising food demand parallel to the population growth. Therefore, smart agriculture can be regarded as an approach that focuses on farming operations that enhance productivity while reducing greenhouse gas emissions (Andrieu et al., 2017). Accordingly, Climate Smart Agriculture (CSA), precision farming, and ecological monitoring, with the use of Internet-of-Things (IoT), sensors, and servers can be considered as the key elements of a smart agricultural framework and it could be successfully integrated into a smart agricultural waste management system (Bong et al., 2018).

When considering the smart agricultural systems sound management and disposal of agricultural waste are of key importance to achieve food security and environmental sustainability. A smart agricultural waste management approach can be enabled by implementing IoT network sensors and cloud computing at each level from waste generation to disposal (Ojha et al., 2015). A simplified structure of an IoT-based smart waste management system is shown in figure 2.

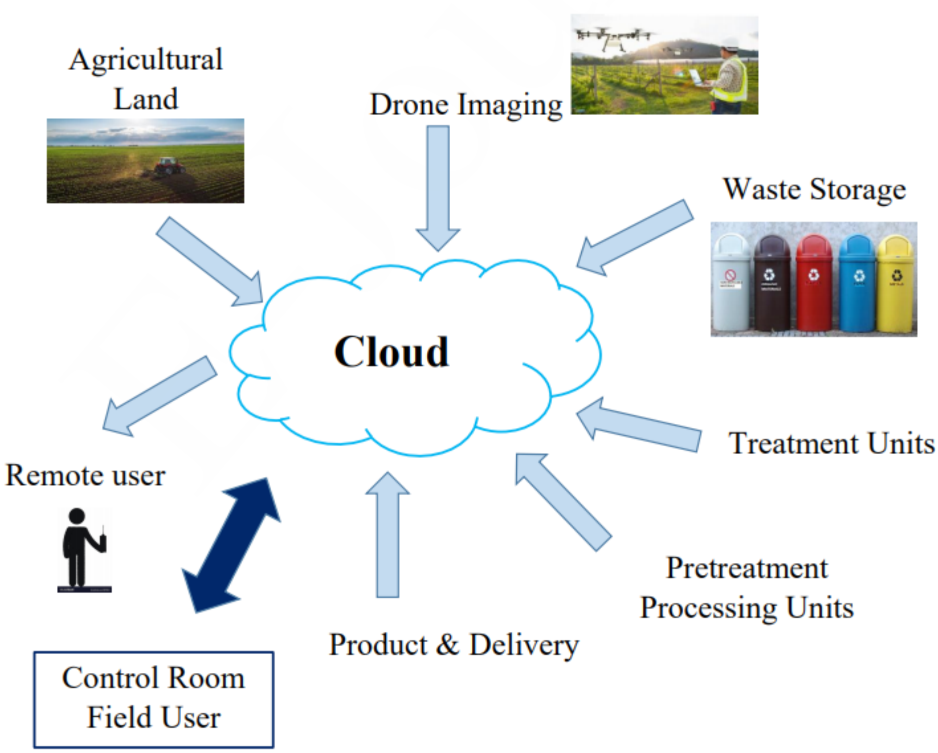

Figure 2: A simplified structure of an IoT-based smart waste management system (Modified from Bong et al., 2018).

The smart waste collecting bins equipped with Radio-Frequency Identification (RFID) tags and Global Positioning System (GPS) modules is a novel technology that has been introduced to farmlands. In this system, signals are sending for "smart" trucks when the bins are a quarter to full. The bins are weighed, and the reading is transmitted to the cloud that can be assessed among users. The waste pre-treatment unit will convey the signal regarding their treatment capacities. Upon receiving such information, the suitable amount of agricultural waste could be transported to the waste pretreatment unit by the trucks (Ward et al., 2008). Moreover, the concept of intelligent disposal through a design that uses solar energy to feed the system and presence sensors for monitoring the amount of waste accumulated inside the collecting bins is another inventive technology that can be integrated into agricultural systems to reduce the emissions, contaminations, and reach sustainability (Saha et al., 2017). The waste pre-treatment technologies are also significantly important when implementing smart waste management concepts. Generally, in smart waste management systems, waste pretreatments units are equipped with technologies to convey the signal regarding their treatment capacities. In these systems, pre-treatment technologies such as alkali pre-treatment, thermal and thermos-chemical, ultrasonic pretreatment, etc. are commonly applied to break down the recalcitrant polymers via physical, thermal, or chemical treatment (Ward et al., 2008). Furthermore, IoT systems permit a platform for precision agriculture and ecological monitoring by enabling functions such as smart spraying and irrigation, assessment of the marine environment, and real-time data on queries, statistics, and abnormality warnings Hence, it facilitates the optimization of agricultural inputs, monitoring for sound collection, transportation and disposal of agricultural wastes and identifying potential illegal disposal or emergency, such as the spilling of waste (Wen et al., 2018). Accordingly, due to the real-time and continuous acquisition and analysis of decisive variables, smart technologies allow the identification, monitoring, improvement, and optimization of various components and the design of the supply chain, and it aids in the generation of desired products with optimum quality and quantity. Therefore, promoting smart agriculture with a smart waste management perspective will reduce waste generation and associated food losses while mitigating the adverse impacts on the natural ecosystems (Bong et al., 2018).

Further, IoT systems can be used for livestock management, crop growth monitoring, and soil analysis. Accordingly, it has been predicted that intensified livestock farming will enhance meat and milk productivity by 30% depending on the region while contributing to a 10% decrease in all agricultural emissions (Campbell et al., 2014). Besides, the IoT system includes sensors for soil moisture, nutrients, and air quality analysis which has the potential to optimize the crop and animal produce while reducing the quantity of waste generation. Hence, smart farming will boost the harvest while minimizing the usage of chemical fertilizers and it will be much beneficial to achieve the sustainable development of a nation (Parker, 2018).

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Future perspectives for agricultural waste utilization

Even with the existing technologies, the continuous generation of massive quantities of agricultural wastes remains an unsolved global issue. Hence, it is important to draw global attention towards the future perspectives of agricultural waste utilization (Duque-Acevedo et al., 2020). Accordingly, Malucelli et al., (2017) investigated future perspectives towards the utilization of agricultural industrial residues for nanocrystal preparation. Consequently, it was found that cellulose, hemicellulose, and pectin-like constituents in the crop residues could be successfully integrated into nanocrystal and nanofiber formation. However, it has been highlighted the importance of replacing hazardous reagents and acidic treatments with eco-friendly reagents and technologies. Hence, it is important to have further studies in this regard. Furthermore, it has also been identified the importance of paving the attention towards the green extraction technologies over conventional solvent extraction technologies in phytochemical extraction from agricultural wastes as a means of reducing excessive amounts of organic solvents, energy, and time (Moro et al., 2021). Accordingly, supercritical fluid extraction (SFE), microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), and pulsed electric field (PEF), etc. have been identified as eco-friendly greener extraction approaches that could be successfully incorporated into phytochemical extraction (Chemat et al., 2019). Therefore, to utilize agricultural wastes for phytochemical extraction as a sustainable move towards enhancing food security and environmental sustainability, further research should be conducted for optimizing green extraction technologies for different agricultural waste constituents (Dahmoune et al., 2015).

Furthermore, researchers have conducted numerous research on using agricultural waste as an adsorbent in wastewater treatment. Rice husk, sugarcane bagasse, sawdust, coconut husk, oil palm-like agricultural waste materials can be used as a low-cost adsorbent in the treatment of wastewater (Mohammed et al, 2014). Accordingly, Khan et al., (2004) present that the above adsorbents show a high degree of heavy metal removal efficiency for heavy metals such as chromium, nickel, lead, copper, mercury, zinc, and cadmium. Therefore, it is important to focus more on the examination of agricultural waste as an adsorbent in wastewater treatment and improving this technology for sustainable utilization of agricultural waste.

Additionally, Agricultural waste can be used for the innovation of low-cost and environmentally friendly construction materials (Madurwar et al., 2013). Development of rice husk ash-based sand-cement block (Lertsatitthanakorn et al.,2009) and development of a Binder-less Cotton Stalk Fiberboard (BCSF) made from the cotton stalk (Zhou et al., 2010) are two instances which research have been conducted for innovation of construction material from agricultural waste. Accordingly, research should be conducted by manufacturers to develop innovative construction materials.

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Moreover, the lack of knowledge among the general public on smart-farming and other novel strategies and technologies that is potential to integrate for sustainable agricultural waste management is another challenging issue that needs to be addressed. Hence, more research should be focused on the formulation of a new generation of agricultural system data, models, and knowledge products considering more on user needs to accelerate towards food security and sustainable development challenges (Antle et al., 2017).

4. Conclusion

Conversion of waste to energy, food, and animal feed production, composting are the most common conventional technologies that are in practice for sustainably utilizing agricultural wastes.

Bioremediation, biofertilizer production, and smart waste management technologies were the recently emerged effective technologies for sustainably utilizing agricultural wastes. However, further research needs to conduct on these approaches to maximize their potential benefits more towards sustainability.

Novel and sophisticated techniques for expanding the alternative uses of agricultural waste have been developed based on industrial innovation and high technology. However, future research focus on the optimization of these techniques based on the composition of different agricultural wastes are of immense importance. Moreover, the formation of a new generation of agricultural system data, models, and knowledge products should be a high focus in the future to guarantee resource efficiency, food security, and environmental sustainability through the effective utilization of agricultural wastes.

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