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Recent advances in valorization of agro-waste: a step towards sustainable development

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ABSTRACT

Excessive wastes from the agricultural sector, which are typically discarded, endanger global health and food safety. The production of these biomolecules has been the subject of a great deal of research as of late as a direct result of the potential significance of agro-residues in industries like the chemical industry, agriculture, the food processing industry, and the pharmaceutical industry for the development of novel human products. This article presents a discussion on the numerous categories of agro-waste and the industrial uses for each. Within the scope of this assessment, we also reviewed the most recent advancements made in the field of agro-residue-based applications. Furthermore, this review looks at the future prospects for enhancing and improving bioconversion technology in order to convert agricultural waste into high-value products. The biorefinery industry, which seeks to recycle agricultural waste into valuable products, relies heavily on this manuscript.

1. Introduction

Agriculture makes the biggest contribution toward the economy sector around the globe. It is estimated that Canada makes 36.1 MTs of waste per year, which is 10 MTs more per person than the USA. Every year, Canada makes about 1.33 billion MTs of waste, of which 1.12 billion MTs are industrial waste (Weisz *et al.*, 2020). As of 2020, the United States will use approximately 4532 TBtu, or about 4.9 percent of its total primary energy consumption. Wood and wood-derived biomass accounted for about 2101 TBtu, while biofuels (mostly ethanol) provided 2000 TBtu and municipal garbage generated 430 TBtu (Edodi, 2022). The United States produced the most biofuels of any country in the world in 2020, with production estimated to reach 1347 PJ (Dey, Bhattacharjee, Nag, Ghati, & Kuila, 2021). Agriculturally based industries produce a lot of garbage as a result of their operations. Non-consumable plant portions are referred to as agro-waste, while the edible parts are the primary source of energy for humans. BOD, COD, and suspended solids are all significant in this vast volume of agro-waste. A lack of effective disposal of these types of waste items can harm the earth's surface and groundwater, which in turn contributes to all forms of pollution. A large portion of garbage is still unutilized and disposed of improperly, which only exacerbates the problem. A variety of agricultural and industrial processes generate low-price byproducts from all over the globe. This aids in the creation of value-added goods from those remnants. There is still a lot of untapped potential in many cases, but no practical things are being made out of it. Burning, dumping, or uncontrolled land filling are the most common disposal methods for agro-industrial waste that hasn't been processed or repurposed. These unprocessed wastes contribute to global warming by emitting a variety of greenhouse gases. As a result, the usage of fossil fuels generates greenhouse gases (GHGs) (Bölük & Mert, 2014).

Researchers are increasingly interested in agro-waste management and its processing for the benefit of the globe (Mostafa, Farag, Abo-dief, & Tayeb, 2018). Typically, agro-waste is discharged to the environment untreated or is burned, resulting in landfills and environmental impact. To prevent contamination and the release of dangerous substances into the environment, it is necessary to treat these wastes as potential raw resources, as opposed to simply discarding them. This will require improved use of technology, incentives, and management strategies for agro-waste. Despite the fact that numerous research from around the globe have proven the importance of agricultural-waste, it's far critical to accumulate all statistics approximately agro-

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waste usage in one area. In latest reviews, there aren't any specific investigations of agro-waste applications. The majority of researchers simply reported on specialized topics. Using agricultural-waste as agro-cement in concrete (He, Kawasaki, & Achal, 2020), energy production, and the evolution of agro-waste materials are only a few of the topics that were explored in a pool of published literature in 2020. Other research have investigated the feasibility of utilizing coffee waste to produce bricks (Saberian *et al.*, 2021), in addition to the removal of methylene blue (dye) from waste sawdust, which has a detrimental influence on the process of photosynthesis in aquatic atmospheres (Dey *et al.*, 2021). The viability of using wheat bran from agro-waste to make bio-ethanol is examined (Cheng, Chen, Wu, Mirza, & Liu, 2017). The major goal is to use agro-waste utilization technologies to quickly use and safely store the residues. As a result, the raw materials used in processing are not damaged and appear to be the final products that were intended. There's been an increase in interest in agro-waste management (AWM) in recent years (Hamam *et al.*, 2021). This review seeks to take a look at extensive the numerous packages and studies conducted inside the subject of agricultural biomass, and to compile all records regarding using agro-waste in one place. These manuscripts study the various types of agro-waste and the significance of their recycling for the creation of globally usable products with added value.

2. Different sources of agro-waste

Agricultural waste is the residual from agro operation like processing and manufacture of fruits, vegetables, and dairy products (Pattanaik, Pattnaik, Saxena, & Naik, 2019). There are four main types of agricultural waste: livestock manure; agricultural sector manure; fruit and vegetable manure; and crop residues (Saini, Saini, & Tewari, 2015) (Figure 1).

2.1 Crop residues

In the field, crop leftovers inclusive of seed pods, stovers, straws, leaves, and so on are the primary sources of agricultural waste. As the most considerable and reasonably-priced natural waste, these crop wastes may be easily transformed right into a huge variety of excessive-cost products. Wheat straws, corn stovers, and rice straws are the 3main crop wastes which are utilized to make bioethanol throughout the globe. Only a tiny amount is utilized to make biofuels or feed animals, and the rest is burned, which causes serious environmental problems (Chang & Li, 2019). Among these three primary agricultural leftovers, rice straw is one of the utmost auspicious and valuable biomasses globally, with an annual productivity of approximately 731.1MTs and Asia being the chief producer (S. A. Afolalu *et al.*, 2019). It is predictable that 355.3 million metric tonnes of wheat straws are turn out each year in the world, making wheat straw the majority of the waste recovered from wheat (Sarkar, Ghosh, Bannerjee, & Aikat, 2012). Corn stover is one of the maximum promising crop residues for making lingo-cellulosic ethanol, with an envisioned manufacturing of 4.0 tonnes in keeping with acre and a globally production of approximately 128 MTs in keeping with 12 months. Agro-waste is likewise made up of crop residues (sorghum, oats, and barley) (Jahirul, Rasul, Chowdhury, & Ashwath, 2012).

2.2 Agro-industry wastes

The initial kind of agriculture-waste comes from the processing of crops for use in industry. This includes sugarcane bagasse, vegetables and fruit waste, and the fruit pomace that is left over after oil or juice is extracted. Additionally, it comprises meat, eggs and chicken skin from slaughter houses (Jogi & Bhat, 2020) and meat production factories; starch residue, de-oiled seed cakes from the consumable oil sector, and molasses from the sugar industry. Sugarcane bagasse is the most common of numerous agricultural residues (Charitha, Athira, Jittin, Bahurudeen, & Nanthagopalan, 2021). This bagasse is the dried pulpy fibrous waste generated by enterprises following the extraction of juice. About 180 million tonnes of sugarcane bagasse are thought to be available in the world (Putri *et al.*, 2020). Seed cakes de-oiled from non-edible oil plants like *Jatropha curcas* and *Pongamia pinnata* are examples of agricultural-industrial wastes (Duran *et al.*, 2016; Mitra *et al.*, 2021).

2.3 Livestock wastes

The production of food and an income for millions of farming households around the world comes from the cultivation of crops and the keeping of livestock respectively (Sekaran, Lai, Ussiri, Kumar, & Clay, 2021). Utilizing animal waste as an energy source is common and efficient in specific contexts, such as the creation of biogas or dung cakes for combustion (Canete-Rodriguez *et al.*, 2016). Common instances of this practice include the burning of chicken litter, the digestion of animal slurry, and the use of vast amounts of straw as propellant for the development of power and heat (Chel & Kaushik, 2011). However, a market for the generated heat and the by-products is often necessary to ensure the financial viability of such operations. Energy may be used on the field or in nearby municipalities to which it could be recirculated, and waste heat could be used on the field (Chel & Kaushik, 2011).

2.4 Fruit and vegetable wastes (FVWs)

A large amount of fresh vegetables and fruits are included in FVWs. Some examples of these foods include tomatoes, oranges, mangoes, jack fruits, pineapples, and bananas, among many others. FVWs are an essential component of agro-wastes. The FVWs that are produced by food processing businesses, in addition to wholesale marketplaces, are in large quantities (Pattanaik *et al.*, 2019). Due to their great perishability, these organic wastes also pose a substantial threat to environmental degradation (Sharma, Sarkar, Singh, & Singh, 2017). In countries like the USA, China, the Philippines, and India, fruit and vegetable preparation, packing, distribution, and consumption generate around 15, 32, 6.5, and 1.8 MTs of garbage, respectively (Ariaeenejad *et al.*, 2020). Nearly 5.6 MTs of FVWs are manufactured each year in India, and these are disposed of through dumping on the fringes of various towns (Chel & Kaushik, 2011).

3. Agro-waste composition

Table 1 provides the proximate and final constituents of several agricultural wastes. In addition to the preliminary study, the compositional evaluation is required for the design of the biofuel manufacturing process. According to Table 2, the majority of agricultural residue contains lignocellulosic material (between 80 and 85 percent). Bio-alcohols are produced as a result of the greater cellulose and hemicellulose content. 30 percent to 50 percent cellulose and 20 percent to 38 percent hemicellulose make up the crop residues. In contrast, the lignin concentration of crops ranges from 7% to 21%. Based on the varied sources, agro-processing wastes comprise 22 to 44 percent cellulose, 16 to 34 percent hemicellulose, and 6 to 25 percent lignin. Rice bran waste contains just 5% lignin and has been demonstrated to be a viable feedstock for bioethanol production. Prior to ethanol production, however, high-lignin-content sugarcane bagasse must be processed for lignin removal (Sun & Cheng, 2002). Biohydrogen, biogas and alcohols can be produced from a carbohydrate-rich substrate because of its quick breakdown. Between 40% and 85% of the total solids in the industrial wastes are made up of carbohydrate compounds. Similarly, livestock wastes such as cattle manure have a carbohydrate content of 50-60%, making it an excellent fuel for biogas production because of its abundance (Møller, Sommer, & Ahring, 2004). Similarly, the protein and lipid levels of various agricultural waste feedstock's are critical for determining their biogas potential (Garcia *et al.*, 2019).

4. Sustainability and the role of agro-waste

Every year, 140 billion MTs of biomass are made by agriculture throughout the globe. This biomass has the capability to be grown to become again into quite a few uncooked substances and strength. When agricultural biomass waste is turned into strength, it can replaced oil almost 50 billion tonnes, cut down on greenhouse gasoline emissions, and offer dependable electricity to about 1.6 billion people in terrible international locations. To limit the worst influences of climate alternate, the IEA (International Energy Agency) created a path for reaching net-zero CO_2 emissions inside the electricity zone by 2050, in addition to a aim of proscribing worldwide temperature rise to 1.6˚C (Comello, Reichelstein, & Reichelstein, 2021). In addition, conventional biofuels derived from food crops will see a major decrease in use by the year 2050 as well (Comello *et al.*, 2021). Among the many possible applications for lignocellulosic biomass are the manufacture of biofuels and chemicals such as ethanol, acetone, butanol, biohydrogen, biomethane, and biofertilizers, as well as sugar alcohols (such as xylitol and arabitol) and biopigments (Murphy, Woods, Black, & McManus, 2011). A huge number of agricultural wastes are produced annually by farming operations and agricultural businesses, and inappropriate waste dumping (e.g., illegal dumping, forest fires, landfilling) can contaminate the atmosphere and risk human health. The National Biofuels Policy entered into effect in May 2018, with the primary objective of obtaining a 5 percent biodiesel and 20 percent ethanol blend. These numbers are much greater than the existing blending levels of 1.5% and 0.15%. The ease of use of feedstock's is the key limiting factor for biofuel production (Ho, Ngo, & Guo, 2014). Many greenhouse gases are released as an outcome of unprocessed waste, which contributes to climate change. In addition, the depletion of the ozone layer is facilitated by the use of nonrenewable energy sources. This has led to a global focus on the development of alternative cleaner and renewable sources of energy (S. Afolalu *et al.*, 2021).

4.1 Utilized Argo-waste for dye removal

Although human life and health systems have improved as a result of the industrial revolution, the environment has deteriorated as a result and the planet is now facing a significant threat (S. Afolalu *et al.*, 2021). The textile industry is one of the biggest in the globe, but when it dumps wastewater, it sends out a lot of dyes, dangerous metals or elements, and chemicals. Because there are so many dyes, there is no exact database to figure out how many have been released. However, many countries' economies depend heavily on the textile and fabric industry (Jacob *et al.*, 2018). It was stated that more than 100,000 varieties of dyes are available, with the garment sector being their primary application (S. Mani, Chowdhary, & Bharagava, 2019). As a consequence of this, it is predicted that the textile industry, in addition to other businesses, will contribute more than 300,000 tonnes per year to the stream's runoff (Gupta, 2009). As a result of their findings, these pollutants were determined to be poisonous and hazardous, in addition to producing a wide range of health problems like allergies, skin irritation, hard breathing and nausea (Mohajerani & Karabatak, 2020).

Researchers found that after increasing the concentration of adsorbent (which was kept constant), jojoba seed effectively removed congo red (a dye) from the solution (De & Debnath, 2016).The amount of dye absorbed was influenced by both the adsorbent dose and the duration spent in contact with the surface. Microfiltration and adsorption investigations frequently employ the dye methylene blue as a reference standard. Its molecular weight made it suitable for a wide range of applications, particularly in the medical field. However, if it is not properly processed before release, it may have negative effects on the environment. To remove methylene blue from aqueous solutions, activated carbon was made from pumpkin peels and biomass wastes (Reddy, Sivaramakrishna, & Reddy, 2012). After processing, broad bean peel was employed to eliminate the methylene blue(dye), and its absorption volume was192.8 $mg \cdot g^{-1}$(Rashid, Tehreem, Rehman, & Kumar, 2019).

(Hameed & El-Khaiary, 2008) employed grass, which is considered an agro-waste, to remove methylene blue from aqueous solution without subjecting the grass to any kind of preparation. Using garlic peel to eliminate methylene blue from water has been studied by (Hameed, Krishni, & Sata, 2009). Pomelo peel was employed as a source of biochar and activated with phosphoric acid for the dissociation of malachite green and methylene blue, which released colored dye cations into solution (Hameed *et al.*, 2009). The adsorption of methylene orange is caused by the chemically altered biochar. Cassava peels had been used to supply activated carbon, which became then thermally handled with silver nitrate acid and base, to dispose of several varieties of dye (Zhang, Wu, Sun, Cai, & Lyu, 2020). Malachite green and methylene blue were found to be taken up by rice and wheat bran (Parvathi, Shoba, Prakash, & Sivamani, 2018). The agricultural stable waste groundnut shell became utilized as an adsorbent for the deduction of malachite green (Wang, Zhou, Jiang, & Sun, 2008). Researchers looked at how acid violet and *rhodamine B* dyes adhered to the coir pith (Namasivayam, Radhika, & Suba, 2001). With different contact times and concentrations, basic blues from aqueous solutions are absorbed by the seed coat of *Hevea brasiliensis* (Rashid *et al.*, 2019).

4.2 Nutrient recovery from agro-waste

In the last few decades, research on how nutrients can be recovered in a sustainable way has become very important. Nutrients such as N, P, and K are vital for in depth agriculture and their lengthy-term availability and rising costs are inflicting environmental issues (Namasivayam *et al.*, 2001). Because the Haber-Bosch process requires a lot of energy, the price of nitrogen depends on the accessibility of natural gas (Gurung & Oh, 2015). However, phosphorus rock is a nonrenewable resource and the principal source of phosphorus, which is diminishing at an accelerating rate(Mehta, Khunjar, Nguyen, Tait, & Batstone, 2015). Also, 90 percentages of the world's phosphorus rock reserves are in 5 international locations: Syria, China, Morocco, Iraq, and Algeria (Woods, Williams, Hughes, Black, & Murphy, 2010). This makes it hard for other countries to make sure they have enough food to eat. In the same way, the prices of potassium-based fertilizers went up four times from 2007 to 2009, and there are growing worries about their availability in developing economies. The reason is that most of them are sold in Canada and Europe, and only a small amount in the rest of the world (Puyol *et al.*, 2017). So, conventional fertilizer production of potassium is unlikely to be sufficient in other emerging countries. Demand for food will climb significantly in the future decades as the world's population grows, increasing the need for new methods of nutrient recovery (Cordell, Drangert, & White, 2009; Giacalone *et al.*, 2016; Sharma *et al.*, 2017). As a result, there is an immediate requirement for an approach that is both integrated and comprehensive to the recovery of nutrients. According to this information, the total sum of most important nutrients (NPK) that is included in agricultural wastes range from 40 to 100 kg per tons. The USA alone produces 9 MTs per year of nutrients that are contained in agro-waste, whereas the rest of the globe produces 74 MTs per year (Urrutia *et al.*, 2018). Various feedstock's/agro-wastes, as shown in Table 3, have varying nutrient levels.

4.3 Recovery of energy from agro-waste

Even if a product is generated from renewable resources, it cannot be marketed if its production is not financially viable. Economic analyses on the potential of agro-residue in terms of energy recovery and bio-product valuation have been conducted by numerous researchers and specialists. The most well-known agro-fuel substitutes for gasoline and diesel are ethanol and bio-diesel, respectively. According to (Portugal-Pereira, Soria, Rathmann, Schaeffer, & Szklo, 2015),bioenergy accounted for 8% of total electricity consumption, or 39 TWh. Brazilian agro-waste-based energy output has been estimated at around 9 GW, based on an annual availability factor of 50 percent on average. On the other hand, another investigates (Portugal-Pereira *et al.*, 2015) shows that making electricity in Alberta by directly burning triticale straw is not a good idea compared to making electricity with coal. They found that triticale straw-based energy plants are not commercially viable even at a relatively low electricity price of $71.58/MW. Triticale straw-based bio-energy generation is also more expensive than fossil fuel-based energy due to logistics and the currently available conversion technology, but it might become competitive if carbon offsets are used.
Evaluating the (minimum ethanol selling price) MESP of

sugarcane remaining biomass was the economic analysis (Dassanayake & Kumar, 2012).The biochemical conversion plant's total investment was estimated at 152 million dollars, which resulted in a final MESP value of 318 million dollars, while the thermochemical conversion plant's total investment cost was 127 million dollars and a final MESP value of 329 million dollars. Bio-chemical conversion produces 50 kWh/t of cane of electricity surplus, whereas thermo-chemical conversion produces 32 kWh/t of cane of electricity. This could be achieved through the biological conversion of the residues that cannot be turned into ethanol. At 558 kWh m^{-3}ethanol, the significant number of residues that cannot be processed into ethanol provides a strong potential to export power via the biochemical route. This biorefinery plant's electricity, with a surplus of roughly 50 kWh t^{-1} of electricity from cane, would be an important co-product for biochemical conversion. The process of converting bio-based substances to feed, food, biofuels, medicines, and energies is carried out in manufacturing facilities known as biorefineries. These minerals and chemicals obtained from biological sources have the potential to replace those derived from petroleum and natural gas. In addition, they necessitate less investment and simple innovation technique while reducing air contamination caused by the decomposition of agro-waste when it is burned in fields or rots in the countryside. Transitioning to renewable biomass resources is a step forward for a sustainable industrial society that effectively manages greenhouse gas emissions. Table 4 describes the energy recovery potential of various agro-waste types using various technologies.

Feedstock accounts for 60 to 75% of the total bio-ethanol production expenses (Seabra, Tao, Chum, & Macedo, 2010) due to the extremely volatile raw ingredients utilized in the production process. According to (Kojima & Johnson, 2006), sugar cane-based bio-ethanol costs between \$0.23-0.29 per liter in the United States, while in the European Union and the United States, corn-based bio-ethanol costs between \$0.29-\$0.53 per liter. The price of producing bio-ethanol is often proportional to its energy content. Corn and sugars-based ethanol plants have an impact on food production, and their higher production costs make it difficult for them to compete with fossil fuels. As a result of this significant economic challenge, the vast majority of companies are presently focusing their attention on scientific research in order to develop lignocellulose-based biofuel energy plants that are commercially feasible.

4.4 Agro-waste for the production of essential and edible oils

The main sources of single-cell oils are oleaginous yeast and fungi, but the approach used isn't always cost effective because the carbon substrate used to make the oils is high priced. As the study shows, the usage of agro-waste as an opportunity substrate within the method reduced production charges and prepared the technique more cost effective for making single-cell oil (Johnson & Matsika, 2006). However, there are other plant wastes that are oil-rich and suitable for use in food and industry. Today, rice bran oil is one of the most used cooking oils. Rice bran oil includes cholesterol and monounsaturated fats and successfully decreases LDL; it may be a suitable option for those who experience hypoallergic responses. Additionally, rice bran oil contains gamma oryzanol, which boosts immune system performance, squalene and tocotrienol, which help skin soften and repair (Diwan, Parkhey, & Gupta, 2018). Vegetable oil and fats are naturally found in plant tissues. Supercritical fluid extraction, chemical extraction, mechanical extraction, and steam distillation can all be used to extract oils from plants having oil-concentrated seeds. Essential oils could be made from coriander's dry waste when it was recycled (*Coriandrum sativum*) (Diwan *et al.*, 2018).

4.5 Using agro-waste to immobilize biocatalysts

Since, immobilized biocatalysts are reusable for an extended cycle and distinctive forms of agriculture-waste are utilized within the immobilization approaches, they offer a significant advantage utilized peanut and coconut shells to generate mesoporous activated carbon, it serves as a support material for lipase immobilization (Nayik, Majid, Gull, & Muzaffar, 2015). To create cinnamyl acetate, a transesterification reaction is carried out using the lipase that was successfully immobilized (Duman & Kaya, 2016). Another potential possibility in the process is coconut fibre, which has been successfully employed to assist the immobilization of many enzymes, including amylase, lipase, and laccase (Ariaeenejad *et al.*, 2020). Corn waste, that is a by-product of corn manufacturing, was also used because of its excessive porosity and elevated surface area. After processing this byproduct with various chemicals, it was found to be a useful immobilizing fabric for amylase, peroxidase, trypsin, proteinase, and lipase immobilization (Dhake, Tambade, Qureshi, Singhal, & Bhanage, 2011; Girelli, Astolfi, & Scuto, 2020). However, a number of the several agro-waste products, rice straw are the utmost important addition to the route, as rice is the maximum extensively cultivated crop in the world and rice processing is predicted to generate vast volumes of waste. According to reports, rice husk is mostly used to immobilize lipase, protease, asparaginase, and invertase (Corici *et al.*, 2016; Costa-Silva, Souza, Said, & Oliveira, 2015; Girelli *et al.*, 2020; Nuraliyah, Wijanarko, & Hermansyah, 2018) and chemical treatment, including glutaraldehyde treatment of agricultural residues in the context of polyethylene glycol, hydrochloric acid treatment, or even oxidation of the material, had a significant impact on the immobilization's efficacy. The grain husk can also be burned to make rice husk ash. Since 95 percent of rice husk ash's dry weight is made up of silica, it was seen as a new but promising material for immobilization. The study discovered that amorphous silica has a significant surface area if rice husk is burned at temperatures between 360 and 600 degrees Celsius or treated by acids. For the immobilization of lipase, cellulase, oxylipin, and other enzymes, raw rice husk ash and silica taken from the ash were used.

4.6 Agro waste in heavy metal removal

Numerous harmful and deadly chemicals are emitted into the environment by various sectors, which has an alarming impact on the poisoning of water resources, the atmosphere, and the geosphere (Sabir *et al.*, 2021). Heavy metal-related aqueous medium contamination has emerged as a serious environmental problem (Velusamy, Roy, Sundaram, & Kumar Mallick, 2021). Metals that are particularly dangerous for treating industrial effluent include Zn, Cr, Pb, Hg, Cd, Ni, and Cu. They are inherently non-biodegradable, accumulate in living things, and most of them are carcinogens (Mulligan, Yong, & Gibbs, 2001). The common treatment methods of coagulation, flotation, electrolysis, reverse osmosis, ion-exchange, and complexation have all been used to treat these aqueous phase toxins (Saleh, Mustaqeem, & Khaled, 2022). By choosing the right adsorbent, certain types of contaminants can be eliminated using more commonly accepted and promising adsorption procedures. Clays, activated alumina, the various adsorbents that have been utilized to safely remove heavy metals from aqueous media include activated carbon, zeolites, graphene, metal oxide-based nanoadsorbents, polymer clay-based nanoadsorbents, and carbon nanotubes. Lignin, chitin, glucose, cellulose, and fungus are some examples of other absorbents that were utilized. Wastes from agriculture have a significant capacity for biosorption, especially those that contain cellulose. Pollutants can be removed from aqueous media using adsorbents generated from plant waste either with or without modification. For the elimination of chromium(VI), rice husk is used in both its unaltered and activated forms. Several agricultural waste products, such as peanut shells, soybean hulls, bagasse, rice straw, walnut shells and sugarcane, have been subjected to the process of lead adsorption (Lewoyehu, 2021). To removal of cadmium metal, rice and wheat bran are using. According to a study, tea-based adsorbent converted over 70 percent of the chromium hexavalent into Cr(III) (Debnath, Haldar, & Purkait, 2021). Use of rice husk, moringa seeds, coconut coir, and could be remove up to 99% of copper and nickel. Utilizing rice husk, zinc concentrations can only be decreased by up to 70%. However, the inclusion of coconut coir and moringa seeds led to a 99% clearance rate (Tokay & Akpınar, 2021). Since it offers various advantages over other conventional approaches, it is acknowledged as one of the effective, efficient, labor-saving, useful, and reasonable ways. Figure 2 summarizes an info-graphic depicting the elimination of heavy metals by various agro-wastes.

4.7 Agro waste for production of enzyme

Agro industrial waste has a high nutritional value and promotes microbial development. The majority of agricultural wastes are lignocellulosic in nature, with a significant portion being made up of carbohydrates. Consequently, agricultural waste can be used to create a variety of goods with additional value, such an industrially significant enzyme (Ravindran, Hassan, Williams, & Jaiswal, 2018). Enzymes are biocatalysts that are extremely effective and specific under a variety of environmental circumstances, which is why they have many industrial applications(Paul *et al.*, 2020). Agricultural wastes like crop residues, peanut husks, grasses, coffee cherry husks, corn husks, paddy, jowar straws, wheat etc. are important sources of lignocellulosic materials. These wastes have been used as a substrate to produce a variety of lignocellulolytic enzymes, including pectinase, cellulase, mannanase, laccase and xylanases of enzymes by a strain of *Sphingobacterium* sp. (Nahak *et al.*, 2022). Cellulase, xylanase, pectinase, mannanase, and laccase, which are lignocellulolytic enzymes, are used in the biological processing of lignocellulosic agricultural wastes to create value-added products in order to reduce side chain reactions or the production of cell inhibitors while processing downstream (Neelkant, Shankar, Jayalakshmi, & Sreeramulu, 2019). For production of α-amylase enzyme, rice bran agro-waste used as an alternative source of production of low cost enzyme, which has been using in food, textile, detergent, sugar, paper, and pharmaceutical industry (Raveendran *et al.*, 2018). The generation of fungi *Amyloglucosidases* has also been successfully carried out using agricultural residues like cassava, yam, banana (and peels), and plantains. Applications of *Amyloglucosidases* in the food, brewing, and bread industries. Yacon and sugar cane baggase have both been utilized as substrates for the synthesis of inulinase in various investigations. Utilization of inulinase in the production of bioethanol, butanediol, citric acid, and lactic acid. Banana skin, pulverized nuts, used coffee grounds, rice straw, and wheat bran flake are examples of lignocellulosic biomass that have been identified as appropriate carbon sources for laccase production. They are utilized for xenobiotic degradation, bio-bleaching, baking, bio-pulping, dye decolorization, and effluent treatment (Ravindran *et al.*, 2018).

4.8 Agro waste for production of nanofibers and nano particles

The term "biomaterial" refers to any material specifically designed to interact with the biotic system in order to replace live material that has lost its function. For promoting the creation of new tissues, it can act as a carrier, matrix, and support (Sangeetha *et al.*, 2017). Nanotechnology's quick development has changed all areas of science, including biomaterials, resulting in the creation of bio-nanomaterials. Cellulose is a significant characteristic polymer obtained from agricultural activity waste and a significant source for industrial uses. Cellulose nanofibers are removed from cell walls by chemical, mechanical, and biological processes such as cryo-crushing, high-pressure homogenization, granulation, and enzyme-assisted hydrolysis and corrosive hydrolysis (Oraon, Rawtani, Singh, & Hussain, 2022). Cellulose nanofibers have been isolated and described from a variety of sources, including potato tubers, cotton, soybeans, banana rachis, coir, pea structure fibre, wood strands, wheat straw and soybean hulls, citrus and corn, beetroot, bark of mulberry trees, and pineapple leaf fibres. The cellulose fibre found in banana peels can then be used as a biomaterial because 40% of a banana's total fruit weight is made up of the peel (Mngomezulu & John, 2017). Cellulose and nano-cellulose from Citrus and Orange Wastes, Various agro wastes, including rice husk, corn hub, and other plant sources, An important development in the large-scale manufacture of grapheme oxide is the synthesis of grapheme oxide from sugarcane bagasse and rice husk ashes (Liou *et al.*, 2021), carbon nanomaterials from agro wastes. Some of the nano-biomaterials currently in use include nano-cellulose based nanocomposites with a variety of other nanomaterials, such as mineral nanomaterials (SiO_2,$CaCO_3$, montmorillonite), carbonaceous nanomaterials (graphene, carbon nanotube), and Ag, Au, CuO, Pd, Ni, TiO_2. The implications of several nanoparticles produced from agro-waste residues are presented in Table 4. As nanomaterials (Figure 3) and composites for biosensors, biomaging, drug delivery, supercapacitors, and molecular imaging techniques, silica generated from plants is utilized.

5. Conclusion

Environmental policies, as well as the increased need for biobased products, have advocated for the recycling and use of materials. Because of its more nutrient and bioactive substances, the scientists have been paying a substantial degree of interest to the utilization of waste from agricultural production. Agricultural waste was the subject of this review because it may be used to promote healthy living for the general public and to reduce pollution in the environment at a low cost and with an efficient approach in all directions. With some restrictions, controlled using agricultural waste as raw resources in various processes can contribute to environmental sustainability.

Table 1. Proximate and ultimate composition of agro-wastes

Feedstock	Proximate analysis (wt %)				Ultimate analysis (wt %)					Heating value (MJ/kg)	Reference
Crop residue	Moisture	Fixed carbon	Ash	Total volatile solid (TVS)	C	H	O	N	S		
Rice straw	4.2-6.0	14.5	8.2-16.0	71.6-92.8	34.0-41.5	4.6-6.7	32.8-41.2	0.2-0.8	4.2-6.0	14.5-15.5	(Kumar, Paritosh, Pareek, Chawade, & Vivekanand, 2018)
Oat straw	5.38	19.53	5.9	74.48	48.8	6.0	44.6	0.5	0.08	-	(T. Mani, Murugan, & Mahinpey, 2011)
Corn straw	5.3-7.4	16.9	4.2-6.3	86.5-96.8	35.2-45.6	5.4-6.3	43.4-45.7	0.3-0.8	0.1-0.3	16.2-16.5	(Morgan *et al.*, 2015)
Barley straw	-	19.79	5.3-9.8	76.2	49.4	6.2	43.6	0.7	0.13	16.42	(Serrano, Monedero, Lapuerta, &

											Portero, 2011)
Wheat straw	4.4-8.4	17.3	7.3-12.8	74.4-92.7	41.7-46.7	5.1-6.3	34.1-51.4	0.4-0.5	0.1-0.3	17-18.9	(Bridgeman, Jones, Shield, & Williams, 2008)
Agro industry waste											
Rice bran	7.70	9.20	18.8	64.30	38.69	5.40	0.67	0.21	-	13.36	(Ji-Lu, 2007)
Coffee husk	-	19.1	2.4	78.50	47.50	6.40	-	-	43.7	19.80	(Yin, 2011)
Sugarcane bagasse	16.07	-	3.20-4.34	79-83.66	45.48	5.96	45.21	0.15	-	18.61-18.73	(Tsai, Lee, & Chang, 2006)
Fruit and vegetable wastes											
Oil palm empty fruit bunch	67	8.65-18.3	3.02-7.54	71.2-79.7	45.0-48.8	6.40-7.33	47.3-40.2	0.0-0.25	0.68-1.06	19.0	(Omar, Idris, Yunus, Khalid, & Isma, 2011)
Orange peel	-	-	-	-	16.23	17.1	60.28	0.76	2.99	-	(Joshi, Waghmare, Sonawane, & Waghmare, 2015)
Livestock waste											
Cattle manure	38.6	-	45.1	50-0	29.0	3.23	2.46	0.82	19.30	-	(Sweeten, Heflin, Auvermann, Annamalai, & McCollum, 2013)

Table 2. Biochemical and lignocellulosic composition of agro-wastes

Feed stocks	Biochemical composition (Wt %)			Lignocellulosic composition (Wt %)			Reference
	Carbohydrate	Protein	Lipid	Cellulose	Hemicellulose	Lignin	
Crop residue							
Rice straw	-	-	5.9	30.3-52.3	19.8-31.6	7.2-12.8	(Kumar *et al.*, 2018)

Oat straw	-	5.34	1.65	37.6-44.8	23.3-33.4	12.9-21.8	(T. Mani *et al.*, 2011)
Corn straw	7.9	3.6-8.7	0.7-1.3	31.3-49.4	21.1-26.2	3.1-8.8	(Morgan *et al.*, 2015)
Wheat straw	-	3.48	5.34	32.9-44.5	37.8-33.2	8.5-22.3	(Bridgeman *et al.*, 2008)
Barley straw	-	3.62	1.91	29.2-48.6	35.8-29.7	6.7-21.7	(Serrano *et al.*, 2011)
Agro industrial waste							
Rice straw	23.58	14.6-15.4	16.1-23.8	39	31	4	(Kumar *et al.*, 2018)
Sweet sorghum bagasse	-	-	-	44.6	27.1	20.7	(Kim & Day, 2011)
Sugarcane bagasse	-	-	-	43.6-45.8	31.3-33.5	18.1-22.9	(Tsai *et al.*, 2006)
Soya stalks	-	-	-	34.5	24.8	19.8	(Hiloidhari *et al.*, 2020)
Coffee husk	58-85	8-11	0.5-3	24.5-43	7-29.7	9-23.7	(Sinha *et al.*, 2021)
Barley straw	-	-	-	33.8	21.9	13.8	(Serrano *et al.*, 2011)
Fruit and vegetable wastes							
Apple pomace	55.86	-	-	21.22	14.75	18.50	(Yahya, Al-Qodah, & Ngah, 2015)
Orange peel	38-40	6.95	-	-	-	-	(Yahya *et al.*, 2015)
Oil palm empty fruit bunch	-	-	-	23.6-63.0	21.5-32.0	29.2-36.6	(Yahya *et al.*, 2015)
Olive de-oiled cake	-	-	-	2.0	18.3	50.0	(Tsonis, Tsola, & Grigoropoulos, 1989)
Pineapple peel	-	-	-	18.11	-	1.37	(Kyawt, San Win, San Mu, Aung, & Aung, 2020)

Livestock wastes							
Pig manure	52.08	23.9	14.3	-	-	-	(Sweeten *et al.*, 2013)
Cattle manure	62.46	15.09	6.85	32.7	24.5	42.8	(Sweeten *et al.*, 2013)

Table 3. Nutritional value of several possible agro-wastes

Agricultural waste	Nitrogen (%)	Potassium (%)	Phosphorus (%)
Gaint brown kelp	1.22	0.00	0.00
Pine	0.10	0.00	0.00
Corn cob	1.38	0.46	0.09
Peach leaves	0.00	2.45	0.14
Wood	0.07-0.39	0.00	0.00
Sugarcane bagasse	0.73	0.00	0.00
Water hyacinth	1.95	0.00	0.00
Cereals	0.20	0.00	0.00
Corn leaves	1.30	1.48	0.21
Corn stem	0.48	1.23	0.09
Corn grain	2.16	0.43	0.35
Corn silage	1.35	0.90	0.16

Table 4: Depicts the potential for energy recovery from various types of agricultural-waste in various world regions.

Nation	Area	Profits	Residents	Biomass waste production (tonnes/day)	Biomass energy resource	Units	Potential energy	By the year	Reference
Algeria	MENA	Low-Middle Income	19,225,336	23,289	Biomass	Mtoe	3.5	-	(Benseghir & Bachari, 2021)
Germany	OECD	High-Income Country	60,530,217	127,817	ASW	PJ/yr	205	2025	(de Oliveira, de Oliveira Ribeiro, & Qadrdan, 2022)
Finland	OECD	High-Income Country	3,301,955	7,035	ASW	PJ/yr	92	2025	(de Oliveira *et al.*, 2022)
Brazil	LCR	High-Income Country	144,508,186	159,097	Sugarcane biomass	TWh	65 - 95	2009	*(de Oliveira et al.*, 2022)
Norway	OECD	High-Income Country	3,605,500	10,082	ASW	PJ/yr	17	2025	(Negri *et al.*, 2021)
India	SAR	Low-Middle Income	1,359,137,718	97,195	Rice-straw	PJ/yr	312.5	2003	(Liu, Wang, Lim, Kraft, & Wang, 2021)

Table 5: Various kinds of nanoparticles made from agricultural-waste by-products and their utilization.

Nanomaterials	Agro-waste	Applications	Reference
Nano cellulose	Banana peels	Materials for packaging syntheses.	(Rabeharitsara, Hanitriniaina, Fabrice, Rijalalaina, & Randriana, 2021)
	Rice husk	Production of polymeric materials with mechanical reinforcement, tissue scaffolding, and environmental cleanup.	(Elbasiouny *et al.*, 2021)
	Eucalyptus saw dust	Paper making	(Tarrés, Aguado, Pèlach, Mutjé, & Delgado-Aguilar, 2021)
Nano adsorbents	Papaya skin	Lead removal through adsorption from water.	(Jaihan, Mohdee, Sanongraj, Pancharoen, & Nootong, 2022)
	Garlic skin	Superior high-temperature superconductors.	(El-Ramady *et al.*, 2020)
	Pomegranate skin	The production of titanium dioxide as a possible adsorbent for the elimination of arsenic trioxide from water.	(Poudel *et al.*, 2020)

Metal nanoparticles	Wheat and paddy straw	Production of biogenic nano iron oxide with exceptional super-paramagnetic and potent antioxidant properties	(Periakaruppan *et al.*, 2021)
	fruit peel waste	Production of titanium dioxide (TiO_2) nanomaterials.	(Ajmal *et al.*, 2019)

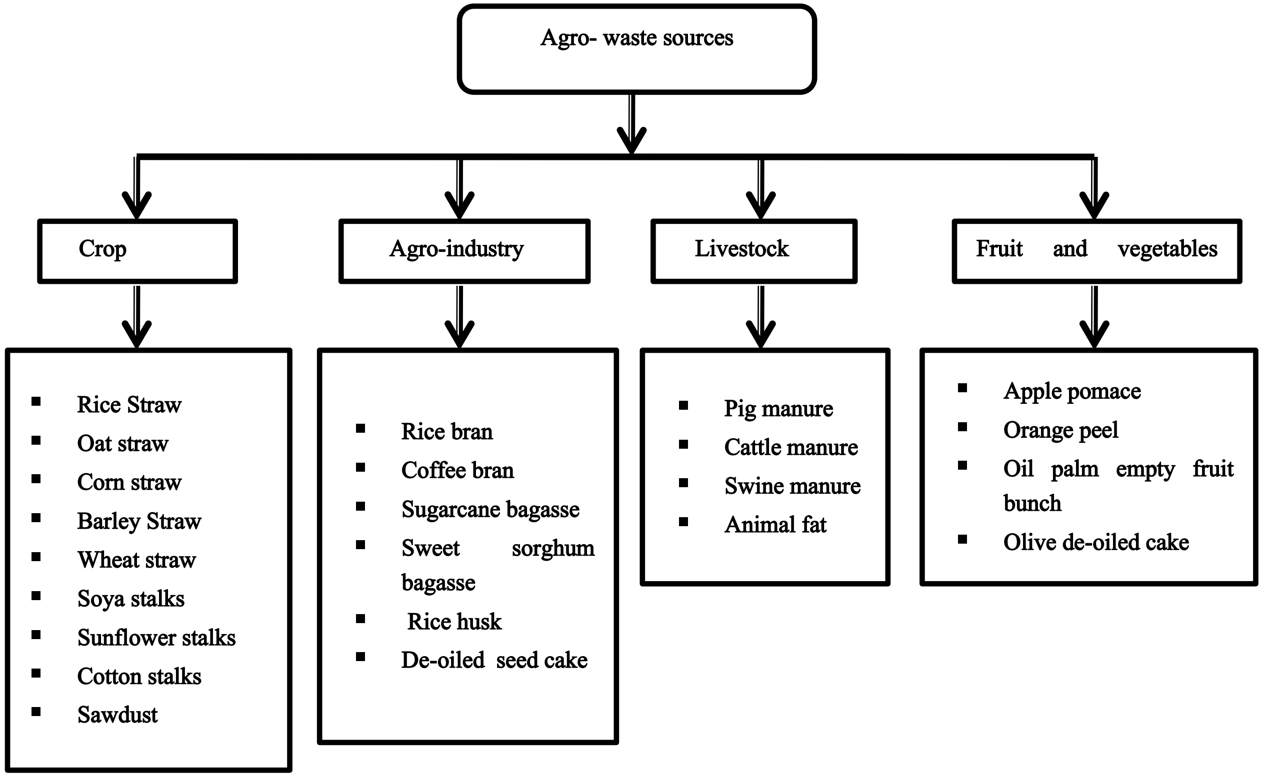

Figure1. Source of agro-wastes

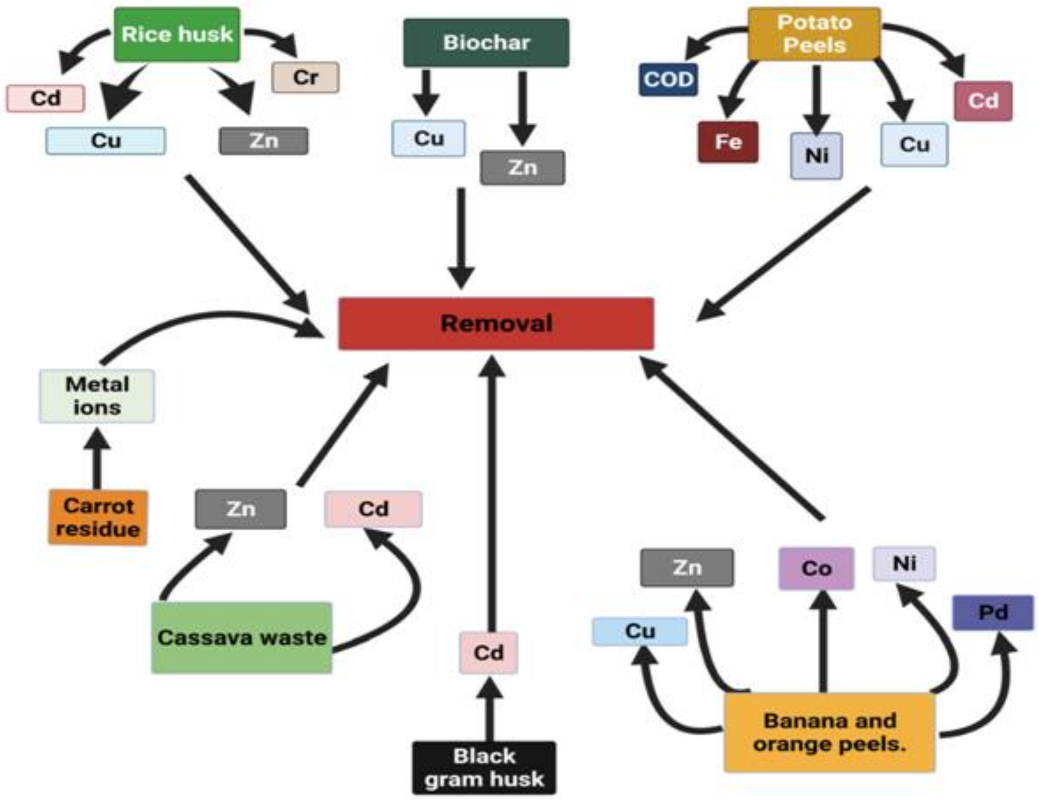

Figure 2. Removal of heavy metals by different agro-wastes

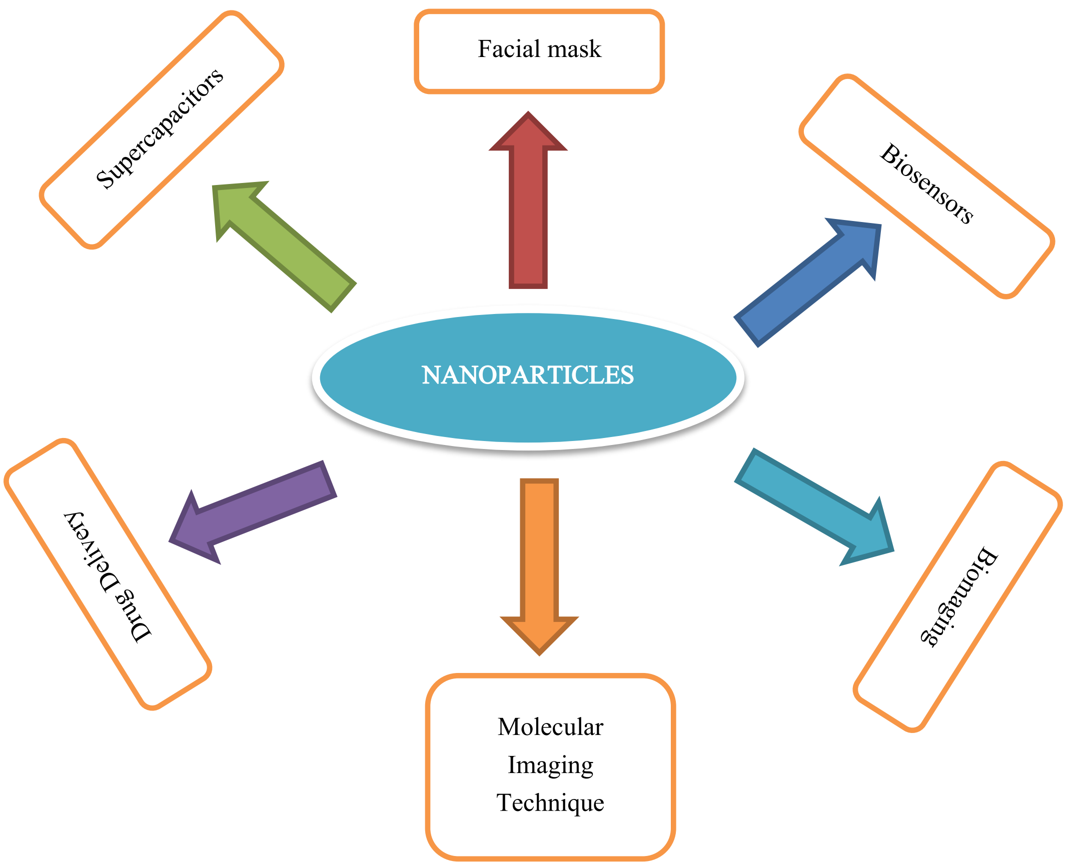

Figure 3. Different roles of nanoparticles

List of abbreviations

TBtu, trillion British thermal units
AWM, Agro-Waste Management
BOD, Biological Oxygen Demand
COD, Chemical Oxygen Demand
FVWs, Fruit and Vegetable Wastes
IEA, International Energy Agency
MESP, Minimum Ethanol Selling Price

6. Reference

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