A Waste-to-Wealth Prospective Through Biotechnological Advancements

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12.1 Introduction

Agricultural wastes are end-products or by-products of the production of agricultural commodities and the indecorous management of these wastes may contribute to various environmental hazards. Usually, the agro-wastes are discharged into the environment without any proper treatment or are burnt off, which leads to municipal landfilling and environmental load along with potential contamination and transmission of hazardous materials to the environment (Chia et al. 2018). Also, the incineration of such wastes produces greenhouse gases that are dangerous to the environment and human health (Bosio et al. 2013). Amounting to 350 million tonnes annually, India produces agricultural wastes whose appropriate handling is still in its primary stage (Saikia et al. 2020a, b). The majority of these leftovers are utilized as wood fuels, and also they might serve as the raw materials for a variety of commercial goods. The valorization of waste materials including agro-wastes is an appealing economic approach, due to the existence of cellulose backbone (Ren et al. 2009; Saikia et al. 2020c; Rathankumar et al. 2020a). Yet, the current research gap around essential scientific investigations makes large-scale management becomes difficult. The absence of appropriate treatment and downstream technologies and the viability of different integrated waste treatment procedures serve as typical examples of this gap. Moreover, the improper classification of the agro-wastes poses another obstacle

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in the development of recycling and valorization procedures, which have immensely affected the conversion of agro-industrial activity into a closed loop biorefinery model and the access to sustainable raw materials. Even though there have been several scientific studies on the viability and desirability of valorization technologies, the majority of these technology have been merely developed as theoretical models and have yet to be implemented in the industry. This chapter discusses an summary of the processing and agro-wastes application as a veritable resource to produce industrially important products like biofuels, enzymes, adsorbents and organic acids, for commercialization and environmental applications with their simultaneous management.

12.2 Types of Agro-Wastes

12.2.1 Crop Residues

The agricultural residues obtained after the harvesting of crops represent the most abundant, economic, and easily available source of organic waste that can be bio-transformed. This class of agro-wastes includes husk, bagasse, straw, peelings, cobs, and other lignocellulosic residues (Mtui 2009). These residues are biodegradable and can be subjected to various processes like anaerobic digestion and solid-state fermentation (Ren et al. 2009) to produce biofuels and several other industrially important biological macromolecules.

12.2.2 Animal Manure-Livestock Wastes

The production of animal manure is more than 1500 annually, out of which cattle manure corresponds up to 1284 million tons and pig manure corresponds to 295 million tons (Mtui 2009). The unused manure when not managed or treated poses a great threat to the air and water systems. Moreover, animal manure releases up to 18% CO_2 equivalent and 37% methane, which directly contribute to the greenhouse effect (Ren et al. 2009). In the past few years, extensive work has been done in the anaerobic digestion of animal manure which can be subsequently used as fertilizer in agriculture. Moreover, this manure can also be co-digested with agro-waste for the production of methane and biohydrogen, etc.

12.2.3 Food Wastes

Food wastes constitutes up to 75–80% moisture and 85–90% of volatile solids which favors the growth of microorganisms with high energy content (Li et al. 2008). In general, these wastes are mostly landfilled which create foul odors and leachates which potentially pollute the groundwater table and nearby water bodies. Over the last few years, food wastes have been studied extensively as potential feedstock for the production of biofuels and other value-added commercial products (Li et al. 2008).

12.3 Agro-Waste Utilization Routes

12.3.1 Conventional Methods of Agro-Waste Management

12.3.1.1 Direct Combustion

Direct combustion of agro-waste as fuel is the oldest method of biomass conversion. The complete combustion of agro-waste involves the rapid oxidation of biomass with oxygen and the subsequent release of energy. However, this method is environmentally not friendly due to the release of CO2 during combustion, which adds to the greenhouse gases (Obi et al. 2016). Despite the adverse effect of combustion on the environment, it is the most widely used method for addressing agro-waste and accounts for up to 95% of the total biomass energy.

12.3.1.2 Pyrolysis

Pyrolysis is a thermochemical process where agricultural waste is heated at 400–600 °C in the absence of an oxidizing agent to produce char and bio-oil. Pyrolysis of agro-wates has garnered great attention in Europe and America in recent time and many researchers have utilized various lignocellulosic wastes for bio-oil production by pyrolysis (Aravind et al. 2020). Bio-oil has a high calorific value, can be easily stored or transferred, and can be converted to other useful chemicals due to the low content of sulfur and nitrogen. The maximum yield of 70%, w/w, bio-oil from rice husk was obtained at 450 °C by Guedes et al. 2018. The valorization of agro-wastes by pyrolysis is shown Fig. 12.1.

12.3.1.3 Vermicomposting

Vermicomposting is the solid phase decomposition of the organic residues by combined action of microorganisms and earthworms in an aerobic environment. Agro-waste, which is a by-product or end product of agricultural materials, can serve

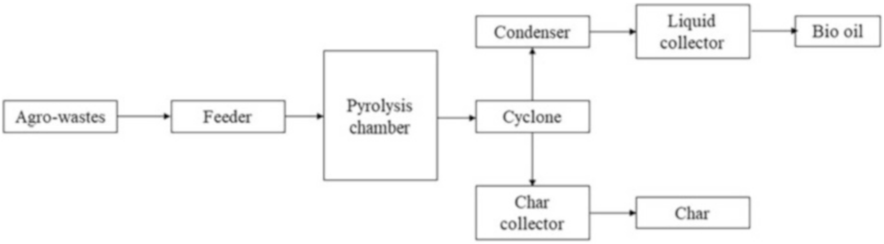

Fig. 12.1 Schematic flow for pyrolysis of agro-wastes to produce biochar and bio-oil. Pyrolysis becomes a thermal process which is performed in the absence of an oxidizing agent at high temperatures generally for the production of biofuels

Table 12.1 Different agro-wastes tested for vermicomposting

Agro-waste	Species of earthworm	References
Crop residues of post harvest	*Eudrilus eugeniae*	Suthar (2008)
Bagasse	*Eudrilus eugeniae*	Sen and Chandra (2007)
Wood waste	*Eisenia fetida*	Maboeta and Van Rensburg (2003)
Olive pomace	*Eisenia Andrei*	Plaza et al. (2008)
Rubber leaf litter	*Eudrilus eugeniae, Eisenia fetida*	Chaudhuri et al. (2003)
Vegetable wastes	*Eudrilus eugeniae, Perionyx excavates, Eisenia foetida, Pheretima elongate*	Pattnaik and Reddy (2010)
Sugar cane bagasse	*Drawida willsi*	Tambe (2011)
Organic matter, dried yard waste and crushed leaves	*Eisenia foetida*, *Lumbricus rubellis*	Pattnaik and Reddy (2010)
Wheat straw	*Eisenia foetida*	Suthar (2008)

Table 12.2 Chemical composition of vermicompost

Parameters	Values
Total carbon (%)	9.1–17.8
Total nitrogen (%)	0.5–0.9
Phosphorus (%)	0.1–0.2
Sodium (%)	0.05–0.3
Potassium (%)	0.15–0.25
Copper (mg/kg)	2.0–9.5
Sulfur (mg/kg)	128.0–548.0
Zinc (mg/kg)	5.7–9.3

as potential substrates for earthworms (Pattnaik and Reddy 2010). Presently, these wastes are not utilized completely due to in situ land disposal or burning. Thus, these wastes could be selected for resource recovery through vermicomposting for agricultural land restoration (Tambe 2011). Table 12.1 shows various agricultural wastes that have been explored for vermicomposting.

The vermicompost obtained after the composting process has high humus content and exhibits nominal phytotoxicity. It consists of most of the nutrients required for plant growth, such as nitrates, phosphates, and calcium (Table 12.2). Thus, the vermicompost can be utilized as a fertilizer for the restoration of land applications (Pattnaik and Reddy 2010). The major benefits of vermicomposting are as follows:

- Increases soil fertility
- Improves the holding capacity of water in soil
- Mediates the restoration of soil microbial population

12.3.2 Valorization of Agro-Wastes

Agro-wastes generated from different activities which can be valorized in various ways to produce many value-added products as shown in Fig. 12.2.

12.3.2.1 Production of Biofuels

Energy is the backbone of global economic growth and the rapid economic growth over the past decades has urged energy consumption considerably, which has anticipated unprecedented pressure to save energy (Srivastava et al. 2020). The change in lifestyles along with industrialization and globalization are the key drivers for the rise in energy demands and the 2010 World Energy Outlook predicted that the global energy demand will rise by 36% by 2035 (Birol 2008). In this context, a global energy transition from fossil fuels to low-carbon solutions is essential, which could be addressed by technological innovations in renewable energy. Bioenergy can substitute heat, electricity, or transport fuels and accounts for 11–14% of the world's present total energy supply (Kumar et al. 2019). Renewable energy can constitute the largest low-cost substitute for energy security and reduce the dependency on limited energy sources.

Biofuels, compared to the other sources of renewable energy, constitute the most popular source as they can be transported and stored, and can be used for power generation on demand (Srivastava et al. 2017). The initial copious views on the production of biofuels were challenged due to the dawdled pace of development and the varied understanding of the impacts of this technology on sustainability.

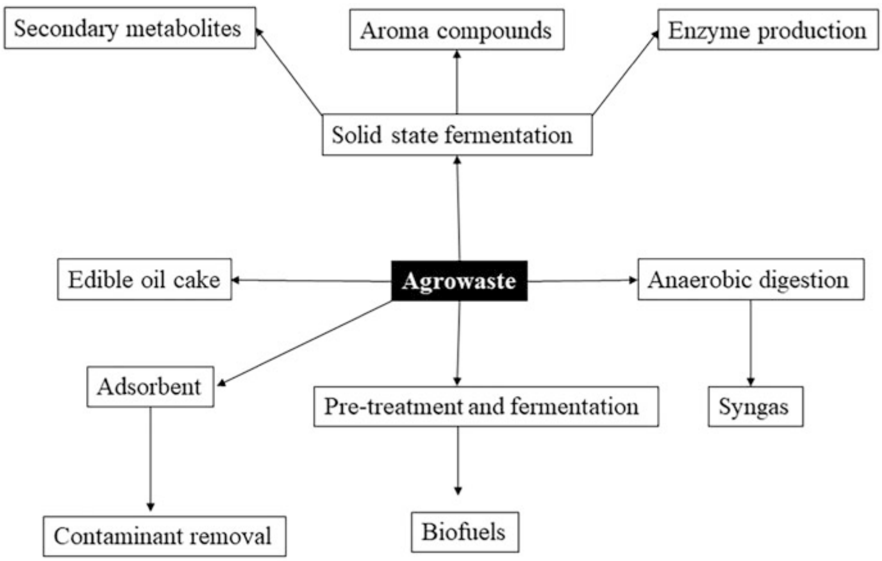

Fig. 12.2 Schematic pathway to convert the agro-wastes into industrial bioproducts and biofuels through biotechnological processes like aerobic and anaerobic fermentation

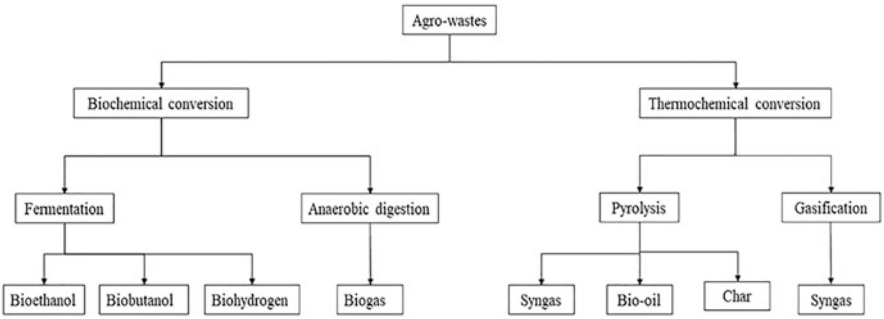

Fig. 12.3 Potential biochemical and thermal treatment routes to convert the agro-wastes towards the production of biofuel. The biochemical route mostly involves the utilization of aerobic and anaerobic fermentation processes to produce bioethanol, biobutanol, etc. Pyrolysis and gasification are the commonly used thermochemical treatments for the production of syngas, bio-oil, etc.

Table 12.3 Biofuel potential of various agro-wastes

Agro-waste	Yield of bioethanol	Yield of biomethane	Yield of biohydrogen	References
Rice straw	12–29[a]	302[b]	3.40[c]	Akhtar et al. (2017)
Wheat straw	11–79[a]	290[b]	21.40[d]	Yuan et al. (2018)
Rice bran	–	–	2.75[c]	Tandon et al. (2018)
Barley straw	11–46[a]	–	47.20[d]	Qureshi et al. (2014)
Corn stover	40–55[a]	338[b]	50.10[d]	Qureshi et al. (2014)
Sugarcane bagasse	23–59[a]	278[b]	14.10[c]	Hu et al. (2018)
Apple pomace	8.44[e]	–	12.92[d]	Wang et al. (2010)
Orange Peel waste	6[e]	217[b]	–	Joshi et al. (2015)

[a]L/kg of dry mass
[b]L/kg of volatile solids
[c]g/L acetone-butanol-ethanol
[d]g/L
[e]%

However, biofuel production reached 143 billion liters in 2017; the five major countries in the area of biofuel production include the United States, China, Germany, Argentina, and Brazil (Kumar et al. 2019).

Using agricultural wastes like rice bran, rice straw, and sugar cane bagasse are regarded as a common method of producing biofuel feedstock (Fig. 12.3). The biofuel potential of various agro-wastes is shown in Table 12.3. When compared to grain crops, the main benefit of employing agricultural wastes is that no extra land is needed for cultivation, minimizing land competition and reducing direct influence on commercial farming. Moreover, removing agricultural waste helps some crops indirectly and perhaps reducing insect attacks (Kumar et al. 2019; Yuan et al. 2018).

Biotechnological processes to convert the and residues to produce biofuels are efficient in decreasing greenhouse gas and hazardous by-product emissions, which will help in solving the crisis of fuels.

12.3.2.2 Production of Organic Acids

Organic acids are soluble, hygroscopic, and chelating in nature that makes them suitable for various formulations at 37°C. These advantages of organic acids have established their importance in the food and beverage industries. Various scientists have widely evaluated the production of organic acids from agricultural residues through solid-state fermentation (Table 12.4). The use of agro-wastes provides a cheaper and easily available raw material which is produced in large quantities.

Table 12.4 Solid state fermentation utilizing various agro-wastes to produce the organic acids

Agro-waste	Microorganism	Organic acid	Acid production (g/kg)	References
Sugarcane bagasse	*Lactobacillus sp.*	Lactic acid	249	John et al. (2007)
Pineapple waste	*Aspergillus niger, Aspergillus Foetidus*	Citric acid	132	Lima et al. (1995)
White grape pomace	*Aspergillus niger*	Citric acid	85	Papadaki et al. (2019)
Bagasse	*Aspergillus niger*	Citric acid	–	Vaishnavi et al. (2012)
Sugarcane bagasse	*Rhizopus oryzae*	Lactic acid	–	Pandey et al. (2001)
Corn husk	*Aspergillus niger*	Citric acid	259	Hang and Woodams (1985)
Cassava peel	*Aspergillus niger*	Citric acid	88.73	Adeoye et al. (2015)
Cassava bagasse	*Streptococcus thermophilus*	Furmaric acid	–	Pandey et al. (2001)
Coffee husk	*Aspergillus niger*	Citric acid	150	Hang and Woodams (1985)
Fig waste	*Aspergillus niger*	Gluconic acid	490	Singh et al. (2003)
Sweet potato waste	*Rhizopus sp.*	Oxalic acid	26.4	Leangon et al. (1999)

12.3.2.3 Production of Enzymes

During any fermentation process, substrate selection is an significant factors that determine the success of the process. The economic perspective of the process completely depends on the availability and cost of the substrate. In this context, the use of agro-wastes represents a possible low-cost materilas for the synthesis of microbial enzymes (Robinson and Nigam 2003). Lignocellulosic wastes contribute majorly to the agro-wastes available worldwide and represent the most abundant renewable biomass source (Kumar et al. 2019). The various agro-wastes utilized as substrates for the microbial production of enzymes are listed in Table 12.5.

12.3.2.4 Production of Protein-Enriched Feed

Agricultural residues have found signification applications for the production of energy; but their animal feed usage is greatly constrained due to the low content of protein, vitamins, and other nutritional components. However, after protein enrichment by using various microorganisms through solid-state fermentation, they could be utilized for animal nutrition (Robinson and Nigam 2003). A number of researches are available in the literature on the use of agro-waste as animal feed after protein enrichment which is listed in Table 12.6. The choice of microorganisms used for the fermentation process depends on the substrate used. Although these wastes are cheap sources of raw materials to produce protein-rich feed, the scale-up of these processes is constrained mostly due to logistic costs.

12.3.2.5 Production of Aroma Compounds

The growing interest in the utilization of natural products in the food industry has definitely stimulated in developing the biotechnological processes to produce various aroma compounds. These compounds also find their application in the manufacture of perfumes and cosmetics among many (Medeiros et al. 2001). On this front, the development of biotechnological processes to produce these metabolites by microbial bioconversion or fermentation constitutes an economical alternative to the higher cost extraction processes involved with raw materials like plants. In recent years, constant efforts have been undertaken in utilizing agricultural wastes like coffee husk, cassava bagasse, and sugarcane bagasse as substrates to produce of food aromas through solid-state fermentation. Even though numerous microorganisms are employed for the synthesis of potentially valuable aromas, the yields are very low which restricts their industrial application (Christen et al. 2000). The common agro-wastes utilized for the production of aroma compounds are listed in Table 12.7.

12.3.2.6 Production of Secondary Metabolites

The production of econdary metabolites are microbial secretions produced at the log phase and in the stationary phase. They constitute a class of industrially important microbial products and majorly include antibiotics, steroids, and alkaloids. In recent years, various agricultural wastes, like rice husk, rice bran, corncobs, wheat straw, etc., have been globally considered as cheaper and easily available raw materials for

Table 12.5 Utilization of various agro-wastes as substrates for enzymes production

Enzymes	Agro-waste support	Microorganisms	Productivity	References
Cellulase	Wheat bran	*Rhizopus oryzae*	437 U/g, 5 days	Pandey et al. (2016)
	Corn stover	*Aspergillus fumigatus*	526 U/g, 4 days	Liu et al. (2011)
	Rice husk	*Aspergillus niger*	401 U/g, 96 h	Dhillon et al. (2012)
	Apple pomace	*Aspergillus niger*	134 U/g, 48 h	Dhillon et al. (2012)
	Wheat bran	*Aspergillus niger*	395 U/g, 96 h	Bansal et al. (2012)
Amylase	Date waste	*Bacillus licheniformis*	209 U/g, 7 days	Afrisham et al. (2016)
	Wheat straw	*Bacillus sp.*	6900 U/g, 5 days	Qureshi et al. (2016)
	Wheat bran	*Aspergillus oryzae*	1491 U/g, 3 days	Kaur et al. (2012)
Laccase	Sugarcane bagasse	*Pleurotus ostreatus*	167 U/g, 5 days	Karp et al. (2012)
	Rice straw	*Pyrenophora phaeocomes*	10,859 U/g, 4 days	Rastogi et al. (2016)
	Wheat bran	*Coriolus sp.*	2661 U/g, 10 days	Mathur et al. (2013)
Lipase	Castor bean waste	*Penicillium simplicissimum*	155 U/g, 96 h	Godoy et al. (2011)
	Jatropha seed cake	*Pseudomonas aeruginosa*	932 U/g, 9 days	Joshi et al. (2011)
	Sugarcane bagasse	*Burkholderia cenocepacia*	72.3 U/g, 96 h	Liu et al. (2013)
	Sugarcane bagasse and soybean oil	*Thermomucor indicae seudaticae*	15 U/g, 72 h	Ferrarezi et al. (2014)
Pectinase	Sugarcane bagasse	*Aspergillus oryzae*	40 U/g, 18–24 h	Biz et al. (2016)
	Citrus peel	*Aspergillus niger*	265 U/g, 96 h	Sethi et al. (2016)
Protease	Wheat bran	*Aspergillus niger*	262.78 U, 48 h	de Castro et al. (2015)
	Jatropha seed cake	*Aspergillus versicolor*	3366 U/g, 96 h	Veerabhadrappa et al. (2014)
	Wheat and rice bran	*Pleurotus sajor-caju*	85 U/g, 192 h	Ravikumar et al. (2012)
Xylanase	Wheat bran	*Bacillus aerophilus*	45.9 U/g, 24 h	Gowdhaman et al. (2014)
	Wheat bran	*Aspergillus oryzae*	2830 U/g, 24 h	Pirota et al. (2013)
	Rice straw	*Promicromonospora sp*	85 IU/g, 96 h	Kumar et al. (2011)

Table 12.6 Valorization of agro-waste to produce the protein-rich feed

Substrate	Microorganism used	Product	References
Cassava bagasse	*Lactobacillus sp., Saccharomyces cerevisae, Rhizopus oryzae, Brevibacterium divaricatus., Cephalosporium eichhorniae, Pleurotus sp., Lentinus sp., Aspergillus sp., Geotricum fragrans*	Animal feed and food; protein-enriched biomass, single cell protein	Ubalua (2007), Oboh and Elusiyan (2007), Oboh (2006), Obadina et al. (2006), Fagbemi and Ijah (2006), Sriroth et al. (2000), Jyothi et al. (2005), Damasceno et al. (2003)
Apple pulp and waste, grape waste, pineapple waste	*Rhizopus oligosporus, Penicillium funiculosum,*	Protein-rich feed	Villas-Bôas et al. (2003)
Waste fiber of cactus	*Myrothecium verrucaria, Aspergillus niger, Saccharomyces sp. Saccharomyces cerevisae*	Protein-rich feed	Araujo et al. (2005)
Rice bran/ straw; paddy straw; sawdust; lignocellulosic waste	*Trichoderma viridae; Aspergillus niger; Pleurotus ostreatus Trichoderma reesei,*	Protein-rich feed/ biomass	Bonatti et al. (2004), Yang et al. (2003), Banik and Nandi (2004)
Cane bagasse	*Trichoderma viride; Trichoderma reesei*	Protein-rich feed	Valino et al. (2002)

Table 12.7 Aroma compounds production from agro-wastes

Substrate	Microorganism used	Aroma compounds	References
Coffee husk	*Ceratocystis fimbriata*	Pineapple aroma	Sugawara et al. (1994)
Cassava bagasse	*Kluyveromyces marxianus*	Fruity aroma	Medeiros et al. (2000)
Palm bran	*Kluyveromyces marxianus*	Fruity aroma	Medeiros et al. (2000)
Apple pomace	*Ceratocystis fimbriate*	Fruity aroma	Medeiros et al. (2000)
Rice waste	*Neurospora sp.*	Fruity aroma	Bramorski et al. (1998)
Tropical agro-waste	*Rhizopus oryzae*	Volatile compounds	Christen et al. (2000)

the production of secondary metabolites at a commercial level. In this context, the culturing of microorganisms on agro-wastes for the generation of secondary metabolites is an ideal approach. This is mainly done by solid-state fermentation with a lower moisture content which allows the microbial transformation of biological molecules. Apart from other microbes, the majority of fungal species

Table 12.8 Production of secondary metabolites from agro-wastes

Substrate	Microorganism used	Secondary metabolite	Yield (mg/g)	Application	References
Cottonseed oil cake	Streptomyces clavuligerus	Cephamycin	15	Antibiotic	Kota and Sridhar (1999)
Rice husk/ bran	Aspergillus oryzae	Aflatoxin, Ochratoxin	–	Mycotoxin	Pandey et al. (2001)
Wheat straw	Acremonium chrysogenum	Cephalosporin C	22.28	Antibiotic	Adinarayana et al. (2003a)
Wheat waste	Streptomyces marinensis	Neomycin	17.15	Antibiotic	Adinarayana et al. 2003b
Wheat bran	Tolypocladium infautum	Cyclosporin A	–	Immuno suppressive	Pandey et al. (2001)
Wheat bran	Bacillus subtilis	Iturin	3.66	Antibiotic	Ohno et al. (1992)
Peanut shells	Streptomyces sp.	Tetracyclin	13.18	Antibiotic	Asagbra et al. (2005)
Sugarcane bagasse	Penicillium chrysogenum	Penicillin	10.55	Antibiotic	Barrios-González et al. (1993)
Wheat bran	Bacillus licheniformis	Bacitracin	4.82 iu/g	Peptide	Farzana et al. (2005)
Soyabean residues	Bacillus subtilis	Surfactin	–	Antibiotic	Pandey et al. (2001)

Table 12.9 Types of oil cakes and their composition

Oil cake	Protein (%)	Fat (%)
Coconut	21	8
Cotton seed	40	8
Groundnut	51	1
Linseed	29	8
Mustard	35	8
Sesame	37	8

are used in solid state fermentation to produce secondary metabolites is shown in Table 12.8.

12.3.2.7 Edible Oil Cakes

Oil cakes could be a the solid waste which are generated after the extraction of oil from the plants by solvent extraction or pressing. Because to their excellent nutritional properties, these cakes are typically utilized to meet the nutritional needs of both livestock feed and human consumption (Table 12.9). The major edible oil cakes that dominate the global oil cakes market are soybean, rapeseed, cottonseed, linseed, groundnut, sunflower, and copra cake. Out of them, soybean cake represents up to 54% of the total production, followed by 10% cottonseed and 10% rapeseed (Gangadharan and Sivaramakrishnan 2009).

12.3.2.8 Agro-Waste as Adsorbents for Contaminant Removal

Due to rapid industrialization and urbanization, there is an excessive discharge of organic and inorganic contaminants into the environment which affects human health (Akpomie and Conradie 2020, Rathankumar et al. 2020b). Due to various disadvantages of the already available treatment processes, like low metal removal, high energy requirements, generation of toxic by-products, etc., Many studies have been conducted recently with the agricultural wastes as biomass which acts as adsorbents to facilitate the removal of pollutants (Kulshreshtha 2019). Numerous works have been published on the heavy metals adsorption on agro-waste and a number of studies showed the immobilization of heavy metals on agro-waste (Najam and Andrabi 2016). Further, the adsorption of contaminants, mainly dyes and organic pollutants, in various studies have established agro-waste as an excellent environmentally friendly and economical adsorbent for the removal of contaminants from the ecosystem (Dupont et al. 2005; Sahmoune 2019). The various agro-wastes utilized for the contaminants removal are shown in Table 12.10.

12.4 Conclusion

The global discernment for agro-waste generation and management is rapidly shifting towards sustainable utilization due to the necessity for environmental conservation and world's food security. Due to this elevated requirement for sustainability, different techniques were developed for the effective utilization and reprocessing of these wastes. Biotechnological approaches, such as solid-state fermentation, have laid down efficient platforms with low substrate cost and low energy requirements for the utilization of agro-wastes to produce various value-added commercial compounds. Further, the protein-enriched feed produced from agro-wastes offers renewable opportunities for animal nutrition. Thus, future research on biotechnological approaches and technologies will improve the deployment of improved products from waste thereby addressing the management of the surplus agro-wastes produced annually.

Table 12.10 Utilization of various agro-wastes as adsorbent for contaminant removal

Contaminants	Agricultural waste	Adsorption capacity (mg/g)	References
Organic pollutants			
Tetracycline	Rice straw	14.16	Wang et al. (2017)
Tetracycline	Sugarcane bagasse	48.35	Wang et al. (2017)
Fluoroquinolone	Rice husk	63.5	Ashrafi et al. (2016)
2,4-dichlorophenoxyacetic acid	Bagasse	7.14	Deokar et al. (2016)
Phenol	*Typha orientalis*	7.23	Feng et al. (2015)
Dyes			
Synolon black HWF-FS	Linseed oil cake	6.89	Safa (2016)
Congo red	*Stipa tenassicima* fibers	7.93	Chebli et al. (2015)
Malachite green	Solanum tuberosum	27	Gupta et al. (2016)
Cationic dye	Coconut coir waste	29.5	Etim et al. (2016)
Crystal violet	Coconut coir waste	33.22	Etim et al. (2016)
Heavy metals			
Cd (II)	Sugarcane straw	8	Farasati et al. (2016)
	Walnut shell	7.29	Najam and Andrabi (2016)
Cu (II)	Watermelon shell	9.54	Mohammed and Ibrahim (2016)
	Banana waste	6.49	Mokkapati et al. (2016)
	Walnut shell	14.54	Najam and Andrabi (2016)
Ni (II)	Apple pomace	83.33	Chand and Pakade (2015)
	Hemp fiber	206	Kyzas et al. (2015)
Zn (II)	Walnut shell	7.48	Najam and Andrabi (2016)
Cr (VI)	Teff straw	3.51	Tadesse et al. (2015)
	Rice husk	18.2	Ding et al. (2016)
Hg (II)	Rice straw	91.74	Song et al. (2015)
	Rice husk	98.33	Song et al. (2015)
	Peanut shell		Bai et al. (2015)

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