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REVIEW

Utilisation of agro-industrial waste for sustainable green production: a review

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Abstract

Agro-industry generates large amount of waste with diverse characteristics. The accumulation of agricultural waste is in the excess of 2 billion tons worldwide. This makes it imperative to investigate how agro-industrial waste utilization can be advanced to the next phase to maximise benefits from the sector. Improper management of these wastes leaves undesirable footprints in environment as well as on the economic health of many nations. In this direction, development of proper clean and green waste management approaches is the need of the hour, firstly, efficient conversion of wastes to value added products, by-products within affordable treatment costs and secondly, impact assessment on soil quality and productivity. This review fills the existing research gap on how agro-based waste can be productively harnessed. The review comprehends elaborately the industrial innovations and technology for recovery of agro-industrial wastes, which has triggered high resource efficiency, sustainable production and safe disposal.

Keywords Agro-industrial waste · Recycling · Value added products · Soil quality · Environment

Introduction

Increased per capita energy usage due to overexploitation of natural resources, combined with an ever-increasing global population, leads to instability in our ecological systems (Sadh et al. 2018). Every year, roughly 500 million tonnes of agricultural residue are produced, of which 18.4% (92 million tonnes) is burned in India, which is more than the total waste generated in Bangladesh, Indonesia, and Myanmar combined (NPMCR 2019; Jeff et al. 2017). Crop residues generated in large volumes after harvest pose major challenges for policy makers and farmers in India. Improper disposal of these crop residues have resulted in environmental pollution, greenhouse gas (GHG) emission, climate change, as well as a negative impact on human and animal health (Sadh et al. 2018; Bharathiraja et al. 2017; Bos and Hamelinck 2014). As a result, there is an imperative need to explore viable recycling options in order to address these issues. The agro-industry, particularly the food industry, contributes significantly to waste generation, resulting in environmental pollution, climate change, and economic development deterioration (FAO 2019). According to Caldeira et al. (2019), the European Union generates over 30 Mt of inedible food waste each year, which is projected to

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increase dramatically with fast growing food processing industry. Reduction of agro-industrial waste to 30–50% can enhance the available food supply to 15% (Wanga et al. 2016). The need of developing valorisation pathways is highlighted by the United Nations' pledge on Sustainable Development Goals (SDGs) to halve per capita food waste in supply chains, retail, and manufacturing. According to Kurnik et al. (2018), the valorisation of agro-industrial waste is gaining momentum not just due to a necessity, but also due to recent breakthroughs in engineering approaches for turning waste into valuable products. Prasertsan et al. (2011) proposed four possible ways for agro-waste management: (a) waste minimization or waste reduction, (b) waste conservation, (c) waste segregation and (d) waste utilization (reuse, recovery/recycling). These management options, however, will necessitate not just engineering solutions, but also business models to implement them. There has been a significant shift in global perceptions towards the use of agro-industrial waste for resource conservation.

Given bio-technological interventions, the potential of agro-industrial wastes can be completely realised in a variety of ways, including the development of numerous value-added and by-products such as bio-fuel, bio-products, biodegradable plastics and organic fertilisers in the form of manure compost etc. As a result, this review article will concentrate on the valuation, classification, and environmental effect of agro-industrial wastes, as well as their present level of knowledge and possible applications. Therefore, focus will be on the valorization, categorisation, and environmental impact of agro-industrial waste, as well as their current state of art and potential applications.

Categorisation of agro-industrial wastes

Annually, India produces 187.7 million tonnes of milk, 296 million tonnes of fruits and vegetables, 515 million livestock, 15.2 million tonnes of fish, and 532 million tonnes of poultry. In India, about 45% of large and medium scale industries use agricultural products as raw materials (MOFPI 2020). Large volumes of stalks, shells, husks, rinds, scales and waste water generated during the processing and refining of raw materials are rarely used as animal feed or manure, can be further refined to make usable and marketable products.

Agro-based industries can be grouped into three different segments i.e. plant-based, animal-based food, and non-food based agro-industrial wastes (Table 1). Plant based wastes can be further divided into field residues and process residues. Field residues are the waste materials (leaves, stalks, seed pods, and stems) that remain in the field after the crop has been harvested. Some of these wastes are used on farms as animal bedding and feed, as well as for various horticultural uses. The processed residues, on the other hand, are the wastes generated after processing and refinement of raw produce. By-products of grain-flour mills, sugar industries, fermentation-based industries, food and fruit processing are the most common plant-based agro-wastes (Table 1). On the other hand, huge amounts of organic residues from the fish, poultry, and meat processing sectors are stacking up, containing perishable proteins that have the potential to cause public nuisance through foul smell. Non-food based agro-industries produce effluents that are largely biodegradable in nature. The effluents are non-toxic except in the tannery and textile industries. The majority of these wastes go unused or untreated, posing a threat to the environment as well as human and animal health.

Environmental impact of agro-industrial waste

Untreated and huge amounts of agro-industrial wastes are a major concern in every country, and it is becoming worse by the year (Sadh et al. 2018). The agro-industrial waste and effluents are usually discharged on land or into water bodies. These have variable chemical characteristics and metal contents that may prove harmful to environment. Uncontrolled burning of agro-industrial waste releases toxic (nitrogen oxides, SO_2, respirable particulate matter), carcinogenic (dioxins, furans, polycyclic aromatic hydrocarbons), and greenhouse gases (CH_4, N_2O) as well as smoke, contributing to significant haze, global warming and detrimental to human health (Sharma et al. 2020).

A few agro-industrial wastes, such as those from pulp and paper mills, textile mills, contain hazardous contaminants that can pollute air, water, and soil (Gupta and Shukla 2020; Paritosh et al. 2017) Organic and inorganic compounds present in the pulp and paper industry waste have been shown to have negative effects on aquatic ecosystems (mutagenicity, carcinogenicity, and endocrine disruption) (Servos 2020). Agro-industrial waste is normally high in nutrients, but if left untreated, it can become a source of pathogenic diseases (Ravindran et al. 2018), herbicide or pesticide residues, harmful faecal coliform bacteria (James 2020). The repeated application of such wastes without any treatment build ups pesticide and herbicide residue in soil, which can be harmful to beneficial soil microbes (Ramírez et al. 2019). Runoff from nutrient-rich wastes, such as those produced by the fertiliser industry, poultry, and aquaculture, can induce eutrophication, resulting in massive algal blooms and a disruption of the aquatic ecosystem (Smith et al. 2016; Withers et al. 2014; Merel et al. 2013). Those wastes are sometimes water soluble, end up in drinking water and eventually into the food chain, causing severe health problems in humans such

Table 1 Potential by-products of various agro-based industries

	Industry segment	By product	References
I	Plant-based food		
1	Grain and flour mills, starch products	Rice straw	Sharma and Garg (2018, 2019)
		Rice bran	Agrawal et al.(2019)
		Wheat straw	Biswas et al. (2017)
		Barley straw	Kulikowska and Sindrewicz (2018)
		Oat straw	Zhou and Li (2016)
		Corn stalks and cobs	Li et al. (2017)
		Soya stalks	Biswas et al. (2017)
		Soy meal	Madej et al. (2017)
2	Sugar industry	Bagasse	Kanwal et al. (2019), Veana et al. (2014)
		Molasses	Kanwal et al. (2019)
		Pressmud	Kumar and Chopra (2016)
		Spent wash	Chattha et al. (2019)
3	Fermentation (i) Distillery (ii) Brewery (iii) Maltry	Effluent Waste water Waste water	Talukdar (2017)
4	Edible oils and Vanaspati	Sunflower stalks	Sadh et al. (2018)
		Groundnut stalks/shells	Adeniran et al. (2010)
		Crude olive pomace	Leite et al. (2016)
		Oil cakes	Arora et al. (2017)
5	Food and fruit processing	Potato peel waste	Al-Weshahy and Rao (2012)
		Cassava peel waste	Adeniran et al. (2010)
		Banana peel	Adeniran et al. (2010)
		Cashew shells	Adeniran et al. (2010)
		Spent coffee waste	Ravindran et al. (2018)
II	Animal-based food		
1	Milk processing and dairy products	Waste water	Abdulgader et al. (2019)
2	Fish processing and feed production	Solid fish waste	Arruda et al. (2007)
3	Poultry units	Litter	Seidavi et al. (2019), Moyin-Jesu (2015)
4	Slaughter house/Meat processing	Sludge Waste water	Santagata et al. (2019), Okoro et al. (2017), Jayathilakan et al. (2012)
III	Non-food based		
1	Paper and pulp industry	Effluent sludge	Servos (2020), Pathak et al. (2013)
2	Jute/ coir retting units	Lignocellulose residues (coir dust, residual pith)	Ansi (2017)
3	Textile industry	Effluent	Khan and Malik (2018), Babu et al. (2007)
4	Tannery	Effluent	Riaz et al. (2019)

as Parkinson's disease, cancer, birth defects, Alzheimer's disease, and reproductive problems (Kim et al. 2017). Antibiotic residues present in animal-derived wastes such as milk, meat, and eggs have a detrimental effect on community health as well as food safety in terms of carcinogenicity, drug toxicity, allergic responses and immune-pathological illnesses (Costa et al. 2019; Manyi-Loh et al. 2018). The pollution load of various untreated agro-industrial wastes is mentioned in Table 2. The solution to waste disposal and related environmental challenges is to repurpose waste to make valuable products (Yusuf 2017). As a result, effective disposal and economic exploitation of agricultural wastes not only mitigates pollution but also leads to long-term sustainability.

Valorisation of agro-industrial waste

Agro-industrial waste can be converted to valuable products majorly by either thermochemical or biochemical pathways. This section includes significant highlights for each of the

Table 2 Waste water and pollution load of agro-based industrial waste Source: MOEF. 2016, Recategorization of industries, Ministry of Environment and Forests, Government of India, New Delhi (http://pib.nic.in/newsite/PrintRelease.aspx?relid=137373)

S. no	Agro-industry	per unit production	Specific water consumption (m^3)	Waste water (m^3)	Pollution load (kg of BOD)
1	Dairy processing	Per kilo litre of milk	8.7	6	11
2	Edible oils and Vanaspati	Per tonne oil	3	2	7.5
3	Pulp and paper	Per tonne of paper	300	250	375
4	Starch (maize) products	Per tonne of maize	8	5.5	44
5	Sugar industry	Per tonne of cane	2	0.4	0.5
6	Fermentation				
	(i) Distillery	Per kilo litre of alcohol	130	90	600
	(ii) Brewery	Per kilo litre of beer	11.5	9.5	24
	(iii) Maltry	Per tonne of grain	8.5	3.5	2

major food groups, including meat, dairy, fish, eggs, fruits, vegetables, cereals, sugar crops, oil crops, and tubers.

To use agro-industrial waste as a feedstock, preliminary operations like drying (< 50% moisture) and chopping are inevitable, making the conversion process expensive. In combustion process, the feed stock rich in cellulose and hemicellulose is subjected to temperature range 800–1000 °C in presence of air. Fouling and slagging are typical in low carbon biomass due to the reaction of inorganic constituents. The exact mechanism behind fouling and ash slagging, however, remains unclear. Oxygenated compounds from combustion of cellulosic biomass were successfully used in few studies to run a compression ignition engines (Baumgardner et al. 2015). Thermal decomposition of biomass to solid biochar, liquid bio-oils and gas products in the absence of oxygen is known as pyrolysis. Based on heating rate and residence time, pyrolysis is of three types: slow, fast and flash pyrolysis (Biswas et al. 2017). Slow pyrolysis is conventionally used in production of low-grade charcoals from crop residues at 300–700 °C/h or even days. Fast pyrolysis is carried out (103–104 °C/s) with short residence time (Amutio et al. 2012). In terms of bio-oil yield, the conversion efficiency of fast pyrolysis is 15–20% greater in flash pyrolysis than in fast pyrolysis. Carbonization is used to relatively increase carbon content and calorific value of raw materials with 60–70% weight loss (Meyer et al. 2011). Carbonation is a slow process of heating biomass to drive out the moisture and volatile matter under an inert or low-oxygen. In opposite to carbonation, this process of gasification converts biomass into low calorific value combustible gases of energy 3.6–6.8 MJ/Nm^3 by partial oxidation process at 700–800 °C. It is one of the suitable methods for production of producer gas. The selection of gasifier depends on chemical composition of biomass feedstock and energy density (Alauddin et al. 2010). Hydrothermal Conversion includes thermal depolymerisation of biomass at high temperatures and pressures. Water provides exceptional reaction environment as hydrothermal media acts as catalyst, especially under acid or base catalyzed conditions (Kruse et al. 2013). Depending on the severity of the conditions, it can be divided into distinct processes: (1) hydrothermal carbonization (below 247 °C)—it mimics natural coalification process in subcritical water giving out peat or hydro-coal (Toor et al. 2011), (2) hydrothermal liquefaction (247–374 °C)—a combination of hydrolysis and depolymerization of macromolecules forming bio-oils (Toor et al. 2011), (3) hydrothermal gasification (above 374 °C) triggers the process forming higher fuel gas mixtures.

Agro-industrial wastes are wet biomass and majorly containing cellulose, hemicellulose and lignin. They can act as constant source for production of value-added chemicals by hydrothermal conversion. Factors like composition of feedstock, temperature and hydrothermal media highly affects conversion efficiency of agro-industrial waste. Cellulose and hemicellulose constitute 25–40% of plant biomass. Cellulose rich feedstocks subjected to hydrolysis followed by depolymerization process was given by Lorby de Bruyn–Alberda van Ekenstein. The process is pH sensitive. Acidic environment generates more 5-hydroxy methyl furfural (5-HMF) and its acid derivatives; alkaline conditions lead to retro aldol production, hydration-dehydration, reshuffling of –CHO, to form simpler acids and alcohols (Yin and Tan 2012).

Factors influencing valorization process include (1) type of feedstock: hemicellulose with its simple structure and more side-groups are highly soluble and hydrolyzed both in acidic and alkaline conditions at 180 °C. Lignin in its complex structure contains *p*-hydroxy phenyl propanoids viz., sinapyl, coniferyl and coumaryl alcohols. Unlike cellulose and hemicellulose, it is more resistant to both enzymatic and chemical breakdown. Lignin undergoes hydrothermal hydrolysis in an alkaline environment and produces a variety of phenols; (2) temperature: based on type of the feed stock, the temperature varies in between 250 and 370 °C. Increase in the operating temperature results in depolymerization reaction and further dissociation of complex bonds (Dimitriadis and Bezergianni

2017); (3) solvent to feed ratio: it is important to note that solvents improve the stability and solubility of the fragmented macromolecules. Solvent to feed ratio is assessed in such a manner to cease gasification of all leftovers in the reactor. Some studies show that when a portion of water replaced with compounds like ethanol, methanol, acetone, 2-propanol, they act as a tarry material enhancing the ionic product of the mixture yielding higher bio-oil.

Table 3 primarily throws light on noteworthy research completed in recent past in the field of valorisation pathways for agro-industrial products/waste. This provides clear indication that there is scope for developing multi-feedstock bio-refinery in which similar value added product may be obtained from a wide range of resources reducing the pressure on supply chain and reliance on single source of food waste (Rood et al. 2017). Donner et al. (2020) presented circular business model valorisation pathways for agro-waste. The author's value pyramid emphasised that new products should be inexpensive to customers and provide uppermost possible added value, as indicated in the value pyramid. Thus, there are diverse valorisation prospects in various sectors which can be developed as new products and applications with varying value addition (Fig. 1).

Approaches for value addition of agro-industrial waste

The agro-industrial waste are nutritionally very rich and contain vitamins, fibres, lignin and cellulose, proteins, lipids, polyphenols, pectin, and sugars (Barcelos et al. 2020). The majority of lignocellulose-rich agro-industrial waste are not properly valorized and are left to degrade (Ramírez et al. 2019). Lignocellulose residues are the abundant renewable resource on planet earth (Seidavi et al. 2019), with a potential to be transformed into biofertilizers, biofuels (Ansi 2017) and value added products. They can also be used to produce enzymes, mushrooms (Kumla et al. 2020), and as a substrate for many other important products. Currently, the production of bioethanol and related liquid fuels by microbes utilising agro-industrial waste as raw materials is triggering a snowball effect in biofuel production.

Biorefineries

Bioeconomy and biorefinery are the new concepts emphasized by agro-industries where one industry runs by using the waste material of another industry (Acevedo et al.

Table 3 Summary of valorisation for various key agro-industrial waste

Waste type	Key features	References
Fish processing waste	Requirement of protein for the production of aqua feed for fish meal Making of bioplastic as new packaging materials Use of bioactive peptides Omega 3 fatty acids	Yaghoubzadeh et al. (2019), Swanepoel and Goosen (2018), Uranga et al. (2018), Ferdosh et al. (2015)
Meat processing waste	Contributes about 60–70% of the slaughtered carcass out of which 40% is edible whereas 20% inedible Proteins from lungs Horns, hooves, and feathers Collagen from bovines using Sodium Dodecyl Sulfate	Udhayakumar et al. (2017), Selmane and Christophe (2008), Bhaskar et al. (2007)
Dairy processing waste	Main product arising from diary section is whey Milk concentration permeate	Paseephol et al. (2008), Barba et al. (2001)
Layer units	Production of considerable quantity of eggshells Used in heavy metal removal from water and soil	Oliveira et al. (2013)
Oil crops	Phenolic compounds N source chlorogenic acid and sunflower protein	Ye et al. (2015), Tsakona et al. (2012), Wang et al. (2011)
Fruit manufacturing waste	Essential oils coming from seeds and peels Extraction of pectin Bioactive compounds namely phenolic compounds, flavonoids, and carotenoids	Ekinci and Gürü (2014), Mirabella et al. (2014), Wang et al. (2014)
Vegetables manufacturing waste	Extraction of bioactive compounds (phenolic acids, glucosinolates and flavonoids) Nutrients (minerals, vitamin C and trace elements)	Fuentes-Alventosa et al. (2013), Domínguez-Perles et al. (2010)
Cereals manufacturing waste	High lignocellulosic and starch levels Value components such as glucurono-arabinoxylans, phenolic compounds, peroxidases and β-glucan	Kurnik et al. (2018), Reisinger et al. (2013)
Sugar-crops and tubers	Bioactive compounds	Wijngaard et al. (2012), Singh et al. (2011)

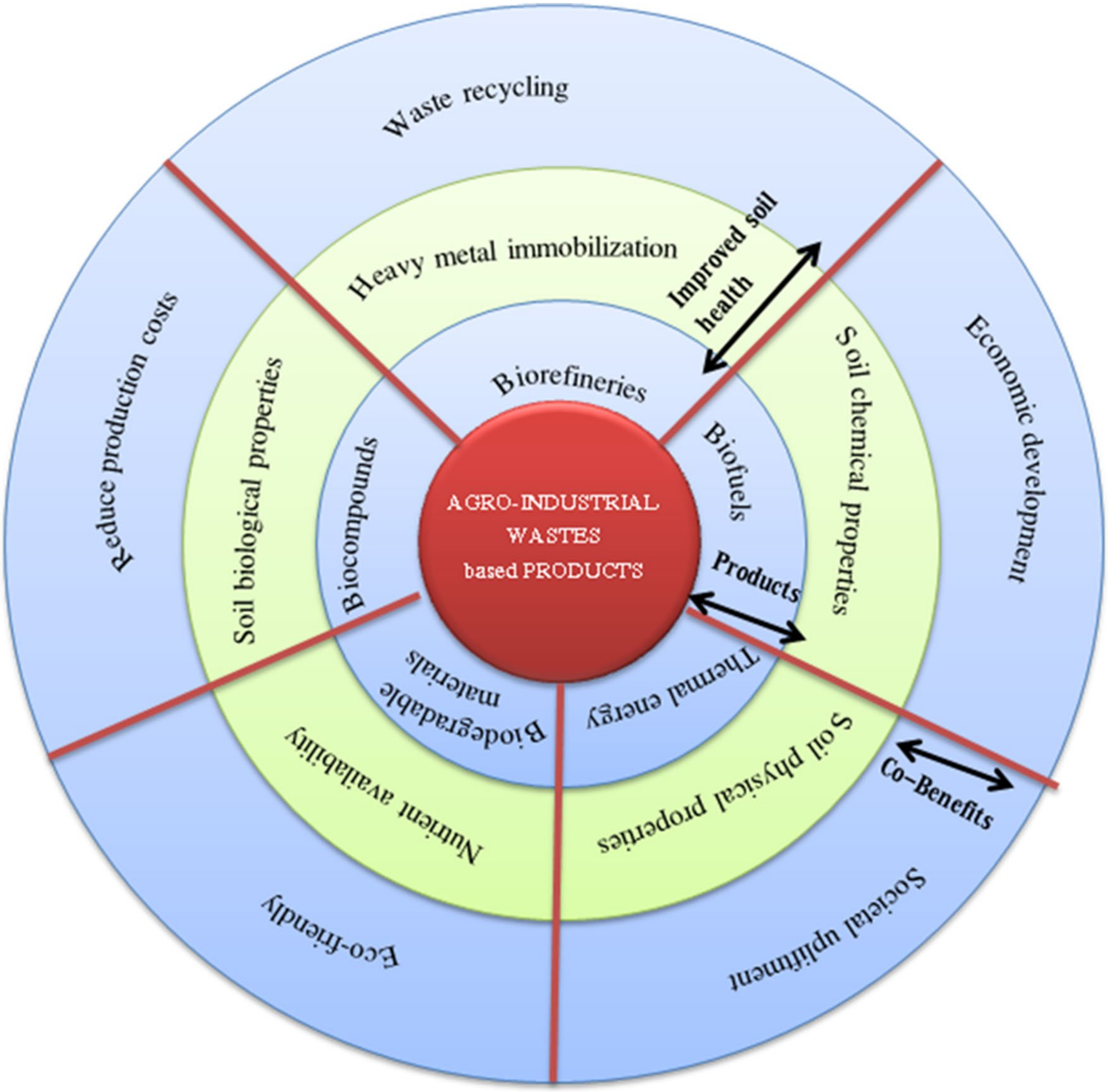

Fig. 1 Schematic illustration of valorisation pathways for agro-industrial wastes, effect on soil health and co-benefits

2020; Ravindran and Jaiswal 2016). Biorefinery naturally includes a complex, integrated network of physical and chemical conversion processes, such as mechanical and physical biomass pre-treatment, pyrolysis, catalytic and enzymatic reactions and downstream purification procedures. They facilitate sustainable conversion of biomass into energy and chemicals viz., pharmaceutical constituents, plastics and food additives. For instance, a lignocellulosic feedstock (LCF) biorefinery that produces ethanol, succinic acid, acetic acid and power has been found to be cost effective and eco-friendly (Luo et al. 2010). The lignin-enriched residue in the refinery may be utilized as a feedstock for chemicals and materials or for on-site electricity generation by integrating geothermal heat into a biochemical lignocellulosic biorefinery (Sohel and Jack 2010).

The biological nature of these approaches makes them require far less energy inputs, reduces maintenance costs, and minimizes ecological disturbance. From a sustainability viewpoint, this is a far better option than other mechanical or chemical treatment methods. This requires social cohesion and integration among policy makers, researchers, technology developers, project developers, and society (Li et al. 2018).

Biofuels

Conversion of biomass to fuel is not a new concept, and direct combustion of solid biomass is the most common approach, but it is also inefficient owing to low density and incomplete biomass combustion. Various types of agro-industrial residues e.g. rice straw, sweet potato waste, sawdust, potato waste, corn stalks, sugarcane bagasse, and sugar beet waste have been used for the production of biofuels (Kumar et al. 2014, 2016; Duhan et al. 2013). The major one of them is bioethanol, which is produced almost entirely by sugarcane molasses in India. In today's world, biofuels are produced in one of two ways: first-generation or second-generation, with the latter being preferred owing to the added benefit of waste utilisation (Ramos et al. 2016). For example, research into cultivation of *Rhodococcus* and *Yarrowia* on agro-waste/industrial biomass pre-treatment waste streams to produce second generation biodiesel is underway (Le et al. 2019).

Bioethanol is produced in billions of litres across the world due to technical advancements and raw material availability (Agrawal et al. 2019). Availability of waste is in abundant in the developing countries for the production of biofuels. Bioethanol can be produced from vegetable wastes such as potato peels, carrot peels, and onion peels by fermenting them with *Saccharomyces cerevisiae* (Mushimiyimana and Tallapragada 2016); or by treating banana pseudo stems with *Aspergillus ellipticus* and *Aspergillus fumigatus* (Ingale et al. 2014). Maiti et al. (2016) utilized *Clostridium beijerinckii* to produce butanol from agro-waste (Maiti et al. 2016). The use of wastes such as spent coffee grounds to produce biofuel reduces investment and production costs (Banu et al. 2020).

Microbial enzymes

Many successful efforts have been made utilizing biotechnology as a tool to get valuable products, such as enzymes, from lignocellulosic materials for industrial uses at a low cost (Leite et al. 2016). Enzymes including chitinase, amylase, phytase etc. are biocatalysts used in variety of industrial processes and can be produced from microbial fermentation of agro-industrial waste. For example, enzyme keratinase produced using keratinous waste from meat producing sectors (Preczeski et al. 2020). The use of solid state fermentation technology (SSF) for bioconversion of agro-industrial waste has been proved to be both eco-friendly and economical (Marzo et al. 2019). In this technology, lignocellulose residues are hydrolyzed enzymatically into fermentable sugars, and then into a marketable product. SSF is advantageous over conventional fermentation technology due to its closeness to nature and simplicity (Ravindran et al. 2018a). Various studies have been reported using agro-industrial waste as a substrate (Carbon source) in SSF with different micro-organisms, such as wheat bran for production of gibberallic acid using *Fusarium monoliforme* (Prema et al. 1988); oat straw for lignin degradation using *Polyporovs* spp. (Bone and Munoz 1984); corn and soya for mycotoxin production using *Aspergillus flavus* (Hesseltine 1972) and various moulds (Bhumiratna et al. 1980); oat cereal using *Rhizopus oryzae* for lactic acid (Koutinas et al. 2007); Agro distiller grains using *Aspergillus niger* for citric acid (Prado et al. 2004) etc.

SSF based enzyme production is yet another microbial biotechnological intervention (Adrio and Demain 2014) that is gaining popularity and lowering production costs (El-Naggar et al. 2014). SSF can produce xylanase and exo-polygalacturonase (Marzo et al. 2019), lignocellulosic enzymes (Kumla et al. 2020), polygalacturonase and pectin methylesterase (Patidar et al. 2018), cellulase (Abdullah and Greetham 2016) etc. Cellulases, xylanases and ligninases and cinnamoyl esterases are produced using agricultural and agro-industrial by-products through SSF processes (Abdullah and Greetham 2016). SSF was used for *Aspergillus awamori* to produce amylase and glucoamylase, with field residues such as rice bran and wheat bran as substrates (Suganthi et al. 2011). *A. niger* MTCC 104 has been reported for production of α-amylase employing SSF (Duhan et al. 2013; Kumar et al. 2016). Buenrostro et al. (2013) produced Ellagitannase, an enzyme used for biodegradation of ellagic acid and ellagitannins, using four different agro-industrial wastes, including sugarcane bagasse, corn cobs, candelilla stalks, and coconut husks, where corn cobs delivered the best results as a substrate. Oil cakes, particularly palm kernel oil cakes, were also employed as substrates for the manufacture and optimization of lipase enzyme by *Aspergillus ibericus* (Oliveira et al. 2017). Similarly, Saharan et al. (2017) studied the release of polyphenols and antioxidants using various enzymes e.g. α-amylase, xylanase, and β-glucosidase during SSF of cereals. Likewise, fermentation of peanut press cake with *Aspergillus oryzae* led to a significant increase in key enzyme activities for industry, such as α-amylase, β-glucosidase, lipases, and xylanase (Sadh et al. 2017). Table 4 gives an overview on production of enzymes from various agro-waste.

Single cell protein production (SCP)

Bioconversion of agro-industry wastes produces a very high quality of protein which is economical and nutritionally valuable (LaTurner et al. 2020). The cost of SCP production can be dramatically reduced by using low-value agro-wastes, such ascitric waste, yam peels, pineapple cannery effluent, corn stover, whey concentrates, soy molasses, rice effluent and hydrolyzed sugar cane bagasse (Aruna et al. 2017). Mondal et al. (2012) studied the synthesis of SCP by *S. cerevisiae* from fruit waste fermentation waste, especially cucumber and orange peels, with cucumber peels producing more protein. Several studies have shown the production of protein-enriched feed using SSF technology (Rompato and Somoza 2015; Mahawar et al. 2012), as well as silage making and nutrient enrichment of agro-industrial waste (Silva et al. 2016; Alemu 2013; Nasir and Butt 2011). On the one

Table 4 Use of agro-waste to produce various enzymes from micro-organisms

Substrate	Enzyme	Microorganism	References
Rice bran	Endoglucanase	*Trichoderma reesei* QM9414	Rocky-Salimi and Hamidi (2010)
Corn straw,wheat bran, soy bran, corncob soy peel	β-Glucosidase	*Aspergillus sydowii* BTMFS 55 *Thermoascus aurantiacus* CBMAI 456	Madhu et al. (2009) Leite et al. (2008)
Coconut oil cake, black gram bran, and soybean	α-Amylase	*Aspergillus oryzae* *Aspergillus niger*	Ramachandran et al. (2004) Akpan et al. (1999)
Horticultural wastes Peanut shell	Laccase	*Trametes versicolor* *Pleurotus ostreatus*	Xin and Geng (2011) Mishra and Kumar (2007)
Wheat straw	Manganese peroxidase	*P. chrysosporium*	Fujian et al. (2001)
Sugarcane bagasse	Lignin peroxidase	*Pleurotus ostreatus, Phanerochaete chrysosporium*	Pradeep and Datta (2002)
Papaya waste	α-Amylase	*A. niger*	Sharanappa et al. (2011)
Fruits peel waste	Invertase	*A. niger*	Mehta and Duhan (2014)
Linseed oil cake	Lipase	*P. aeruginosa*	Dharmendra (2012)

hand, this can handle the problem of animal feed, while on the other hand, it can address protein enrichment. If the right technology are put in place, questions about agro-industrial waste valorization and protein energy malnutrition (PEM) can be addressed.

Antibiotic production

Agricultural wastes, such as maize cobs and sawdust, are used to make a variety of antibiotics. The utilisation of a low-cost carbon source derived from agro-industrial waste led to a significant reduction in the production cost of antibiotics, such as neomycin and rifamycin (Vastrad and Neelagund 2011). *Streptomyces rimosus* was used to make oxytetracycline using groundnut shell as a raw material (Tobias et al. 2012). Synthesis of extra cellular rifamycin B using oil cake as a raw material and *Amycolatopsis mediterranean* MTCC 14 by SSF was studied. Coconut oil cake and ground nut shell are reported to show maximum antibiotic production in comparison to other agro-industries waste (Arora et al. 2017).

Biodegradable plastics

Plastics have a wide range of applications in today's world due to their versatility and flexibility. Many single-use plastics, like disposable bags, cutlery, and wet wipes, are among the worst environmental offenders. Biodegradable plastic can be produced using various kinds of agro-industrial wastes, such as banana/fruit peels, cassava starch, cellulose, corn, wheat straw and rice straw (Mostafa et al. 2018; Broeren et al. 2017). Cassava is a useful source of starch for bioplastic synthesis since it is non-toxic, biocompatible, low-cost, and renewable carbon-rich organic raw material (Nanang and Heru 2018). Other starch-rich raw materials for biodegradable plastic production include potato starch (Karana 2012), potato peel (Spiller et al. 2020; Ezgi and Duygu 2019), and maize (Nasir and Butt 2011). Because they are readily available, nutrient-rich, and easily decomposable by bacteria, they are the best options for bioplastic production. *Bacillus licheniformis* and *Bacillus megaterium* produced polyhydroxybutyrate utiling wheat straw (Gasser et al. 2014).

Biocompounds: biostimulants, biocomposites and bioactive peptides

Many phytochemicals used in food, cosmetics and medicines have been identified in the barks, shells, husks, leaves, and roots of various fruits, vegetables and crops (Shirahigue and Antonini 2020; Usmani et al. 2020; Yusuf 2017). One such example are polyphenols, such as flavonoids, tannins, anthocyanins, and alkaloids. Phenolic compounds found in the plants have been used as food preservatives. Simple phenols like cresol, hydroquinone, and gallic acid are found in wood smoke used for food preservation (Quinto et al. 2019). Lampronti et al. 2013 extracted polyphenols (apigenin, oleuropein, and cyanidin chloride) from olive mill waste water and demonstrated their efficacy in cystic fibrosis cells by inhibiting NF kappa B/DNA complexes. NF kappa B activity is responsible for inflammation in cystic fibrosis, osteoporosis, rheumatoid arthritis and cancer. It is feasible to extract phenolic compounds using green technologies such as microwave or ultrasound assisted extraction (Panzella 2020). Another class of compounds generated from waste are biostimulants. The use of biostimulants improves plant nutrient use efficiency, potentially reducing the need for chemical fertilizers. These originate from organic waste streams, comprising vermicompost, sewage sludge, protein hydrolyzates, chitin and chitosan. If the valorization chain is well established, bio stimulants produced from by-products can be more widely employed (Xu and Geelen 2018).

Many biocomposites derived from agro-industrial wastes are structural compounds that can well replace wood, plastic, or glass-based materials in automobile components on one hand, and film and soft tissue scaffolds in the food, cosmetic, and medical industries on the other (Johnson et al. 2017). Bioplastics such as polylactic acid (PLA) can be made from maize or sugarcane, and their properties can be improved by adding cellulose nanofibers. These nanocomposites are used to make packaging films (Lau et al. 2010). Biocomposites of silk fibres (sericin and fibroin) with other resins like polyurethane, polyvinyl alcohol (PVA), chitosan or alginate are of great use in tissue engineering (Santos et al. 2020; Lau et al. 2010). Such biomaterials can be employed in regenerative medicine, as drug delivery vehicles, and wound dressings.

Bioactive peptides are yet another type of compounds that have potential for use in foods and pharmaceuticals. Bioactive peptides have various therapeutic properties, including cholesterol-lowering, antiprotozoal, antiviral, antithrombotic, antioxidant, antihypertensive and antimicrobial activities (Lemes et al. 2016). Table 5 shows some biocompounds produced from agro-industrial wastes.

As discussed in previous sections, the core notion of agro-industrial waste management lies in the adoption of new technologies that are both cost effective and ecologically safe. Table 6 lists a few cutting-edge studies along with their environmental advantages.

Agri-industrial waste utilization for improving soil health

Organic matter has long been recognised for its favourable effects on soil and the environment (Atalia et al. 2015). Farmyard manure (FYM) has traditionally been utilised as the primary organic amendment by farmers in many countries to improve soil quality and fertility (Lakhdar et al. 2010). However, in present scenario, using agro-industrial wastes as soil amendments has become an unconventional alternative to improve soil health and quality (Mandal et al. 2016) in a cost effective way (Zoghlami et al. 2016; Lakhdar et al. 2010). Zoghlami et al. (2016) reported that soil organic matter content and fertility were restored after two successive annual amendments with urban sewage sludge.

Effect on soil physical and chemical properties and nutrient availability

Many studies have shown that agro-industrial waste application increases soil organic carbon levels significantly, thereby improving soil tilth, aeration, pH, cation exchange capacity and microbial activity (Erana et al. 2019). Das and Dkhar (2012) reported press mud and bagasse (bio wastes from sugar cane industries) contains substantial amount of plant nutrients and bio degradable organic matter which improve soil physico-chemical properties. According to Raju et al. (2016), the press mud generated through sulphitation process, contains $CaSO_4$, which acts as a soil amendment in alkaline soils (Raju et al. 2016). Similarly, improved water holding capacity and electrical conductivity of soil with sugarcane industrial effluents (Raju et al. 2016); cotton ginning and paper mill discharge (Narasimha et al. 2009) have also been reported.

Using agricultural waste in the form of vermicompost enhances soil structure, making it more porous and permeable to air and water (Rekha et al. 2018). Walker and Bernal (2008) found that combining by-products from olive industries with poultry manure in the form of compost improved soil pH, soluble and exchangeable-K+, and soil CEC even under saline soil environment. Furthermore, Wang et al. (2014) reported that combining with furfural residue, sedge peat, pig manure and rice straw decreased EC, ESP, and bulk density of treated soil while increasing total porosity and organic C. Application of cassava-industrial waste compost (Oo et al. 2015) and gin crushed compost (Chattha et al. 2019) yielded similar results.

Researchers have further demonstrated the release of different organic acids during the decomposition of organic residues (Dotaniya et al. 2016), are responsible for the mobilization of P from fixed locations and its availability to plants (Dotaniya et al. 2016). P availability in soil and its availability to plants improved by application of bagasse and press mud from sugarcane industry (Dotaniya and Datta 2014); rice straw + pressmud (Dotaniya and Datta 2014). Rice straw and pressmud are the potential sources of silica and organic carbon and have been shown to greatly increase nutrient content (Baiyeri et al. 2019; Ghorbani et al. 2019; Hossain et al. 2018).

Effects on heavy metal immobilization in soil

Application of organic amendments generated from agro-industrial wastes help in the immobilization of toxic metals in soil, lowering their bioavailability to plants (Alvarenga et al. 2015; Khan et al. 2015; Sabir et al. 2013; Alamgir et al. 2011). This immobilizing capacity of organic residues is mainly due to the presence of acidic groups that can bind a wide range of metal (loids) viz., lead (Pb), cadmium (Cd), chromium (Cr), and copper (Cu) (Khanam et al. 2020; Lwin et al. 2018; Alvarenga et al. 2015). The most commonly used soil amendments to immobilise toxic metals in soil include biosolids, composts, and manures from various bio wastes, rice husk, straw, saw dust, and wood ash (Sabir et al. 2013).

Soil pH influences the in-solubilization and precipitation of toxic metals and also affects the formation of insoluble organic complexes (Walker et al. 2004). It is also the main parameter for monitoring changes in toxic metals in agro-waste treated soils (Huang et al. 2017). Secondly, soil organic

Table 5 Biocompounds from waste valorization from agriculture based industries

	Waste	Process	Application	References
Pigment				
Carotenoids	Glycerol, corn steep liquor and parboiled rice water	*Sporidiobolus pararoseu* fermentation	–	Valduga et al. (2014)
	Orange Waste	SSF by *Monoascus purpureus*	Food and Pharmaceutical industry	Kantifedaki et al. (2018)
Flexirubin	Pineapple waste	Fermentation by *Chryseobacterium artocarpi* and purification	Natural soap colorant	Aruldass et al. (2016)
Peptides				
Antioxidant activity	Sheep wool	Hydrolysis by *Bacillus pumilus* A1	–	Fakhfakh et al. (2013)
Antioxidant, ACE- and DPPH-IV inhibitory activities	Chicken feathers	Hydrolysis by *Chryseobacterium* sp. and purification	–	Fontoura et al. (2014)
Anti-oxidant and anti-tyrosinase activity	Liquid residue of Ricotta cheese production	Enzymatic hydrolysis by pancreatin and papain	Neutraceutical and cosmetic industry	Monari et al. (2019)
Chum salmon (Oncorhynchus keta) skin	ACE-inhibitory activity	Trypsin digestion	–	Lee et al. (2014)
Polyphenols and other bioactive compounds				
Catechins, theaflavins, and gallic acid	Black tea processing waste	Solvent extraction	Antimicrobial and antioxidant additives in food, pharma and cosmetic industry	Üstündag et al. (2016)
Acetogenin	Avacado seed	Solvent extraction	Antimicrobial food additive	Salinas-Salazar et al. (2016)
Biocomposites				
Chitin/chitosan	Shrimp waste	Protease + fermentation by Lactic acid bacteria	Tissue engineering, nanoparticle drug delivery, antimicrobial agent, food preservation and water treatment	Santos et al. (2020)
Cellulose biocomposites	Rice husk and coir pith	Reinforcement in epoxy matrix	Low load bearing needs	Prithvirajan et al. (2015)
Others				
Acetic acid	Onion waste	SSTF (Simultaneous saccharification and two step fermentation)	–	Kim et al. (2019)
Keratinase	Swine hair	Fermentation by *Fusarium oxysporum*	–	Preczeski et al. (2020)

Table 6 Innovative agro-industrial waste based products with their environmental impacts

Agro-industrial product	Agro-industrial waste	Agro-industrial waste recycling process	Agro-industrial waste based product	Environmental impacts	References
Oleaginous yeast based biodiesel production	De-oiled biomass carbohydrate, protein and some polar lipid fraction	Hydrothermal liquefaction of residual de-oiled biomass	Energy-dense bio-crude	CO_2 emissions reduction—16% sustainable way towards energy security	Chopra et al. (2020)
Potato products	Starch reclaimed from potato wastewater	Compounding	Starch plastics	Compared with petrochemical plastics reduce net GHG emissions reduction—up to 80%	Broeren et al. (2017)
Barley based alcoholic beverage	Brewer's spent grains	Autohydrolysis and fermentation	Bioethanol and xylooligosaccharides	Reducing residues production and resources consumption	González-García et al. (2018)
Food industry	Food waste	Purple non-sulfur bacteria photobioreactor,	Single cell protein	Improve environmental and/or economic viability	LaTurner et al. (2020)
Potato products	Potato wastewater	Fermentation	Microbial Protein for animal feed	Solution for contaminated wastewater contains pathogens and other harmful pollutants	Spiller et al. (2020)
Crop produce	Agricultural waste	Gasification for biochar production	Raw mulch and biochar	Maintains soil moisture, soil nutrients, soil organic C, and soil biological activity	Dey et al. (2020)

matter is considered as an important absorbent for metal ions in soil with 4–50 times higher cation exchange capacity compared to clay (Hamdi et al. 2019). The strong negative charge generated through the dissociation of organic acids strongly binds the positively charged metal in soil. Researchers revealed that the application of organic matter by wastes application enhances the fixation of toxic metals and reduces their mobility, phytotoxicity (Hamdi et al. 2019) and the bioavailability (Huang et al. 2017; Fleming et al. 2013). Many researchers reported variable responses of heavy metals to compost application in soil. For example, the affinity of organoc matter (OM) for arsenic (As) was less compared to other cationic metals; Cu availability reduced, but As availability was raised (Fleming et al. 2013). In contrast, Clemente et al. (2010) reported increased solubility and mobility of As and Cu in soil when treated with green wastes. Application of olive husk compost reduced the availability of Pb by forming complex with humic substances (de la Fuente et al. 2011). Similar results were reported by Zhou et al. (2012) in alkaline soil environment. However, direct application of untreated agro-industrial wastes or immature composts may have a deleterious effect on crop growth as they contain relatively high soluble OM content (Huang et al. 2017).

Effects on soil biological properties

Soil microorganisms are very essential for long-term sustainability of agricultural systems as they can control various soil processes which are important for soil formation and nutrient cycling (Li et al. 2017). Soil microbes are the living entity of soil and also important aspect of soil quality (Jacoby et al. 2017; Osman 2013). Addition of organic matter from agro-industrial waste, produces manure which greatly affects the activity and diversity of soil microbes as well as soil quality (Liu et al. 2010). The diverse group of soil microorganisms mineralize soil organic matter (SOM) to recycle the organic carbon (C) and nutrients from their unavailable form to available form, thus, they not only act as a source but also a sink for available C and nutrients in soil (Sharma and Garg 2019). Sole application of manure compost enhances soil respiration and enzyme activities ($p < 0.01$), by increasing the number of cultivable microorganisms as well as microbial biomass. In combination with bacterial bio-fertilizers this can improve the structure and diversity of microbial community in degraded soils (Zhen et al. 2014). Further, combined application of compost and inorganic fertilizer for 32 years increased microbial biomass carbon (MBC) by 89% (Nayak et al. 2007). When compared to composted swine manure, composted cattle manure increased the species richness. Cattle manure commonly decomposes complex organic compounds in a better way and play important roles in plant growth and lignocellulose degradation (Das et al. 2017). Crushed Cotton gin compost (CCGC) is prepared from the by-product of cotton industry, and used to recover degraded soils in semiarid regions (Tejada et al. 2006).

It was also found that vermicompost based on agro-industrial waste has the potential to be used as a substitute of FYM to improve and maintain the microbial activity even in an alkaline calcareous soil of Mediterranean region of Turkey (Uz and Tavali 2014). The relative abundance of beneficial fungi increases, and pathogenic fungi decreases in vermicompost amended soil compared to the other organic amendments (Zhao et al. 2017). In rice–wheat system, crop residue retention with green manuring and zero tillage significantly increased organic carbon, MBC, basal respiration, microbial quotient and mineralization quotient in soil (Saikia et al. 2020). The vast number of by-products generated by sugarcane industries, such as press mud, bagasse, vinasse, and molasses, have a storage problems across the countries (Dotaniya et al. 2016). Among the by-products, press mud alone contains 21% organic C and other macro- and micro-nutrients, which promote the growth and activity of soil microbes (Dey et al. 2020) and also functions as substrate in the bio-composting processing (Chand et al. 2011). Several researchers documented the vital role of sugarcane by-products like filter cake (Chattha et al. 2019); pressmud and bagasse (Dotaniya et al. 2016); molasses (Boopathy et al. 2001) in improving soil organic carbon, MBC and microbial diversity and population (Singh et al. 2009). The populations of bacteria, fungi and actinomycetes, biomass C and N contents increased in press mud and vinasse amended soils compared to the chemical fertilizer treated soil. Besides, the activity of different enzymes such as phosphatase, cellulase, and aminopeptidase were higher with press mud treatment compared to the chemical fertilizer. Hence, press mud and vinasse can be used as a potential substitute to chemical fertilizers. These not only improve soil health and sugarcane productivity, but they can also be disposed off without polluting the environment (Yang et al. 2013).

Conclusion

The valorisation and subsequent value addition of agro-industrial wastes not only enables waste recycling in eco-friendly manner, but also helps to reduce production costs while promoting economic development and societal upliftment. This paves the way for a circular economy model in the agriculture sector, in which waste becomes transient phase and reintegrated into the economy. There are numerous ways to utilise agro-industrial wastes for the production of value-added products such biofuels, microbial enzymes, single cell protein, bio compounds, bioplastics and soil amendments. The use of existing products to produce new products reduces investment and production costs. Undoubtedly, regulatory policies, markets and waste specific research are required to convert agro-industrial wastes into valuable commodities.

Soil health is of paramount importance in agriculture sector. The use of agro-industrial waste for improving soil health or treating the soil is also taking momentum and providing better and sustainable alternative to the current practices. Handling of agro-industrial waste adds a significant cost to an agro-based industry in terms of space, transportation and safe disposal. Their sustainability depends on gradual adoption of innovative approaches that are both cost-effective and eco-friendly. The rice burning and associated issues are such an example. In future there is potential of further research in the field of naturally rich wastes containing vitamins, fibres, lignin and cellulose, proteins, lipids, polyphenols and pectin, sugars, etc. These factors make agro-industrial wastes very promising candidates for development of future circular economy. Among many other agro-industrial wastes, lignocellulose residues are considered as the biggest renewable resource on planet earth and have huge potential applications as biofertilizers and in biofuel generation.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Abdulgader M, Yu J, Zinatizadeh AA, Williams P, Rahimi Z (2019) Process analysis and optimization of single stage flexible fibre biofilm reactor treating milk processing industrial wastewater using response surface methodology (RSM). Chem Eng Res Des 149:169–181

Abdullah J, Greetham D (2016) Optimizing cellulase production from municipal solid waste (MSW) using solid state fermentation (SSF). J Fundam Renew Energy Appl. https://doi.org/10.4172/2090-4541.1000206

Acevedo MD, Urena LJB, García FJC, Ferre FC (2020) Agricultural waste: review of the evolution, approaches and perspectives on alternative uses. Glob Ecol Conserv 22:1–23

Adeniran HA, Abiose SH, Ogunsua AO (2010) Production of fungal β-amylase and amyloglucosidase on some Nigerian agricultural residues. Food Bioprocess Technol 3:693–698

Adrio JL, Demain AL (2014) Microbial enzymes: tools for biotechnological processes. Biomolecules 4:117–139

Agrawal T, Jadhav SK, Quraishi A (2019) Bioethanol production from an agro-waste, deoiled rice bran by *Saccharomyces cerevisiae* MTCC 4780 via optimization of fermentation parameters. Int J Thai Soc High Educ Inst Environ Environ Asia 12(1):20–24

Akpan I, Bankole MO, Adesemowo AM, Latunde DG (1999) Production of amylase by *A. niger* in a cheap solid medium using rice bran and agricultural materials. Trop Sci 39:77–79

Alamgir M, Kibria MG, Islam M (2011) Effects of farmyard manure on cadmium and lead accumulation in Amaranth (*Amaranthus oleracea* L.). J Soil Sci Environ 2(8):237–240

Alauddin ZABZ, Lahijani P, Mohammadi M, Mohamed AR (2010) Gasification of lignocellulosic biomass in fluidized beds for renewable energy development: a review. Renew Sustain Energy Rev 14(9):2852–2862

Alemu T (2013) Process of optimization and characterization of protein enrichment of orange wastes through solid state fermentation by *Aspergillus niger* isolate No. 5. J Biol Sci 13(5):341–348

Alvarenga P, Mourinha C, Farto M, Santos T, Palma P, Sengo J, Morais MC, Cunha-Queda C (2015) Sewage sludge, compost and other representative organic wastes as agricultural soil amendments: Benefits versus limiting factors. J Waste Manag 40:44–52

Al-Weshahy A, Rao VA (2012) Potato peel as a source of important phytochemical antioxidant nutraceuticals and their role in human health—a review. In: Rao V (ed) Phytochemicals as nutraceuticals-global approaches to their role in nutrition and health. IntechOpen

Amutio M, Lopez G, Aguado R, Bilbao J, Olazar M (2012) Biomass oxidative flash pyrolysis: autothermal operation, yields and product properties. Energy Fuels 26(2):1353–1362

Ansi L (2017) Comparative studies of the effect of different microorganisms on coir pith composting. Ind J Life Sci 6(1):55

Arora K, Sharma S, Krishna SB, Adam JK, Kumar A (2017) Non-edible oil cakes as a novel substrate for DPA production and augmenting biocontrol activity of *Paecilomyces variotii*. Front Microbiol 8:753

Arruda LFD, Borghesi R, Oetterer M (2007) Use of fish waste as silage: a review. Braz Arch Biol Technol 50(5):879–886

Aruldass CA, Aziz A, Venil CK, Khasim AR, Ahmad WA (2016) Utilization of agro-industrial waste for the production of yellowish orange pigment from *Chryseobacteirum artocarpi* CECT 8497. Int Biodeterior Biodegrad 113:342–349

Aruna TE, Aworh OC, Raji AO, Olagunju AI (2017) Protein enrichment of yam peels by fermentation with *Saccharomyces cerevisiae* (BY4743). Ann Agric Sci 62:33–37

Atalia KR, Buha DM, Bhavsar KA, Shah NK (2015) A review on composting of municipal solid waste. J Environ Sci Toxicol Technol 9(5):20–29

Babu BR, Parande AK, Raghu S, Kumar TP (2007) Cotton textile processing: waste generation and effluent treatment. J Cotton Sci 11:141–153

Baiyeri KP, Chukwudi UP, Chizaram CA, Aneke N (2019) Maximizing rice husk waste for Daucus carota production. Int J Recycl Org Waste Agric 8(1):399–406

Banu JR, Kavitha S, Kannah RY, Kumar MD, Atabani AE, Kumar G (2020) Biorefinery of spent coffee grounds waste: viable pathway towards circular bioeconomy. Bioresour Technol 302:122821

Barba DF, Beolchini D, Cifoni FV (2001) Whey protein concentrate production in a pilot scale two-stage diafiltration process. Sep Sci Technol 36:587–603

Barcelos MCS, Ramos CL, Kuddus M (2020) Enzymatic potential for the valorization of agro-industrial by-products. Biotechnol Lett 42(10):1799–1827. https://doi.org/10.1007/s10529-020-02957-3

Baumgardner ME, Vaughn TL, Lakshminarayanan A, Olsen D, Ratcliff MA, McCormick RL, Marchese AJ (2015) Combustion of lignocellulosic biomass based oxygenated components in a compression ignition engine. Energy Fuels 29(11):7317–7326

Bharathiraja S, Suriya J, Krishnan M, Manivasagan P, Kim SK (2017) Production of enzymes from agricultural wastes and their potential industrial applications. Adv Food Nutr Res 80:125–148

Bhaskar N, Modi VK, Govindaraju K, Radha C, Lalitha RG (2007) Utilization of meat industry by products: protein hydrolysate from sheep visceral mass. Bioresour Technol 98:388–394

Bhumiratna A, Flegel TW, Glinsukon T, Somporan W (1980) Isolation and analysis of moulds from soy sauce koji in Thailand. Appl Environ Microbiol 39:430–435

Biswas B, Pandey N, Bisht Y, Singh R, Kumar J, Bhaskar T (2017) Pyrolysis of agricultural biomass residues: comparative study of corn cob, wheat straw, rice straw and rice husk. Bioresour Technol 237:57–63

Bone DH, Munoz EL (1984) Solid-state fermentation of oat straw by *Poyporus* spp. Biotechnol Lett 6(10):657–662

Boopathy R, Beary T, Templet PJ (2001) Microbial decomposition of post-harvest sugarcane residue. Bioresour Technol 79(1):29–33

Bos A, Hamelinck C (2014) Greenhouse gas impact of marginal fossil fuel use. Project number: BIENL14773 2014. https://www.sugarcane.org/wp-content/uploads/2020/12/ecofys-2014-ghg-impact-of-marginal-fossil-fuels.pdf

Broeren MLM, Kuling L, Worrell E, Shen L (2017) Environmental impact assessment of six starch plastics focusing on wastewater-derived starch and additives. Resour Conserv Recycl 127:246–255

Buenrostro J, Ascacio A, Sepulveda L, De la Cruz R, Prado-Barragan A, Aguilar-Gonzalez MA, Rodriguez R, Aguilar CN (2013) Potential use of different agro-industrial by products as supports for fungal ellagitannase production under solid state fermentation. Food Bioprod Process 92(4):376–382

Caldeira C, De Laurentiis V, Corrado S, van Holsteijn F, Sala S (2019) Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. Resour Conserv Recycl 149:479–488

Chand K, Shahi NC, Lohani UC, Garg SK (2011) Effect of storage conditions on keeping qualities of jaggery. Sugar Tech 13(1):81–85

Chattha MU, Hassan MU, Barbanti L, Chattha MB, Khan I, Usman M, Ali A, Nawaz M (2019) Composted sugarcane by-product press mud cake supports wheat growth and improves soil properties. Int J Plant Prod 13(3):241–249

Chopra J, Tiwari BR, Dubey BK, Sen R (2020) Environmental impact analysis of oleaginous yeast based biodiesel and bio-crude production by life cycle assessment. J Clean Prod 271(122349):1–10

Clemente R, Hartley W, Riby P, Dickinson NM, Lepp NW (2010) Trace element mobility in a contaminated soil two years after field-amendment with a green waste compost mulch. Environ Pollut 158(5):1644–1651

Costa A, Alfaia RGDSM, Campos J (2019) Landfill leachate treatment in Brazil – An overview. J Environ Manage 232:110–116

Das BB, Dkhar M (2012) Organic amendment effects on microbial population and microbial biomass carbon in the rhizosphere soil of soybean. Commun Soil Sci Plant Anal 43:1938–1948

Das S, Jeong ST, Das S, Kim PJ (2017) Composted cattle manure increases microbial activity and soil fertility more than composted swine manure in a submerged rice paddy. Front Microbiol 8(1702):1–10

de la Fuente C, Clemente R, Martinez-Alcala I, Tortosa G, Bernal MP (2011) Impact of fresh and composted solid olive husk and their water-soluble fractions on soil heavy metal fractionation; microbial biomass and plant uptake. J Hazard Mater 186:1283–1289

Dey D, Gyeltshenb T, Aicha A, Naskarc M, Roy A (2020) Climate adaptive crop-residue management for soil-function improvement; recommendations from field interventions at two agroecological zones in South Asia. Environ Res 183:109164

Dharmendra KP (2012) Production of lipase utilizing linseed oilcake as fermentation substrate. Intl J Sci Environ Technol 1:135–143

Dimitriadis A, Bezergianni S (2017) Hydrothermal liquefaction of various biomass and waste feedstocks for biocrude production: a state-of-the-art review. Renew Sustain Energy Rev 68:113–125

Domínguez-Perles R, Martínez-Ballesta MC, Carvajal M, García-Viguera C, Moreno DA (2010) Broccoli-derived by-products—a promising source of bioactive ingredients. J Food Sci 75:383–392

Donner M, Romane G, Hugode V (2020) A new circular business model typology for creating value from agro-waste. Sci Total Environ 716:137065

Dotaniya ML, Datta SC (2014) Impact of bagasse and press mud on availability and fixation capacity of phosphorus in an Inceptisol of north India. Sugar Tech 16(1):109–112

Dotaniya ML, Datta SC, Biswas DR, Dotaniya CK, Meena BL, Rajendiran S, Regar KL, Lata M (2016) Use of sugarcane industrial by-products for improving sugarcane productivity and soil health. Int J Recycl Org Waste Agric 5(3):185–194

Duhan JS, Kumar A, Tanwar SK (2013) Bioethanol production from starchy part of tuberous plant (potato) using *Saccharomyces cerevisiae* MTCC-170. Afr J Microbiol Res 7:5253–5260

Ekinci MS, Gürü M (2014) Extraction of oil and β-sitosterol from peach (*Prunus persica*) seeds using supercritical carbon dioxide. J Supercrit Fluids 92:319–323

El-Naggar N, Abdelwahed NA, Saber WI, Mohamed AA (2014) Bioprocessing of some agro-industrial residues for endoglucanase production by the new subsp; *Streptomyces albogriseolus* subsp. cellulolyticus strain. Braz J Microbiol 45(2):743–756

Erana FG, Tenkegna TA, Asfaw SL (2019) Effect of agro industrial wastes compost on soil health and onion yields improvements: study at field condition. Int J Recycl Org Waste Agric 8:161–171

Ezgi B, Duygu BH (2019) Production of bioplastic from potato peel waste and investigation of its biodegradability. Int Adv Res J Sci Eng Technol 3(02):93–97

Fakhfakh N, Ktari N, Siala R, Nasri M (2013) Wool-waste valorization: production of protein hydrolysate with high antioxidative potential by fermentation with a new *keratinolytic bacterium*, *Bacillus pumilus* A1. J Appl Microbiol 115:424–433

FAO (2019) The state of food and agriculture—moving forward on food loss and waste reduction. Rome. Licence: CC BY-NC-SA 3.0 IGO. http://www.fao.org/3/ca6030en/ca6030en.pdf

Ferdosh ZI, Sarker N, Norulaini A, Oliveira K, Yunus AJ, Chowdury J, Akanda M (2015) Quality of tuna fish oils extracted from processing the by-products of three species of neritic tuna using supercritical carbon dioxide. J Food Process Preserv 39:432–441. https://doi.org/10.1111/jfpp.12248

Fleming M, Tai Y, Zhuang P, McBride MB (2013) Extractability and bioavailability of Pb and as in historically contaminated orchard soil: effects of compost amendments. Environ Pollut 177:90–97

Fontoura R, Daroit DJ, Correa APF, Meira SMM, Mosquera M, Brandelli A (2014) Production of feather hydrolysates with antioxidant, angiotensin-I converting enzyme- and dipeptidyl peptidase-IV-inhibitory activities. New Biotechnol 31:506–513

Fuentes-Alventosa JM, Jaramillo-Carmona S, Rodríguez-Gutiérrez G, Guillén-Bejarano R, Jiménez-Araujo A, Fernández-Bolaños J, Rodríguez-Arcos R (2013) Preparation of bioactive extracts from asparagus by-product. Food Bioprod Process 91:74–82

Fujian X, Hongzhang C, Zuohu L (2001) Solid-state production of lignin peroxidase (lip) and manganese peroxidase (Mnp) by *Phanerochaete chrysosporium* using steam-exploded straw as substrate. Bioresour Technol 80(2):149–151

Gasser E, Ballmann P, Droge S, Bohn J, Konig H (2014) Microbial production of biopolymers from the renewable resource wheat straw. J Appl Microbiol 117:1035–1044

Ghorbani M, Asadi H, Abrishamkesh S (2019) Effects of rice husk biochar on selected soil properties and nitrate leaching in loamy sand and clay soil. Int Soil Water Conserv Res 7(3). https://doi.org/10.1016/j.iswcr.2019.05.005

González-García S, Morales PC, Gullón B (2018) estimating the environmental impacts of a brewery waste-based biorefinery: bioethanol and xylooligosaccharides joint production case study. Ind Crops Prod 123:331–340

Gupta GK, Shukla P (2020) Insights into the resources generation from pulp and paper industry wastes: challenges, perspectives and innovations. Bioresour Technol 297:122496. https://doi.org/10.1016/j.biortech.2019.122496

Hamdi H, Hechmi S, Khelil MN, Zoghlami IR, Benzarti S, Mokni-Tlili S, Hassen A, Jedidi N (2019) Repetitive land application of urban sewage sludge: effect of amendment rates and soil texture on fertility and degradation parameters. CATENA 172:11–20

Hesseltine CW (1972) Biotechnology report: solid-state fermentations. Biotechnol Bioeng 14:517–532

Hossain SS, Mathur L, Roy PK (2018) Rice husk/rice husk ash as an alternative source of silica in ceramics: a review. J Asian Ceram Soc 6(4):299–313

Huang C, Zeng G, Huang D, Lai C, Xu P, Zhang C, Cheng M, Wan J, Hu L, Zhang Y (2017) Effect of *Phanerochaete chrysosporium* inoculation on bacterial community and metal stabilization in lead-contaminated agricultural waste composting. Bioresour Technol 243:294–303

Ingale S, Joshi SJ, Gupte A (2014) Production of bioethanol using agricultural waste: banana pseudo stem. Braz J Microbiol 45(3):885–892

Jacoby R, Peukert M, Succurro A, Koprivova A, Kopriva S (2017) The role of soil microorganisms in plant mineral nutrition—current knowledge and future directions. Front Plant Sci 8(1617):1–19

James GS (2020) Sources of water pollution. Natural Water Remediation Chemistry and Technology, Oxford, pp 165–198

Jayathilakan K, Sultana K, Radhakrishna K, Bawa AS (2012) Utilization of byproducts and waste materials from meat, poultry and fish processing industries: a review. J Food Sci Technol 49(3):278–293

Jeff S, Prasad M, Agamuthu P (2017) Asia waste management outlook. UNEP Asian waste management outlook. United Nations Environment Programme Nairobi, Kenya

Johnson RDJ, Prabu VA, Amuthakkannan P, Arun K (2017) A review on biocomposites and bioresin based composites for potential industrial applications. Rev Adv Mater Sci 48:112–121

Kantifedaki A, Kachrimanidou V, Mallouchos A, Papanikolaou S, Koutinas AA (2018) Orange processing waste valorisation for the production of biobased pigments using the fungal strains *Monascus purpureus* and *Penicillium purpurogenum*. J Clean Prod 185:882–890

Kanwal S, Chaudhry N, Munir S, Sana H (2019) Effect of torrefaction conditions on the physicochemical characterization of agricultural waste (sugarcane bagasse). Waste Manag 88:280–290

Karana E (2012) Characterization of 'natural' and 'high-quality' materials to improve perception of bioplastics. J Clean Prod 37:316–325

Khan S, Malik A (2018) Toxicity evaluation of textile effluents and role of native soil bacterium in biodegradation of a textile dye. Environ Sci Pollut Res 25(5):4446–4458

Khan F, Khan MJ, Samad A, Noor Y, Rashid M, Jan B (2015) In-situ stabilization of heavy metals in agriculture soils irrigated with untreated wastewater. J Geochem Explor 159:1–7

Khanam R, Kumar A, Nayak AK, Shahid M, Tripathi R, Vijayakumar S, Bhaduri D, Kumar U, Mohanty S, Panneerselvam P, Chatterjee D (2020) Metal (loid) s (As, Hg, Se, Pb and Cd) in paddy soil: Bioavailability and potential risk to human health. Sci Total Environ 699:134330

Kim KH, Kabir E, Jahan SA (2017) Exposure to pesticides and the associated human health effects. Sci Total Environ 575:525–535

Kim HM, Choi IS, Lee S, Yang JE, Jeong SG, Park JH, Ko SH, Hwang IM, Chun HH, Wi SG, Kim JC, Park HW (2019) Biorefining process of carbohydrate feedstock (agricultural onion waste) to acetic acid. ACS Omega 4:22438–22444

Koutinas AA, Malbranque F, Wang RH, Campbell GM, Webb C (2007) Development of an oat-based biorefinery for the production of lactic acid by *Rhizopus oryzae* and various value added co-products. J Agric Food Chem 55:1755–1761

Kruse A, Funke A, Titirici MM (2013) Hydrothermal conversion of biomass to fuels and energetic materials. Curr Opin Chem Biol 17(3):515–521

Kulikowska D, Sindrewicz S (2018) Effect of barley straw and coniferous bark on humification process during sewage sludge composting. Waste Manag 79:207–213

Kumar V, Chopra AK (2016) Effects of sugarcane pressmud on agronomical characteristics of hybrid cultivar of eggplant (*Solanum melongena* L.) under field conditions. Int J Recycl Org Waste Agric 5:149–162

Kumar A, Duhan JS, Gahlawat SK (2014) Production of ethanol from tuberous plant (sweet potato) using *Saccharomyces cerevisiae* MTCC170. Afr J Biotechnol 13(28):2874–2883

Kumar A, Sadh PK, Surekha DJS (2016) Bio-ethanol production from sweet potato using co-culture of saccharolytic molds (*Aspergillus* spp.) and *Saccharomyces cerevisiae* MTCC170. J Adv Biotechnol 6(1):822–827

Kumla J, Suwannarach N, Sujarit K (2020) Cultivation of mushrooms and their lignocellulolytic enzyme production through the utilization of agro-industrial waste. Molecules 25(12):2811

Kurnik K, Krzyżyński M, Tredef K, Tretyn A, Tyburski J (2018) Study on utilizing solid food industry waste with brewers' spent grain and potato pulp as possible peroxidase sources. J Food Biochem 42:12446

Lakhdar A, Scelza R, Scotti R, Rao MA, Jedidi N, Gianfreda L, Abdelly C (2010) The effect of compost and sewage sludge on soil biologic activities in salt affected soil. Revista De La Ciencia Del Suelo y Nutrición Vegetal 10(1):40–47

Lampronti I, Borgatti M, Vertuani S, Manfredini S, Gambari R (2013) Modulation of the expression of the pro inflammatory IL-8 gene in cystic fibrosis cells by extracts deriving from olive mill waste water. Evid Based Complement Altern Med 960603:1–11

LaTurner ZW, Bennett GN, San K, Stadler LB (2020) Single cell protein production from food waste using purple nonsulfur bacteria shows economically viable protein products have higher environmental impacts. J Clean Prod 276:123114

Lau KT, Ho MP, Yeung CTA, Cheung HY (2010) Biocomposites: their multifunctionality. Int J Smart Nano Mater 1:13–27

Le RK, Mahan KM, Ragauskas AJ (2019) Rhodococcus and yarrowia-based lipid production using lignin-containing industrial residues. In: Balan V (ed) Microbial lipid production. Methods in molecular biology, vol 1995. Humana, New York. https://doi.org/10.1007/978-1-4939-9484-7_5

Lee JK, Jeon JK, Byun HG (2014) Antihypertensive effect of novel angiotensin I converting enzyme inhibitory peptide from chum salmon (*Oncorhynchus keta*) skin in spontaneously hypertensive rats. J Funct Foods 7:381–389

Leite RSR, Alves-Prado HF, Cabral H, Pagnocca FC, Gomes E, Da-Silva R (2008) Production and characteristics comparison of crude glucosidases produced by microorganisms *Thermoascus aurantiacus* and *Aureobasidium pullulansin* agricultural wastes. Enzyme Microb Technol 43:391–395

Leite P, Salgado JM, Venâncio A, Domínguez JM, Belo I (2016) Ultrasounds pretreatment of olive pomace to improve xylanase and cellulase production by solid-state fermentation. Bioresour Technol 214:737–746

Lemes AC, Sala L, Ores JC, Braga ARC, Egea MB, Fernandes KF (2016) A Review of the latest advances in encrypted bioactive peptides from protein-rich waste. Int J Mol Sci 17:1–24

Li S, Li D, Li J, Li G, Zhang B (2017) Evaluation of humic substances during co-composting of sewage sludge and corn stalk under different aeration rates. Bioresour Technol 245:1299–1302

Li SY, Ng IS, Chen PT, Chiang CJ, Chao YP (2018) Biorefining of protein waste for production of sustainable fuels and chemicals. Biotechnol Biofuels 11:256

Liu E, Yan C, Mei X, He W, So HB, Ding L, Liu Q, Liu S, Fan T (2010) Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. Geoderma 158:173–180

Luo L, Voet E, Huppes G (2010) Biorefining of lignocellulosic feedstock-technical, economic and environmental considerations. Bioresour Technol 101:5023–5032

Lwin CS, Seo BH, Kim HU, Owens G, Kim KR (2018) Application of soil amendments to contaminated soils for heavy metal immobilization and improved soil quality—a critical review. Soil Sci Plant Nutr 64(2):156–167

Madej JP, Nowaczyk RM, Janeczek M, Chrószcz A, Korczyński M (2017) The effect of dietary supplementation with chromium-enriched soya meal on lymphatic cells in caecal tonsil of laying hens. Anim Feed Sci Technol 223:53–58

Madhu KM, Beena PS, Chandrasekaran M (2009) Extracellular B-glucosidase production by a marine *Aspergillus Sydowii* BTMFS 55 under solid state fermentation using statistical experimental design. Biotechnol Bioprocess Eng 14(4):457–466

Mahawar M, Singh A, Kumbhar BK, Sahgal M, Chand K (2012) Solid state fermentation of apple pomace as affected by combinations of enzymatic treatment and yeast strains. J Progress Agric 3(1):59–62

Maiti S, Sarma SJ, Brar SK, Le Bihan Y, Drogui P, Buelna G, Verma M (2016) Agro-industrial wastes as feed stock for sustainable bio-production of butanol by *Clostridium beijerinckii*. Food Bioprod Process 98:217–226

Mandal S, Thangarajan R, Bolan NS, Sarkar B, Khan N, Ok YS, Naidu R (2016) Biochar-induced concomitant decrease in ammonia volatilization and increase in nitrogen use efficiency by wheat. Chemosphere 142:120–127

Manyi-Loh C, Mamphweli S, Meyer E, Okoh A (2018) Antibiotic use in agriculture and its consequential resistance in environmental sources: potential public health implications. Molecules 23(4):795

Marzo C, Díaz AB, Caro I, Blandino A (2019) Valorization of agro-industrial wastes to produce hydrolytic enzymes by fungal solid-state fermentation. Waste Manag Res 37(2):149–156

Mehta K, Duhan JS (2014) Production of invertase from *Aspergillus niger* using fruit peel waste as a substrate. Intern J Pharm Biol Sci 5(2):B353–B360

Merel S, Walker D, Chicana R, Snyder S, Baurès E, Thomas O (2013) State of knowledge and concerns on cyanobacterial blooms and cyanotoxins. Environ Int 59:303–327

Meyer S, Glaser B, Quicker P (2011) Technical, economical, and climate-related aspects of biochar production technologies: a literature review. Environ Sci Technol 45(22):9473–9483

Mirabella N, Castellani V, Sala S (2014) Current options for the valorisation of food manufacturing waste: a review. J Clean Prod 65:28–41

Mishra A, Kumar S (2007) Cyanobacterial biomass as N-supplement to agro-waste for hyper-production of laccase from *Pleurotus ostreatusin* solid state fermentation. Process Biochem 42(4):681–685

MOFPI (2020) Ministry of food processing industries Government of India. Annu Rep 2019–20:1–105

Monari S, Ferri M, Russo C, Prandi B, Tedeschi T, Bellucci P, Zambrini AV, Donati E, Tassoni A (2019) Enzymatic production of bioactive peptides from scotta, an exhausted by-product of ricotta cheese processing. PLoS One. https://doi.org/10.1371/journal.pone.0226834

Mondal AK, Sengupta S, Bhowal J, Bhattacharya D (2012) Utilization of fruit wastes in producing single cell protein. Int J Sci Environ Technol 1:430–438

Mostafa NA, Farag AA, Abo-dief HM, Tayeb AM (2018) Production of biodegradable plastic from agricultural wastes. Arab J Chem 11(4):546–553

Moyin-Jesu EI (2015) Use of different organic fertilizers on soil fertility improvement, growth and head yield parameters of cabbage (*Brassica oleraceae* L.). Int J Recycl Org Waste Agric 4:291–298

Mushimiyimana I, Tallapragada P (2016) Bioethanol production from agro wastes by acid hydrolysis and fermentation process. J Sci Ind Res 75:383–388

Nanang W, Heru S (2018) Properties of cassava starch based bioplastic reinforced by nanoclay. J Mech Eng Sci Technol. https://doi.org/10.17977/um016v2i12018p020

Narasimha G, Babu GV, Reddy BR (2009) Physico-chemical and biological properties of soil samples collected from soil contaminated with effluents of cotton ginning industry. J Environ Biol 20:235–239

Nasir M, Butt MS (2011) Maize germ: a nutrient dense substance for food value-addition. LAP Lambert Academic Publishing, Berlin, p 240

Nayak DR, Babu YJ, Adhyaa TK (2007) Long-term application of compost influences microbial biomass and enzyme activities in a tropical Aeric Endoaquept planted to rice under flooded condition. Soil Boil Biochem 39:1897–1906

NPMCR (2019) online: http://agricoop.nic.in/sites/default/files/NPMCR_1.pdf. Accessed 15 Dec 2020

Okoro OV, Sun Z, Birch J (2017) Meat processing waste as a potential feedstock for biochemicals and biofuels—a review of possible conversion technologies. J Clean Prod 142:583–1608

Oliveira DA, Benelli P, Amante ER (2013) A literature review on adding value to solid residues: egg shells. J Clean Prod 46:42–47

Oliveira F, Carlos ES, Peclat Veronica ROL, Salgado JM, Bernardo DR, Maria AZC, Armando V, Isabel B (2017) Optimization of lipase production by *Aspergillus ibericusfrom* oil cakes and its application in esterification reactions. Food Bioprod Process. https://doi.org/10.1016/j.fbp.2017.01.007

Oo AN, Iwai CB, Saenjan P (2015) Soil properties and maize growth in saline and nonsaline soils using cassava-industrial waste compost and vermicompost with or without earthworms. Land Degrad Dev 26(3):300–310

Osman KT (2013) Biological properties of soils. In: Osman KT (ed) Soils principles, properties and management. Springer, Dordrecht, pp 113–128

Panzella L (2020) Natural phenolic compounds for health, food and cosmetic applications. Antioxidants 9(5):427. https://doi.org/10.3390/antiox9050427

Paritosh K, Kushwaha SK, Yadav M, Pareek N, Chawade A, Vivekanand V (2017) Food waste to energy: an overview of sustainable approaches for food waste management and nutrient recycling. Biomed Res Int. https://doi.org/10.1155/2017/2370927

Paseephol T, Small DM, Sherkat F (2008) Lactulose production from milk concentration permeate using calcium carbonate-based catalysts. Food Chem 111:283–290

Pathak C, Chopra AK, Srivastava S (2013) Accumulation of heavy metals in *Spinacia oleracea* irrigated with paper mill effluent and sewage. Environ Monit Assess. https://doi.org/10.1007/s10661-013-3104-8

Patidar MK, Nighojkar S, Kumar A, Nighojkar A (2018) Pectinolytic enzymes-solid state fermentation, assay methods and applications in fruit juice industries: a review. Biotech 8(4):199

Pradeep V, Datta M (2002) Production of ligninolytic enzymes for decolorization by cocultivation of white-rot fungi *Pleurotus ostreatus* and *Phanerochaete chrysosporium* under solid-state fermentation. Appl Biotechnol Biochem 102–103(1–6):109–118

Prado FC, Vandenberghe LPS, Lisboa C, Paca J, Pandey A, Soccol CR (2004) Relation between citric acid production and respiration rate of *Aspergillus niger* in solid state fermentation. Eng Life Sci 4(2):179–186

Prasertsan P, Prasertsan S, HKittikun A (2011) Recycling of agro-industrial wastes through cleaner technology. Biotechnology 10. https://www.eolss.net/Sample-Chapters/C17/E6-58-09-02.pdf

Preczeski KP, Dalastra C, Czapela FF, Kubeneck S, Scapini T, Camargo AF, Zanivan J, Bonatto C, Stefanski FS, Venturin B, Fongaro G, Treichel H (2020) *Fusarium oxysporum* and *Aspergillus* sp. as keratinase producers using swine hair from agroindustrial residues. Front Bioeng Biotechol 8:1–8

Prema P, Thakur MS, Prapulla SG, Ramakrishnan SV, Lonsane BK (1988) Production of gibberellic acid by solid-state fermentation. Indian J Microbiol 28:78–81

Prithivirajan R, Jayabal S, Bharathiraja G (2015) Bio-based composites from waste agricultural residues: mechanical and morphological properties. Cellul Chem Technol 49:65–68

Quinto EJ, Caro I, Delgado LHV, Mateo J, Silleras BDM, Río MPRD (2019) Food safety through natural antimicrobials. Antibiotics 8:208–238

Raju MN, Golla N, Vengatampalli R (2016) Soil enzymes: influence of sugar industry effluents on soil enzyme activities. Springer, Berlin, p 51

Ramachandran S, Patel AK, Nampoothiri KM, Francis F, Nagy V, Szakacs G, Pandey A (2004) Coconut oil cake—a potential raw material for the production of a-amylase. Bioresour Technol 93:169–174

Ramírez FB, Tamayo DO, Corona IC, Cervantes JLNG, Claudio JJE and Rodríguez EQ (2019) Agro-industrial waste revalorization: the growing biorefinery. In: Abomohra AEF (ed) Biomass for bioenergy—recent trends and future challenges. IntechOpen. https://doi.org/10.5772/intechopen.83569

Ramos JL, Valdivia M, Lorente FGI, Segura A (2016) Benefits and perspectives on the use of biofuels. Microb Biotechnol 9:436–440

Ravindran R, Jaiswal AK (2016) Exploitation of food industry waste for high-value products. Trends Biotechnol 34:58–69

Ravindran R, Desmond C, Jaiswal S, Jaiswal AK (2018) Optimisation of organosolv pretreatment for the extraction of polyphenols from spent coffee waste and subsequent recovery of fermentable sugars. Bioresour Technol Rep 3:7–14

Ravindran R, Hassan SS, Williams GA, Jaiswal AK (2018a) A review on bioconversion of agro-industrial wastes to industrially important enzymes. Bioengineering 5(4):93

Reisinger MÖ, Tirpanalan M, Prückler F, Huber W, Kneifel S (2013) Novel in wheat bran biorefinery—a detailed investigation on hydrothermal and enzymatic treatment. Bioresour Technol 144:179–185

Rekha GS, Kaleena PK, Elumalai D, Srikumaran MP, Maheswari VN (2018) Effects of vermicompost and plant growth enhancers on the exo-morphological features of *Capsicum annum* (Linn.) Hepper. Int J Recycl Org Waste Agric 7:83–88

Riaz M, Yasmeen T, Arif MS, Ashraf MA, Hussain Q, Shahzad SM, Rizwan M, Mehmood MW, Zia A, Mian IA, Fahad S (2019) Variations in morphological and physiological traits of wheat regulated by chromium species in long-term tannery effluent irrigated soils. Chemosphere 222:891–903

Rocky-Salimi K, Hamidi EZ (2010) Evaluation of the effect of particle size, aeration rate and harvest time on the production of cellulase by *Trichoderma reesei* QM9414 using response surface methodology. Food Bioprod Process 88(1):61–66

Rompato K, Somoza S (2015) Protein enrichment of fruit processing byproducts using solid state fermentation with *Saccharomyces cerevisiae* and *Bacillus subtilis*. Biotecnol Apl 32:4221–4227

Rood T, Muilwijk H, Westhoek H (2017) Food for the circular economy. https://www.pbl.nl/en/publications/food-for-a-circular-economy. Accessed 15 Dec 2020

Sabir M, Hanafi MM, Aziz T, Ahmad HR, Zia-Ur-Rehman M, Saifullah GM, Hakeem KR (2013) Comparative effect of activated carbon, pressmud and poultry manure on immobilization and concentration of metals in maize (*Zea mays*) grown on contaminated soil. Int J Agric Biol Eng 15:559–564

Sadh PK, Chawla P, Bhandari L, Duhan JS (2017) Bio-enrichment of functional properties of peanut oil cakes by solid state fermentation using *Aspergillus oryzae*. J Food Meas Character 12:622–633

Sadh PK, Duhan S, Duhan JS (2018) Agro-industrial waste and their utilization using solid state fermentation: a review. Bioresour Bioprocess 5:1

Saharan P, Sadh PK, Duhan JS (2017) Comparative assessment of effect of fermentation on phenolics, flavonoids and free radical scavenging activity of commonly used cereals. Biocatal Agric Biotechnol 12:236–240

Saikia R, Sharma S, Singh H, Singh TY (2020) Tillage and residue management practices affect soil biological indicators in a rice–wheat cropping system in north-western India. Soil Use Manag 36:157–172

Salinas-Salazar C, Hernández-Brenes C, Rodríguez-Sánchez DG, Castillo EC, Navarro-Silva JM, Pacheco A (2016) Inhibitory activity of avocado seed fatty acid derivatives (acetogenins) against listeria monocytogenes. J Food Sci. https://doi.org/10.1111/1750-3841.13553

Santagata R, Viglia S, Fiorentino G, Liu G, Ripa M (2019) Power generation from slaughterhouse waste materials. An emergy accounting assessment. J Clean Prod 223:536–552

Santos VP, Marques NSS, Maia PCSV, Lima MABD, Franco LDO, Campos GMD (2020) Seafood waste as attractive source of chitin and chitosan production and their applications. Int J Mol Sci 21:1–17

Seidavi AR, Zaker-Esteghamati H, Scanes CG (2019) Present and potential impacts of waste from poultry production on the environment. Poult Sci J 75(1):29–42

Selmane DV, Christophe DG (2008) Extraction of proteins from slaughterhouse by-products: influence of operating conditions on functional properties. Meat Sci 79:640–647

Servos MR (2020) Environmental fate and effects of pulp and paper: mill effluents. CRC Press, Boca Raton

Sharanappa A, Wani KS, Pallavi P (2011) Bioprocessing of food industrial waste for α-amylase production by solid state fermentation. Int J Adv Biotechnol Res 2:473–480

Sharma K, Garg VK (2018) Comparative analysis of vermicompost quality produced from rice straw and paper waste employing earthworm *Eisenia fetida* (Sav.). Bioresour Technol 250:708–715

Sharma K, Garg VK (2019) Vermicomposting of waste: a zero-waste approach for waste management. In: Taherzadeh MJ, Bolton K, Wong J, Pandey ZWA (eds) Sustainable resources recovery and zero waste approaches. Elsevier, pp 133–164. https://doi.org/10.1016/B978-0-444-64200-4.00010-4

Sharma P, Gaur VK, Kim SH, Pandey A (2020) Microbial strategies for bio-transforming food waste into resources. Bioresour Technol 299:122580

Shirahigue LD, Antonini SRC (2020) Agro-industrial wastes as sources of bioactive compounds for food and fermentation industries. Ciência Rural 50:1–17

Silva YPA, Borba BC, Reis MG, Caliari M, Ferreira TAPC (2016) Tomato industrial waste as potential source of nutrients. Int Techn Symp Food Tree Sustains Life 51:2108–3111

Singh S, Dubey A, Tiwari L, Verma AK (2009) Microbial profile of stored jaggery: a traditional Indian sweetener. Sugar Tech 11:213–216

Singh A, Sabally K, Kubow S, Donnelly DJ, Gariepy Y, Orsat V, Raghavan GSV (2011) Microwave-assisted extraction of phenolic antioxidants from potato peels. Molecules 16:2218–2232

Smith V, Wood SA, McBride CG, Atalah J, Hamilton DP, Abell J (2016) Phosphorus and nitrogen loading restraints are essential for successful eutrophication control of Lake Rotorua, New Zealand. Inland Waters 6:273–283

Sohel MI, Jack M (2010) Efficiency improvements by geothermal heat integration in a lignocellulosic biorefinery. Bioresour Technol 101:9342–9347

Spiller M, Muys M, Papini G, Sakarika M, Buyle M, Vlaminck SE (2020) Environmental impact of microbial protein from potato wastewater as feed ingredient: comparative consequential life cycle assessment of three production systems and soybean meal. Water Res 171:115406

Suganthi R, Benazir JF, Santhi R, Kumar RV, Hari A, Meenakshi N, Nidhiya KA, Kavitha G, Lakshmi R (2011) Amylase production by *Aspergillus niger* under solid state fermentation using agro-industrial wastes. Int J Eng Sci Technol 3:1756–1763

Swanepoel JC, Goosen NJ (2018) Evaluation of fish protein hydrolysates in juvenile African catfish (*Clarias gariepinus*) diets. Aquaculture 496:262–269

Talukdar S (2017) A review of water pollution abatement strategies in India: the case of Gujarat. In: 3rd international conference on public policy (ICPP3) June 28–30, 2017, Singapore. https://www.academia.edu/37230771/A_review_of_water_pollution_abatement_strategies_in_India_The_case_of_Gujarat

Tejada M, Hernandez MT, Garcia C (2006) Application of two organic amendments on soil restoration: effects on the soil biological properties. J Environ Qual 35:1010–1017

Tobias I, Ezejiofor N, Duru CI, Asagbra AE, Ezejiofor AN, Orisakwe OE, Afonne JO, Obi E (2012) Waste to wealth: production of oxytetracycline using streptomyces species from household kitchen wastes of agricultural produce. Afr J Biotechnol 11(43):10115–10124

Toor SS, Rosendahl L, Rudolf A (2011) Hydrothermal liquefaction of biomass: a review of subcritical water technologies. Energy 36(5):2328–2342

Tsakona S, Galanakis CM, Gekas V (2012) Hydro-ethanolic mixtures for the recovery of phenols from mediterranean plant materials. Food Bioprocess Technol 5:1384–1393

Udhayakumar S, Shankar KG, Sowndarya S, Rose C (2017) Novel fibrous collagen-based cream accelerates fibroblast growth for wound healing applications: in vitro and in vivo evaluation. Biomater Sci 5:1868–1883

Uranga J, Etxabide A, Guerrero P, de la Caba K (2018) Development of active fish gelatin films with anthocyanins by compression molding. Food Hydrocoll 84:313–320

Usmani Z, Sharma M, Sudheer S, Gupta VK, Bhat R (2020) Engineered microbes for pigment production using waste biomass. Curr Genom 21:80–95

Üstündag OG, Sevcan E, Ezgi Ö, Gizem Ö, Neslihan K, Ekinci F (2016) Black tea processing waste as a source of antioxidant and antimicrobial phenolic compounds. Eur Food Res Tecnol 242:1523–1532

Uz I, Tavali IE (2014) Short-term effect of vermicompost application on biological properties of an alkaline soil with high lime content from Mediterranean Region of Turkey. Sci World J 395282:1–11

Valduga E, Ribeiro AH, Cence K, Colet R, Tiggemann L, Zeni J, Toniazzo G (2014) Carotenoids production from a newly isolated *Sporidiobolus pararoseus* strain using agroindustrial substrates. Biocatal Agric Biotechnol 3:207–213

Vastrad BM, Neelagund SE (2011) Optimization and production of neomycin from different agro industrial wastes in solid state fermentation. Intern J Pharma Sci Drug Res 3:104–111

Veana F, Martínez-Hernández JL, Aguilar CN, Rodríguez-Herrera R, Michelena G (2014) Utilization of molasses and sugar cane bagasse for production of fungal invertase in solid state fermentation using *Aspergillus niger* GH1. Braz J Microbiol 45:373–377

Walker DJ, Bernal MP (2008) The effects of olive mill waste compost and poultry manure on the availability and plant uptake of nutrients in a highly saline soil. Bioresour Technol 99(2):396–403

Walker DJ, Clemente R, Bernal MP (2004) Contrasting effects of manure and compost on soil pH, heavy metal availability and growth of *Chenopodium album* L. in a soil contaminated by pyritic mine waste. Chemosphere 57(3):215–224

Wang L, Zhao B, Li F, Xu K, Ma C, Tao F, Li Q, Xu P (2011) Highly efficient production of d-lactate by *Sporolactobacillus* sp. CASD with simultaneous enzymatic hydrolysis of peanut meal. Appl Microbiol Biotechnol 89:1009–1017

Wang X, Chen Q, Lü X (2014) Pectin extracted from apple pomace and citrus peel by subcritical water. Food Hydrocoll 38:129–137

Wanga B, Donga F, Chena M, Zhua J, Tana J, Fua X, Wang C, Chen S (2016) Advances in recycling and utilization of agricultural wastes in China: based on environmental risk, crucial pathways, influencing factors, policy mechanism. Procedia Environ Sci 31:12–17

Wijngaard HH, Ballay M, Brunton N (2012) The optimisation of extraction of antioxidants from potato peel by pressurised liquids. Food Chem 133:1123–1130

Withers PJA, Neal C, Jarvie HP, Doody DG (2014) Agriculture and eutrophication: where do we go from here? Sustainability 6:5853–5875

Xin F, Geng A (2011) Utilization of horticultural waste for laccase production by *Trametes Versicolor* under solid-state fermentation. Appl Biochem Biotechnol 163(2):235–246

Xu L, Geelen D (2018) Developing biostimulants from agro-food and industrial by-products. Front Plant Sci 9:1–13

Yaghoubzadeh Z, Ghadikolaii FP, Kaboosi H, Safari R, Fattahi E (2019) Antioxidant activity and anticancer effect of bioactive peptides from rainbow trout (*Oncorhynchus mykiss*) skin hydrolysate. Int J Pept Res Ther 26:625–632

Yang SD, Liu JX, Wu J, Tan HW, Li YR (2013) Effects of vinasse and press mud application on the biological properties of soils and productivity of sugarcane. Sugar Tech 15(2):152–158

Ye F, Liang Q, Li H, Zhao G (2015) Solvent effects on phenolic content, composition, and antioxidant activity of extracts from florets of sunflower (*Helianthus annuus* L.). Ind Crop Prod 76:574–581

Yin S, Tan Z (2012) Hydrothermal liquefaction of cellulose to bio-oil under acidic, neutral and alkaline conditions. Appl Energy 92:234–239

Yusuf M (2017) Agro-industrial waste materials and their recycled value-added applications: review. In: Martínez LMT (ed) Handbook of ecomaterials. Springer International Publishing, pp 1–11

Zhao HT, Li TP, Zhang Y, Hu J, Bai YC, Shan YH, Ke F (2017) Effects of vermicompost amendment as a basal fertilizer on soil properties and cucumber yield and quality under continuous cropping conditions in a greenhouse. J Soils Sediments 17:2718–2730

Zhen Z, Liu H, Wang N, Guo L, Meng J, Ding N, Wu G, Jiang G (2014) Effects of manure compost application on soil microbial community diversity and soil microenvironments in a temperate cropland in China. PLoS ONE 9(10):e108555

Zhou L, Li L (2016) Novel fungal consortium pretreatment of waste oat straw to enhance economic and efficient biohydrogen production. Ecocycles 2(2):36–42

Zhou YF, Haynes RJ, Naidu R (2012) Use of inorganic and organic wastes for in situ immobilisation of Pb and Zn in a contaminated alkaline soil. Environ Sci Pollut Res 19(4):1260–1270

Zoghlami RI, Hamdi H, Mokni-Tlili S, Khelil MN, Aissa NB, Jedidi N (2016) Changes in light-textured soil parameters following two successive annual amendments with urban sewage sludge. Ecol Eng 95:604–611