Chapter

Perspective Chapter: Environmental-Friendly Agro Waste Management

Manabendra Patra and Duryodhan Sahu

Abstract

Abundant amount of agro wastes is produced day by day globally to manage the escalating needs of billons of human population. The agro wastes are produced from various sources mainly crops left out, agro industries, aquaculture, and livestock. The major ingredient of agro wastes are of cellulose, lignin, hemicelluloses, etc. Conventionally, most of the crops left out were used for composting, animal fodder, domestic fuel, etc. Due to modernization technology in agriculture sector, people from Third World countries prefer cost-effective methods such as combustion process. Improper management of agro waste generated in the process has been contributing toward escalating air, soil, and water pollution. A proper environmental-friendly management of agro waste is the need of the time for sustainability, food, and health security of human. Lignin and hemicellulose can be used for generation of biofuels and biofertilizer. Cellulose can be sustainably used for the production of nanosilica, biodegradable polymer, paper, pulp, etc. This chapter emphasizes sustainable agro waste management without affecting the environment at lower cost in timely manner. In particular, the agro waste biomass could be used as a source of value-added bio-product, which has wide applications and impacts the bio-economy without hampering the climatic change issue.

Keywords: agro waste, composting, activated carbon, nanocellulose, biofuels, ethanol

1. Introduction

Agro waste is called undesirable material that is generated from agriculture farming practices and includes crop residues, leaf litter, livestock waste, sawdust, weeds, and forest waste. Agro waste is misled or discarded in most part of this earth due to either unawareness or proper route to transfer and its utilization. These agro wastes can create a great constraint, if proper measures will not be taken off for its proper discard, as it can lead to a clearly impact on the environment issue. In addition to the hazards of burning and land filling, the synthetic chemicals adopted during farming and agriculture are able to instigate pollution if these wastes wind up in the undesirable places. Agriculture sector is the major backbone of the developing nations, and it is one of the greatest contributors to the GDP. Millions of people are adopting agriculture as their primary occupation in this earth. With the ever-increasing of the world population, there is an escalation in the demand for food and food product supplies, so nowadays many people make use of modern agriculture to encounter the need. Modern agriculture uses the up-to-date cultivation technique along with synthetic fertilizers. Urban people are also adopting garden farming using modern methods. The demand for animal products such as milk products, poultry, and meat is also high, and producers have been developing new strategy to enhance the productivity and lower the unit cost of production. Chemicals such as fossil fuels, inorganic fertilizers, and organic pesticides improved genetics of production species and are enhancing the increase in the generation. The agro waste and its processing are a universal issue, as its major part is going for burning or to be buried in soil, which is responsible for pollution of air, water, and soil, a general loss of aesthesis. The degradation of water quality can affect adjoining water bodies and groundwater both on-site and off-site. Such kind of degradation in the water quality reduces the ability of water resource to support aquatic life and water consumption for humans and animals. Unplanned burying of agro waste leads to greenhouse emission and a major concern for climatic change. Conventionally, a large volume of agro waste is utilized as animal fodder, domestic combustion fuel, composting, roof thatching, etc. The management of agro waste and the reformation of its transition into a fit for use product through the utilization of biotechnology in agriculture are getting a lot of recognition nowadays [1]. Solid state fermentation can be considered as the better process for transition of agro waste into usable bioproducts. Different agro wastes such as wheat straw [2], barley straw [3], cotton stalks [4], sunflower stacks [5], etc., from abundant agriculture goods, as well as significant horticulture wastes such as apple [6], mango [7], orange peels [8], and potato [9] were used to create beneficial products in this review. Agro wastes can be used for contributing to guaranteeing resource efficiency, sustainable production and consumption, and the reduction of negative environmental impact on adopting recent and superior scientific methods in disposal of it [10]. The main objective of this chapter is to emphasize on the use of agro waste as a source for generating ecofriendly material such as (i) compost to enhance soil productivity, biodiversity, and sustainable environment; (ii) activated carbon, which can be used as adsorbent for removal of heavy metals from drinking and industrial wastewater; (iii) nanocellulose, which is widely applicable as membrane in water purification; (iv) the agro waste containing lignocellulosic residues can be used to produce different bioproducts including biofuel, biofertilizer, bioplastic, organic acid, etc. Furthermore, these value-added products can enhance the bioeconomy without affecting the environment.

2. Methods of agro waste utilization and management

2.1 Composting

Composting is one of the old-age methods for transforming agro wastes into hygienic, stabilized, and non-polluting materials, thus retrieving the beneficial nutrients and enhancing soil fertility [11]. Therefore, composting is commonly adopted as a biological treatment method for agro wastes, but enhancing compost maturity is essential for the safe use of composting products [12]. The agro waste can be converted into valuable compost on utilization of proper role of certain microorganism. The generated product obtained by microbial action has a lot of superiority in agriculture as it helps in enhancing productivity, better soil biodiversity, and sustainable environment. Thus, composting can be one of the better options for the processing of the large volume of agro wastes generated worldwide [13]. Gusmawartati et al. [14] have studied the quality of compost generated from taking various combinations of agro wastes such as cassava peel, empty fruit bunches of oil palm, banana skin, and rice straw. Mastouri et al. [15] have studied the growth of lettuce using compost obtained from a mixture of tree bark wastes obtained from orchid, aldar, horn beech, oak, hard wood tree, etc. Pergola et al. [16] had emphasized on the restoration of soil organic matter function in agricultural soil with various agricultural additives of reconverted waste biomasses. Aslam et al. [17] have studied vermin composting of rice straw, wheat straw, and cow dung by Eisenia fetida on-farm management of nutrients such as NPK, beneficial humus, soil microbes, phosphate-solubilizing bacteria, actinomycets, micronutrients, nitrogen fixing, growth hormones such as auxins, etc. Yu et al. [18] had taken multiple combinations of agro waste (from mushroom industry) compost and biofertilizer for enhancing yield and higher sustainability of a pepper crop. Trillas et al. [19] have studied the reduction of solani diseases in cucumber seedlings by application of compost obtained from agro waste such as olive marc, grape marc, spent mushroom, and cork. Particularly, Trichoderma Asperellum reduces the relevance of solani pathogen in the soil on amending at 103 cfu/ml. Karak et al. [20] had investigated the maturity of compost obtained with various ratios of agro wastes, such as wheat straw, rice straw, mustard stover, and potato plant obtained in both the presence and absence of fish pond bottom sediment. Gea et al. [21] had studied on controlling dry bubble diseases in mushroom farming caused by Verticillium fungicola. They had used various agro-based waste composts generated from a mixture of olive oil husk, used mushroom substrate, cotton grit thrashed along with compost from grape marc compost, rice husk, and cork compost.

2.2 Activated carbon

The activated carbon, a low-cost and high-quality material, can be utilized for adsorption purpose in various applications. Generally, the activated carbon is prepared by burning lignite, coal, wood, etc., in pyrolysis over 600–900°C. Nowadays, a lot of emphasis has been given to lignocellulosic biomass, readily available in agriculture sector as waste, for generation of the activated carbon [22]. The activated carbon generated from agro-based waste has its own advantage due to its low cost and ubiquitous availability [23]. During the last few decades, there was growing research interest on the utilization of alternative origin of waste materials from industry and agriculture for activated carbon production [24–27]. A sizable numbers of reports have been published on generation of activated carbon from agro waste such as palm shell [28, 29], coconut shell [30, 31], corn cob [32], olive stones [33] and walnut shell [34], coir pith [35], rice bran [36], chickpea husks [37], oil palm shell [38], etc. Ioannidou et al. [23] have used the agricultural residues such as soya stalks, corn cobs, rapeseed stalks, and olive kernels as precursors for the generation of activated carbon. The pyrolysis were done in two stages: (a) the pyrolysis had been carried out over 800°C for about 1 h under nitrogen atmosphere (15 ml/min) along with heating rate at 27°C/min for the sake of producing char, (b) the physical activation of char was then carried out over 800°C for about ½ h under the flow of steam (40 g/min) at pressure of ½ bar. The obtained activated charcoals were subjected to study of removal of Bromopropylate, common pesticides in fruits crop, from water. Tay et al. [39] have isolated activate carbon on pyrolysis of soybean oil cake by chemical activation with potassium hydroxide and potassium carbonate at different temperatures of 600 and 800°C. Potassium carbonate was found to be more effectual as compared with potassium hydroxide under similar conditions.

The maximum surface area of activated carbon obtained with potassium carbonate at 800°C is found to be 1352.86 m^2/g, which is in accordance with the range of commercial activated carbons. Anne A. Nunes et al. [40] derived activated charcoal from defective coffee press cake by heating it under nitrogen atmosphere at 600/800°C for elimination of methylene blue from water up to 99% removal. The maximum adsorption capacity obtained for the coffee cake activated carbon/methylene blue system was observed to be 14.9 mg/g. The equilibrium data fitted favorable into Freundlich model as compared with others. Rice is one of the widely grown crops in the world, generating a large volume of waste. That has to deal with proper management due to short duration in between two crops. During last few decades, people have reported on generation of activated carbon from rice straw [41]. The utmost value of carbofuran adsorption capacity was observed to be 26.52 mg/g. Chang et al. [42] had studied elimination of bisphenol-A from water by using activated carbon obtained by with the help of chemical (potassium hydroxide) treatment of rice husk. At pH 2.5, the maximum adsorption capacity of bisphenol-A was found to be 181.191 mg/g. The experimental values perfectly fitted the Langmuir model for equilibrium data. It was found to be more inclination toward pseudo second order as compared with that pseudo first order. Isoda et al. [43] reported the generation of activated carbon from rice husk with more surface area, of about 1500 m^2/g and high mesopore volume of about 1.22 cm^3/g using chemical (zinc chloride) treatment over an activation temperature of 600°C without carbonization and using sodium hydroxide as chemical activating agent, with carbonization. Köseoğlu et al. [44] had studied the generation of activated carbon from orange peels using potassium carbonate and zinc chloride as chemical reagents for the purpose. The surface area of the activated carbon was observed to be 9–1352 m^2/g for potassium carbonate and that for zinc chloride 804–1215 m^2/g. Potassium carbonate was observed to have much potential as compared with zinc chloride as a chemical activating reagent in light of high surface area, development of porosity, and surface analysis of the activated carbon. Mahamad et al. [45] had studied the generation of activated carbon from solid pine apple waste mass such as leaves, stem, and crown using zinc chloride as chemical reagent at 500°C for 1 h. It can be deduced that the activated carbon obtained by a 1:1 ratio has the better removal of dye capacity, which can be attributed to its high surface area (914.67 m^2/g) and dye adsorption capacity (288.34 m^2/g). The Langmuir adsorption isotherm model is perfectly suited to the obtained adsorption equilibrium data with R^2 of 0.969. The maximum uptake of methylene blue with obtained activated carbon was observed to be 288.34 m^2/g. Baysal et al. [46] had prepared activated carbon from sunflower piths using NaOH and KOH as chemical reagents. The activated carbon prepared has high surface area of about 2690 and 2090 m^2/g. Activated carbon obtained from mahogany fruit shell successfully used for about 99.7% uptake of lead ion from wastewater [47] . Xue et al. [48] have used Angelica keiskei as a source for generation of activated carbon, which could be utilized as efficient adsorbent of organic dyes from wastewater. As shown in **Table 1**, activated carbon made up of various agro wastes with different temperatures of activations used as adsorbent for the removal of different impurities from wastewater. Furthermore, the maximum capacities of removal are complying well with the disposal standard of wastewater.

2.3 Nanocellulose from agro waste

The nanocrystalline cellulose can be generally isolated from different subsequent chemical process: starting with bleaching and alkali treatment succeeded by acid

Adsorbent source	Adsorbate	Activation temperature (°C)	Capacity	References
Soya stalks, Corn cobs, Rapeseed Stalks and Olive kernels	Bromopropylate (isopropyl 4,4′-dibromobenzilate)	800	0.0948 mg/g	Ioannidou et al. [23]
Coffee Press Cake	Methylene blue	600/800	14.9 mg/g	Nunes et al. [40]
Rice Straw	Carbofuran	850	296.52 mg/g	Chang et al. [41]
Rice Straw	Bisphenol-A	850	181.19 mg/g	Chang et al. [42]
Orange Peel	Iodine Methylene Blue	500–1000	1564 mg/g 150 mg/g	Köseoğlu et al. [44]
Pineapple Waste	Methylene Blue	500	288.34 mg/g	Mahamad et al. [45]
Sunflower Piths	Methylene Blue	500	965.349 mg/g	Baysal et al. [46]
Mahogany Fruit Shell	Pb(II)		322.28 mg/g	Patil et al. [47]
Ashitaba waste	Methylene Blue	900	491.56 mg/g	Xue et al. [48]

Table 1.
Activated carbon generated from various agro wastes.

hydrolysis of the natural fibers. The nanocellulose isolated from various sources of agro waste is becoming an attractive research avenue for its multifaceted utilization [49]. Nowadays, a lot attention has been given to generation of nanocellulose from various ago wastes such as olive tree pruning [50], pine cones [51], pineapple leaf [52], rice husk [53], sisal fiber [54], sorghum stalk [55], sunflower stalks [56], etc. Ferreira et al. had successfully isolated cellulose nanocrystals from sugarcane bagasse, on hydrolysis by sulfuric acid, which had very good hydrophilic properties with a high crystallinity. Adipic acid was used for surface modification of nanocrystal for suppressing the crystal dimension by elimination of amorphous region [57]. Johar et al. reported on the isolation of nanocellulose fibers from rice husk. They adopted alkali (NaOH) and bleaching ($NaCl_2O$) treatment followed by acid (H_2SO_4). They observed a remarkable enhancement in crystallinity of the obtained nanocellulose [53]. Lu and Hsieh et al. had extracted an unblended form of nanocellulose from rice straw with about yield of 36%. The acid hydrolysis for about ½ h resulted in nanocellulose of size of 270 nm length and 5.95 nm diameter, whereas acid hydrolysis for 45 min resulted in nanocellulose of size of 117 nm length and 5.06 nm diameter [58]. do Nascimento et al. had successfully extracted cellulose nanocrystals from coconut fiber [59]. de Carvalho Mendes et al. isolated crystalline nanocellulose from various agro wastes such as garlic skin, palm oil, sesame, and rice husks [60] . Walnut shell (*Juglans regia* L.) was utilized as the raw material for the production of purified cellulose [61]. The lignin and hemicellulose present in walnut shell had been perfectly eliminated by sodium hydroxide treatment and followed by bleaching with equal amounts of 1.7 wt.% sodium chlorite and acetate buffer solution, which leads to the enhancement of cellulose content up to 89%. Sijabat et al. had isolated nanocellulose from waste media of Kepok bananas (*Musa paradisiaca* L.) applying Gluconacetobacter xylinusbacteria in the fermentation procedure in utilization for membrane applications in water filter [62].

2.4 Biofuels

The second-generation biofuels, commonly prepared from inedible crops, woody crops or lignocellulosic biomass, agro waste, or unwanted plant, are potent reply to the food versus fuel feud as they utilize leftover portion of agro waste. Inedible feedstock is commonly used for the second-generation biofuels, i.e., jatropha, grasses, wastes vegetable oil, wood chips, etc. Alcohol generation from rapid growth plants could be produced by enzymatic activities to isolate out the sugars from lignin fibers of the biomass. Syngas, a mixture of hydrogen and carbon monoxide, can be synthesized on thermochemical treatment of biomass. Hydrogen thus prepared can be used as fuel, and other hydrocarbons can be used as add-on to the gasoline [63] . Recently, most of the gasoline available is blended with certain percentage of ethanol to reduce carbon footprint. The effective conversion of cellulose into ethanol has got major prospective due to the ubiquitous obtainability, plentitude, and comparable inexpensive cellulosic plant materials. The banana residue includes banana fruit (pulp and peels) and lignocellulosic biomass can be a potential source for biofuels [64]. Srivastava et al. [65] had successfully utilized Saccharomyces cerevisiae for generation of bioethanol out of rice husk up to yield of 250 mg/g dry biomass after 6 days of fermentation. Singh et al. [66] had enzymatically hydrolyzed the pretreated rice husk with alkali under microwave condition for the generation of biofuel. They have successfully utilized Scheffersomyces stipites and S. cerevisiae yeast for the fermentation. The ethanol production with S. cerevisiae was to be 0.3–0.39 g/g; with Scheffersomyces stipites, waste 0.24–0.35 g/g, respectively. Chukwuma et al. [67] had adopted fermentation process of rice husk using Aspergillus fumigatus, Aspergillus niger, and Saccharomyces cerevisae for the generation of biofuel. On fermentation with Aspergillus fumigatus, treating rice husks shows the at most cellulose of 45 ± 3.31%, hemicelluloses of 31 ± 3.00%, reducing sugar of 2.60 ± 0.30%, carbohydrate of 19.52 ± 10.05%, and non-reducing sugar of 16.92 ± 9.75% producing ethanol yield of 6.60 ± 0.48% with palm wine yeast, while 5.60 ± 0.42% yield was with bakers. Slow pyrolysis activity by thermogravimetric analysis had been investigated to estimate and compare the effective utilization agro waste such as corncob, rice husk, wood chips, wheat straw, bagasse, etc., for biofuel conversion. [68] The corncob was observed to deteriorate with an enhanced rate over lower temperature. On the whole, the activation energy was observed to be enhanced at the reduced temperature range (250–400°C), and that was reduced in the enhanced temperature range (450–600°C). The corncob had been observed to be a suitable contender out of the rest of the wastes for pyrolysis with activation energy of 29.71 and 4.23 kJ/mol in reduced and enhanced temperature range, respectively. Buenrostro-Figueroa et al. [69] had used *Kluyveromyces marxianus* for fermentation of mango fruit for ethanol generation. *K. marxianus* in Tommy Atkins mango juice exhibits encourage finding over Haden mango juice. The finding showss that of 4 g/l/day, a yield of up to about 49% of ethanol and a process efficiency of about 80%. Mihajlovski et al. [70] had utilized Streptomyces fulvissimus for fermentation of lignocellulosic waste such as wheat bran, barley bran, and rye bran, to obtain alcohol. Rye bran observed to be one of the most perfect waste substrates that can be used for bioconversion. Najafi et al. [71] had reported enzymatic potential of the bacterial strain S. fulvissimus during the hydrolysis of lignocellulosic agro waste such as rice, wheat, sugar cane, barley, and corn for the generation of ethanol. Pistachio waste such as pruning trees, green (soft) shell, and hard shell could be transformed into beneficial fuel using the fermentation processes, anaerobic digestions, and thermochemical degradation (i.e., pyrolysis) methods for production of biofuels [72]. Yuliansyah et al. [73] had evaluated the feasibility of upgrading oil palm fronds and trunks for their decomposition behavior over hydrothermal treatment to generate solid biofuels. The rice straw biomass is constituted of different variety of biopolymers, mainly cellulose, hemicellulose, and lignin. Through the hydrolysis of cellulose and hemicellulose, monomeric sugars are liberated that can be converted into ethanol by fermentation as an alternative to biogas by anaerobic digestion. Laobussararak et al. had utilized the bacterium *Zymomonas mobilis* and distillery yeast, *S. cerevisiae* and a co-culture of *Z. mobilis* and *S. cerevisiae* for fermentation of rice straw waste for production of ethanol [74]. The rice straw had been treated with 2% sodium hydroxide solution, then followed by enzymatic hydrolysis making use of cellulase prior to the fermentation. It was found to be that 2% NaOH pretreatment is perfectly suitable for the rice straw waste as a type of pretreatment context able to generate the high cellulosic content about of 88.96% and diminishing sugar content of 9.18 g/l. The distillery yeast was found to be a befitting microorganism for the generation of ethanol out of the rice straw, as ethanol yield on enzymatic hydrolysis found to be 15.94–19.73%, 20.48–35.70%, and 21.56–29.89% for the bacterium, yeast, and co-culture, respectively. Kumar et al. [75] had comprehensively investigated over green solvent-pretreated rice straw and cellobiose fermenting yeast strain Clavispora for production of cellulosic ethanol. Green solvent (cholinechloride/glycerol) treated rice straw leads to maximum reduction of sugars about 226.7 g/l with a saccharified capability of about 87.1% at 20% solids loading and 12FPU cellicctec2. The generation of ethanol yield of 36.7 g/l was found out of 8% of glucose within 36 h with a conversion capability up to 90.1%. Sasaki et al. [76] had successfully studied that the perfluoropolymer membrane has been suitable used in vapor permeation to isolate aqueous ethanol from combined product obtained out of rice straw with recombinant S. cerevisiae. Kluyveromyces sp. is explored as thermophilic ethanologen, which effectually makes use of hexose for the fermentation of ethanol at high temperature (45–50°C) [77]. The rice straw waste had been hydrolyzed at temperature of 140°C along with dilute H_2SO_4 of 0.6%v/v over 90 min for utmost retrieval of pentose monomer yield of 12.52 g/100 g. Using commercial cellulose, saccharification efficiency was observed to be 79 ± 0.05% with acid-hydrolyzed biomass. The fermentation of saccharified broth utilizing thermophilic yeast Kluyveromyces sp. with cell recycle produced ethanol with an overall yield and productivity of 93.5 ± 0.05% and 0.90 ± 0.2 g/l/h, respectively, and with a negligible amount residual sugar found in fermentation broth. Assis Castro et al. [78] had investigated multiple approaches of saccharification as well as fermentation utilizing rice straw waste that is pretreated with dilute acid for ethanol production using thermo-tolerant yeast Kluyveromyces marxianus. On concurrently saccharification and fermentation, in the absence of type of any pre-hydrolysis, it was observed to be as the utmost perfect condition owing to the enhanced ethanol generation (1.4 g/l. h), about two times more in contrast to the alternate approach. Mahajan et al. [79] had accessed glycosyl hydrolases produced by different thermophilic fungal strains for the saccharification of alkali as well as biologically (Trametes hirusita/Myrothecium roridum) treated Parthenium hysterophorus (carrot grass) as well as rice straw waste. The integrative examination of hydrolysates observed clear-cut outline of hexose, pentose, and oligomeric sugars. Malbranchea cinnamomea was utmost orderly origin of glycosyl hydrolases producing 283.8, 35.9, 129.6, 27,193, 4.66, 7.26 (units/gds) of endoglucanase, cellobiohydrolase, b-glucosidase, xylanase, a-arabinofuranosidase, and b-xylosidase, respectively. The fermentation of outcome hydrolysates having glucose/xylose was competently yield of ethanol by *S. cerevisiae* due to the presence of xylose isomerase (0.8 units/gds) activity in culture extract of *M. cinnamomea* resulting in generation of 16.5 and 15.0 g/l of ethanol from alkali-treated rice straw and carrot grass, respectively. Sasaki et al. [80] had utilized a xylose-fermenting *S. cerevisiae* strain in ethanol fermentation activities for accessing in perfect usage of hemicellulose generate from rice straw waste. The xylose fermenting recombinant *S. cerevisiae* helps in generating bioethanol yield of about 34.5 ± 2.2 g/l. Momayez et al. [81] had investigated utilizing the liquid anaerobic digester, the biogas liquid waste, for the pretreatment process of the rice straw at different ambience. The rice straw had been pretreated at varying temperature 130–190°C for ½/1 h duration and put through to enzymatic hydrolysis, simultaneous saccharification and fermentation, dry anaerobic digestion, and liquid anaerobic digestion. The hydrolysis is enhanced by 100%, while the yield of ethanol enhanced by 125% on treating the rice straw waste at temperature of 190°C over 1 hour. There was also enhancement of yield of methane in 24 and 26% on using pretreatment process of rice straw through liquid anaerobic digestion and dry anaerobic digestion. Molaverdia et al. [82] had utilized Mucor indicus fungus for fermentation of rice, which was pretreated with 0.5 M Na_2CO_3 solution over 3–10 h to enable improving the efficiency of ethanol production. The maximum ethanol yield of about 99.4 g/l generated from the pretreated rice straw waste on simultaneous saccharification and fermentation for about 10 h. Whereas the ethanol yield of about 66.3 g/l was generated on moderate enzymes loading for fermentation about 12 h. Lü et al. [83] studied improving ethanol generation by the pretreating the rice straw waste with the microwave-assisted $FeCl_3$ solution followed by applying simultaneous saccharification and fermentation using *S. cerevisiae* and Pichia stipites. The concentration of ethanol is about 5.51 g/l on fermentation. Trametes hirsute, a white rot fungus, was competed of directly fermenting starch, wheat bran, and rice straw, for generating ethanol in the absence of acid or enzymatic hydrolysis [84]. *T. hirsuta* appeared comparable xylose consumption and ethanol production with a yield of 0.44 g/g. On growing the fungus in a medium containing 20 g/l starch, wheat bran, or rice straw, it was observed that ethanol yield of 9.1, 4.3, and 3.0 g/l, respectively. Karimi et al. [85] had studied for ethanol production out-of rice straw, pretreated with dilute acid, with the yields of 74, 68, and 61% using Rhizopus oryzae, Mucor indicus, and *S. cerevisiae*, respectively. The yield of ethanol was found to be 74 and 68% while using *R. oryzae* and *M. indicus*, respectively. Kaur et al [86] had reported low-cost process involving solid state fermentation of rice straw producing high titers of cellulases and hemicellulases for hydrolysis of alkali pretreated rice straw leading to ethanol yield of 15.6 g/l. Sharma et al. [87] had utilized the charred wood ash from Acacia nilotica as the diversified base catalyst. The wood ash catalyst that charred at 800°C shows an improved catalytic effect owing to its enhanced surface area, which leads to produce a 98.7% biodiesel transformation. It was also observed that the wood ash catalyst was found to be steady for the reaction of jatropha oil without any leaching of catalyst material. Uprety et al. [88] had investigated synthesis of biodiesel from palm oil utilization of ash from Birch bark as a diversified catalyst. It was observed that the biodiesel yield of 69.70% in the effective context like a catalyst load of 3 wt.% while a methanol to oil molar ratio of 12:1 at temperature of 60°C within 3 h. Betiku et al. [89] reported synthesis of biodiesel from *Azadirachta indica* oil transesterification utilizing a catalyst obtained on calcination of cocoa pod husk ash. It was observed that the cocoa pod husk ash catalyst charred over temperature of 700°C producing good interest owing to its high potassium content of about 59.2% and formation of the microstructure. While taking catalyst amount of 0.65 wt.% and a methanol: oil ratio of 0.73 (v/v) at temperature of 65°C within 57 min, the yield of biodiesel transformation was found to be 99.3%. Vadery et al. [90] had investigated generation of biodiesel from jatropha oil by utilizing a catalyst on calcination of coconut husk. While taking catalyst amount of 7 wt.% and a methanol: oil ratio of 0.73 (v/v) at temperature of 45°C within 45 min, the yield of biodiesel transformation was found to be 99.86%. The present demand of the time is to find out the perfect catalyst that can be both eco-friendly and economical aside from showing excellent catalytic activity for synthesis of biodiesel. Nowadays, a lot of attention is given on the designing of perfect green catalysts derived out of agro-based waste for the trans-esterification of vegetable oils, banana stem ash [91, 92], and banana peel ash [93–97], are few examples of the catalysts, obtained from agro-based waste, which had been perfectly made use of as basic catalysts for the generation of biodiesel.

3. Removal of heavy metal

A significant deal of interest has been focused in the research for the removal of heavy metals from industrial effluent using agricultural by-products as bio-adsorbents. The use of agro waste in bioremediation of heavy metal ions, i.e., biosorption utilizes inactive (nonliving) microbial biomass to bind and aggregates heavy metals from waste water by physicochemical pathways (mainly chelation and adsorption) of uptake [98]. Agro waste such as hazelnut shell, rice husk, pecan shells, jackfruit, maize cob, or husk can be used as bioadsorbent for heavy metal removal after chemical modification or conversion of these agro wastes into activated carbon.. Orange peel was employed for Ni(II) removal from simulated wastewater and was found maximum metal removal occurred at pH 6.0 [99]. Coconut shell charcoal (CSC) modified with oxidizing agents and/or chitosan was used for Cr(VI) removal was investigated well by Babel and Kurniawan [100]. Further, Cu(II) and Zn(II) were removed from real wastewater using pecan-shells-activated carbon [101] and potato peels charcoal [102]. The Cr(VI) removal from an aqueous solution by rice-husk-activated carbon has been studied extensively [103]. It was found that the maximum metal removal by rice husk took place at pH 2.0. Rice husk, containing cellulose, lignin, carbohydrate, and silica, was investigated for Cr(VI) removal from simulated solution [104]. To enhance its metal removal, the adsorbent was modified with ethylenediamine. The maximum Cr(VI) adsorption of 23.4 mg/g was reported to take place at pH 2. Other types of biosorbents, such as the biomass of marine dried green alga (biological materials) [21–25], were investigated for uptake of some heavy metals from aqueous solution. Some of the used alga wastes were *Spirogyra* species [105], Ecklonia maxima [106], *Ulva lactuca* [107], *Oedogonium* sp. and *Nostoc* sp. [108], and brown alga *Fucs serratus* [109]. On the whole, an acidic pH ranging 2–6 is effective for metal removal by adsorbents from biological wastes. The mechanism of uptaking heavy metal ions can take place by metabolism-independent metal binding to the cell walls and external surfaces [110]. This involves adsorption processes such as ionic, chemical, and physical adsorption. A variety of ligands located on the fungal walls are known to be involved in metal chelation. These include carboxyl, amine, hydroxyl, phosphate, and sulfhydryl groups. Metal ions could be adsorbed by complexing with negatively charged reaction sites on the cell surface shows the adsorption capacities of different biosorbents. Several studies have demonstrated the ability of rice husk to remove heavy metals from water sources. A study of the removal efficiencies of nine different heavy metals using rice husk observed maximum adsorption capacities ranging from 5.5 to 58.1 mg/g, with the values increasing in the following order: Ni(II) < Zn(II) < Cd(II) < Mn(II) < Co(II) < Cu(II) < Hg(II) < Pb(II) [111]. The rice straw and rice bran have been shown to remove Cu(II) with maximum adsorption capacities of 18.4 and 21.0 mg/g, respectively [112]. In a study on the use of rice husks for the adsorption of Cr(VI), significant removal (>95%) occurred in the case of low pH (<3.0), primarily due to the speciation of the Cr(VI) ions [113]. Bansal et al. [114] evaluated the removal of Cr(VI) using rice husk and achieved a maximum adsorption capacity of 8.5 mg/g; they also found that treating rice husk with formaldehyde enhanced removal by approximately 23%. Another study used phosphate-treated rice husk to evaluate the removal of Cd(II) from wastewater and achieved a high maximum adsorption capacity (103 mg/g at 20°C) [115]. Residuals from peanuts were also found to be an effective adsorbent for the removal of heavy metals. A maximum adsorption capacity of 39 mg/g was achieved for the removal of Pb(II) using peanut shells; significant removal was observed at various temperatures and pH conditions [116]. Peanut shells were also shown to removal of Cr(VI) at low pH values, achieving a maximum adsorption capacity of 4.3 mg/g [117]. Moreover, researchers achieved effective removal of Cr(III) and Cu(II) using peanut shells with maximum adsorption capacities of 27.9 and 25.4 mg/g, respectively [118]. Researchers also observed significant heavy metal removal with peanut husks, achieving maximum adsorption capacities of 7.7, 10.2, and 29.1 mg/g for Cr(III), Cu(II), and Pb(II), respectively [119]. Peanut hull, which is an abundant agricultural by-product, has also been shown to remove Cu(II) with a maximum adsorption capacity of 21.3 mg/g [120]. Wastes from other nuts have also been shown to remove heavy metals from different water sources. Several studies have investigated the ability of cashew nut shells to remove heavy metals from aqueous solutions. When evaluating the removal of Cu(II), researchers achieved significant removal (>85%) and a maximum adsorption capacity of 20 mg/g with cashew nut shells [121]. Another study evaluated the removal of Ni(II) using cashew nut shells and achieved 60–75% and a maximum adsorption capacity of 18.9 mg/g [122]. The removal of these heavy metals using cashew nut shells has been attributed primarily to its high surface area, which allows for significant number of active sites for adsorption to occur [121, 122]. Sunflower-derived adsorbents were efficiently applied against heavy in water [123]. The activated carbons generated, from chickpea (Cicer arietinum) husks by chemical treatment with KOH and K_2CO_3, efficiently removed heavy metals from aqueous solutions [37]. Pistachio hull waste also demonstrated significant removal (>98%) of Cr(VI) from various water sources, achieving a maximum adsorption capacity of 116.3 mg/g [124]. The high adsorption capacity of Cr(VI) by pistachio hull waste was attributed to the electrostatic attraction, as well as binding to various functional groups on the surface of the adsorbent [124]. Another study investigated the use of pecan shells to remove Cu(II), Pb(II), and Zn(II) by utilizing a variety of modification techniques to enhance removal, including acid, steam, and carbon dioxide activation [101]. In this study, Pb(II) was removed at the highest rate, followed by Cu(II) and Zn(II), for each type of modified pecan shell, with maximum adsorption observed for acid-activated pecan shells [101]. Tangerine peel can be used as a potential adsorbent of heavy metal ions, such as Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn, from aqueous solution [125]. Almond shells also demonstrated approximately 20–40% removal of Cr(VI) when adjusting the pH and the adsorbent dose in the solution [126]. Hazelnut shells also demonstrated effective removal of Cu(II), achieving a maximum adsorption capacity of 58.3 mg/g [127]. Groundnut shells were also used as an adsorbent in the removal of heavy metals [128]. Shukla and Pai achieved maximum adsorption capacities of 4.9, 8.05, and 11.0 mg/g for Cu(II), Ni(II), and Zn(II), respectively, with groundnut shells. These adsorption capacities were also enhanced by 40–70% with chemical modifications to the groundnut shells using reactive dye. Various fruit wastes have been shown to effectively remove heavy metals from aqueous solutions. For instance, lemon peel was shown to effectively remove Zn(II), Pb(II), Cd(II), Cu(II), and Ni(II), achieving maximum adsorption capacities of 27.9, 37.9, 54.6, 71.0, and 80.0 mg/g, respectively [129]. Orange peel also demonstrated effective heavy metal removal in a variety of studies. Ajmal et al. [99] achieved significant removal of Ni(II) (97.5%) with orange peel, along with lower removal efficiencies of Cu(II), Pb(II), Zn(II), and Cr(VI). Thirumavalavan et al. [46] investigated the adsorption of Cd(II), Cu(II), Ni(II), Pb(II), and Zn(II) with orange peel and demonstrated significant removal, achieving maximum adsorption capacities of 41.8, 63.3, 81.3, 27.1, and 24.1 mg/g, respectively. The biochars derived from agricultural wastes were utilized to remove Cd(II) and Cu(II) from aqueous [130]. Lucerne biochar had the highest Langmuir sorption capacity of Cd(II) (6.28 mg/g), and vetch-derived biochar had the highest Cu(II) sorption capacity (18.0 mg/g) at pH 5.5. Another study demonstrated similar removal of Pb(II) using orange peel, achieving a maximum adsorption capacity of 27.9 mg/g [131]. Annadurai et al. [132] also achieved much lower removal of five different heavy metals using orange peel with maximum adsorption capacities ranging from 1.9 to 7.8 mg/g in the following order of adsorption: Pb(II) > Ni(II) > Zn(II) > Cu(II) > Co(I I). Significant removal of Cd(II), Cu(II), Pb(II), and Ni(II) was also achieved with chemically modified orange peel with maximum adsorption capacities of 293, 289, 476, and 162 mg/g, respectively [133, 134]. Banana peel also exhibited varying degrees of heavy metal removal in aqueous solution. Thirumavalavan et al. [129] demonstrated significant removal of a variety of heavy metals, achieving maximum adsorption capacities of 21.9, 25.9, 34.1, 52.4, and 54.4 mg/g for Zn(II), Pb(II), Cd(II), Cu(II), and Ni(II), respectively. A study conducted by DeMessie et al. [135] achieved a maximum adsorption capacity of 7.4 mg/g for Cu(II) using banana peel, which increased to 38.3 and 38.4 mg/g after the banana peel was pyrolyzed at 500 and 600°C, respectively. Banana peel, watermelon peel, and grape waste reported to be the most efficient adsorbents for the removal of heavy metal from wastewater over pH 2.0 and 5.5 [136]. Melia et al. [137] had investigated over agricultural wastes and by-products (AWBs) from grape, wheat, barley, and flax production, to reduce the concentration of Cd in contaminated water. Another study observed relatively low removal for several heavy metals using banana peel, achieving maximum adsorption capacities ranging from 2.6 to 7.9 mg/gin the following order of adsorption: Pb(II) > N i(II) > Zn(II) > Cu(II) > Co(II) [132]. Grapefruit peel was also found to be an effective adsorbent for the removal of Cd(II) and Ni(II) from aqueous solution, achieving maximum adsorption capacities of 42.1 and 46.1 mg/g, respectively [138]. The adsorption onto the grapefruit peel was attributed to the ion-exchange mechanism and, to a lesser extent, complexation with –OH functional groups [138]. Grape stalk wastes have also demonstrated the ability to remove heavy metals, achieving maximum adsorption capacities of 10.1 and 10.6 mg/g for Cu(II) and Ni(II), respectively [139]. Other types of vegetable wastes have been shown to remove heavy metals from water source. Mushroom residues were shown to be effective in the removal of heavy metals. Based on an evaluation of four different types of mushroom residues, removal efficiencies for Cu(II), Zn(II), and Hg(II) ranged from 39.7 to 81.7% [140]. Another study investigated the removal of Cd(II) and Pb(II) using three different mushrooms and achieved maximum adsorption capacities of 35.0 and 33.8 mg/g, respectively [141]. Corncob was also shown to remove heavy metals from aqueous solutions. When investigating its removal of Cd(II), researchers achieved a maximum adsorption capacity of 5.1 mg/g, along with an 4–10-fold increase in removal when the corncob was chemically modified using nitric and citric acid [142]. Moreover, corncob successfully removed Pb(II), with a maximum adsorption capacity of 16.2 mg/g. The adsorption capacity for the removal of Pb(II) using corncob increased significantly (43.4 mg/g) when the corncob was treated with sodium hydroxide. As summarized in **Table 2**, the different bioadsorbents made from different kinds of agro wastes such as orange peel, coconut shell, potato peel, rice waste, spirogyra, peanut shell, cashew nut shell, which are potentially used for the removal of various heavy metals including Cr(VI), Ni(II), Cu(II), Pb(II), Zn(II), etc. Nevertheless, the adsorption capacities

Adsorbent source	Adsorbate	Optimum pH	Removal capacity (max)	References
Orange peel	Ni(II);Cu(II);Pb(II);Zn(II);Cr(IV)	6.0	96%	Ajmal et al. [99]
Coconut shell charcoal	Cr(VI)	6.0	15.47 mg/g	Babel and Kurniawan [100]
Pecan shells	Cu(II); Pb(II); Zn(II)	4.8	~88%; ~90%; ~27%	Bansode et al. [101]
Potato peels charcoal	Cu(II)	6.0	99.8%	Amana et al. [102]
Rice husk	Cr(VI)	2.0	88.88%	Bishnoi et al. [103]
Rice hull	Cr(VI); Cu(II)	2.0; 5.5	0.17 mg/g 0.02 mg/g	Tang et al. [104]
Spirogyra	Cu(II)	5.0	133 mg/g	Gupta et al. [105]
Ecklonia maxima	Cu(II); Pb(II); Cd(II);	5.0 5.0 5.0	85–94 mg/g: 227–243 mg/g: 83.5 mg/g	Feng et al. [106]
Ulva lactuca	Cr(VI)	6.0	92%	El-Sikaily et al. [107]
Oedogonium sp.; Nostoc sp.	Pb(II)	5.0	145.0 mg/g; 93.5 mg/g	Gupta et al. [108]
Fucus serratus	Cu(II)	5.5	3.15 mmol/g	Ahmady-Asbchin et al. [109]
Rice husk	Ni(II); Zn(II); Cd(II); Mn(II); Co(II); Cu(II); Hg(II); Pb(II);	6.0	0.094 mmol/g; 0.124 mmol/g; 0.149 mmol/g; 0.151 mmol/g; 0.162 mmol/g; 0.172 mmol/g; 0.18 mmol/g; 0.28 mmol/g;	Krishnani et al. [111]

Adsorbent source	Adsorbate	Optimum pH	Removal capacity (max)	References
Coconut shell; Neem leaves; Hyacinth roots; Rice straw; Rice bran; Rice husk	Cu(II)	6.0	19.888 mg/g; 17.488 mg/g; 21.79 mg/g; 18.351 mg/g; 20.977 mg/g; 17.869 mg/g	Singha et al. [112]
Rice husk	Cr(VI)	2.0	99.5%	Georgiev et al. [113]
Rice husk	Cr(VI)	2.0	76.5%	Bansal et al. [114]
Rice husk	Cd(II)	12.0	99%	Ajmal et al. [115]
Peanut shell	Pb(II)	6.0	32.87 mg/g	Tasar et al. [116]
Peanut shell	Cr(VI)	2.0	4.48 mg/g	Ahmad et al. [117]
Peanut shell	Cu(II)	5.0	25.39 mg/g	Witek-Krowiak et al. [118]
Peanut husk	Pb(II); Cr(III); Cu(II)	4.0	4.66 mg/g; 3.02 mg/g; 3.80 mg/g	Li et al. [119]
Peanut hull	Cu(II)	5.5	21.3 mg/g	Zhu et al. [120]
Cashew nut shell	Cu(II)	5.0	20.0 mg/g	Kumar et al. [121]

Table 2.
Removal of heavy metal using agro waste adsorbent.

of adsorbent materials are dependent of the adsorption dosage, contact time, concentration, and pH. The maximum adsorption capacities were predominant at lower pH and proportional to the adsorption dosage.

4. Conclusions

Agro wastes or residues such as sugars, cellulose, minerals, and proteins are well off with nutrient composition and valuable bioactive compounds. Consequently, agro wastes having heterogeneity composition can be considered as “precursor” for other industrial processes instead of “wastes” keeping in mind sustainable development. Solid-state fermentation is a familiar approach for the production of microbial metabolites over agro waste with a low moisture content, with the advantages of a high yield concentration but only a proportionate minimum energy being needed. Various microbes have prospective to utilize the agro waste as raw materials for their growth through fermentation processes going for generation of biofuel as an alternative to faster depleting fossil fuel. The agro waste direct or active carbon generated from it can be suitable use for wastewater treatment. Vermicompost can be produced on the degradation of various agro wastes using numerous species of worms within 3–4 month time periods, which have advantages as (a) it can proceed as biofertilizers, reinstate soil nutrients, stabilizes the soil, and augmented the fertility of soil over an extended period; (b) it sorts out the social demands and recycles the waste; and (c) it is observed to be a beneficial endeavor as a circular economy. Vermicompost is found to be better option as compared with the normal composting, commonly adopted in Asian countries, owing to its enhanced nutrient contents, i.e., nitrogen, phosphorus, and potassium content. The vermicomposting also has capability to enhance the soil structure and to improve its water-holding capacity. The vermicomposting is considered to be ideal organic manure for better growth and yield of agricultural product. The agro waste can be suitably used as lowcost adsorbent for wastewater treatment. One of the most ways to generate revenue from agro waste by converting into nanocellulose and activated carbon, which have a multidisciplinary applications per today's market demands. The agro waste can have different environmental approach that leads for waste to revenue generation.

Acknowledgements

We express thanks to NIST (Autonomous) and the institute management for providing us the required infrastructure, the support, and encouragement to write and publish the book chapter.

Conflict of interest

The authors declare no conflict of interest in publication of this book chapter.

Notes/thanks/other declarations

Thanks to the authors of all references cited in this chapter whose research findings helped many ways to inculcate for this chapter.

Author details

Manabendra Patra and Duryodhan Sahu*
Department of Chemistry, National Institute of Science and Technology, Berhampur, Odisha, India

*Address all correspondence to: duryosahu@gmail.com

References

[1] Sivakumar D, Srikanth P, Ramteke PW, Nouri' J. Agricultural waste management generated by agro-based industries using biotechnology tools. Global Journal of Environmental Science and Management. 2022;**8**:281-296

[2] Martin JGP, Porto E, Correa CB, Alencar SM, Gloria EM, Cabra ISR, et al. Antimicrobial potential and chemical composition of agro industrial wastes. Journal of Natural Products. 2012;**5**:27-36

[3] Nigam PS, Gupta N, Anthwal A. Pre-treatment of agroindustrial residues. In: Nigam PS, Pandey A, editors. Biotechnology for Agro-Industrial Residues Utilization. Heidelberg: Springer; 2009. pp. 13-33

[4] El-Tayeb TS, Abdelhafez AA, Ali SH, Ramadan EM. Effect of acid hydrolysis and fungal biotreatment on agroindustrial wastes for obtainment of free sugars for bioethanol production. Brazilian Journal of Microbiology. 2012;**43**:1523-1535

[5] Motte JC, Trably E, Escudié R, Hamelin J, Steyer JP, Bernet N, et al. Total solids content: A key parameter of metabolic pathways in dry anaerobic digestion. Biotechnology for Biofuels. 2013;**6**:1-9

[6] Ferrentino G, Morozova K, Mosibo OK, Ramezani M, Scampicchio M. Biorecovery of antioxidants from apple pomace by supercritical fluid extraction. Journal of Cleaner Production. 2018;**186**:253-261

[7] Garcia-Mendoza MP, Paula JT, Paviani LC, Cabral FA, Martinez Correa HA. Extracts from mango peel byproduct obtained by supercritical CO_2 and pressurized solvent processes. LWT—Food Science and Technology. 2015;**62**:131-137

[8] Ozturk B, Parkinson C, Gonzales-Miquel M. Extraction of polyphenolic antioxidants from orange peel waste using deep eutectic solvents. Separation and Purification Technology. 2018;**206**:1-13

[9] Kelly NP, Kelly AL, Mahony JA. Strategies for enrichment and purification of polyphenols from fruit-based materials. Trends in Food Science and Technology. 2019;**83**:248-258

[10] Duque-Acevedo M, Belmonte-Urena LJ, Cortés-García FJ, Camacho-Ferre F. Agricultural waste: Review of the evolution, approaches and perspectives on alternative uses. Global Ecology and Conservation. 2020;**22**:e00902

[11] Zhang L, Zeng G, Don H, Chen Y, Zhang J, Yan M, et al. The impact of silver nanoparticles on the co-composting of sewage sludge and agricultural waste: Evolutions of organic matter and nitrogen. Bioresource Technology. 2017;**230**:132-139

[12] Qian X, Shen G, Wang Z, Guo C, Liu Y, Lei Z, et al. Co-composting of livestock manure with rice straw: Characterization and establishment of maturity evaluation system. Waste Management. 2014;**34**(2):530-535

[13] Singh S, Nain L. Microorganisms in the conversion of agricultural wastes to compost. Proceedings of the Indian National Science Academy. 2014;**80**:473-481

[14] Gusmawartati H, Yusuf M. Effect various combination of organic waste on compost quality. Journal of Tropical Soils. 2015;**20**:59-65

[15] Mastouri F, Hassandokht MR, Padasht Dehkaei MN. The effect of application of agricultural waste compost on growing media and greenhouse lettuce yield. Acta Horticulturae. 2005;**697**:153

[16] Pergola M, Persiani A, Pastore V, Palese AM, D'Adamo C, De Falco E, et al. Sustainability assessment of the green compost production chain from agricultural waste: a case study in southern Italy. Agronomy. 2020;**10**:230

[17] Aslam Z, Ahmad A, Ibrahim M, Iqbal N, Idrees M, Ali A, et al. Microbial enrichment of vermicompost through earthworm *Eisenia fetida* (Savigny, 1926) for agricultural waste management and development of useful organic fertilizer. Pakistan Journal of Agricultural Science;**58**(2021):851-861

[18] Yu Y, Li S, Qiu J, Li J, Luo Y, Guo J. Combination of agricultural waste compost and biofertilizer improves yield and enhances the sustainability of a pepper field. Journal of Plant Nutrition and Soil Science. 2019;**182**(2019):1-10

[19] Trillas MI, Casanova E, Cotxarrera L, Ordovás J, Borrero C, Avilés ML. Composts from agricultural waste and the *Trichoderma asperellum* strain T-34 suppress rhizoctonia solani in cucumber seedlings. Biological Control. 2006;**39**:32-38

[20] Karak T, Bhattacharyya P, Paul RK, Das T, Saha SK. Evaluation of composts from agricultural wastes with fish pond sediment as bulking agent to improve compost quality. Clean—Soil, Air, Water. 2013;**41**:711-723

[21] Gea FJ, Navarro MJ, Tello JC. Potential application of compost teas of agricultural wastes in the control of the mushroom pathogen verticillium fungicola. Journal of Plant Diseases and Protection. 2009;**116**:271-273

[22] Ukanwa KS, Patchigolla K, Sakrabani R, Anthony E, Mandavgane S. A review of chemicals to produce activated carbon from agricultural waste biomass. Sustainability. 2019;**11**:6204

[23] Ioannidou OA, Zabaniotou AA, Stavropoulos GG, Islam MA, Albanis TA. Preparation of activated carbons from agricultural residues for pesticide adsorption. Chemosphere. 2010;**80**:1328-1336

[24] Malik R, Ramteke DS, Wate SR. Adsorption of malachite green on groundnut shell waste based powdered activated carbon. Waste Management. 2007;**27**(9):1129-1138

[25] Kadirvelu K, Namasivayam C. Activated carbon from coconut coir pith as metal adsorbent: Adsorption of Cd(II) from aqueous solution. Advances in Environmental Research. 2003;7:471-478

[26] Prahas D, Kartika Y, Indraswati N, Ismadji S. Activated carbon from jackfruit peel waste by H_3PO_4 chemical activation: Pore structure and surface chemistry characterization. Chemical Engineering Journal. 2008;**140**:32-42

[27] Ioannidou O, Zabaniotou A. Agricultural residues as precursors for activated carbon production. Renewable and Sustainable Energy Reviews. 2007;**11**:1966-2005

[28] Buhani S, Luziana F, Rilyanti M, Sumadi S. Production of adsorbent from activated carbon of palm oil shells coated by Fe_3O_4 particle to remove crystal violet in water. Desalination and Water Treatment. 2019;**171**:281-293

[29] Razi MAM, Al-Gheethi A, Al-Qaini M, Yousef A. Efficiency of activated carbon from palm kernel shell for treatment of grey-water. Arab

Journal of Basic and Applied Sciences. 2018;**25**(3):103-110

[30] Keppetipola NM, Dissanayake M, Dissanayake P, Karunarathne B, Dourges MA, Talaga D, et al. Graphite-type activated carbon from coconut shell: A natural source for eco-friendly non-volatile storage devices. RSC Advances. 2021;**11**:2854

[31] Omokafe SM, Adeniyi AA, Igbafen EO, Oke SR, Olubambi PA. Fabrication of activated carbon from coconut shells and its electrochemical properties for supercapacitors. International Journal of Electrochemical Science. 2020;**15**:10854-10865

[32] Feng P, Li J, Wang H, Zhiqiang X. Biomass-based activated carbon and activators: Preparation of activated aarbon from corncob by chemical activation with biomass pyrolysis liquids. ACS Omega. 2020;**5**:24064-24072

[33] Saleem J, Bin Shahid U, Hijab M, Mackey H, McKay G. Production and applications of activated carbons asadsorbents from olive stones. Biomass Conversion and Biorefinery. 2019;**9**:775-802

[34] Lia Z, Hanafy H, Zhang L, Sellaoui L, Netto MS, Oliveira MLS, et al. Adsorption of congo red and methylene blue dyes on an ashitaba waste and a walnut shell-based activated carbon from aqueous solutions: Experiments, characterization and physical interpretations. Chemical Engineering Journal. 2020;**388**:124263

[35] Ash B, Satapathy D, Mukherjee PS, Nanda B, Gumaste JL, Mishra BK. Characterization and application of activated carbon prepared from coir pith. Journal of Scientific and Industrial Research. 2006;**65**:1008-1012

[36] Putra Negara DNK, Nindhia TGT, Septiadi WN. Surface properties and adsorption capacities of rice bran-activated carbon. Journal of Mechanical Engineering Science and Technology. 2020;**4**(2):115-124

[37] Ozsin G, Kilic M, Apaydın-Varol E, Putun AE. Chemically activated carbon production from agricultural waste of chickpea and its application for heavy metal adsorption: equilibrium, kinetic, and thermodynamic studies. Applied Water Science. 2019;**9**:56

[38] Chuayjumnong S, Karrila S, Jumrat S, Pianroj Y. Activated carbon and palm oil fuel ash as microwave absorbers for microwave-assisted pyrolysis of oil palm shell waste. RSC Advances. 2020;**10**:32058

[39] Tay T, Ucar S, Karagöz S. Preparation and characterization of activated carbon from waste biomass. Journal of Hazardous Materials. 2009;**165**:481-485

[40] Nunes AA, Franca AS, Oliveira LS. Activated carbons from waste biomass: An alternative use for biodiesel production solid residues. Bioresource Technology. 2009;**100**:1786-1792

[41] Chang KL, Lin JH, Chen ST. Adsorption studies on the removal of pesticides (Carbofuran) using activated carbon from rice straw agriculture waste. World Academy of Science, Engineering and Technology. 2011;**76**:348

[42] Chang KL, Hsieh JF, Ou BM, Chang MH, Hsieh WY, Lin JH, et al. Adsorption studies on the removal of an endocrine-disrupting comound (bisphenol A) using activated carbon from rice straw agriculture waste. Separation Science and Technology. 2012;**47**:1514

[43] Isoda N, Rodrigues R, Silva A, Gonçalves M, Mandelli D, Figueiredo FCA, et al. Optimization

of preparation conditions of activated carbon from agriculture waste utilizing factorial design. Powder Technology. 2014;**256**:175-181

[44] Köseoğlu E, Akmil-Basar C. Preparation, structural evaluation and adsorptive properties of activated carbon from agricultural waste biomass. Advanced Powder Technology. 2015;**26**:811-818

[45] Mahamad MN, Zaini MAA, Zakaria ZA. Preparation and characterization of activated carbon from pineapple waste biomass for dye removal. International Biodeterioration & Biodegradation. 2015;**102**:274

[46] Baysal M, Bilge K, Yılmaz B, Papila M, Yürüm Y. Preparation of high surface area activated carbon from waste-biomass of sunflower piths: Kinetics and equilibrium studies on the dye removal. The Journal of Environmental Chemical Engineering. 2018;**6**:1702

[47] Patil A, Suryawanshi UP, Harale NS, Patil SK, Vadiyar MM, Luwang MN, et al. Adsorption of toxic Pb(II) on activated carbon derived from agriculture waste (mahogany fruit shell): Isotherm, kinetic and thermodynamic study. International Journal of Environmental Analytical Chemistry. 2020. DOI: 10.1080/03067319.2020.1849648

[48] Xue H, Wang X, Xu Q, Dhaouadi F, Sellaoui L, Seliem MK, et al. Adsorption of methylene blue from aqueous solution on activated carbons and composite prepared from an agricultural waste biomass: A comparative study by experimental and advanced modeling analysis. Chemical Engineering Journal. 2022;**430**:132801

[49] Mateo S, Peinado S, Morillas-Gutiérrez F, La Rubia MD, Moya AJ. Nanocellulose from agricultural wastes: Products and applications—A review. Processes. 2021;**9**:1594

[50] Fillat Ú, Wicklein B, Martín-Sampedro R, Ibarra D, Ruiz-Hitzky E, Valencia C, et al. Assessing cellulose nanofiber production from olive tree pruning residue. Carbohydrate Polymers. 2018;**179**:252-261

[51] Rambabu N, Panthapulakkal S, Sain M, Dalai A. Production of nanocellulose fibers from pinecone biomass: Evaluation and optimization of chemical and mechanical treatment conditions on mechanical properties of nanocellulose films. Industrial Crops and Products. 2016;**83**:746-754

[52] Dos Santos RM, Neto WPF, Silvério HA, Martins DF, Dantas NO, Pasquini D. Cellulose nanocrystals from pineapple leaf, a new approach for the reuse of this agro-waste. Industrial Crops and Products. 2013;**50**:707-714

[53] Johar N, Ahmad I, Dufresne A. Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk. Industrial Crops and Products. 2012;**37**:93-99

[54] Siqueira G, Tapin-Lingua S, Bras J, da Silva Perez D, Dufresne A. Morphological investigation of nanoparticles obtained from combined mechanical shearing and enzymatic and acid hydrolysis of sisal fibers. Cellulose. 2010;**17**:1147-1158

[55] Ohwoavworhua F, Adelakun T. Non-wood fibre production of microcrystalline cellulose from Sorghum caudatum: Characterisation and tableting properties. Indian Journal of Pharmaceutical Sciences. 2010;**7**:295

[56] Fortunati E, Luzi F, Jiménez A, Gopakumar D, Puglia D, Thomas S, et al. Revalorization of sunflower stalks

as novel sources of cellulose nanofibrils and nanocrystals and their effect on wheat gluten bionanocomposite properties. Carbohydrate Polymers. 2016;**149**:357-368

[57] Ferreira FV, Mariano M, Rabelo SC, Gouveia RF, Lona LMF. Isolation and surface modification of cellulose nanocrystals from sugarcane bagasse waste: From a micro- to a nano-scale view. Applied Surface Science. 2018;**436**:1113-1122

[58] Lu P, Hsieh YL. Preparation and characterization of cellulose nanocrystals from rice straw. Carbohydrate Polymers. 2012;**87**:564-573

[59] do Nascimento DM, Almeida JS, Vale MDS, Leitão RC, Muniz CR, de Figueirêdo MCB, et al. A comprehensive approach for obtaining cellulose nanocrystal from coconut fiber. Part I: Proposition of technological pathway. Industrial Crops and Products. 2016;**93**:66-75

[60] de Carvalho Mendes CA, Ferreira NMS, Furtado CRG, de Sousa AMF. Isolation and characterization of nanocrystalline cellulose from corn husk. Materials Letters. 2015;**148**:26-29

[61] Zheng D, Zhang Y, Guo Y, Yue J. Isolation and characterization of nanocellulose with a novel shape from walnut (*Juglans regia* L.) shell agricultural waste. Polymers. 2019;**11**:1130

[62] Sijabat EK, Nuruddin A, Aditiawati P, Purwasasmita BS. Optimization on the synthesis of bacterial nano cellulose (BNC) from banana peel waste for water filter membrane applications. Materials Research Express. 2020;**7**:055010

[63] Panpatte DG, Jhala YK. Agricultural waste: A suitable source for biofuel production. In: Rastegari AA et al., editors. Prospects of Renewable Bioprocessing in Future Energy Systems, Biofuel and Biorefinery Technologies. Vol. 10. Springer Nature Switzerland AG; 2019

[64] Santa-Maria M, Ruiz-Colorado AA, Cruz G, Jeoh T. Assessing the feasibility of biofuel production from lignocellulosic banana waste in rural agricultural communities in Peru and Colombia. Bioenergy Research. 2013;**6**:1000-1011

[65] Srivastava AK, Agrawal P, Rahiman A. Delignification of rice husk andproduction of bioethanol. International Journal of Innovative Research in Science, Engineering and Technology. 2014;**2**:10187-10194

[66] Singh A, Bajar S, Narsi R, Bishnoi NR. Enzymatic hydrolysis of microwave alkali pretreated rice husk for ethanol production by *Saccharomyces cerevisiae*, *Scheffersomyces stipitis* and their co-culture. Fuel. 2014;**116**:699-702

[67] Chukwuma SE, Olawale O, Ikechukwu NE, Chigozie ME, Ositadinma CU, Ephraim NA. Enhanced availability of biofuel and biomasscomponents in aspergillus Niger and aspergillus fumigatus treated rice husk. European Scientific Journal. 2014;**10**:1857-7881

[68] Naqvi SR, Ali I, Nasir S, Ali S, Taqvi A, Atabani AE, et al. Assessment of agro-industrial residues for bioenergy potential by investigating thermo-kinetic behavior in a slow pyrolysis process. Fuel. 2020;**278**:118259

[69] Buenrostro-Figueroa J, Tafolla-Arellano JC, Flores-Gallegos AC, Rodríguez-Herrera R, De la Garza-Toledo H, Aguilar CN. Native yeasts for alternative utilization of

overripe mango pulp for ethanol production. Revista Argentina de Microbiología. 2018;**50**:173-177

[70] Mihajlovski K, Buntić A, Milić M, Rajilić-Stojanović M, Dimitrijević-Branković S. From agricultural waste to biofuel: Enzymatic potential of a bacterial isolate streptomyces fulvissimus cks7 for bioethanol production. Waste and Biomass Valorization. 2021;**12**:165-174

[71] Najafi G, Ghobadian B, Tavakoli T, Yusaf T. Potential of bioethanol production from agricultural wastes in Iran. Renewable and Sustainable Energy Reviews. 2009;**13**:1418-1427

[72] Taghizadeh-Alisaraei A, Assar HA, Ghobadian B, Motevali A. Potential of biofuel production from pistachio waste in Iran. Renewable and Sustainable Energy Reviews. 2017;**72**:510-522

[73] Yuliansyah AT, Hirajim T, Kumagai S, Sasaki K. Production of solid biofuel from agricultural wastes of the palm oil industry by hydrothermal treatment. Waste and Biomass Valorization. 2010;**1**:395-405

[74] Laobussararak B, Chulalak-sananukul W, Chavalparit O. Comparison of bacterial and yeast ethanol fermentation Yield from Rice straw. Advanced Materials Research. 2012;**347-353**:2541-2544

[75] Kumar AK, Parikh BS, Shah E, Liu LZ, Cotta MA. Cellulosic ethanol production from green solvent-pretreated rice straw. Biocatalysis and Agricultural Biotechnology. 2016;**7**:14-23

[76] Sasaki K, Matsuda F, Hasunuma T, Ogino C, Urairi M, Yoshida K, et al. Ability of a perfluoropolymer membrane to tolerate by-products of ethanol fermentation broth from dilute acid-pretreated rice straw. Biochemical Engineering Journal. 2013;**70**:135-139

[77] Jain RK, Ghosh D, Agrawal D, Suman SK, Pandey D, Vadde VT, et al. Ethanol production from rice straw using thermotolerant Kluyveromyces sp. IIPE453. Biomass Conversion and Biorefinery. 2015;**5**:331-337

[78] de Assis Castro RC, Roberto IC. Effect of nutrient supplementation on ethanol production in different strategies of saccharification and fermentation from acid pretreated rice straw. Biomass and Bioenergy. 2015;**78**:156-163

[79] Mahajan C, Chadha BS, Nain L, Kaur A. Evaluation of glycosyl hydrolases from thermophilic fungi for their potential in bioconversion of alkali and biologically treated *Parthenium hysterophorus* weed and rice straw into ethanol. Bioresource Technology. 2014;**163**:300-307

[80] Sasaki K, Tsuge Y, Sasaki D, Hasunuma T, Sakamoto T, Sakihama Y, et al. Optimized membrane process to increase hemicellulosic ethanol production from pretreated rice straw by recombinant xylose-fermenting Saccharomyces cerevisiae. Bioresource Technology. 2014;**169**:380-386

[81] Momayez F, Karimi K, Horváth IS. Enhancing ethanol and methane production from rice straw by pretreatment with liquid waste from biogas plant. Energy Conversion and Management. 2018;**178**:290-298

[82] Molaverdia M, Karimia K, Mirmohamadsadeghia S, Galbec M. High titer ethanol production from rice straw via solid-state simultaneous saccharification and fermentation by Mucor indicus at low enzyme loading.

Energy Conversion and Management. 2019;**182**:520-529

[83] Lü J-L, Zhou P-J. Ethanol production from microwave-assisted $FeCl_3$ pretreated rice straw. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2015;**37**(21):2367-2374

[84] Okamoto K, Nitta Y, Maekawa N, Yanase H. Direct ethanol production from starch, wheat bran and rice straw by the white rot fungus *Trametes hirsute*. Enzyme and Microbial Technology. 2011;**48**:273-277

[85] Karimi K, Emtiazi G, Taherzadeh MJ. Ethanol production from dilute acid pretreated rice straw by simultaneous saccharification and fermentation with *Mucor indicus*, *Rhizopus oryzae*, and *Saccharomyces cerevisiae*. Enzyme and Microbial Technology. 2006;**40**:138e144

[86] Kaur J, Chugh P, Soni R, Soni SK. A low-cost approach for the generation of enhanced sugars and ethanol from rice straw using in-house produced cellulase-hemicellulase consortium from a. niger P-19. Bioresource Technology Reports. 2020;**11**:100469

[87] Sharma M, Khan AA, Puri SK, Tuli DK. Wood ash as a potential heterogeneous catalyst for biodiesel synthesis. Biomass and Bioenergy. 2012;**41**:94-106

[88] Uprety BK, Chaiwong W, Ewelike C, Rakshit SK. Biodiesel production using heterogeneous catalysts including wood ash and the importance of enhancing byproduct glycerol purity. Energy Conversion and Management. 2016;**115**:191-199

[89] Betiku JE, Etim AO, Pereao O, Ojumu TV. Two-step conversion of neem (*Azadirachta indica*) seed oil into fatty methyl esters using a heterogeneous biomass-based catalyst: An example of cocoa pod husk. Energy & Fuels. 2017;**31**:6182-6193

[90] Vadery V, Narayanan BN, Ramakrishnan RM, Cherikkallinmel SK, Sugunan S, Narayanan DP, et al. Room temperature production of jatropha biodiesel over coconut husk ash. Energy. 2014;**70**:588-594

[91] Sarma K, Kumar P, Aslam M, Chouhan APS. Preparation and characterization of *Musa balbisiana* Colla underground stem nano-material for biodiesel production under elevated conditions. Catalysis Letters. 2014;**144**:1344-1353

[92] Aslam M, Saxena P, Sarma AK. Green technology for biodiesel production from *Mesua ferrea* L. seed oil. Energy & Environmental Science. 2014;**4**(2):11-21

[93] Gohain M, Devi A, Deka D. *Musa balbisiana* Colla peel as highly effective renewable heterogeneous base catalyst for biodiesel production. Industrial Crops and Products. 2017;**109**:8-18

[94] Betiku E, Ajala SO. Modeling and optimization of *Thevetia peruviana* (yellow oleander) oil biodiesel synthesis via *Musa paradisiacal* (plantain) peels as heterogeneous base catalyst: A case of artificial neural network vs. response surface methodology. Industrial Crops and Products. 2014;**53**:314-322

[95] Etim AO, Betiku E, Ajala SO, Olaniyi PJ, Ojumu TV. Potential of ripe plantain fruit peels as an ecofriendly catalyst for biodiesel synthesis: Optimization by artificial neural network integrated with genetic algorithm. Sustainability. 2018;**10**:707

[96] Betiku E, Akintunde AM, Ojumu TV. Banana peels as a biobase catalyst for fatty acid methyl esters production using napoleon's plume (*Bauhinia monandra*) seed oil: A process parameters optimization study. Energy. 2016;**103**:797-806

[97] Odude VO, Adesina AJ, Oyetunde OO, Adeyemi OO, Ishola NB, Etim AO, et al. Application of agricultural waste-based catalysts to transesterification of esterified palm kernel oil into biodiesel: A case of banana fruit peel versus cocoa pod husk. Waste and Biomass Valorization. 2019;**10**:877-888

[98] Igwe JC, Ogunewe DN, Abia AA; Competitive adsorption of Zn(II), Cd(II) and Pb(II) ions from aqueous and non-aqueous solution by maize cob and husk African Biotechnol J; **4**(2005):1113-1116.

[99] Ajmal M, Rao R, Ahmad R, Ahmad J. Adsorption studies on *Citrus reticulata* (fruit peel of orange) removal and recovery of Ni(II) from electroplating waste water. Journal of Hazardous Materials. 2000;**79**:117-131

[100] Babel S, Kurniawan TA. Cr(VI) removal from synthetic wastewater using coconut shell charcoal and commercial activated carbon modified with oxidizing agents and/or chitosan. Chemosphere. 2004;**54**(7):951-967

[101] Bansode PR, Losso JN, Marshall WE, Rao RM, Portier RJ. Adsorption of metal ions by pecan shell-based granular activated carbons. Bioresource Technology. 2003;**89**:115-119

[102] Amana T, Kazi AA, Sabri MU, Banoa Q. Potato peels as solid waste for the removal of heavy metal copper(II) from waste water/industrial effluent. Colloids and Surfaces B: Biointerfaces. 2008;**63**:116-121

[103] Bishnoi NR, Bajaj M, Sharma N, Gupta A. Adsorption of Cr(VI) on activated rice husk carbon and activated alumina. Bioresource Technology. 2003;**91**(3):305-307

[104] Tang P, Lee CK, Low KS, Zainal Z. Sorption of Cr(VI) and Cu(II) in aqueous solution by ethylenediamine modified rice hull. Environmental Technology. 2003;**24**:1243-1251

[105] Gupta VK, Rastogi A, Saini VK, Jain N. Biosorption of copper(II) from aqueous solutions by Spirogyra species. Journal of Colloid and Interface Science. 2006;**296**:59-63

[106] Fenga D, Aldrich C. Adsorption of heavy metals by biomaterials derived from the marine alga *Ecklonia maxima*. Hydrometallurgy. 2004;**73**:1-10

[107] El-Sikaily A, El Nemr A, Khaled A, Abdelwehab O. Removal of toxic chromium from wastewater using green alga ulva lactuca and its activated carbon. Journal of Hazardous Materials. 2007;**148**:216-228

[108] Gupta VK, Rastogi A. Biosorption of lead(II) from aqueous solutions by non-living algal biomass Oedogonium sp. and Nostoc sp.—A comparative study. Colloids and Surfaces B: Biointerfaces. 2008;**64**:170-178

[109] Ahmady-Asbchin S, Andre's Y, Ge'rente C, Le Cloirec P. Biosorption of Cu(II) from aqueous solution by *Fucus serratus*: Surface characterization and sorption mechanisms. Bioresource Technology. 2008;**99**:6150-6155

[110] Deliyanni EA, Peleka EN, Matis KA. Removal of zinc ion from water by sorption onto iron-based nanoadsorbent.

Journal of Hazardous Materials. 2007;**141**:176-184

[111] Krishnani KK, Meng X, Christodoulatos C, Boddu VM. Biosorption mechanism nine different heavy metals onto biomatrix from rice husk. The Journal of Hazardous Materials. 2008;**153**:1222-1234

[112] Singha B, Das SK. Adsorptive removal of Cu(II) from aqueous solution and industrial effluent using natural/agricultural wastes. Colloids and Surfaces. B, Biointerfaces. 2013;**107**:97-106

[113] Georgieva VG, Tavlieva MP, Genieva SD, Vlaev LT. Adsorption kinetics of Cr(VI) ions from aqueous solutions onto black rice husk ash. Journal of Molecular Liquids. 2015;**208**:219-226

[114] Bansal M, Garg U, Singh D, Garg VK. Removal of Cr(VI) from aqueous solutions using pre-consumer processing agricultural waste: A case study of rice husk. Journal of Hazardous Materials. 2009;**162**:312-320

[115] Ajmal M, Rao RA, Anwar S, Ahmad J, Ahmad R. Adsorption studies on rice husk: Removal and recovery of Cd(II) from wastewater. Bioresource Technology. 2003;**86**:147-149

[116] Taşar S, Kaya F, Özer A. Biosorption of lead(II) ions from aqueous solution by peanut shells: Equilibrium, thermodynamic and kinetic studies. Journal of Environmental Chemical Engineering. 2014;**2**:1018-1026

[117] Ahmad A, Ghazi ZA, Saeed M, Ilyas M, Ahmad R, Khattaka AM, et al. A comparative study of the removal of Cr(VI) from synthetic solution using natural biosorbents. New Journal of Chemistry. 2017;**41**:10799-10807

[118] Witek-Krowiak A, Szafran RG, Modelski S. Biosorption of heavy metals from aqueous solutions onto peanut shell as a low-cost biosorbent. Desalination. 2011;**265**:126-134

[119] Li Q, Zhai J, Zhang W, Wang M, Zhou J. Kinetic studies of adsorption of Pb(II), Cr(III) and Cu(II) from aqueous solution by sawdust and modified peanut husk. Journal of Hazardous Materials. 2007;**141**:163-167

[120] Zhu CS, Wang LP, Chen WB. Removal of Cu(II) from aqueous solution by agricultural by-product: Peanut hull. Journal of Hazardous Materials. 2009;**168**:739-746

[121] Kumar PS, Ramalingam S, Sathyaselvabala V, Kirupha SD, Sivanesan S. Removal of copper(II) ions from aqueous solution by adsorption using cashew nut shell. Desalination. 2011;**266**:63-71

[122] Kumar PS, Ramalingam S, Kirupha SD, Murugesa A, Vidhyadevi T, Sivanesan S. Adsorption behavior of nickel(II) onto cashew nut shell: Equilibrium, thermodynamics, kinetics, mechanism and process design. Chemical Engineering Journal. 2011;**167**:122-131

[123] Anastopoulos I, Ighalo JO, Igwegbe CA, Giannakoudakis DA, Triantafyllidis KS, Pashalidis I, et al. Sunflower-biomass derived adsorbents for toxic/heavy metals removal from wastewater. Journal of Molecular Liquids. 2021;**342**:117540

[124] Moussavi G, Barikbin B. Biosorption of chromium(VI) from industrial wastewater onto pistachio hull waste biomass. Chemical Engineering Journal. 2010;**162**:893-900

[125] Abdić Š, Memić M, Šabanović E, Sulejmanović J, Begić S. Adsorptive

removal of eight heavy metals from aqueous solution by unmodified and modified agricultural waste: Tangerine peel. International journal of Environmental Science and Technology. 2018;**15**:2511-2518

[126] Dakiky M, Khamis M, Manassra A, Mer'eb M. Selective adsorption of chromium(VI) in industrial wastewater using low-cost abundantly available adsorbents. Advances in Environmental Research. 2002;**6**:533-540

[127] Demirbas E, Dizge N, Sulak MT, Kobya M. Adsorption kinetics and equilibrium of copper from aqueous solutions using hazelnut shell activated carbon. Chemical Engineering Journal. 2009;**148**:480-487

[128] Shukla SR, Pai RS. Adsorption of Cu(II), Ni(II) and Zn(II) on dye loaded groundnut shells and sawdust. Separation and Purification Technology. 2005;**43**:1-8

[129] Thirumavalavan M, Lai Y, Lin L, Lee J. Cellulose-based native and surface modified fruit peels for the adsorption of heavy metal ions from aqueous solution. Journal of Chemical & Engineering Data. 2010;**55**:1186-1192

[130] Bandara T, Xu J, Potter ID, Frankse A, Chathurika JBAJ, Tang C. Mechanisms for the removal of Cd(II) and Cu(II) from aqueous solution and mine water by biochars derived from agricultural wastes. Chemosphere. 2020;**254**:126745

[131] Abdelhafez AA, Li J. Removal of Pb(II) from aqueous solution by using biochars derived from sugar cane bagasse and orange peel. Journal of the Taiwan Institute of Chemical Engineers. 2016;**61**:367-375

[132] Annadurai G, Juang RS, Lee DJ. Adsorption of heavy metals from water using banana and orange peels. Water Science and Technology. 2002;**47**:185-190

[133] Feng N, Guo X, Liang S. Adsorption study of copper(II) by chemically modified orange peel. Journal of Hazardous Materials. 2009;**164**:1286-1292

[134] Feng N, Guo X, Liang S, Zhu Y, Liu J. Biosorption of heavy metals from aqueous solutions by chemically modified orange peel. Journal of Hazardous Materials. 2011;**185**:49-54

[135] De Messie B, Sahle-Demessie E, Sorial G. Cleaning water contaminated with heavy metal ions using pyrolyzed biochar adsorbents. Separation Science and Technology. 2015;**50**:2448-2457

[136] Lorenzo M, Antonella G, Astolfi ML, Congedo R, Masotti A, Canepari S. Efficiency evaluation of food waste materials for the removal of metals and metalloids from complex multi-element solutions. Materials. 2018;**11**:334

[137] Melia M, Busquets PR, Ray S, Cundy AB. Agricultural wastes from wheat, barley, flax and grape for the efficient removal of Cd from contaminated wate. RSC Advances. 2018;**8**:40378-40386

[138] Asadollahzadeh M, Torab-Mostaedi M, Hemmati A, Khosravi A. Equilibrium, kinetic, and thermodynamic studies for biosorption of cadmium and nickel on grapefruit peel. Journal of the Taiwan Institute of Chemical Engineers. 2013;**44**:295-302

[139] Villaescusa I, Fiol N, Martinez M, Miralles N, Poch J, Serarols J. Removal of copper and nickel ions from aqueous solutions by grape stalks wastes. Water Research. 2004;**38**:992-1002

[140] Li X, Zhang D, Sheng F, Qing H. Adsorption characteristics of copper(II), zinc(II) and mercury(II) by four kinds of immobilized fungi residues. Ecotoxicology and Environmental Safety. 2018;**147**:357-366

[141] Vimala R, Das N. Biosorption of cadmium(II) and lead(II) from aqueous solutions using mushrooms: A comparative study. Journal of Hazardous Materials. 2009;**168**:376-382

[142] Tan G, Yuan H, Liu Y, Xiao D. Removal of lead from aqueous solution with native and chemically modified corncob. Journal of Hazardous Materials. 2010;**174**:740-745