Asghar Zamani,* Ahmad Poursattar Marjani* and Zahra Mousavi

Agricultural waste biomass-assisted nanostructures: Synthesis and application

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Abstract: Metal oxide nanoporous materials and nanoparticles have main potential uses in several different fields such as nanoelectronics, biomedical science, renewable solar energy, drug-gene delivery, thermal insulation, and so on. On the other hand, it is vital for scientists to understand that agricultural waste biomass-assisted synthesis is less costly, environmentally friendly and renewable strategy, and therefore, agricultural wastes are ideal renewable resources for production of nanostructures as a substitute for toxic chemicals. This present review includes significant recent improvements concerning the synthesis of agricultural waste biomass-assisted metal oxide nanostructures and their application. The goal is to provide a vision for the use of non-extracted agricultural waste, especially lignocellulosic biomass an inexpensive, green, differentiated resource and policy for the synthesis of valuable nanoporous materials and nanoparticles.

Keywords: agricultural waste; metal oxide; nanoparticles; nanoporous materials; catalysis; textural properties

1 Introduction

Synthesis of nanostructures is often a key step in preparation of many important targets including nanocatalysts, nanomedicines, nanosensors, nanodevices and nanosystems [1]. There are various types of methods for the synthesis of a large number of nanostructures in the form of nanoparticles, nanorods and nanotubes, thin films and nanoporous materials. Some of the already existing classical procedures to synthesis of diverse types of nanomaterials are improved to acquire novel

nanostructures and some new methods are developed. Nanoscience is an interdisciplinary field, so there are numerous bottom-up, top-down and hybrid procedures available to produce nanostructures. The procedure to be applied depends upon the morphology of material, textural properties (pore size, particle size, and surface area) chemical and thermal stability, and type of nanomaterial.

Due to semiconductor, or insulator character of metal oxide nanomaterials these nanostructures play a very important role in the production of micro and nanoelectronic circuits, nanosensors, piezoelectric devices, fuel cells, and catalysts [2]. Although various methods for the synthesis of metal oxide nanostructures including sol-gel route [3], reverse micelle technique [4] and coprecipitation process [5] have been reported, these methods usually use the expensive, moisture sensitive, and toxic chemicals which encounter the environmental and economical challenges in large scale application.

In the recent years, bio-based economy and use of renewable biomass as the raw material have been considered as sustainable options to tackle the problems associated with local and global pollutions. Agricultural waste biomass especially lignocellulosic ones (e.g. rice husk and walnut shell) has progressively attracted some attention as a low cost renewable resource for the production of fuels [6] and more recently chemicals and materials [7].

The aim of this review is description of recent advancements in the synthesis of agricultural waste biomass-assisted metal oxide nanomaterials and their significant uses in recent five years. The advantages of using low cost renewable agricultural residues as feedstock for nanomaterial synthesis are also highlighted. The main focus of this article is on the vital role of agricultural waste in nanoparticle and nanoporous material synthesis. Moreover, the various uses of agricultural residues-derived nanomaterial especially in catalysis are discussed in this review.

1.1 Rice husk and straw

Rice husks (or rice hulls) are the hard protecting pods of rice seeds that are 20-22% of total produce of rice, and

* **Corresponding author: Asghar Zamani**, Nanotechnology Research Center, Urmia University, Urmia 57154, Urmia, Iran, e-mail: a.zamani@urmia.ac.ir and **Ahmad Poursattar Marjani**, Department of Organic Chemistry, Faculty of Chemistry, Urmia University, Urmia, Iran, e-mail: a.poursattar@urmia.ac.ir, tel.: +98-912-630-1594; fax: +98-4432752746.

Zahra Mousavi, Nanotechnology Research Center, Urmia University, Urmia 57154, Urmia, Iran

large amounts of rice husk are currently prepared by rice mill industry as a one of the most abundant agricultural waste which contains cellulose 28.7-35.6%, hemicellulose 12.0-29.3%, and lignin 15.4-20.0% [8]. Interestingly, the high silica content (8.7-12.1%) is observed in its husk, [9]. Mostly in form amorphous hydrated SiO_2 similar to that found in most of the other objects in the biosphere [10]. This section reviewed recent reports in syntheses of rice husks-derived SiO_2 nanomaterials and their various applications, especially in catalysis.

In 2013, Thuc et al. used acid-washed Vietnamese rice husk for the synthesis of silica nanoparticles [11]. Acid treatment removes the small quantities of cations causing the increase of SiO_2 extracted from rice husk by calcination followed by preparation of sodium silicate solution by addition of sodium hydroxide. Subsequently, this sodium silicate solution was slowly added into the cetyltrimethylammonium bromide (CTAB) solution in water/butanol mixture. The precipitation of silica nanoparticles (SiO_2NPs) was performed at $\text{pH}=4$ by adding H_2SO_4 . Controlling of the size of nanoparticles was done by surfactant concentration, aging time and aging temperature.

In a separate study, Wang et al. described the use of ionic liquid to extract lignocellulose from rice husk followed by calcination of separated rice husk residue at 700°C for 2 h to prepare 70 nm-sized SiO_2NPs with $241.1\text{ m}^2/\text{g}$ surface area [12]. Use of HCl instead of ionic liquid 50 nm-sized SiO_2NPs with $283.3\text{ m}^2/\text{g}$ surface area. Amorphous organo-functionalized SiO_2NPs can be obtained from calcination of nitric acid treated rice husk followed by NaOH treatment, addition of 3-(chloropropyl) trimethoxysilane and pH reduction of resulted solution [13]. Along with this line, it was shown that silica-supported imidazole could be synthesized by these organo-functionalized SiO_2NPs [14]. Mesoporous silicas have been fabricated from sodium silicate solution using rice husk ash, NaOH solution and CTAB as the structure-directing agent where fusion temperature of rice husk plays a crucial role in mesopore sizes and pore volumes [15]. It is proved that the silica materials possessed mesoporous structure with specific surface area, pore volume and average pore diameter in the range of $211\text{-}518\text{ m}^2/\text{g}$, $1.36\text{-}1.92\text{ cm}^3/\text{g}$ and $11.8\text{-}25.8\text{ nm}$, respectively. In addition, these silica materials can be used as supports for CO_2 adsorption by dispersion of tetraethylenepentamine on the support.

In 2014, Andas et al. prepared sodium silicate solution by stirring the acid-treated and washed rice husk in NaOH solution to yield dark brown solution [16]. Addition of an acidic solution of Cobalt (II) to sodium silicate solution until $\text{pH}=3$ followed by aging resulted in high surface area

mesoporous silica-supported cobalt catalysts (Co@SiO_2). This catalyst was studied in the oxidation of phenol with hydrogen peroxide (Scheme 1). A recyclability study of this catalyst has also been successfully performed for five runs.

Andas, and Adam reported the preparation and characterization of immobilized AgNPs (25 nm) on rice husk-derived silica with $514\text{ m}^2/\text{g}$ BET surface area [17]. Synthesis of layered sodium silicates from rice husk developed by Lin et al. [18]. Phase transformation from β through δ to α was observed as the temperature and time of synthesis was enlarged. Produced silica with a higher content of the δ phase exhibited greater Mg^{2+} and Ca^{2+} binding capacities providing an appropriate substitute for polluting phosphorus-based detergents. Mukti and coworkers conducted the preparation of hierarchical ZSM-5 below 100°C by silica from rice husks and sodium aluminate in the presence of tetrapropylammonium bromide as structure-directing agent [19]. The synthesized zeolite exhibits hierarchical microporosity (0.55 nm) and the additional intercrystallite mesoporosity (3.5 nm) originated from the spherical morphology of zeolite, which was composed of nanocrystallites. In 2017, Mor and coworkers described the preparation of 10-15 nm rice husk-derived porous silica particles acidification of sodium silicate solution [20].

Hsu and co-workers prepared carbon-silica nanocomposite with $349\text{ m}^2/\text{g}$ BET surface area by calcination of acid-washed rice husk agricultural waste under an inert atmosphere followed by hydrothermal treatment to decrease inorganic impurities [21]. Carbon-silica composite was mixed with the epoxy resin, curing agent and catalyst which resulted in epoxy/carbon-silica composite. The thermal conductivity and thermal-mechanical properties of CTE and storage modulus of epoxy/carbon-silica composite have been studied and improvement of this properties compared with pure epoxy polymer has been proved. In a separate study, Rangari and co-workers described the preparation of 14 nm sized silica/carbon hybrid nanoparticles from using pyrolysis of rice husk powder in high-pressure/temperature reactor [22]. This nanomaterial has been used to synthesis of nanocomposite from Ecoflex, a biodegradable

Scheme 1: Co@SiO_2 -catalyzed oxidation of phenol.

compostable polymer, using 3D printing technique. This 3D printed biocomposite was further experienced for their mechanical and thermal properties. TGA and Tensile tests showed sensible improvement in thermal stability, due to the addition of silica based nanomaterial.

Silica-coated magnetic nanoparticles ($\text{Fe}_3\text{O}_4\text{NP@SiO}_2$) have been prepared from dispersion of Fe_3O_4 nanoparticles and rice husk-derived silica in ammonia solution and used for supporting palladium ($\text{Fe}_3\text{O}_4\text{NP@SiO}_2\text{-Pd}$) [23]. This nanomaterial was then studied as catalyst in the Suzuki coupling of electron-rich and electron-poor aryl iodides and bromides in the presence of waste eggshell as inexpensive and green solid base. with phenyl boronic acid (Scheme 2) with Pd loadings of 0.03 mol% (yields: 85-93%). The recovered catalyst could be reused at least four times without loss of activity.

In 2017, carbon quantum dot grafted silica nanoparticles have been prepared by calcination of under a nitrogen atmosphere followed by dispersion in H_2SO_4 and oxidation treatment in HNO_3 [24]. Since the photoluminescence property of this nanomaterial can easily be detected under UV light at a pH=7–8, carbon quantum dot grafted silica nanoparticles can be used in biomedical fields. 34 nm sized SiO_2NPs prepared from rice husk-extracted sodium silicate solution was used for the preparation of nanocomposite with styrene and wood and presented the best improvement in all physical and mechanical properties [25]. Also this nanocomposite considerably growths the decay resistance against white rot fungi.

It is noteworthy that, in addition to silica based-nanomaterials, nanoporous MnO_2 have been prepared using rice husk by Lin and co-workers [26]. Washed and dried rice husk was calcined under an inert atmosphere and treated with NaOH solution to remove to remove of silica impurity. The resulted carbon powder after treatment with KOH solution and calcination was neutralized by HCl. Nanoporous MnO_2 was synthesized by dispersion of MnSO_4 and rice husk-derived carbon in propyl alcohol/water solution followed by addition of KMnO_4 . The product is nanocomposite of carbon and MnO_2 with $1645 \text{ m}^2/\text{g}$ surface area. 52% of total pore volume in this nanocomposite is volume of mesopores. Based on cyclic voltammetric data MnO_2 nanocomposite can be used as

Scheme 2: $\text{Fe}_3\text{O}_4\text{NP@SiO}_2\text{-Pd}$ catalyzed Suzuki reaction.

electrode material for high-performance supercapacitors. Raman et al. reported the application of rice husk-extracted silica nanoparticles as a green additive for the production of sustainable concrete [27].

Burri and co-workers prepared PdNPs of 3.5-4.5 nm in size supported on high surface area nanoporous silica-carbon (PdNP@Si-C) by calcination of acid wash husk rice under inert atmosphere [28]. This catalyst was studied in the carbonylative Suzuki coupling reaction of various types of aryl iodides in 1,4-dioxane at 120°C under carbon monoxide atmosphere (Scheme 3).

In 2018, in a study reported by Mathur et al., the synthesis of 80-85 nm forsterite (Mg_2SiO_4) nanoparticle by rice-husk extracted silica and magnesium oxide through solid-state method has been described [29]. A polymeric membrane nanocomposite was synthesized using rice husk-derived silica nanoparticle as filler and polyether-polyamide block co-polymer for separation of CO_2 from other gases [30]. Chauhan and co-workers prepared silica nanowires diameter in the range of 15-35 nm and length about $0.5 \mu\text{m}$ using rice husk ash [31]. In addition to the rice husk, 15-20 nm sized SiO_2NPs has been synthesized using rice straw by Yadav and Kauldhar [32].

1.2 Sugar cane bagasse and leaves

Sugar cane bagasse (SCB) is the agricultural waste biomass of sugar and ethanol industries that is abundantly available. Pereira and co-workers in 2015 reported a simple and low-cost technique for modifying the textural properties and stability of mesoporous gamma-alumina using bayerite as aluminum source and SCB as sacrificial template [33]. The effect of waste biomass was evaluated by changing the template/bayerite ratio. The presence of biomass as a template improved surface area and pore volume up to $209 \text{ m}^2/\text{g}$ and $0.44 \text{ cm}^3/\text{g}$, respectively. In addition, mean pore diameters are adjusted from 5.2 to 7.9 nm by varying the template/bayerite ratio.

Due to high content of silica in SCB, Norhasyimi and co-workers prepared SBA-15 using acid washed SCB ash as silica source and P123 as neutral template [34]. The BET surface area and total pore volume of synthesized

Scheme 3: PdNP@Si-C catalyzed carbonylative Suzuki reaction.

SBA-15 were $466 \text{ m}^2/\text{g}$ and $0.14 \text{ cm}^3/\text{g}$, respectively. In a separate study, SCB has been used for tuning the size of titanium oxide nanoparticles (TiO_2NPs) where the amount of biomass template played an important role in size controlling [35]. TiO_2 sol from titanium tetraisopropoxide in $\text{pH}=4$ was calcined under 200°C for 5 h resulted in TiO_2 powder gel. Various amounts of SCB was added to this gel and stirred for 2 h at room temperature. SCB-supported TiO_2NPs are in the range from 5–20 nm. The photocatalytic activity of SCB-supported TiO_2NPs was tested in the degradation of azo dye methyl orange under visible light.

In 2018, Jabasingh and co-workers prepared 50–200 nm magnetic iron oxide nanoparticles by coprecipitation of Fe(III)/Fe(II) in the presence of ammonia and sugar cane bagasse under inert atmosphere followed by calcination in furnace [36]. This magnetic material can be used as supports for adsorption of Cr^{6+} . Also, MgO hybrid sponge-like carbonaceous composite has been synthesized using magnesium acetate and sugarcane leafy trash as a sacrificial template by thermal decomposition method under N_2 flow [37]. This nanomaterial was comprised of nano-size magnesium oxide flakes and nanotube-like carbon sponge with surface area and pore volume up to $40.61 \text{ m}^2/\text{g}$ and $0.323 \text{ cm}^3/\text{g}$, respectively.

1.3 Bamboo leaf

From ancient times bamboo was considered to have many applications such as food source and building material. Bamboo species are native to warm and humid climates especially areas in China, Japan, Korea, India, and Australia. Because of silica content of acid washed bamboo leaf ash, it has also been used successfully as silica source in synthesizing of 13.8 nm sized SiO_2NPs by Venkatachalam and Rangaraj [38]. Based on nontoxicity nature of bamboo leaf-derived SiO_2NPs , it has been proposed that these nanoparticles can be considered as a potential candidate for drug delivery and other medical applications. In 2017, aluminosilicate zeolite A has been synthesized from bamboo leaf ash by Ng and co-workers [39]. The catalytic activity of biomass-derived zeolite A was tested in cyanoethylation of methanol with 82% conversion and 100% product selectivity (Scheme 4). The

Scheme 4: Zeolite A catalyzed cyanoethylation of methanol.

recovered catalyst could be reused at least nine times without significant loss in activity.

1.4 Egg shell

The eggshell is 95–97% calcium carbonate crystals, stabilized by a protein matrix and may be considered as calcium source [40,41]. In this regard, Jayasankar and co-workers prepared Dy^{3+} -doped calcium silicate (Ca_2SiO_4) nanoparticles by calcined waste egg shell and rice husk through solid-state reaction technique at 1250°C [42]. Dysprosium (III) ions-doped materials are used in making laser materials, optical sensors and solar energy harvesting [43,44]. Luminescence and excitation spectra of Dy^{3+} -doped calcium silicate were investigated and the results indicate that the Dy^{3+} -doped calcium silicate phosphors are appropriate for production of low cost white light emitting devices. Hen egg shell has also been used successfully to synthesize calcium oxide nanoparticles by Fulekar and Pandit [45]. Crushed egg shell was decomposed to CaO above 800°C . Resulted calcium oxide was refluxed in water and again calcined in furnace. The average size of calcium oxide nanoparticles were found 75 nm based on XRD pattern. This nanomaterial was then studied as catalyst in the transesterification of dry microalgae biomass (*A. Obliquus*) into biodiesel.

1.5 Walnut shell

In 2017, we synthesized 11 nm sized walnut shell-supported $\text{Cu/Cu}_2\text{O}$ nanoparticles ($\text{Cu/Cu}_2\text{ONP@WS}$) [46]. Abundance of walnut shell as worthless lignocellulosic waste [47] in nature is main benefit of this protocol. Copper acetate solution in water was mixed with an aqueous mixture of walnut shell powder followed by addition of NaBH_4 resulted in $\text{Cu/Cu}_2\text{O}$ NPs. This copper nanocomposite was employed in the synthesis of propargylamines via the three-component reaction between benzaldehydes, secondary cyclic amines and phenyl acetylene (Scheme 5). Also, walnut

Scheme 5: $\text{Cu/Cu}_2\text{ONP@WS}$ catalyzed synthesis of propargylamines.

shell-stabilized copper nanoparticles were found to be an efficient, inexpensive, easy to prepare, green and reusable catalyst in the reduction of aromatic nitro and nitrile compounds to their corresponding amines with NaBH_4 at 35°C in an aqueous medium (Scheme 6) [48]. We continued our studies on the application of this nanocomposite in the classic Ullman reaction to synthesize biaryl (Scheme 7) [48]. Also a size-dependence study showed that the catalytic efficiency of larger Cu nanoparticles was much lower than that of smaller ones under similar reaction conditions.

Quite recently, we synthesized high surface area magnesia (MgO) [49], high surface area alumina (Al_2O_3) [50] and ceria (CeO_2) nanoparticles [51] by walnut shell as sacrificial template. Walnut shell powder was mixed with an aqueous solution of magnesium nitrate hexahydrate in different weight ratios [49]. After stirring followed by evaporation of water, the solid was calcined at 500°C . Produced magnesium oxides have BET surface area up to $79\text{ m}^2/\text{g}$. Hydrothermal treatment of this magnesium oxide followed by annealing in air surprisingly increase surface area up to $212\text{ m}^2/\text{g}$ (MgO-212). To test the catalytic activity of magnesia materials as heterogeneous catalysts we selected Meerwein-Ponndorf-Verley reduction of cyclohexanone with 2-propanol (Scheme 8). It is of interest that different

Scheme 6: $\text{Cu/Cu}_2\text{ONP@WS}$ catalyzed reduction of aromatic nitro and nitrile compounds.

Scheme 7: $\text{Cu/Cu}_2\text{ONP@WS}$ catalyzed Ullman reaction.

Scheme 8: MgO -catalyzed Meerwein-Ponndorf-Verley reduction.

surface areas of magnesia materials showed different catalytic activities. Magnesium oxides with the highest surface area exhibited maximum yields. Also, MgO-212 was tested as the support of palladium nanoparticles (PdNP@MgO-212) for the aerobic oxidation of alcohols (Scheme 9). Satisfying results were observed for the PdNP@MgO-212 catalyzed aerobic oxidation of benzylic and aliphatic alcohols under air without the use of exogenous base.

We continued our studies on the synthesis of walnut shell-templated high surface area alumina and boehmite by the same way [50]. Produced aluminum oxides and boehmite has BET surface area up to 218 and $304\text{ m}^2/\text{g}$, respectively. Additionally, boehmite was studied as the support of vanadium catalyst for the oxidation of alcohols by hydrogen peroxide. We have found that resulting V-loaded material act as an effective catalytic system for the oxidation of a wide range of alcohols in 1,4-dioxane by hydrogen peroxide. The catalyst can be recovered and reused four times without loss of activity.

Along this line, it was shown that 9-21 nm sized cerium oxide nanoparticles (CeO_2NPs) have been synthesized using cerium nitrate and walnut shell as a sacrificial template by thermal decomposition method [51]. Particle sizes can be adjusted by changing cerium nitrate/walnut shell ratio. To test the catalytic activity of ceria nanoparticles as a solid catalyst, we selected three-component synthesis of 3,4-dihydroquinoxalin-2-amine by *tert*-butyl isocyanide, acetone, and *o*-phenylenediamine in an aqueous medium (Scheme 10). We have studied the effect of ceria particle size in this process. It is of interest that smaller ceria NPs showed the highest activity.

Scheme 9: PdNP@MgO-212 catalyzed aerobic oxidation of alcohols.

Scheme 10: CeO_2NPs -catalyzed synthesis of 3,4-dihydroquinoxalin-2-amine.

1.6 Wheat straw

Recently Patel and co-workers prepared 100-200 nm silica nanoparticles by calcination of acid-washed wheat straw followed by treatment with NaOH solution and neutralization by HCl [52]. This catalyst was studied in the synthesis of pyrano[2,3-*c*]pyrazole derivatives by one-pot, four-component process of benzaldehydes, hydrazine hydrate, ethyl acetoacetate, and malononitrile in an aqueous medium (Scheme 11). In a separate study, Chen et al. described the use wheat straw and $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ to preparation of porous carbon-supported Fe_2O_3 ultrathin film by calcination of KOH-containing wheat straw under inert atmosphere followed by addition of Fe(II) solution to aqueous mixture of calcined powder and annealing at 200°C [53].

1.7 Coconut shell

In 2016, Asefa and co-workers prepared magnetic activated carbon by carbonization of coconut shell in the presence of ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) under an inert atmosphere with different FeCl_3 /coconut shell ratios [54]. The BET surface area, total pore volume and average pore size of the resulted porous materials were 238-372 m^2/g , 0.118-0.210 cm^3/g , and 1.98-2.26 nm, respectively. Authors proposed that Fe_3O_4 was formed via formation of Fe_2O_3 and reduction of Fe (III) by carbon. It was shown that these nanomaterials are efficient adsorbents for toxic dyes such as Sunset yellow. 10-100 nm sized Iron oxide nanoparticles synthesized from coconut husk extract and ferric chloride by Sebastian and co-workers have been used to remove Ca and Cd from aqueous media [55].

1.8 Banana peel

In 2014, 20-50 nm Mn_3O_4 nanoparticles have been synthesized using banana peel extract by Yan and co-workers [56]. It is believed that banana peel extract plays a dual role, reducing KMnO_4 to form Mn_3O_4 and preventing the agglomeration of nanoparticles during

Scheme 11: SiO_2 NPs-catalyzed synthesis of pyrano[2,3-*c*]pyrazole derivatives.

preparation. Also 20 nm SiO_2 NPs have been synthesized by addition of banana peel extract to an alkaline solution of tetraethylorthosilicate in ethanol followed by calcination of precipitate [57]. These nanoparticles can be employed for the adsorption of methylene blue.

1.9 Miscellaneous agricultural waste

Ahmaruzzaman et al. synthesized Fe_3O_4 nanocomposites (Fe_3O_4 -NC) using papaya leaves as lignocellulosic agricultural waste by a simple thermal decomposition method [58]. Fe(II) and Fe(III) solution were mixed with washed and dried powder of papaya leaves followed by addition of NaOH solution. Resultant black precipitate was dried at 353 K (Fe_3O_4 -NC353) and calcined in a furnace under air atmosphere at 573 K or 773 K (Fe_3O_4 -NC573 and Fe_3O_4 -NC773) to make nanoparticle with size 18-46 nm. Fe_3O_4 -NC773 was found to be the most efficient nanocomposite for the removal of chlorazol black E, with an efficiency of 96%.

In 2015, the use of tea waste for the synthesis of supported hydrous aluminium oxide nanoparticles was reported by Wan et al. [59]. This porous nanomaterial has been synthesized by co-precipitation between aluminium sulfate and NaOH in the presence of tea waste and anionic polyacrylamide. Supported porous alumina was employed for defluoridation of drinking water by anion exchange of fluoride with sulfate ions.

In 2017, the use of pine needles for the synthesis of nanocomposites of nanocellulose and NiFe_2O_4 nanoparticles was reported by Singhal et al. [60]. These nanocomposites were fabricated by synthesis of carbon nanofibers (CNF) from pine needles followed by Silanization of these nanofibers (SCNF) by tetraethyl orthosilicate. Ni(II) and Fe(III) solutions were added to the aqueous mixture of CNF or SCNF. After adjusting pH of this mixture to 7.5 and stirring for 2 h, mixture hydrothermally treated at 160°C to make of nanocellulose/ NiFe_2O_4 nanocomposites. Authors found that SNCF-supported NiFe_2O_4 (NiFe_2O_4 @SCNF) act as an effective catalytic system for the oxidative degradation of Remazol Black 5 (RB5) and reduction of nitrophenols (Scheme 12). The catalyst can be used three times without loss of activity.

Scheme 12: NiFe_2O_4 @SCNF-catalyzed reduction of nitrophenols.

Recently Sinağ and co-workers prepared 10 nm titanium oxide nanoparticles supported on hazelnut shell or olive residue activated carbon and employed as a photocatalyst in photodegradation of methylene blue [61]. Tan et al. synthesized NiCo_2O_4 nanocomposites using honey pomelo peel derived porous carbon [62]. Ni(II) , Co(II) and urea solution was mixed with porous carbon followed by treatment in 120°C resulted in carbon-supported NiCo_2O_4 nanosheets.

2 Conclusion

The use of biomass and phytochemicals in the design and synthesis of nanomaterials creates a significant connection between plant sciences and nanoscience that referred to as “green nanotechnology”. Green nanotechnology emphasizes use of green chemistry principles to the design and synthesis of nanostructure products and the application of these nanomaterials. Many synthesis methods of nanomaterials include toxic chemicals, low conversions, high energy necessities, and difficult, wasteful purifications; thus, there are multiple opportunities to improve greener procedures for the synthesis of nanomaterials. Many of the green chemistry principles apply readily to the synthesis of nanostructure product.

Advancement of clean and bio-based approaches to nanomaterials is one of the most attractive fields of scientific and industrial researches in the recent years for the growth of green technologies, namely bio-derived nanostructures that are compatible with environmental necessities. Biomass derived materials with related uses (e.g., separation, adsorption, catalysis, sensing, semiconductivity and thermal insulation), will be absolutely necessary for research and development for renewable resources based fabrication especially non-extracted agricultural waste derived material synthesis. However, recent developments in the environmentally friendly nano synthesis opened a novel window to innovate new routes in large scale synthesis of thoroughly purified, morphologically well-defined, and metal or organo-functionalized nanostructures. In this article, an overview of the synthesis of agricultural waste biomass-assisted metal oxide nanostructures, and their potential uses in different fields were presented. Despite the growth over recent decades, substantial challenges exist that must be addressed to achieve optimal efficiency and deliver maximum benefits from the complete and comprehensive application of these agricultural waste biomass-assisted metal oxide nanostructures.

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