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CRITICAL REVIEWS

Green synthesis of nanoparticles from biodegradable waste extracts and their applications: a critical review

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Abstract
The contemporary world is concerned only with non-biodegradable waste management which needs more sophisticated procedures as compared to biodegradable waste management. Biodegradable waste has the potential to become useful to society through a simple volarization technique. The researchers are behind sustainable nanotechnology pathways which are made possible by using biodegradable waste for the preparation of nanomaterials. This review emphasizes the potentialities of biodegradable waste produced as a viable alternative to create a sustainable economy that benefits all humans. Volarization results in the utilization of biowastes as well as provides safer and hazard-free green methods for the synthesis of nanoparticles. Starting from different sources to the application which includes therapeutics, food industry and water treatment. The review hovers over the pros and cons of biowaste-mediated nanoparticles and concludes with possible advances in the application. In the present scenario, the combination of green synthesis and biowaste can bring about a wide variety of applications in nanotechnology once the hurdles of bulk-scale industrial production are resolved. Given these points, the review is focused on the cost-effective synthesis of metal and metal oxide nanoparticles.

Keywords Green synthesis · Biodegradable wastes · Metal and metal oxide nanoparticles · Sustainable environment · Eco-friendly

Introduction

Waste management has evolved into a local and worldwide concern affecting society, wildlife and the environment. In developing countries, garbage generation has increased in tandem with population growth, resulting in increased per capita waste generation and economic growth. Waste generated from numerous human activities, both industrial and household can pose health risks and a harmful influence on the environment without a comprehensive and efficient solid waste management program [1]. When comparing biodegradable and non-biodegradable waste, both have their drawbacks and ill effects which can dreadfully affect society if the waste is not treated properly or disposed of properly. Biodegradable wastes include both plant waste and animal waste. In most Asian developing countries, the urban population could grow by over 50% by 2025 because waste generation rates are directly tied to a country's population and per capita waste generation. Figure 1 shows the 4R's of waste management which should be implemented to overcome the hazards of waste degradation.

In this scenario, a study on waste extracts shows that a decrease in waste generation is observed with increasing income. High-income countries possess 28% biodegradable municipal solid waste, upper-middle-income countries possess 54% biodegradable municipal solid waste, and lower-middle-income countries possess 59% biodegradable municipal solid waste [2]. Many biodegradable wastes are currently disposed of in hazardous ways, such as by burning, unscientific dumping, or discharge into bodies of water. Furthermore, bio-resources like animal dung cakes, crop residue, and firewood are often used as cooking fuel, polluting interior air. Kitchen wastes such as vegetable peels, fruit peels, spent tea leaves and juices can be decomposed by bacteria or other decomposers. When biodegradable trash is abundant in the ecosystem it can contaminate the environment. They produce a lot of microbial flora in the vicinity of wastes. In humans, plants and animals, these bacteria can cause a variety of infectious diseases. These wastes emit a

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Fig. 1 The 4 R's of waste management which needs implementation in every sources of waste generation

foul odour when burned due to the production of specific gases and can also lead to the emission of greenhouse gases such as methane and carbon dioxide. Waste dumps serve as breeding sites for disease carriers and vectors such as mosquitos and rodents which spread a variety of diseases. As evidence of the effects of climate change become more widespread, scientists continue to look for ways to mitigate the havoc produced by harmful manufacturing practices [3].

One way to make use of this biodegradable waste or biomass is to use it as raw material for nanoparticle formation via green synthesis. It is a renewable source which is heterogeneous and can be chemically combined and a suitable option for the generation of desired products since it is easily available, cheap, sustainable and with usual affluence [4]. Nanotechnology has gotten a lot of attention in recent years. Materials with a diameter of 1–100 nm are classified as nanotechnology. They are used in practically every industry, including electronics, agriculture and the medical field. The use of nanoparticles aids in improving thermal, mechanical and barrier characteristic properties. The fine-tuning of numerous reaction conditions results in nanoparticle with different morphologies which includes spheres, rods, quantum dots and particles which allow for a wide range of applications and perhaps endless technological improvement potential. For the synthesis of nanosized material, classical synthesis methods like the top-down approach were used, which relied on both carcinogenic chemicals and significant energy input. The traditional synthesis method causes pollutants, necessitating the development of environmentally friendly synthesis techniques. As a result, the synthesis of nanoparticles from biodegradable wastes is a means to reduce and reuse the waste that pollutes our ecosystem. Natural biological systems are used to produce nanomaterials in green material synthesis processes [3].

Green nanoscale particles such as zerovalent metallic NPs are produced via a redox process involving metabolites. Phenolic acids, terpenoids, alkaloids and flavonoids are among the main secondary metabolites found in biowaste [5]. Primary metabolites are substances which are produced by all plant groups that play a vital part in their normal development, growth and reproduction, whereas secondary metabolites are compounds produced by only a few plant species [6]. Almost all agro-industrial and food residues contain phenolic compounds (fruits, vegetables, oilseeds, nuts, cereals and drinks) containing specific functional groups which enhance reduction and stabilization properties. The phenolic compound in fruits and vegetables helps to replace synthetic preservatives as they can scavenge free radicals and prevent oxidation reactions in food and also contains other bioactive components which include carotenoids, vitamins, oils, enzymes, etc. Biomass waste generated from fruit residues contains a variety of flavonoids which can chelate and reduce metal ions into NPs. Thus, they are used for nanoparticle production.

Synthesis of nanoparticles using different biogenic wastes

In this review, we mainly focus on the synthesis of nanoparticles from different sources which include banana peel, coconut coir, eggshell, groundnut shell, mango peel, onion peels, pomegranate peel, sapota peel, rice husks, watermelon rind, orange peel, tamarind shell as mentioned below (Fig. 2), human hair, algal extract, tea waste, marine waste and slaughterhouse waste.

Out of these, orange peel constitutes between 50 and 65% of total fruit weight and is rich in soluble fibres, proteins, bioflavonoids and insoluble fibres, which have potential applications in the synthesis of NPs. For example, according to Skiba et al. [7], orange peel extract obtained by plasma chemical extraction technique and methylene blue degradation under solar irradiation used to synthesize silver NPs.

Nuts can act as an environmentally benign resource for the synthesis of nanoparticles. The waste nut residue from different parts of nuts such as shell, kernel and extract are rich in various components such as hemicellulose, lignin and cellulose. It can aid in the synthesis of bionanomaterials as a green reducing agent and bio nanocatalyst, which provides a cheaper catalytic system that can be applied in oxidation reactions, hydrogen evolution reactions, hydrolysis, degradation of pollutants, etc. This is of great advantage as the source is of natural origin, environmentally friendly, economical and reduces waste generation [8].

One of the agricultural wastes that have garnered attention recently is eggshells. Every day, a large number of eggshells are generated as biowaste all over the world. Not only does the odour of eggshell attract flies and make it abrasive,

Fig. 2 Commonly used biowastes for the synthesis of nanoparticles **a** banana peel, **b** coconut coir, **c** eggshell, **d** groundnut shell, **e** mango peel, **f** onion peels, **g** pomegranate peel, **h** sapota peel, **i** rice husks, **j** watermelon rind, **k** orange peel and **l** tamarind shell

but it also causes the loss of numerous useful materials [9]. Eggshell waste is mostly generated from households, restaurants and bakeries. Pure calcium carbonate with low porosity is the major component of eggshells which has the potential to be turned into useful products. Nano-calcium oxide can be synthesized from a waste egg shell by the sol–gel method [10]. Due to its hierarchical and porous structure, the eggshell membrane is used for the synthesis of magnetic $CuFe_2O_4$ nanomaterials with multifunctional properties such as catalytic and and antibacterial functions that have an application in the industrial water treatment [11].

Volarization, co-pyrolysis, anaerobic digestion and recycling of waste paper biomass can help in saving landfill space and reduce the requirement for incineration, resulting in value-added products with lower air pollution risks [12]. Cellulose, the world's most prevalent biopolymer, is widely recycled [13] and that waste paper can be used to synthesize cellulose nanocrystals [14]. These synthesized cellulose nanocrystals are used in drug delivery, catalysis, biomedical engineering, material science, etc. Highly porous carbon nanoparticles can be synthesized from a waste paper by isothermal reactions at 1000 °C for 2 h followed by HCl treatment, which results in conversion of the dominant cellulosic component in waste paper into highly porous carbon nanoparticles. These highly porous carbon nanoparticles can be applied in wastewater treatment for the removal of dyes and heavy metals, the studies revealed that the molecule concentration of dye molecule and Pb + 2 ion decreased significantly [15].

Human hair is also a biowaste which is a complex tissue containing lipids, water, protein and pigments. The traditional practice is to burn human hair which badly affects the environment. Gold and silver nanoparticles can be synthesized using human hair-derived keratin. They are stabilized using a capping agent such as cysteine amino acid with amine and thiol functional groups which are found abundantly in human hair. Both silver and gold NPs exhibited effective antibacterial activity against *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Klebsiella pneumoniae* and *Escherichia coli* [16].

The algal extract (Microalgae and cyanobacteria) serves as a living cell factory for efficient green synthesis of nanoparticles due to their unique characteristics which include the absence of toxic by-products, minimum energy input, the biomolecules (enzymes and pigments) present act as reducing and capping agent, hyperaccumulation of heavy metals, higher growth rate [17]. For example, silver nanoparticles can be synthesized from aqueous extract of Marine Algae *Sargassum myriocystum* which have potential application in inhibition of *Aedes aegypti* and *Culex quinquefasciatus* mosquito vectors, HeLa cells in anticancer activity, clinical human pathogens. Further studies revealed that it can be used as an effective drug for anticancer and bacterial infections and also shows potential efficiency in photocatalytic degradation of methylene blue dyes [18].

Tea waste constitutes components such as polysaccharides, caffeine and tannic acid which has the potential to stabilize metal and metal oxide nanoparticles as it can act as a reducing and capping agent. Silver nanoparticles can be synthesized using an aqueous extract of tea waste. It has potential catalytic activity in degrading cationic organic dyes [16]. Gautam et al. reported that iron nanoparticles can be synthesized from tea waste extract. The synthesized iron nanoparticles exhibited a very high zeta potential of − 45 mV at pH 10 indicating their high stability in an aqueous medium.

According to the reports, the discards from the fisheries exceed 20 million tons per year which corresponds to 25% (approximately) of processed fish waste and total production including by-catch (non-target species). The fish biowaste contains value-added components such as chitin, collagen, bioactive peptides, pigments and gelatin. Carbon dots and nanocarbons can be prepared from fish biowaste using chitosan as the starting material [19]. Chitosan is a marine waste made of amino polysaccharides that aids in the synthesis of nitrogen-doped carbon nanomaterial with varied applications which include the removal of contaminants from liquid and gas phases, acting as catalysts, sequestration of carbon dioxide [20]. Another study showed the synthesis of nickel nanoparticles capped on the N-doped carbon obtained via pyrolysis from chitosan as a source of carbon and nitrogen. The formation of closely coupled, extremely stable and uniform nickel nanoparticles is aided by nitrogen doping in the carbon nanotube network, which offers an adsorption site. It also offers a large number of reactive sites for nitroarene adsorption, as well as molecular hydrogen diffusion and dissociation thereby, acts as an efficient, recyclable catalyst and chemoselective hydrogenation of nitroarenes to corresponding amines [21].

Only a small fraction of animal food (meat) is consumed by humans. A large percentage of meat is discarded as waste. After processing, approximately 50–54% of each cow, 52% of each sheep or goat, 60–62% of each pig, 68–72% of each chicken, and 78% of each turkey end up as meat consumed by humans, with the rest going to waste (Regulations 2003). After evisceration (the removal of the body's interior organs such as the heart, lungs, intestines and kidneys), the difficulty of disposing of them arises. Slaughterhouse trash is mainly biodegradable, but owing to a lack of awareness, it is not properly disposed of and is allowed to fester, producing pollution and becoming a great source of disease-causing bacteria. As a result, the problem is no longer restricted to a single region or country but has grown to enormous proportions all across the world. So, the wastes should be recycled, reused, and redirected towards an efficient and useful product. For example, zinc oxide nanoparticles can be synthesized from goat slaughter waste [22].

Methods of nanoparticle synthesis

Conventional technologies used a top-down approach to synthesize nanoparticles. The nanoparticles are synthesized from bulk material as the starting material and then it is broken down into smaller pieces using different physical, chemical and mechanical processes [23]. It includes different techniques such as laser ablation, mechanical milling and sputtering [24]. Alternatively, a bottom-up approach was developed for the biosynthesis of nanoparticles. This method involves the utilization of a biological system to produce metal nanoparticles at ambient pressure and temperature without using harmful chemicals and reagents in which oxidation–reduction is the main reaction [23]. Here atoms or molecules act as the starting material in the formation of nanoparticles. It includes different methods such as solid-state methods (physical vapour deposition, chemical vapour deposition), gas-phase methods (sol–gel methods, hydrothermal method, etc.) and liquid state synthesis methods (spray pyrolysis, laser ablation, etc.) [24]. There are different types of nanomaterials produced from biowaste however we are limiting our study to metal and metal oxide nanoparticles.

Metal and metal oxide nanoparticles

Metallic nanoparticles (MNPs) possess an inorganic metal or metal oxide core that is usually surrounded by a shell made up of organic or inorganic material or metal oxide. The shape of MNPs is an important component that influences biological response. The shapes include metal rods, spheres, ellipsoids, cylinders, triangular, hexagonal and more. The ability of NPs to traverse biological barriers, the process by which NPs enter cells, cycling duration, and targeting effect are all said to be influenced by NP geometry. For example, when compared to rod-shaped gold NPs of identical size, spherical gold NPs had a higher tendency to be taken up by HeLa cells [25]. MNPs can also exhibit a range of behaviours, including agglomeration or aggregation, interactions with natural organic matter (NOM) in water, and particle adsorption onto surfaces. Physicochemical features are partly responsible for these behaviours [26]. The properties of MNPs are also influenced by the effect of solubility. MNPs are designed to function as a source of metal ions in cells, continually releasing metal ions into the cytoplasm. The release of the metal ion is determined by its solubility and rate of dissolution. Although some MNPs have poor solubility, they still cause tremendous toxicity in the physiological medium [26]. Out of the metal nanoparticles, most of the studies are concentrated on noble metal nanoparticles.

Metal oxide nanoparticles (MONPs) are usually made by the hydrolysis of metal salts at ambient temperature or temperatures below 100 °C [27], because of their small size and high density of corner or edge surface sites, metal oxide nanoparticles can have exceptional physical and chemical properties. Beneficial bioactive substances found in fruits and vegetable waste, such as alkaloids, amino acids, enzymes, phenolics, proteins, polysaccharides, tannins, saponins, vitamins and terpenoids, as well as other compounds, operate as reducing agents in the creation of metal nanoparticles (NPs) [28, 29].

It has been reported that metal oxide NPs can be synthesized from the peels of fruits such as banana, *Citrus sinensis*, jackfruit, lemon, mango, Musa *paradisiacal*, pomegranate, tangerine, *Punica granatum*, *Garcinia mangostana*, *Citrus aurantifolia* and *Nephelium lappaceum* [30]. Agro waste can be employed in the synthesis of nanoparticles. Metal and metal oxide nanoparticles can be synthesized from weeds in an agricultural field, the weeds act as bioreactors for the synthesis of nanoparticles. Copper nanoparticles can be synthesized from *Lantana camara*, silver nanoparticles can be synthesized from *Ipomoea carnea* and copper oxide nanoparticles can be synthesized from *Gloriosa superba L* [23]. A variety of plant-mediated extracts and various microorganisms such as yeast, fungi and bacteria act as nanofactories for intra and extra-cellular synthesis of metal and metal oxide nanoparticles. This approach was considered a potential alternative for large-scale production of metal and metal oxide nanoparticles as it is eco-friendly, cost-effective and economical. Some of the metal nanoparticles and metal oxide nanoparticles discussed in this review are:

Silver nanoparticles (Ag NPs)

Synthesis of AgNPs from plant extract is considered to be a beginner-level experiment in the nanotechnology world due to the low cost and exciting applications in every field of invention. Proper tuning of the reaction conditions and parameters results in small size (< 10 nm) and different shapes of AgNPs with unique properties instead of spherical shapes. For the preparation of Ag nanoparticles, a variety of methods are available including reduction in solutions, chemical and photochemical processes in reverse micelles, radiation-assisted electrochemical, sonochemical, thermal decomposition and recently via green chemistry routes [30]. For example, the reducing property of pomegranate peel extract, which contains phenolic compounds, gallic acid and other fatty acids, flavanols, flavones, flavanones, and anthocyanidins, has been used to produce silver nanoparticles [31]. Additionally, an inexpensive, non-toxic and eco-friendly approach is used to synthesize silver NPs from the fruit shell of *Tamarindus indica.* The silver NPs synthesized from this fruit shell extract act as a therapeutic agent for human breast cancer treatment [32]. Furthermore, the *geranium* leaf residue and terpenoids play an important role in the conversion of silver ions into nanoparticles [33]. Likewise, banana peel extract is a natural reducing agent that is also high in polymers such as lignin, cellulose, hemicellulose, and pectin, which is why it is used to make silver nanoparticles.

According to Skiba et al., AgNPs were synthesized from orange peel water extract by dissolving $AgNO_3$ in bidistilled water to make solutions with different concentrations. For 0.1 min, both orange peel extract and silver nitrate solution were mixed with constant stirring. The resulting mixture was then heated to 75 °C. The change in colour of the mixture to brown colour indicates the formation of Ag NPs. The characterization of Ag NPs was done by UV–visible spectra at the range between 400 and 450 nm. A similar method is followed in the synthesis of silver nanoparticles from grape pomace extract. Synthesis of silver nanoparticles from sapota pomace extract was done in which, an aqueous solution of silver nitrate (7 mM) was combined with the extract in a ratio of 1:0.5 (v/v) and vigorously stirred for 20 min. The reaction was centrifuged for 30 min at 20 °C. The AgNPs-containing pellet with attached organic material was re-dispersed in DI water after discarding the supernatant. Furthermore, AgNPs were re-precipitated using acetone to eliminate clinging organic debris and again it was centrifuged for 30 min at 20 °C. The nanoparticles were produced and dried in a 60 °C oven before being recovered in powdered form. The characterization was done using UV–visible spectroscopy, Fourier transform infrared spectroscopy (FTIR), X-ray Diffraction (XRD) Analysis, Energy Dispersive X-ray Analysis (EDX), Transmission Electron Microscopy (TEM) [34].

Synthesis of silver NPs from Bilberry and red currant waste, silver NPs were made in glass vials with a magnetic bar that was thermostated and screw-capped, the phenolic extract and silver nitrate solution were combined and were constantly stirred. The temperature of the reaction varied between 20 and 60 °C, and the pH was controlled between 8 and 12 by adding NaOH as needed. The characterization of Ag Np was done using UV visible spectra at 420 nm, DLS, and Zeta potential [35]. When the stability of AgNPs is too high the colloidal AgNPs are generated which adds to the list of applications. The description of all the methods of synthesis and application of AgNPs is out of the scope of this review.

Gold nanoparticles (Au NPs)

Gold nanoparticles (Au NPs) are the most stable NPs with tuneable properties in the nanoscale and for their biosynthesis, several fruit peel extracts have been used [36]. Pomegranate peel extracts have been used as reducing and stabilizing agents in the biosynthesis of AuNPs. Appropriate concentrations of both pomegranate peel extract and chloroauric acid solution (HAuCl4) were mixed. The reaction mixture was held at room temperature for 24 h with periodic shaking and the colour change from gold to pink confirmed the formation of pomegranate extracted-Au NPs [37]. The synthesis of Au NPs from red and green waste parts of watermelon extract is a simple process that does not need the use of specialized equipment. UV–visible spectroscopy, X-ray diffraction analysis, energy-dispersive spectroscopy (EDS) analysis and scanning electron microscopy (SEM) were used to characterize the Au nanoparticles that were formed. Additionally, the Kirby–Bauer sensitivity technique was used to assess antibacterial activity against *E. coli* and *Staphylococcus epidermidis* [38]. The biological potentials of using a food waste material (aqueous extract of dried onion peels (OP)) to synthesize gold nanoparticles (OP-AuNPs) were studied. UV–Vis spectroscopy, field emission scanning electron microscopy, energy-dispersive X-ray (EDX) analysis, X-ray powder diffraction (XRD), Fourier transform infrared spectroscopy (FTIR) and differential thermogravimetric analysis (DT-TGA) were used to characterize the produced OP-AuNPs [39]. Even though Au NPs find application in all fields of innovation, the high price demands a good reason for using gold precursor in any experiment.

Palladium nanoparticles (Pd NPs)

The physicochemical features of noble palladium nanoparticles (Pd NPs) are exceptional, including great thermal stability, strong chemical stability, remarkable photocatalytic activity, electrical properties, and optical properties [40]. Pd NPs have a wide range of applications in organic coupling synthesis, hydrogen storage, fuel cells, sensors, catalysis [40] and also in making active membranes [41]. They are photothermal agents, photoacoustic agents, gene/drug carriers, prodrug activators, anticancer agents and antimicrobial agents that have all been identified with Pd NPs [40]. Palladium NPs can be synthesized by electrochemical or sonochemical, or chemical methods [41].

According to Bankar et al., banana peel extract (BPE) a non-toxic and environmentally acceptable substance, was also used to make bio-inspired palladium nanoparticles. For the novel-green synthesis of palladium NPs, palladium chloride was reduced using boiled, crushed, acetone precipitated and air-dried peel powder. UV–visible spectroscopy, scanning electron microscope–energy-dispersive spectra (SEM–EDX) and X-ray diffraction (XRD) analysis were used to analyse Palladium NPs. The aqueous extract of watermelon rind, an agricultural waste was tested as a capping agent and reducing agent for palladium NP biosynthesis. The formation of Pd NPs was first observed visually, with the colour changing from pale yellow to dark brown, which was monitored using UV–visible spectroscopy. Further characterization of Pd NPs was done by X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), DLS, AFM and TEM techniques. The nanoparticles formed are spherical and exhibit catalytic activity [42].

Copper nanoparticles (Cu NPs) and copper oxide nanoparticles (CuO–NPs)

Copper nanoparticles have been synthesized using both physical and chemical methods. The most prevalent chemical method is microemulsion; however, it requires a high concentration of surfactant and is expensive [43]. Although laser ablation, aerosol approaches, and radiolysis are widespread physical methods for synthesizing nanoparticles, their high cost and high energy consumption make them less popular [43]. Due to its availability, cost-effectiveness, eco-friendly nature and lack of hazardous by-products, biodegradable waste extract (biowaste) can be utilized as a green synthesis source for the production of copper nanoparticles. According to Sharon. et.al, at a dosage of 10 mg/L, copper nanoparticles from *Artocarpus heterophyllus* killed 100% of *Aedes aegypti* larvae from the first to fourth instars. Phang et al. reported that CuO NPs synthesized using a nontoxic and sustainable aqueous extract of waste papaya peel exhibit a high photocatalytic efficacy in the degradation of POME (Photocatalytic Degradation of Palm Oil Mill Effluent with low phytotoxicity), making them a suitable photocatalyst for POME wastewater treatment.

The seaweed *S. longifolium* (brown algae) can act as bionanofactory for the synthesis of copper oxide nanoparticles as it contains a significant amount of reducing agents that aid in the conversion of metal salts into their corresponding metal nanoparticles without producing any harmful by-products. The biosynthesized CuO-NPs exhibit antibacterial and antioxidant activities. $CuSO_4$ solution was added to water and placed in a beaker. The algal extract was added to this $CuSO_4$ solution drop by drop with constant stirring and then placed in a rotary shaker (Room temperature, 150 rpm). After 6 h, the colour of the solution has been observed (from green to brown), indicating the formation of CuO-NPs. The solution is then centrifuged at 7000 rpm for 5 min and subjected to further studies.

The absorbance of the CuO-NPs was measured using a UV–visible spectrophotometer as the primary confirmation. The infrared spectrophotometer was used to measure the secondary metabolites functional groups found in S. longifolium extract (resolution: 1 cm^{-1}; 4000–400 cm^{-1} regions). TEM and SEM were used to determine the surface structure, size, and morphology of CuO-NPs. The degree of crystallinity (range 10–90 2Θ) and phase confirmation was measured by XRD [36].

Din et al. used aqueous extracts of (i) bilberry (*Vaccinium myrtillus* L.) waste residues from the production of fruit juices and (ii) non-edible "false bilberry" fruits (*Vaccinium uliginosum* L. subsp. gaultherioides), green synthesis of copper nanoparticles (Cu-NPs) was achieved. Because of their high number of phenolic compounds, notably anthocyanins, which are potent reducing agents, these extracts could be potential candidates for the green synthesis of Cu-NPs. For the synthesis, several cupric salts ($CuCl_2$, $Cu(CH_3COO)_2$ and $Cu(NO_3)_2$) were utilized. Transmission electron microscopy was used to examine the development of stable nanoparticles (Cu NP), and X-ray photoelectron spectroscopy was used to monitor the oxidation status of copper in these aggregates. The antibacterial activity of the produced Cu-NPs was generally higher than that of equal quantities of cupric salts, and it was effective against Gram-negative and Gram-positive bacteria and fungi.

Zinc oxide nanoparticles (ZnO)

Excess reactive oxygen species (ROS) generation, such as superoxide anion, hydroxyl radicals and hydrogen peroxide production, can be induced by ZnO NPs. Due to its unique qualities, such as high specific surface area and high activity to block a wide range of pathogenic agents, zinc oxide nanoparticles (ZnO NPs) act as an antibacterial material. Zinc oxide nanoparticles have been synthesized from the waste fruit peels of *Punica granatum* and *Musa acuminata*. UV–visible spectroscopy, x-ray diffraction analysis, and scanning electron microscopy were used to characterize ZnO nanoparticles. These NPs could also have a role in biology and biomedicine, as well as the environment, industries, food, and agriculture [44]. The influence of synthesis temperature on the size and shape of zinc oxide (ZnO) nanoparticles (NPs) generated using pineapple peel waste, as well as the antibacterial activity of ZnO NPs in starch sheets, was examined. Pineapple peels are high in phytochemical components, so it is used to extract bioactive chemicals like ZnO. When ZnO NPs were synthesized at 60 °C, they produced a mixture of spherical and rod-shaped structures, whereas when they were synthesized at 28 °C, they produced spherical flower-shaped structures [45].

The discovery of a unique method for effectively utilizing goat slaughter waste has led to the notion that dead animals and their tissue and/or organ wastes can also be used to synthesize nanoparticles. This work could aid in the control of pollution in the environment and, as a result, many diseases could be prevented. Jha et al. synthesized ZnO NPs from goat slaughter waste. The production of ZnO nanoparticles is investigated using X-ray and transmission electron microscopy [22]. Aminuzzaman et al. reported the synthesis of zinc oxide nanoparticles from aqueous extract of dragon fruit (*Hylocereus polyrhizus*) peel biowaste which acts as stabilizing and reducing agent. The synthesized zinc oxide nanoparticles are with an average size of 56 nm, spherical in shape and crystalline in nature. ZnO NPs were synthesized using an aqueous extract of dragon fruit peel. In an aqueous solution of zinc nitrate, freshly prepared dragon fruit peel extract was added drop by drop and heated at 70–80 °C with continuous stirring. The reaction solution's colour gradually changed from red to pale yellow, and further heated until a yellow colour paste was formed. The paste was placed in a ceramic crucible and held at 450 °C for 2.5 h in a temperature-controlled muffle furnace (air ambient). The resulting pale white powder was further characterized using different analytical tools. Zinc oxide nanoparticles exhibited a hexagonal wurtzite phase which was detected from XRD and Raman spectroscopic results.

Zinc oxide nanoparticles can be synthesized from longan seeds extract constituting phytochemical extracts such as catechin, vitamin, protein, sugar and flavonoids which act as reducing and capping agents. The longan seeds are obtained from the dried pulp of longan (*Dimocarpus longan* Lour). These seeds due to their continuous disposal serve as a source of pathogens and attract flies causing hygienic and environmental-related problems. For the synthesis of ZnO NPs, zinc acetate ($Zn(CH3COO)_2 \cdot 2H_2O$) solution was dissolved in the seed extract to varying concentrations. The reaction was carried out in a microwave oven that was set to various powers (450–800 W) and irradiation cycles. The size of ZnO nanoparticles ranges between 40–60 and 40–80 nm. The pure phase of hexagonal ZnO was measured by powder X-ray diffraction, and the shapes of ZnO nanoparticles were mostly irregular according to TEM results. ZnO nanoparticles aid in photocatalysed decolourization of methylene blue (MB), malachite green (MG), methyl orange (MO), and orange II (OII) thereby useful in wastewater treatment disposed of textile industries [46].

Titanium dioxide nanoparticles (TiO_2)

Different sizes of titanium dioxide nanoparticles have been investigated for various uses. Because of its photocatalyst, high chemical stability, and lack of toxicity, titanium dioxide is environmentally friendly. Titanium dioxide nanoparticles are believed to be the most valuable materials for cosmetics, pharmaceuticals, and most significantly, skin protection from ultraviolet (UV) rays, in papers, food colourants and toothpaste. TiO_2 NPs have a strong antibacterial effect [47].

Ajmal et.al synthesized cost-effective, inexpensive eco-friendly titanium dioxide nanoparticles using a methanolic extract of fruits peel agro-waste. TiO_2 NPs were found nanocrystalline from the X-ray diffraction spectrum. Fourier transform infrared revealed the presence of O–H, C=O, C–O and C–H functional groups in the fruit peel, all of which are involved in the formation of TiO_2 NPs. Plum, Kiwi, and Peach mediated TiO_2 NPs were found to be cylindrical in SEM images. The antibacterial and antioxidants exhibited by all of the TiO_2 NPs were size and dose dependant.

Titanium dioxide nanoparticles are synthesized via bacterial cellulose (BC) produced from agricultural wastes, where bacterial cellulose (BC) currently known as biotype is synthesized using sugar cane molasses and also from rotten apple waste. The green process was utilized to reduce titanium tetraisopropoxide into titanium dioxide nanoparticles using bacterial cellulose (BC) produced by Achromobactin sp. M15. Utilizing 3-glycidyloxypropyltrimethoxysilane (GPTMS), titanium dioxide nanoparticles (TiO2NPs) were added to the solution and the process was carried out via the sol–gel method. The produced titanium dioxide NPs were characterized using transmission electron microscopy (TEM), and their particle sizes were within a range of 5–10 nm. Fabrics treated with TiO_2 -NPs were characterized using FTIR, thermal gravimetric analysis (TGA), mechanical characteristics, scanning electron microscopy (SEM) and EDX [48]. More examples of different nanoparticles synthesized from vegetable and fruit extract are included in Table 1 and examples of other biowaste-assisted NPs syntheses are included in Table 2.

Silica nanoparticles

Numerous studies have documented the use of waste as a silica source, with the majority of them focusing on the abundant agricultural waste such as rice husk, corn cob and sugarcane bagasse. According to Mohamed. et.al, banana peel ash was used to make mesoporous silica nanoparticles (MSN), which were tested for their ability to adsorb methyl orange (MO) and phenol under a variety of conditions, including pH, adsorbent dosage, starting concentration and temperature. As a result, the synthesized MSNs have the potential to be used as a low-cost adsorbent in the treatment of wastewater contaminated with dyes [60]. According to Araichimani et al., amorphous silica nanoparticles with sizes ranging from 50 to 80 nm have been synthesized via rapid microwave-assisted combustion from rice husk biowastes. A powder X-ray diffractometer was used to measure the crystalline property of the synthesized nanoparticles and an FTIR spectrometer with a range of 4000–400 cm^{-1} was used to determine the chemical composition of the produced sample. A scanning electron microscope (SEM) with an energy-dispersive X-ray (EDX) analyser was used to study the morphological features and elemental composition of the synthesized sample. From sugarcane bagasse, amorphous silica nanoparticles with spherical morphology with an average size of 30 nm, and a specific surface area of 111 m^2/g^{-1} have been synthesized using the extraction and precipitation method. The confirmation of the silica nanoparticles in the sample was obtained from the IR spectra which showed the vibration peak of Si–O–Si. The morphology and particle size of synthesized nanoparticle was obtained by scanning electron microscope (SEM). X-ray powder diffraction confirms the structural characteristics of the produced silica nanoparticles (XRD). While the functional group's vibration is obtained by Fourier transform infrared (FTIR) spectroscopy and a BET surface area analyser was used to estimate the surface area of silica nanoparticles.

Hydroxyapatite nanoparticles

Eggshells are usually discarded since they have no nutritional value and they promote microbial growth if discarded untreated, However, CaO can be used as a source for the commercial synthesis of hydroxyapatite nanoparticles. According to Aal et al., hydroxyapatite nanoparticles were synthesized by chemical precipitation method using chicken eggshell as biowaste and phosphoric acid solution as starting material. Hydroxyapatite nanoparticles can be synthesized from fish scales. The scales of fish (*Lethrinus lentjan*) could be used to make hydroxyapatite bio-precursors at a low cost. Organic (collagen, proteins and lipids) and inorganic (hydroxyapatite) compounds can be found in fish waste. So, these substances present in fish scales are converted to hydroxyapatite nanoparticles (solid form) by a hydrothermal method which is carried out at 280 °C. The physiochemical characteristics of fish scale-derived hydroxyapatite nanoparticles can be characterized by using different techniques such as high-resolution transmission electron microscope

Table 1 Different types of vegetable and fruit peel extracts derived nanoparticles

Sl. No	Vegetable/fruit	Scientific name	Part of plant used as waste	Nanoparticles (NPs) synthesized	Applications	References
1	Onion	Allium cepa	Outer peels	Ag	Used in Acetylation reaction	[49]
				Au	Used in biomedical, cosmetic, food sector and pharmaceutical industries	[39]
2	Sapota	Manilkara zapota	Outer peels	Ag	Used in antibacterial activities	[34]
3	Lemon	Citrus limon	Outer peels	Ag	Used in antibacterial activities	[50]
				TiO_2	Optical and photocatalytic properties	[51]
				MnO_2	As positive electrode for lithium-ion batteries	[52]
4	Grapes	*Vitis vinifera*	Pomace	Ag	Used as Antioxidant, Antidiabetic Potential and Antibacterial Activity Against Human Pathogens	[53]
			Stalk	Ag	Used in modification of screen-printed electrodes	[54]
			Pomace	Au	Used in medical applications, molecular imaging and cancer therapy	[31]
5	Pineapple	*Ananas comosus*	Leaf	Ag	Used in antibacterial activities and enhance the optical properties	[55]
			Peel	ZnO	Antibacterial Activity and can be used in food packaging	[45]
6	Cauliflower	*Brassica oleracea var. botrytis*	Waste extract	Ag	Used in photocatalytic degradation of methylene blue (MB) dye and Hg2 + biosensing	[56]
7	Jackfruit	*Artocarpus heterophyllus*	Seed powder	Ag	Biomedical application	[57]
			Peel	Fe	Act as heterogeneous Fenton-like catalyst for the degradation of Fuchsin Basic dye	[58]
8	Banana	*Musa*	Leaves extract	Cu	It can act as a vector control against Aedes aegypti	[59]
			Peel ash	Mesoporous silica	It can act as an adsorbent in the remediation of dyes contamination in wastewater	[60]
			Peel	Ag	Can be used in catalysis, biosensing, imaging, drug delivery, nanodevice fabrication and medicine	[61]
			Peel	Pd	It can be used in catalysis, in devising sensors and in making active membranes	[41]
9	Mango	*Mangifera indica*	Peel	Ag	Antibacterial activity can be used in fruit and vegetable preservation	[62]

Table 1 (continued)

Sl. No	Vegetable/fruit	Scientific name	Part of plant used as waste	Nanoparticles (NPs) synthesized	Applications	References
10	Papaya	*Carica papaya*	Peel	CuO	Act as photocatalyst for the degradation of palm oil mill effluent (POME)	[28]
			Leaf extract	ZnO	Used for Photocatalytic application	[29]

(HRTEM), Fourier transform infrared spectroscopy (FTIR), X-ray diffractometer and thermogravimetric analyser (TGA). Sharifianjazi et.al used the ball milling method for the preparation of hydroxyapatite nanoparticles, after annealing waste pigeon bones at 850 °C, cold-pressing the nanoparticles and re-sintering at 850, 950, 1050 and 1150 °C. The typical particle size of the ball-milled pigeon-derived nano-hydroxyapatite (PHA) was 50–250 nm.

Nano-cellulose crystals

Lei et al., introduced a new approach for the synthesis of cellulose nanocrystals (CNCs) from recycled office waste papers. This approach has a lot of significance as every year, a massive volume of office waste paper (OWP) is wasted, polluting the environment. OWP being cellulose-rich biomass was employed for the production of cellulose nanocrystals (CNCs) by acid hydrolysis with different acid concentrations but without subjecting OWP to alkali and bleaching treatments. CNCs produced with a 65% acid concentration coated on a PET sheet not only had improved water vapour barrier properties but also had the same transparency as PET. CNCs are a potential new material with unique qualities such as nanoscale size, high specific strength and modulus, high surface area, high crystallinity and distinctive optical properties, among others.

Mehanny et al. synthesized CNCs from palm wastes (fronds, leaves and coir) by the chemical extraction method in which amorphous regions of cellulosic structure are attacked by acid leaving cellulose nanocrystals. Further characterization was done by scanning electron microscope (SEM) to determine the morphological structure, transmission electron microscopy (TEM), particle size analyser was used to measure the average diameter, size distribution and the zeta potential of the sample, FTIR spectrometer was used to determine infrared spectroscopy with the range between 4000 and 400 cm^{-1}, and for XRD analysis X-ray diffractometer is used with radiation at 30 kV and 10 mA. Zheng et al. synthesized nanocrystals from walnut shells and also highlights a few sustainable and environmentally friendly approaches based on recyclable chemicals that have been emerged as a result of recent technological advancements. Hydrolysis using solid acids (for example, phosphor tungstic acid) or treatment with ionic liquids or deep eutectic solvents are two examples. The most often utilized acid for synthesizing sulfonated cellulose nanocrystals with good water dispersibility is sulfuric acid. The Para crystalline or disordered regions of cellulose are hydrolysed and dissolved in the acid solution during the hydrolysis process; however, the crystalline parts of cellulose are chemically resistant to the acid and stay intact. As a result, the cellulose fibrils are cleaved transversely, resulting in short cellulose nanocrystals with high crystallinity.

Application of biosynthesized nanoparticles

Green nanotechnology-based approaches based on biowaste have been accepted as an environmentally friendly and cost-effective approach with a variety of applications as depicted in Fig. 3.

In therapeutics

Anticancer activity

Cancer is a group of diseases characterized by uncontrolled cell division [81]. Cancer has resulted in 8.2 million deaths per year. Nearly 200 different forms of cancer have been identified. Nanotechnology and immunology have been combined to form nano-immune-chemotherapy, which is effective in cancer treatment. Various metal and metal oxide nanoparticles exhibit cytotoxicity against cancerous cells without affecting the normal cell thereby working efficiently in anticancer activities. Das et al. synthesized Ag NPs from pineapple peel waste extract which exhibited antioxidative, antidiabetic, and cytotoxic activity against HepG2 cancer cells, as well as antibacterial activity. It is effective in the treatment of acute ailments as well as in the development of drugs to cure diseases like cancer and diabetes. It also has uses in wound dressing and the treatment of bacterial infections. MgONPs were synthesized from aqueous extracts of brown seaweed *Sargassum wightii*. They are rich in constituents such as polyphenols, carotenoids, amino acids, vitamins

Table 2 Different types of nanoparticles derived from biodegradable waste extracts other than vegetable and fruit peel extracts, synthesis methods and their application

Sl. No	Biodegradable materials	Parts used	Method used	Types of nanoparticles/ nanomaterials synthesized (NPs)	Applications	References
1	*Tamarindus indica*	Fruit shell extract	CVD Technique	Ag	Anticancerous activities	[32]
				Carbon nanosheets	Supercapacitor applications	[63]
			Hydrothermal method	Cu	Antibacterial activities medical applications	[64]
2	*Cocos nucifera*	Coconut shell	Solvent extraction	Ag	Antibacterial activity	[65]
			Green synthesis	Ag	Used in mosquito control, Biomedical application, agricultural application	[66]
		Skewer coconut leaves	Sol–gel method	Silica	Removal of methylene blue (dye) from aquatic environment thereby preventing water pollution	[67]
3	*Oryza sativa*	Rice husk	Thermal-assisted seed particle formation and particle growth by acidification of the solvent sodium silicate solution	Silica	It aids to obtain a clear and sharp photograph of latent fingermarks. Useful for crime investigation identification	[68]
			Microwave oven (MO) technique	Carbon nanotube	Applicable in the electrochemical electrode. It can also be used to reduce huge quantity of waste biomass	[69]
			Sol–gel method	Silica	It aids to control rice husk pollution Silica Np can act as medical additives, fillers in composite material, and carriers	[70]
			Wet milling method	Silica	Applicable for chemical enhanced oil recovery	[71]
			Green synthesis	Poly(Vinyl Alcohol)-Ag	It has good antibacterial activity against gram-positive and gram-negative bacteria strains. It can also act as a reducing agent	[72]
4	*Areca catechu*	Areca nut	Microwave-assisted nanoparticle synthesis method	Ag	It can act as an efficient antimicrobial agent	[73]
		Areca nut husk	Green synthesis	Pd	To Access α-keto imides and Stilbenes	[74]
		Areca nut husk	(i) Sulphuric acid hydrolysis (ii) Alkali treatment (iii) Bleaching treatment (iv) filtered and dried (v) Acid hydrolysis (vi)centrifugation	Cellulose nanocrystals (CNCs)	It helps to develop nanocomposites and packaging films. It can act as a reinforcing agent in biocomposite films	[75]

Table 2 (continued)

Sl. No	Biodegradable materials	Parts used	Method used	Types of nanoparticles/nanomaterials synthesized (NPs)	Applications	References
5	Egg	Eggshell	Sol–gel method	Hydroxyapatite	Used as a source of calcium and as a substitute for bones and teeth Medical application	[76]
			Sol–gel method	CaO	Industrial application Used in Waste water treatment	[10]
			Bio-templating method	CeO_2	Used for high CO_2 adsorption	[77]
			Acid Hydrolysis	Cellulose nanocrystals (CNCs)	Applicable in PET packing material	[78]
6	Paper	Office waste paper	(i) Alkali treatment (ii) Bleaching (iii) Acid hydrolysis	Nanocrystalline cellulose	It can be used as an inexpensive biobased filler in polymer nanocomposites	[79]

and polysaccharides which help them act as a capping agent and reducing agent in the synthesis of MgONPs. These biosynthesized MgONPs lead to apoptosis of cancerous cells thereby exhibiting potential cytotoxic activity against lung cancer cell line A549 by increasing ROS generation [82]. Another study reported the synthesis of bimetallic nanoparticles from *Trapa natans* peel extract. Silver (Ag) (15 nm) and gold (Au) (25 nm) nanoparticles have been synthesized using Trapa peel extract, with potential cytotoxic activity against various cancer cells. Bimetallic nanoparticles are more advantageous than unimetallic nanoparticles as it combines the features of both Ag and Au nanoparticles. The studies have shown that the bimetallic composites NPs can be a potential alternative for p53 as they can induce mitochondrial stress and apoptosis, thereby exhibiting ROS-mediated p53-independent apoptosis in cancer cells. Bimetallic composite NPs have the potential to be used in nanomedicine for cancer treatments in the future as it is an efficient, cost-effective and easy method [83].

Antibacterial activity

The antibacterial activity of metal and metal oxide nanoparticles commonly involves the formation of reactive oxidative species (ROS); superoxide radicals (O^{-2}), hydroxyl radicals (OH^{-1}), singlet oxygen (O^{-2}), etc., are a few short-lived oxidants of ROS. It can lead to inhibition of transcription, translation, enzymatic activity and the electron transport chain, and second, it involves protein inactivation and DNA destruction leads to the destruction of bacterial cells [84]. Metal and metal oxide nanoparticles have shown potential efficiency in bacterial growth inhibition and to tackle antibacterial resistance. Basumatari et al. reported the synthesis of ZnO NPs from aqueous extract of *Musa balbisiana* Colla pseudostem biowaste of size ranges between (45 and 65 nm). It exhibited efficient antibacterial activity against both gram-positive and gram-negative bacteria including *E. coli*, *S. aureus*, *Bacillus subtilis* and *P. aeruginosa* by *the* release of Zn^{2+} ions from ZnO NPs, which binds to the bacterial cell membrane and produce reactive oxidative species (ROS) that stops the cellular function inside the bacterial cell and leads to proteins, lipids, DNA denaturation. ZnO NPs can also exhibit antibiofilm activity against *P. aeruginosa* thereby can also be used as a water disinfectant in the drug industry and food conservation.

Various types of agri-food by-products such as rapeseed pomace, sugar beet pulp, fodder radish cake, grape pomace and pomegranate peels or bio waste extracts were used to produce nanoparticles which were prepared by the ultrasound-assisted water extraction with subsequent oxidation by oxygen purge and characterized

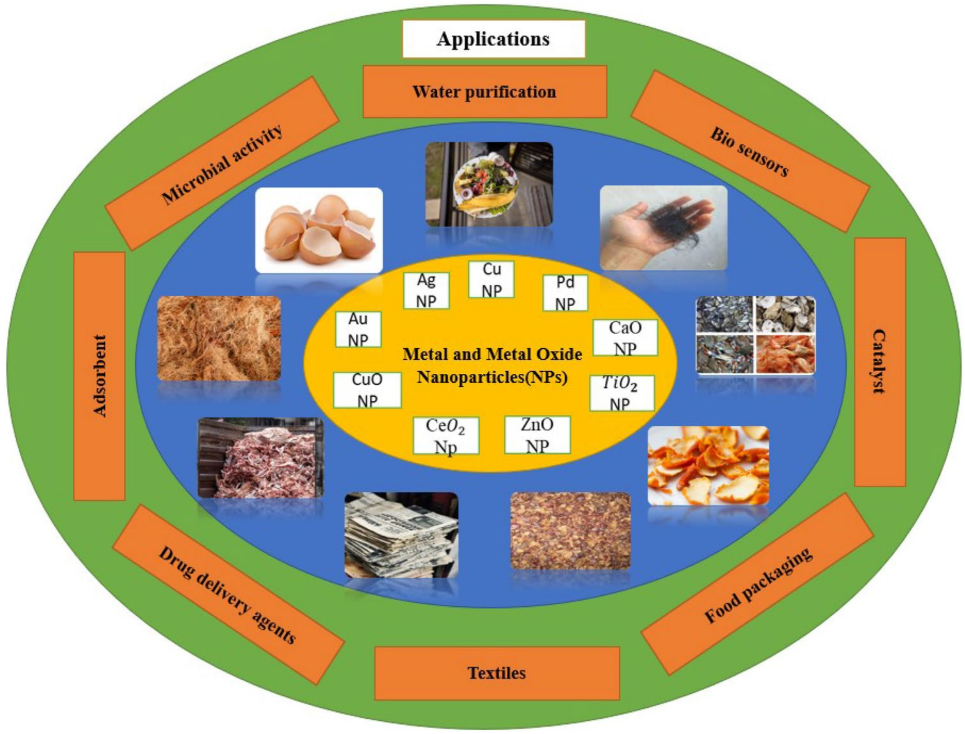

Fig. 3 Various applications of green synthesized nanoparticles derived from biogenic waste extracts [80]

by liquid chromatography-mass spectroscopy (LC–MS), and these Ag NPs synthesized from oxidized aqueous black currant, apricot, grape pomace and pomegranate peel extracts exhibited antimicrobial activity against common pathogenic bacteria *E. coli* and *B. subtilis* [85].

Grape pomace extract (GPE)-synthesized AgNPs demonstrated significant antibacterial activity against *E. coli* and *S. aureus*. The antibacterial response mechanism was investigated by detecting bacterial cell membrane rupture and cytoplasmic contents, which included nucleic acid, proteins and reducing sugars. The antibacterial potential and synergistic efficacy of GPE-AgNPs in combination with traditional antibiotics were demonstrated against human pathogenic bacterial infections. The potential of GPE as a novel source for the biosynthesis of AgNPs has been demonstrated in this study, which could open up new vistas in nanomedicine [53].

Yuvakumar et al. reported the Antibacterial action of ZnO nanocrystals against pathogenic microorganisms synthesized from rambutan peel waste extract and also applicable in biomedical nanotechnology. AgNPs can also be synthesized from rambutan peel waste extract which has antibacterial efficacy against *Salmonella parathypi A*., with a 4 mm inhibitory zone, where *Salmonella parathypi A*. is prone to cause paratyphoid fever (enteric fever) [86].

Antiviral activity

In the last decade, the importance of nanotechnology in virology has grown at an exponential rate. Various metal and metal oxide nanoparticles are exhibiting virucidal properties which can act against different viruses such as Human immunodeficiency virus (HIV), hepatitis (type A, B, C and E) and herpes simplex virus (HSV-1&2). Metal nanoparticles exhibit antiviral activity when it interacts with viral cell surfaces, metallic nanomaterials may diffuse into the cell and affect the cell by destroying the viral genome (DNA or RNA), in addition, to directly interacting with the viral cell surface glycoproteins. Metallic nanoparticles interact with the genomic components of the cell and inhibit replication thereby preventing the spread of infection.

According to the reports, Ag and Au are the most common metallic nanoparticles exhibiting antiviral activities against enveloped viruses. Algae-mediated silver nanoparticles exhibit antiviral activity and also can be extensively applied in different nano-silver products, AgNp-coated wound dressings, comprising surgical instruments, implants, etc. [87]. There are varied applications found for the metal nanoparticle, on considering silver nanoparticles according to the relevant studies the usage of silver nanoparticles has intensified importance, especially in the covid pandemic situation as the Ag NPs has been reported to exhibit antiviral properties used to inhibit severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [88], by utilizing Ag NPS which inhibits the virus nucleotide replication. It binds to electron donor groups present in the microbe's enzymes, such as sulphur, oxygen and nitrogen. As a result, the enzymes are denatured, thus incapacitating the cell's energy supply, and the microbe dies quickly [89]. Another study reported the efficient antiviral property of CuO-NPs in the treatment of herpes simplex virus (HSV-1) infection, wherein the CuO-NPs interfere with the entry and attachment of HCV infectious virions in hepatic host cells thereby inhibiting HSV-1 infection in the Vero cell culture system [90].

Antioxidant activity

Any compound or substance capable of preventing the oxidation of a suitable substrate even at low concentrations exhibits antioxidant activity. In general, because of their scavenging activities, these antioxidants either prevent or postpone cellular damage [91]. Rajamanikandan et al. reported that carbon quantum dots (CQDs) exhibit antioxidant activity synthesized from Biowaste Ananas comosus by facile hydrothermal treatment. The pineapple peel extracts constitute sugar, high fibre and phenolic compounds as well as antioxidant properties. Antioxidant assay of the CQDs was assessed against DPPH (2, 2-diphenyl-1picrylhydrazyl), hydroxyl radical scavenging, superoxide anion radical scavenging and hydrogen peroxide radical scavenging activities. The CQDs extracted showed fluorescence spectra which displayed blue emission radiation at 438 nm that can be used for photonic devices. The silver nanoparticles of particle size of 40–60 nm and spherical shape synthesized from the aqueous extract of black currant pomaces (BCPE) exhibited antioxidant activity.

The antioxidant activity of the biosynthesized nanoparticles was characterized using different techniques such as total antioxidant capacity, DPPH radical scavenging activity and iron (III) reducing capacity. The antioxidant compounds such as flavonoids, stilbene, aldehyde and phenolic acids contribute to the total antioxidant activity of black currant pomace extract which is found essentially high. These synthesized silver nanoparticles also have the property to inhibit pathogenic organisms such as Gram-negative bacteria [92] The silver nanoparticles synthesized from aqueous and methanol fruit extracts of *Nauclea latifolia* (African peach) exhibit potent antioxidant activity by their ability to scavenge DPPH radicals. The DPPH scavenging activity of the methanolic fruit extract of *Nauclea latifolia* and a standard antioxidant (ascorbic acid) range between 6.1 and 23.9% at a concentration of 100–1000 μg/ mL, their antioxidant property results from their ability to donate hydrogen groups and chelate metal ions involved in generating free radicals. These biosynthesized silver nanoparticles can be applied in various antimicrobial control systems, water treatments and medical processes [93]. Another study reported the synthesis of chitosan nanoparticles (ChNP) from chitosan, which was found to have scavenging activity against free radicals and the ability to chelate metal ions thus making it a potent antioxidant. These ChNP can act as excellent vegetable and fruit coating material as it is non-toxic, biodegradable and have the potential to control the decay of many fruits such as strawberries, papaya cucumber, carrot, apple, citrus, kiwifruit, peach, pear, strawberry and sweet cherry and to extend storage life. The edible coatings made of ChNP prevent the weight loss in many vegetables such as brinjal and chilly by controlling the water vapour transmission and by reducing the water loss [94].

Waste water treatments

The wastewater discharge from textiles and industries is inevitable; however, its treatment is highly necessary. It is a major crisis across the globe. Introduction to nanotechnology in waste treatment has improved its efficiency. The incorporation of biosynthesized nanoparticles from biowaste in wastewater treatment provides an environmentally friendly, toxic-free and sustainable approach, it also prevents the deposition of biowaste causing harmful effects to the environment. A study reported the synthesis of Cu2O nanoparticles from sugarcane bagasse. The sugarcane bagasse extract is rich in reducing carbohydrates which can act as a reducing and stabilizing agent and aid in the synthesis of Cu2O nanoparticles. By utilizing the catalytic efficiency of Cu2O NPs and their reusability, it can be employed in photocatalytic degradation of organic, toxic dyes such as methyl orange (MO), methyl blue (MB), methyl red (MR) and Congo red (CR) present in wastewater. The degradation efficiency of the toxic dyes is in the following order MR < CR < MB < MO. In the future, further improvement in this method will have the potential to remove chemical warfare reagents to toxic heavy metals in wastewater and also aid in the absorption of pollution from the atmosphere [95]. According to Doan et al., an eco-friendly, cost-effective method was introduced for the synthesis of silver and gold nanoparticles from aqueous extract of waste corn-cob and these biosynthesized metallic noble nanoparticles exhibited potential catalytic properties used in the reduction of nitrophenols and degradation of organic dyes, as a result, it can act as an efficient catalyst in the treatment of water. Methylene blue is a cationic thiazine dye which is water-soluble and is widely used in the photographic, printing and textile industries. Methylene blue is toxic to humans and animals, causing permanent eye burns, nausea, profuse sweating, mental confusion, methemoglobinemia and vomiting. It was reported that Green-synthesized ZnO NPs from dragon fruit peel extract under solar irradiation exhibited 95% degradation of Methylene blue dye in 120 min. This approach is an economical, favourable, renewable method for the removal of organic pollutants from an aqueous solution under solar irradiation [44].

Iron nanoparticles from tea extract with an average particle size of 98.79 nm exhibited a zeta potential of − 45 mV at pH 10. The studies have proven that iron nanoparticles from tea extract have the potential to remove phenol red from an aqueous solution by efficient adsorption of phenol red at alkaline pH (pH 8) [96]. Silver nanoparticles made from cauliflower waste have a wide range of applications, including photocatalytic degradation of methylene blue dye and $Hg2+$ biosensing. AgNPs with the right size and shape have a high surface area-to-volume ratio, making them ideal dye degrading catalysts [56].

Food packaging

Food packaging always leads to food safety. It is a healthy way of preserving food and beverages. Packaging helps to protect the food from disease-prone pathogens. Food packaging involves primary and secondary levels of packaging. Secondary packages are usually concerned with transportation, storage and delivery [97]. Nowadays, "Nano food packaging" (food packages were made using nanoparticles) gained a lot of interest in the food industry. But the level of toxicity associated with nanoparticles is of major concern. Debate is still going on among researchers about the safety issues in nanofood packaging.

Nanotechnology-based novel and efficient polymeric materials for food packaging can bring solutions to food industry issues such as product safety and material performance, and economic and also it includes environmental benefits. The use of suitable packaging materials and processes prevents food losses and they always offer safe and healthy food products. Metal and metal oxide NPs as a potential replacement for traditional antibiotics in food processing and medicine [98]. Various industries, including food processing and packaging, may profit from the use of these nanoparticles as antimicrobial materials deposited onto surfaces. ZnO is used in the food industry as a source of zinc, which is an essential micronutrient that plays a crucial and critical role in human and animal well-being [99]. By adding ZnO (obtained by spray pyrolysis) to the polylactic acid matrix, it is investigated that new films based on polylactic acid (PLA) can be used for possible applications in the food packaging sector with improved properties, such as barrier and mechanical properties, and majorly antibacterial activity [100]. Zinc oxide and titanium dioxide NPs are the most commonly used nano-sized antimicrobial metal oxides in active packaging.

Beneficial bioactive chemicals found in fruits and vegetable waste, such as alkaloids, amino acids, enzymes, phenolics, proteins, polysaccharides, tannins, saponins, vitamins and terpenoids, operate as reducing agents in the formation of metal nanoparticles (NPs) [101, 102]. According to Biswal et al., silver nanoparticles (Ag NPs) were synthesized using an aqueous extract of Mahua (*Madhuca latifolia*) oil cake as a reducing and capping agent. According to the study, Mahua oil cake extract could be used for the biogenic production of AgNPs with antibacterial and antioxidant properties that could be used in commercial food packaging, which also aids in waste utilization. Fruit and vegetable peel waste can be used as edible coatings. These edible coatings are thin films added to the surface of the food to extend its shelf life and preserve its features, attributes, and functionality at a low cost [103]. By increasing the shelf life, reducing microbial deterioration, and functioning as a carrier matrix for antimicrobial compounds, all these applications can improve their functionality. AgNPs were synthesized using a Soxhlet extraction system from extract of the sugar industry waste, sugar cane bagasse, which can act as capping and reducing agent with potential application in food, cosmetics, electronics and biomedical applications due to their physical and chemical properties [104]. Titanium, silver, zinc oxide, selenium, copper, magnesia and gold are common antibacterial agents. Various industries, including food processing and packaging, may profit from the use of these nanoparticles as antimicrobial materials deposited onto surfaces [105].

Various other applications

Cuk et al., synthesized silver nanoparticles (in-situ) on cotton fabric from waste extracts of plant food waste (green tea leaves, avocado seed and pomegranate peel) and alien invasive plants (Japanese knotweed rhizome, goldenrod flowers and staghorn sumac fruit) which can act as reducing agents. Such cotton fabrics provide protection against UV radiation and pathogenic bacteria which is very much beneficial in today's world. In an alkaline medium, silica nanoparticles with sizes ranging from 90 to 10 nm were effectively produced from sugarcane bagasse ash by the sol–gel method, which can be used as a filler in natural rubber composites [106]. A method for producing fluorescent carbon nanoparticles (CNPs) from discarded rice husk using thermally-assisted carbonization in the presence of strong sulphuric acid. The CNPs' interfacial interaction with metal ions allows them to be used for sensing applications. This might be used to replace some existing fluorescent dyes or quantum dots that are less environmentally friendly due to their toxicity and production methodology [107]. Nanoparticles synthesized were also used in a wide range of environmental applications, including water treatment, the detection of persistent contaminants and soil/water remediation. Photocatalysis, superconductivity, solar energy harvesting, energy storage (lithium-ion batteries) and antimicrobial devices are only a few of the disciplines where green synthesized CuO Np has found broad use [108]. Copper nanoparticles could be used in optics, electronics, and medicine, as well as in the production of lubricants, nanofluids, conductive coatings and antibacterial agents. They are preferred over silver nanoparticles because of their lower cost, physical and chemical stability, and ease of combining with polymers [43]. The use of these low-cost waste horticulture wastes to create a value-added product is an innovative step toward their long-term sustainability [109].

Merits and demerits of biosynthesized nanoparticles from biowaste

Synthesis of nanoparticles from biowaste offers potential benefits over the chemical-based synthesis approach. This approach is eco-friendly, cost-effective and easy. Here the precursor of natural sources can be reused, recycled and reduced. Furthermore, the abundance of natural precursors aids in the development of large-scale-up technologies. The green synthesis approach eliminates the need for extra capping or stabilizing agents, thereby lowering the cost and simplifying the synthetic process as the natural precursor itself constitutes polyphenols, proteins and pigments which can act as reducing and capping agents. There are varied applications for biosynthesized nanoparticles in energy sectors, it aids in improving the efficiency of solar cells, fuel cells and batteries, in manufacturing sectors which will require materials such as aerogels, nanotubes and nanoparticles to produce desired products, is another area that might profit from nanotechnology. These materials are often more durable, stronger, and lighter. Biosynthesized nanoparticles have efficient application in drug delivery, as the nanoparticles are synthesized from biodegradable materials that aid in sustained release of drug in the target region over days or weeks and effective drug accumulation at the target site is due to the small size of nanoparticles that can penetrate through narrow capillaries that are taken up by the cells thereby increasing the therapeutic efficiency [110].

The major challenge is to scale up the synthesis of nanoparticles from biowaste at the industrial level. In the case of industrial-scale environmental applications, the monodispersity, size, and shape of the NPs should also be considered. Identification of particular biomolecules responsible for the stabilization and reduction of metal NPs from their precursor is another challenge. It is easy to maintain optimum conditions for the synthesis of nanoparticles from biowaste at the small-scale laboratory level, while it is a challenging task to maintain optimum for the synthesis of nanoparticles from biowaste at the large-scale level, wherein the degradation of biowaste is a problem to be addressed [111]. The biowaste-mediated M/MO-NPs sometimes exhibit non-uniform size and indefinite shape which is unfit for various applications as it fails to meet the required criteria. Another problem related to biomedical applications, for example, for cancer therapy is the low toxicity of biosynthesized nanoparticles which makes them incapable to achieve the desired results, also the safety of metal oxide NPs in smart food packaging is one of the main problems, therefore migration from the packaging and cytotoxicity are major concerns for their future use in smart food packaging [112].

Summary and future prospects

As discussed in this review, biowaste generation is inevitable and if not treated and disposed of properly it can lead to many other environmental impacts it is hazardous to human health as it has the potential to cause a variety of diseases. In agriculture, post-harvest waste is about 80% of the total biomass, which is usually discarded by burning it, and it leads to massive volumes of green gas emission, smog and other pollutants resulting in serious health consequences, air pollution, global warming, climate change, etc. Alternatively, the synthesis of nanoparticles from biowaste can act as a potential source, thereby aiding in the long-term use of resources, improving sustainability and reducing high energy demand waste deposits. Biowaste is recognized as an alternative source as it is regenerative, recyclable, reusable, and economical. Out of the many nanoparticles discussed biowaste-mediated synthesis of noble metal nanoparticles has gained a lot of prominence due to their antiviral and antimicrobial activities against pathogens in therapeutics. More study needs to be implemented in improving the toxic properties of nanoparticles against cancerous cells in cancer treatments. Further research is needed to synthesize nanoparticles of desired uniform size and shape without the expenditure of high energy.

One of the major drawbacks in dealing with biowaste is that the chemical composition of different biowaste obtained in different parts of the world will vary resulting in a non-uniform synthesis of nanoparticles at a large scale. Further studies are needed on the time taken for degradation of different biowaste so that timely collection of different biowaste can be implemented or techniques to prevent deterioration of different biowastes before it can be subjected to different methods for nanoparticle synthesis. However, in recent years tremendous effort has been put into tackling the synthesis of nanoparticles from biowaste.

Biowaste-mediated nanoparticles have the potential to be used extensively in the medical field, for therapeutic drugs, antimicrobial activity, antioxidant activity, water treatments and food packaging. It also shows recent advances in utilizing biowaste-mediated nanoparticles in energy storage technology, which has the potential to act as a renewable resource for energy applications. Further research is initiated for the application of biowaste-mediated nanoparticles in wearable technology. The synthesis of nanoparticles from biowaste has paved a pathway to developing an eco-friendly process that limits the usage of hazardous chemical substances. Because of the widespread availability of biowaste and biologically active biomolecules, synthesis of nanoparticles from biowaste could act as an alternate potential precursor or source.

Conclusion

On the whole, this brief review explores the recent advances of the last decade in the utilization of biowaste for the sustainable fabrication of NPs with numerous applications in the medical industry, drug delivery, cancer treatments, food industry and water treatment. Cumulatively, a study on the last two decades shows an exponential increase in the pace of biowaste-assisted nanomaterials synthesis owing to its easy availability, better stability and dispersion in aqueous solutions. In the final analysis, the use of biowaste is found to be more advantageous over other raw materials in terms of zero contamination, simple procedures, low toxicity, high stability and cost-effectiveness in the NPs synthesis. On the contrary, the interaction between the metal precursor and biowaste, mechanism of interaction in reduction of metal precursor, techniques for isolation or purification of the interesting component from biowaste, functionalization, cytotoxicity, bulk industrial production, shape-selective synthesis of nanoparticle synthesis still need extensive investigation to expand eco-friendly implementation of nanomaterials in biomedicine, biosensing, battery storage, energy, crop production, edible packaging and wearable devices. Taking everything into account, biowaste-assisted nanosynthesis has the potential to be scaled up with proper policy-making from the government or concerned authority to meet sustainable green applications which open new horizons and better tomorrow.

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Declarations

Conflict of interest The authors declare no conflict of interest.

Novelty This review emphasizes the biowaste-assisted synthesis of metal and metal oxide nanoparticles. Contrary to the recent reviews on the same topic, authors have included many applications other than a single application or antibacterial and antiviral studies alone. Authors have also listed many sources which are neglected by other review papers. Moreover, advances in the recent innovations are included with 129 articles on the specified field, which not only gives a broader prospect about the topic but also a comprehensive review for beginners in the field of nanotechnology.

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