RESEARCH PAPER

Biological Applications of Nanomaterials Extracted from Fruit Wastes Derived Phytochemicals

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ABSTRACT

Plants have been the most essential components for sustaining life on the Earth and have multiple uses. Fruit waste has been considered as a suitable material for the synthesis of nanoparticles (NPs). Due to the increasing need for sustainable and ecologically friendly nanotechnology. They are extensively used for various applications, such as ecologically friendly developments and the reduction of biological and environmental hazards. Therefore, the formation of nanoparticles (NPs) highly depends on green chemistry. Bioactive compounds from fruits serve as natural reducing and capping agents, enabling the synthesis of a wide range of metal and metal oxide NPs like silver, gold, zinc oxide, iron oxide, tin oxide, and cerium oxide, carbon nanodots, and nanocomposites. Wastes derived from plants based are also utilized for several applications in nanotechnology. The natural product-based synthesis of NPs is eco-friendly and provides morphology and size. Several NPs like gold, silver, copper, carbon nanodots, quantum dots, cellulose nanocrystals, chitosan, zinc oxide, iron oxide, tin oxide, cerium oxide, and cadmium sulfide can be produced from fruit wastes. The fruit waste-based NPs have extensive applications in biomedicine, antimicrobial activity, drug delivery, environmental remediation, and food packaging. Thus, this review has discussed an overview of the types of nanomaterials (NMs) and the applications of NPs synthesized from fruit wastes.

Keywords: Fruit waste; biogenic nanoparticles; environmental remediation; sustainable nanotechnology

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INTRODUCTION

Nanotechnology is a multidimensional field that represents a special strategy in designing and assembling NPs using eco-friendly techniques for multiple applications in biomedical science. Nanotechnology is an expanding area of research that is not only restricted to materials but also includes biological, healthcare, and engineering approaches [1]. Currently, green chemistry is extensively utilized and is considered to be one of the most interesting since it is a sustainable, less complex, economical, and eco-friendly method for the production of NPs from natural products [2-4]. The metallic NPs or their oxides exhibit exceptional biological actions as they have a large surface area-to-volume ratio [3]. The bottom-up method is most generally utilized for the preparation of NPs in which the atoms/molecules self-assemble to synthesize the NPs [5]. Through the biomimetic method, the biological system carries out the processes for the preparation of the metal oxide/metal NPs [6]. Recently, various plant products are used for the process of reducing capping during the synthesis of NPs, thus, contributing to the advancement in the nanotechnology sector [3]. Numerous NPs such as gold, silver, copper, carbon nanodots, quantum dots, cellulose nanocrystals, chitosan, zinc oxide, iron oxide, tin oxide, cerium oxide, and cadmium sulfide can be synthesized from the extracts of plant products. As compared to NPs synthesized from microbial agents, plant-based NPs are

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more stable and mono-dispersed [7]. Moreover, the extracts obtained from plant products lead to the faster reduction of metal ions. Thus, green chemistry not only enables the synthesis of NPs from natural products but also offers a safe, environmental-friendly solvent medium and causes the reduction of substances for the stabilization of NPs [4].There are various phytocompounds like flavonoids, alkaloids, phenols, amines, terpenoids, pigments, and proteins that are essential for the reduction and stabilization of NPs during their biosynthesis [8].Additionally, other compounds like vitamins, water, sugar, and peptides extracted from tea or coffee are also used for the preparation of NPs [9-14]. Therefore, this review has discussed an overview of the types of NMs and the applications of NPs synthesized from fruit wastes.

2. Types of Nanomaterials

The development of a variety of sources, notably particulate substances with at least one dimension smaller than 100 nanometers (nm), is made possible by the revolutionary field of science known as nanotechnology. NMs are compounds that are synthesized chemically and are used on a very small scale, typically in the 1–100 nm range in at least one dimension. Whereas, bulk materials are compounds that are greater than 100 nanometers in all dimensions. Physical characteristics are not dependent on size in bulk materials, however, the size and forms of NMs exhibit different physical characteristics. When researchers discovered that size affects a substance's physicochemical qualities, which include its mechanical, chemical, optical, and electrical characteristics. As a result of their distinctive aspects, NMs have gained considerable interest [15]. Some of the potential applications of NPs include drug delivery, diagnosis of diseases, catalytic processes, oil refineries, construction materials, industrial processes, petrochemical industries, and water treatment plants. Various techniques are used for the production NPs that involve hydrothermal synthesis, attrition, pyrolysis, ion implantation, condensation, and chemical precipitation [16]. NMs can be of different forms on the basis of their dimensionalities like nanosheets, nanorods, and NPs. Films or layers are two-dimensional NMs, Nanotubes or nanorods are one-dimensional and NPs are zero-dimensional. They are mostly used to classify single isolated NMs. The physical characteristics change based on interactions between 2 or more materials. These materials made of various components are known as three-dimensional or bulk nanomaterials.
On the basis of nanoscale dimensions (<100 nm), NMs are categorized in the following ways:

Zero-dimensional NMs (0-D): It includes the NMs that have the 3 dimensions within the nanoscale range and NPs are the 0-D NMs.
One-dimensional NMs (1-D): These include materials in which one dimension lies within the nanoscale range while the rest of the 2 dimensions are beyond the nanoscale range. Examples include nanowires, nanorods, and nanotubes.
Two-dimensional NMs (2-D): In such materials, the 2 dimensions lie within the nanoscale range while one of the dimensions is beyond the nanoscale range. Examples include nanocoatings, nanofilms, and nanolayers.
Three-dimensional NMs (3-D): These materials include those with three dimensions that are all larger than 100 nm or the nanoscale range. Examples include bundles of nanowires, core shells, nanocomposites, bundles of nanotubes, and multi-nanolayers [17].
On the basis of size, morphology, properties, and the constituents present in it, the NMs are of various types like lipid-based NMs, carbon-based NMs, polymeric NMs, metal NPs, and semiconductor NMs.

2.1. Carbon NMs:

Carbon is the primary constituent in such types of NMs. Examples include fullerenes and carbon nanotubes. The carbon nanotubes are implanted into the graphene sheets which are then rolled into tubes. They have more strength as compared to steel and can be subjected to structural modifications. The carbon nanotubes can be of both single or multi-walled types. Fullerenes consist of 60 or more carbon atoms and have a hollow cage-like appearance and they exhibit significantly high strength, electrical conductivity, and electron affinity [17,18]

2.2. Metal NMs:

The divalent and the trivalent metal ions are the key materials of the metal-based NMs. Various techniques are employed for the synthesis of metal NPs like chemical or photochemical techniques. The metal ions undergo reduction to form metal NPs with the help of reducing substances. These materials have significant absorption capability of small compounds and have a significant surface area. They also have varied applications in the field of research, bioimaging, and environmental fields. The combination of 2 or more NPs with size control can be attained. With the help of doping various metals, rare earth metals can alter their primary element properties [19-21].

2.3. Semi-conductor Nanomaterials

These NMs exhibit both metal and non-metal characteristics. By altering them, they exhibit various properties, which are applied in electronic devices and photocatalysis. For example, ZnS [22], ZnO [23], CdS [24], CdSe [25], CdTe belong to group II-VI of semiconductor substances. GaN [26], GaP [27], InP [28], InAs [28] belong to group III-V. Recently, semiconductors of graphene nanocomposites have been an interesting topic of research since graphene can improvise the physical as well as chemical characteristics of the semiconductor. The graphene composite materials are widely used for piezoelectric properties [29,30] and for gas sensing sensitivity [31-33].

2.4. Nanocomposites

They are solid polyphase substances in which each of the layers has 1, 2, or 3 nanoscale-scale sizes. Comparing nanocomposites with regular composites, they show a considerable increase in surface-to-volume ratio. On the basis of size and morphology, their physicochemical characteristics differ [17-34]. There are various kinds of nanocomposites like Metal Matrix Nanocomposites, Ceramic Matrix Nanocomposites, and Polymer matrix Nanocomposites, amongst them, polymer composite of graphene-based composites is being largely developed. Graphene is mainly made of carbon and they are organized in a hexagonal matrix [35,36]. The various categories of semiconductor graphene family nanocomposites comprise of metal chalcogenide/graphene nanocomposites and metal oxide/graphene nanocomposites. The metal oxides demonstrate many applications like ZnO [37,38], In2O3 [39], TiO2 [40], MnO2 [41], Fe2O3 [42], exhibit drug delivery, photovoltaic and photocatalytic [43], gas sensors [43,44], batteries [46,47], and cytotoxicity actions [48].

3. Biological Applications of Nanomaterials

3.1. Silver NPs (Ag NPs)

The Ag NPs exhibit anti-microbial characteristics by adhering to the bacterial cell wall and then its penetration leads to the morphological alterations of the plasma membrane causing increased permeation of the cell membrane and ultimately leading to cell death. Another way of demonstrating the anti-microbial activity is by the free radical formation by the Ag NPs. The electron-spin resonance experiments confirm the presence of free radicals. When the free radicals adhere to the plasma membrane of the bacteria, they make it porous and cause cell death [49]. Ag NPs also demonstrate anti-diabetic activities by a free radical formation that leads to a decrease in the enzyme levels that cause hydrolysis of complex carbohydrates and thus, there is an elevated rate of consumption of glucose [50]. The Ag NPs are used in cancer therapy since they have the ability to damage the respiratory chain in mitochondria and this can be extended to stimulate the synthesis of reactive oxygen species (ROS), ATP, and finally lead to the destruction of the DNA [51].

3.2. Gold NPs (Au NPs)

The Au NPs demonstrate significant mechanisms for the delivery of anti-cancer agents [52]. Moreover, they can be conveniently altered to transport many pharmaceutical products that can be bound to the gold NPs either by chemical bonding (covalent/non-covalent) or physical encapsulation. Some of the drugs can also be conjugated to the gold NPs but one should be careful about the functionalization that causes alteration in toxicity of the gold NPs and also modifying its ability to effectively load/attach the preferred drug. The utilization of the altered gold NPs has not only decreased the potential drug toxicity but also reduced the chances of developing drug resistance in cancer [53]. Some novel research has demonstrated that gold NPs can preserve nucleic acids by inhibiting their disruption by the nucleases enzyme [54]. Due to the distinct characteristics of the gold NPs, they can be effective gene carriers as they can be conjugated to the oligonucleotides by covalent and non-covalent bonds. The covalent gold NPs can stimulate the immune-associated genes in the peripheral blood mononuclear cells; however, they cannot activate such genes in lineage-restricted and immortalized cell lines [55]. Thus, proving its efficacy for gene delivery systems. The Au NPs are important in diagnostics because of their exceptional optical characteristics which primarily include surface-enhanced Raman scattering (SERS) and localized surface plasmon resonance (LSPR) [56,57].

3.3. Carbon Nanodots

Carbon nanodots exhibit multiple applications due to their fluorescence luminescence property; they are used in the case of fluorescent multicolor imaging of microorganisms, mammalian cells, and plant cells [58]. A study demonstrated the antibacterial properties of the carbon nanodots by extracting them from the leaves of the Artemisia argyi plant and observed their effects on the cultures of S. aureus and E. coli. As per the SEM imaging, it had been observed that the cell wall of E. coli was disrupted; but there was no significant distinction between the experimental or control S. aureus, which suggests that carbon dots are more susceptive for gram-negative bacteria than gram-positive bacteria due to the structural characteristics of the cell wall [59]. Researchers have made an effort in order to eradicate cancerous cells by adopting photodynamic [59-61], and photothermal [52-63] therapies, in order to target the tumors. A study conducted an in vivo experiment, where they emitted NIR- II (900- 1200 nm) carbon dots, for laser photothermal therapy (808 nm). As per the in vivo experiment, the temperature was raised to 50 °C within the tumor environment after injecting intravenously. Within six days, there was inhibition of the tumor and shrinkage in its volume, and no damage was observed in tissues or reduction in weight after the therapy, therefore, carbon dots proved significant biocompatibility [64].

3.4. Quantum Dots (QDs)

It has been revealed that multipurpose NP probes based on QDs have been developed for treating cancerous cells and imaging in organisms. Encapsulating luminous QDs with an ABC triblock copolymer and coupling this amphiphilic polymer to tumor-targeting ligands and drug-delivery functions as part of the structural composition. In vivo, targeted investigations on nude mice with human prostate cancer revealed that QD probes aggregated at tumors due to increased permeation and persistence of tumor locations, as well as antibody adherence to the biomarkers of the cancerous cell surface [65]. The magnetic resonance imaging (MRI) compound gadolinium has been coupled with a QDs to synthesize an NP that can detect cell death utilizing both MRI and fluorescence imaging [66]. QDs are unique since they exist in a range of colors, enabling a different colored QD for each biomarker being tested. Multiplexed imaging and computer-aided analysis are used to examine the fluorescence generated by the QD, yielding quantitative findings for each biomarker [65].

3.5. Chitosan NPs

Chitosan NPs demonstrate antibacterial activity since chitosan is a cationic polyelectrolyte polymer. Due to its low molecular weight, chitosan can penetrate into various cellular parts of the microbe, combine with the microbial DNA and restrict the expression of DNA and the activities of mRNA, whereas, the chitosan particles of high molecular weight get coupled with the negatively charged constituents of the cell [67]. Chitosan NPs make the cell membrane impermeable and alter the cellular permeability, thus limiting the transportation of various components into the cell[68]. They are also used for the transportation of drugs in numerous types of cancers like brain cancer[69], breast cancer [70], lung cancer [71], colon cancer [72], and others. A study showed [73] exhibited effective results using xenograft models of mouse-human for employing hydroxyapatite-Chitosan as a transportation agent of celecoxib and various pharmaceutical agents, as a therapeutic intervention for colon cancer. Moreover, Another study demonstrated significant outcomes for a chitosan nanoparticle altered with tripolyphosphate (TPP) for the delivery of IL-12 [74].

3.6. Cellulose Nanocrystals

The cellulose nanocrystals are used for drug delivery. They may not have a direct involvement at the molecular level of the controlled release of drugs via the mechanism of self-assembly but due to their tunable surface chemical properties, they are being utilized for drug delivery. Suspensions, membranes, hydrogels, and films act as carriers of drugs. Controlled drug release by the cellulose nanocrystals is determined by several characteristics such as pH and temperature [75]. Some of the cellulose nanocrystals-based systems that are advantageous for wound healing and delivery of drugs include hydrogels, 3-D printed hydrogels, injectable hydrogels, and magnetic CNC-based hydrogels [76]. There are numerous fabrication methods, like the application of electric fields, evaporation, magnetic field, and high speed to attain the preferred arrangement of cellulose nanocrystals in scaffolds and films. A study reported one of the premier experiments involving the fabrication of cellulose nanocrystal film arranged radially for the regeneration of muscle tissue [77,78].

3.7. Zinc Oxide NPs (ZnO NPs)

ZnO NPs exhibit antioxidant activities due to their significantly small size and also can be due to DPPH (2,2-diphenyl-1-picrylhydrazyl) in which the electron density is transported from the oxygen atom to the nitrogen atom where the odd electron is located, leading to the reduction in transition intensity in the $n \rightarrow \pi^*$ at 517 nm. The mechanism of ZnO NPs antioxidant activity can be explained when ZnO NPs are added to the DPPH's unstable deep-violet colored methanolic solution it changes into a stable pale-yellow color since the free radical scavenging action of DPPH via the transport of an electron from the oxygen atom to the nitrogen atom where the odd electron is placed, enables the synthesis of DPPH molecule which is stable in nature [79]. They also demonstrate anti-diabetic activity. It has been reported that the supplements of zinc enhance the regulation of glucose in diabetic patients [80,81]. Moreover, Zinc can also improvise other problems related to diabetes like cardiomyopathy and nephropathy [82]. ZnO NPs exhibit antihyperglycemic properties because of their ability to release zinc ions, thus enhancing tolerance of glucose and its upregulation biosensors and transporters to maintain the secretion of insulin, improving the functions of the pancreas mainly by regulating the release of glucagon and insulin and maintaining body weight. Other properties of ZnO NPs include anti-inflammatory, anti-dyslipidemic, and disrupting the actions of α-glucosidase and α-amylase for reduction of the postprandial increase in levels of blood glucose and thus enhancing the sensitivity of insulin and antioxidative system to eliminate oxidative stress caused by the ROS [83].

3.8. Iron Oxide NPs (Fe3O4 NPs)

Fe3O4 NPs are used as iron supplements in people with a deficiency of iron. Ferumoxytol is used for therapeutic intervention in chronic kidney disease (CKD) patients suffering from anemia. Initially, Superparamagnetic Iron NPs (SPION) were synthesized for imaging of atherosclerotic plaque and sentinel lymph nodes, then, it was approved for use in CKD patients with iron deficiency, by FDA in 2009 [84]. They are also used for tumor therapy, the Fe3O4 NPs are exposed to an external alternating magnetic field, in magnetic fluid hyperthermia (MFH), which stimulates the movement of the NPs and causes local heating, this effect can cause damage to tissues in a particular area [85]. The primary effect is dependent on the rise of the temperature beyond 42 °C and causing protein denaturation, ultimately resulting in cell death [86]. The Fe3O4 NPs are utilized for numerous activities of regenerative medications, such as, for tracing cells. Extensive research is going on regarding the employment of these cells as a novel alternative for the treatment of neurodegenerative diseases, immunological disorders, and cancers. Based on this, Immune cells like the dendritic cells [87], and T cells [88], and stem cells are being labeled with SPION to enable the non-invasive tracing through magnetic resonance imaging and to assess the in vivo transport to the site of action [89].

3.9. Tin Oxide Nanoparticles (SnO_2 NPs)

Anti-microbial properties of SnO2 NPs have been observed, but its mechanism of action is still not clear, but, metal oxide NPs exhibit anti-microbial activities by electrostatic interaction of NPs with the microbial cell wall, decomposition of NPs, and synthesis of ROS due to light radiation [90-92]. SnO2 NPs prepared with the dried fruit waste (peel) of Annona squamosa, were assessed for cytotoxicity evaluation against the HepG2 (hepatocellular carcinoma cell line) [93]. The TEM assessment demonstrated a decrease in the swelling of the cells, the volume of the cells, and nuclear condensation. The nuclear condensation could be due to the disintegration of chromatin in the nucleus of the SnO2 NP-treated HepG2 cells. The cell proliferation was restricted by the tin oxide NPs in a time and dose-dependent manner with an IC50 value of 148 µg/mL. The tin oxide NPs prepared with the seed extract of Piper nigrum demonstrated enhanced cytotoxic effects against lung (A549) and colorectal (HCT116) cancer cell lines [94]. SnO2 NPs are also widely utilized in gas sensors under atmospheric conditions due to their following characteristics like high selectivity, high sensitivity, economical manufacturing, and convenient reversibility [95].

3.9. Cerium Oxide NPs (CeO_2 NPs)

CeO2 NPs are utilized for the treatment of neurodegenerative disorders, the NPs eradicate reactive oxygen species or disrupt their synthesis and impact primary areas of the central nervous system and brain cells. By decreasing the formation of ROS, the CeO2 NPs impact via both direct as well as indirect signal transduction pathways that is in neuroprotection and death of neurons. It has been exhibited that CeO2 NPs can stimulate neuronal survival in patients suffering from Alzheimer's disease by regulating the BDNF (brain-derived neurotrophic factor) mechanism which regulates the signal-modulating pathways for neuronal activities [96]. Cerium Oxide NPs are effective artificial oxidase enzymes that have the ability to imitate SOD, catalase, and peroxidase-like functions. The CeO2 NPs exhibit oxidase-like functions as the Ce3+ atoms' surface acts as a catalytic center [97]. The NPs demonstrated peroxidase or catalase-like functions, due to the presence of less Ce+3 on their surface [98], and are capable of converting hydrogen peroxidase into oxygen and water. While the NPs with more Ce+3 on their surface demonstrate SOD-like functions and scavenge superoxide radicals and form hydrogen peroxidase.

3.10. Cadmium Sulfide Nanoparticles (CdS NPs)

Semiconducting CdS quantum dots (QDs) are of the CdS NPs, which are fluorescent nanocrystals and have a mean dimension of 1-20 nm and they show different quantum confinement outcomes [99]. The CdS QDs that are photosensitive demonstrate a significant coefficient of visible light absorption and effective surface electrostatic characteristics [100,101]. As a result of their near proximity to the microorganisms responsible for certain biotransformation events, obstructions to charge transfer should be decreased. It has been reported that the formation of CdS QDs-microbial complex has verified the formation of protein capping of the microbe that effectively increased the biocompatibility of CdS QDs with the membrane of the microbe [102]. Because CdS QDs are loaded across the periplasmic region of microbial cells, photoelectrons may be able to engage with both extracellular and intracellular cellular mechanisms. Because of their fluorescence and semiconductor features, CdS QDs have received much interest as a unique type of nanoparticle [103]. At the same time, they hold considerable potential for imaging techniques and therapeutic intervention of various diseases because of their outstanding luminescence, constant excitation spectrum, controlled and narrow emission bands, and flexibility of functionalization for tissue targeting [104].

4.Different types of fruit waste material for nanoparticles synthesis

Food waste is a global problem that affects not only the environment and human health, but also causes financial losses. India and the European Union have significant obstacles in their efforts to reduce food waste. The United Nations Environment Programme estimated that India's annual household food waste was 50 kg per capita (UN Environment Programme, 2021). According to estimates, there is 59 million tonnes of food waste in the EU each year, or 131 kg per person (European Commission Food Safety, 2022). Improving supply chain management, educating customers about food preservation, and turning food waste into new goods are a few strategies to address this problem.

Recently, there has been a noticeable increase in the popularity of the circular economy concept, which tries to create value out of waste resources. This strategy is especially relevant in poor countries, where household food waste amounts to over 2.32 million tonnes per year (UNEP Food Waste Index Report, 2021). Valorizing this waste—mostly fruit and vegetable waste—can provide value-added products and bioactive substances that have positive effects on the environment and society at large. Fruit waste is a good source of bioactive compounds and can be used to make nanoparticles, which can subsequently be used to for various environmental remediations and biological applications. They can also be utilized in active food packaging materials. Important discoveries include the enhanced biological activity of these nanoparticles in packaging applications, the usefulness of different fruit wastes as mediating agents in the production of nanoparticles, and the latest developments in the incorporation of metal oxides in packaging materials. Green synthesis approach emphasizes the transformative power of combining waste management with cutting-edge food packaging technologies and is in line with Sustainable

Development Goal 12.3, which aims to halve food waste by 2030. Fruit materials are rich in bioactive chemicals, they have been used to synthesize nanomaterials. These fruit wastes, which include pomegranate, orange, and apple wastes, are used to create a variety of nanoparticles by utilizing the phytochemicals that are present in them for bio-reduction. Fruit and vegetable waste (after industrial processing) has a variety of bioactive that act as reducing and capping agents for NP synthesis and have antibacterial, antioxidant, and anti-inflammatory properties. These bioactive include flavonoids, tannins, steroids, phenols, glycosides, triterpenoids, anthocyanins, carotenoids, vitamin C, ellagitannins, and essential oils.

4.1. Silver nanoparticles from fruit waste

In a study arange peel extract was plasmochemica-lly extracted and mixed with a silver nitrate solution to synthesize AgNPs and the formed nanoparticles were spherical in shape and size varied from 47–63 nm [105]. In another study AgNPs were produced using the pomegranate peel extract and the resultant synthesised silver nanoparticles were spherical shape with 5-50 nm size [106]. In oane report, authors synthesied silver nanoparticles from mango peel extract and they found the resulatant nanoaprticles were 2.5–6.5 nm in size with spherical shape [112]. K. Baek and J.K. Patra reported AgNPs synthesis by first dissolving the crude extract of lychee peel in distilled water followed by adding the AgNO3 solution and they found the size of the nanoparticles were 3 to 10 nm and spherical in shape [119]. In one study, AgNPs were synthesized by the addition of the aqueous papaya peel extract to the AgNO3 solution where as in another Longan Fruit peel was used [111,112].

4.2. Gold nanoparticles from fruit waste

A study reported gold NPs synthesis from grapevine seed and peel aqueous extracts and the resultant nanoparticles were of 40 to 60 nm in size [115]. In another study gold NPs were synthesized by suspending the watermelon rind aqueous extract into an auric chloride solution and the synthesised nanoparticles were spherical in shape and size ranges from 20–140 nm [118].

4.3. Zinc Oxide nanoparticles from fruit waste

J. Cheng et al., reported ZnO NPs were synthesized by dissolving the pineapple peel extract in Zn(NO3)2·6H2O, followed by centrifugations and drying up the precipitate and the resultant synthesised nanoparticles were of 8–45 nm size and spherical and rod shapes [113]. Another study reported the ZnO nanocrystals synthesis using rambutan peel extract and the resultant nanoparticles were of 450 nm in diameter and 5µm in average length with needle-like structure [120]. One study reported ZnO NPs by adding the aqueous kiwi fruit peel extract to the Zn(NO3)2.6H2O aqueous solution and it was 8.2 nm in size with spherical and hexagonal shape [123].

4.4. Carbon and composites nanoparticles from fruit waste

A study reported formation of Pectin/Apatite Bio-nanocomposites particles by first dissolving the pectin extracted from the peel of jackfruit in DD water which was sonicated, followed by dissolving CaCl2·4H2O, and then again it was sonicated and at the same time, K2HPO4 was dissolved while sonication to derive a white precipitate. The suspension was dehydrated and lastly rinsed with DD water and ethyl alcohol. The synthesised nanocomposites were 6 mm in diameter with height of 12 mm and spherical in shape [110]. A study reported synthesis of quantum dots were by autoclaving, heating, and then cooling after which the reactive compounds were excluded and then vacuum filtered to a brown solution, which was then filtered and dialyzed to exclude the smaller compounds. The resultant material was of diameters of 2.8 nm-3.0nm and height of 4 nm-4.5 nm Quasi spherical in shape [114]. In a study Carbon NPs were synthesized by first hydrothermal treatment of the peel of the pomelo fruit and then it was autoclaved and heated followed by centrifugation and drying of the precipitate. They were crystalline in shape with 2 to 4 nm in size [117]. In one study cellulose nanocrystals were synthesized from the passion fruit peel extract by using the sulphuric acid hydrolysis process wheraseas in another nanocellulose was synthesized from the pear fruit peel extract by a one-pot process[124].

Table 1. Potential Use of Fruit Wastes for the Preparation of NPs

Type of Nanoparticle	Fruit Waste	Technique Used for Extraction	Characterization Techniques	Size and Shape	Reference
Silver	Orange peel	Plasmochemical extract mixed with $AgNO_3$.	UV-Vis, SEM	47–63 nm, spherical	[105]
Silver	Pomegranate peel	Peel extract mixed with $AgNO_3$.	UV-Vis, SEM	5–50 nm, spherical	[106]

Cadmium Sulfide	Banana peel	Cd^{2+} and S^{2-} ions in banana peel micelles.	PL, UV-Vis, XRD, FTIR, TEM	1.48 nm, spherical	[107]
Cerium Oxide	Banana peel	Peel extract mixed with $Ce(NO_3)_3 \cdot 6H_2O$.	Raman, PXRD, FTIR, TEM, FESEM, EDX	4–13 nm, spherical	[108]
Tin Oxide	Apple peel	Extract mixed with $SnCl_2$.	UV-Vis, XRD, TEM	27.5 nm, spherical	[109]
Pectin/Apatite Biocomposite	Jackfruit peel	Pectin + $CaCl_2 \cdot 4H_2O$ + K_2HPO_4 via sonication.	HNMR, CNMR, FTIR, XRD, SEM-EDX, HR-TEM	d = 6 mm, h = 12 mm, spherical	[110]
Cellulose	Jackfruit peel	Acid hydrolysis + solvent extraction.	SEM, TEM, NMR, FTIR, XRD, TGA, HPLC	20×100–200 nm, spherical	[111]
Silver	Mango peel	Extract in dichloromethane + $AgNO_3$.	FTIR, UV, SEM, TEM, TGA, XRD, XPS	2.5–6.5 nm, spherical	[112]
Zinc Oxide	Pineapple peel	Peel extract + $Zn(NO_3)_2 \cdot 6H_2O$.	FTIR, XRD, FESEM, EDX, TEM	8–45 nm, spherical/rod	[113]
Carbonized Polymer Dots	Avocado peel	Autoclaving, heating, dialysis.	TEM, HRTEM, AFM, XRD, UV, FTIR, XPS	2.8–3.0 nm, quasi-spherical	[114]
Gold	Grapevine seeds and peel	Extracts + $HAuCl_4 \cdot 3H_2O$.	TEM, FTIR, UV	40–60 nm	[115]
Iron Oxide	Mangosteen peel	Extract + $FeCl_3 \cdot 6H_2O$ and $FeCl_2 \cdot 4H_2O$.	XRD, TEM, FESEM, VSM, FTIR	6–20 nm, spherical	[116]
Carbon Nanodots	Pomelo peel	Hydrothermal treatment + centrifugation.	UV-Vis, XPS, TEM, FTIR	2–4 nm, crystalline	[117]
Gold	Watermelon rind	Extract + auric chloride.	UV-Vis, SEM, XRD, FTIR	20–140 nm, spherical	[118]
Silver	Lychee peel	Extract + $AgNO_3$.	FTIR, TEM, XRD, UV-Vis	3–10 nm, spherical	[119]
Zinc Oxide	Rambutan peel	Extract + $Zn(NO_3)_2 \cdot 6H_2O$.	XRD, FTIR, SEM, AFM	450 nm diameter, 5 292	[120]

				µm length, needle-like	
Silver	Papaya peel	Extract + $AgNO_3$.	UV-Vis, XRD, FTIR, AFM	28 nm, spherical	[121]

5. Conclusions
The natural environment has a special way of producing extremely effective minuscule multifunctional substances. The need to produce environmental-friendly methods has been prompted by a growing receptivity toward green chemistry and its usage in the production of NPs. Fruit extracts have the characteristics of being cost-effective, safe, efficient, energy-conserving, and eco-friendly, and they also generate fewer waste products and are not impacting the health of people. In the nanotechnology discipline, these environmentally friendly NPs are being assessed for a variety of applications. A further benefit of using fruit extracts for the synthesis of NPs over other techniques is that they do not require much time and the sustenance of microbial cultures to retain precise effectiveness throughout the formation of NPs. Hence, using plant extracts to synthesize NPs could have a substantial effect in the near future. There is enormous ongoing research regarding the synthesis of NPs using plant products. Yet, there is still a significant requirement for an economical, mass-producible, and environmentally acceptable method that investigates the possibility of using natural reductants to produce NPs. Furthermore, fruit extracts from the same plant that are obtained from various parts of the world have chemical compositions that vary significantly, which could lead to inconsistent outcomes in various lab settings. Thus, the investigation of the functions of biomolecules is crucial for the production of NPs and has given rise to novel fields and strategies.
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