

Synthesis of Silver Nanomaterials Capping by Fruit-mediated Extracts and Antimicrobial Activity: A Critical Review

ABSTRACT

Natural silver nanoparticles are currently being used innovatively by a unique simple route. Different bio-mediated fruit peel extracts were used to produce silver nanoparticles (AgNPs) and explore the synthesis of environmentally friendly aspects. To produce biodegradable AgNPs various bio-mediated fruit peel extracts function as reducing and capping agents in the synthesis route. It was discovered that several fruit peel extracts act as a capping agent and silver ions (Ag^+ to Ag^0). Due to reduction, the reaction changes the hydrogel's distinctive hue to a reddish-brown appearance. UV-visible spectra of the AgNPs showed a distinctive surface plasmon resonance (SPR) peak around 460.0 nm. Using X-ray diffraction, the crystallographic nature was discovered with Bragg's diffraction. FT-IR confirmed silver ions function as a capping and reducing agent from peel extract. The transmission electron microscope confirmed that the average size of the nanoparticles was below 100.0 nm and internal morphology. These nanoparticles' ability to combat bacteria, algae and fungi was also well investigated. This manuscript highlights the different bio-mediated and peel extracts that are efficient in producing AgNPs and their function for promising antimicrobial activity.

Keywords: Bio-mediated; nanoparticles (NPs); peel extracts; reducing agent; silver nanoparticles (AgNPs).

1. INTRODUCTION

The function of nanotechnology in science and technology is to create novel, unique and unified materials at the nanoscale [1]. One billionth of a meter like 10^{-9} is denoted by the term nano. In 1974, Tokyo Science University professor Norio Taniguchi first used nanotechnology to refer to the precise synthesis of materials at the nanoscale level [2]. Nanoparticles have distinct chemical, optical and mechanical capabilities, their application is becoming more popular in the twenty-first century [3]. Although the formation of AgNPs by chemical and physical means has been thoroughly investigated, one crucial area of nanotechnology is developing dependable natural technology to produce nanoparticles [4]. Enzymes and bacteria are proposed as potential natural substitutes [5]. Because noble metal nanoparticles like silver have special optical, electrical, mechanical, magnetic, size-dependent and chemical properties. There has been an increase in the focus of current studies on these nanoparticles and the bulk materials differ greatly from one another [6]. Metal nanoparticles have

important uses in electronics, optoelectronics, magnetic, biological and information storage systems because of these size-dependent characteristics [3,6]. Metal nanoparticles can be synthesized using a variety of methods, including chemical, electrochemical, photochemical and radiation. Toxic compounds produced by the chemical technique may negatively affect human health and medical applications [6]. The biosynthesis of nanoparticles is required to serve as the primary driving force underlying the widely recognized bottom-up technique known as metal nanoparticle biogenesis [6]. When compared to chemical approaches, this method produces safer more affordable and ecologically friendly nanoparticles [7]. It is more convenient to use agricultural waste such as bio-mediated peel extracts to produce nanoparticles than it is to use other benign biological processes. Fruit peels are particularly readily available, effective, reasonably priced, natural, eco-friendly and abundant in bioactive components [7]. Since these bioactive substances have potential applications as antibacterial and antioxidants. Most researchers are working to find a

productive method of removing these substances from fruit peels [7]. There are numerous methods for creating silver nanoparticles. For example, facile method [8], thermal decomposition of silver compounds [9], electrochemical [10], Sonochemical [11], microwave-assisted process [12] and recently via green chemistry route [13]. To create ecologically safe methods for synthesizing AgNPs without the use of hazardous compounds is expanding [8,13]. The use of microorganisms or plant extracts in biosynthetic processes has made them a straightforward and practical substitute for physical and chemical synthetic processes. Compared to other biological processes, the extract that serves as a reducing and capping agent for the production of nanoparticles has greater advantages [8,14].

The plant's nanoparticles are favoured because they are affordable, environmentally beneficial, a one-step procedure for biosynthesis and safe for humans [10-13]. Various substances including extracts [11], fruit [12], bark [13], fruit peels [14], root [15] and callus [16,17] have been investigated thus far for the production of silver nanoparticles in different sizes, shapes and forms. Plant extracts are used to synthesize natural nanoparticles. All across the world, people eat bananas, papaya, dragon fruits etc. and after the pulp is eaten the peels are usually thrown away [18]. Among the uses for banana peels that have been covered in the literature are used for their therapeutic qualities [19], production of ethanol [20], foundation for the production of fungal biomass [21], synthesis of laccase [22] and biosorbent to remove heavy metals [23]. Furthermore, banana peels which are naturally abundant in polymers like cellulose, hemicellulose, lignin and pectin might be applied to the production of AgNPs [23]. Catalytic activity and other associated qualities such antibacterial

activity of AgNPs are correlated with specific surface area. Because surface energy rises with increasing specific surface area, nanoparticles may potentially become more biologically useful [23,67]. In medicinal and pharmaceutical uses, noble metal nanoparticles come into direct contact with the human body, like toothpaste, shampoos, soaps, detergents, shoes and cosmetics [24]. Given the increasing microbial resistance to metal ions, antibiotics and the emergence of resistant strains, researchers are becoming increasingly interested in metallic nanoparticles which exhibit promising antibacterial properties due to their large surface area to volume ratio [7,24]. With the use of an extract made from leftover banana peels, phytochemicals [24,69] etc. seek to create silver nanoparticles in an environmentally friendly manner. The AgNPs were characterized using a variety of techniques SEM, TEM, XRD and FTIR [50-55]. AgNPs an inorganic antibacterial agents that are harmless and nontoxic and they can eradicate approximately 650.0 different types of microbes that cause diseases [25-26]. From this point of view, we overview the studies that are easy to find even being envisioned as antibacterial agents of the future any potential aspect.

2. MATERIALS AND METHODS

2.1. Materials

A different variety of fruit peels were screened from the nearby area. After being retrieved from the nearby place such as pomegranate, banana, papaya and dragon fruits in Fig. 1. The peels were taken off and allowed to air dry and investigated crucially. The different parts of these peels were investigated and the best-fitted data was found to be investigated scientifically.

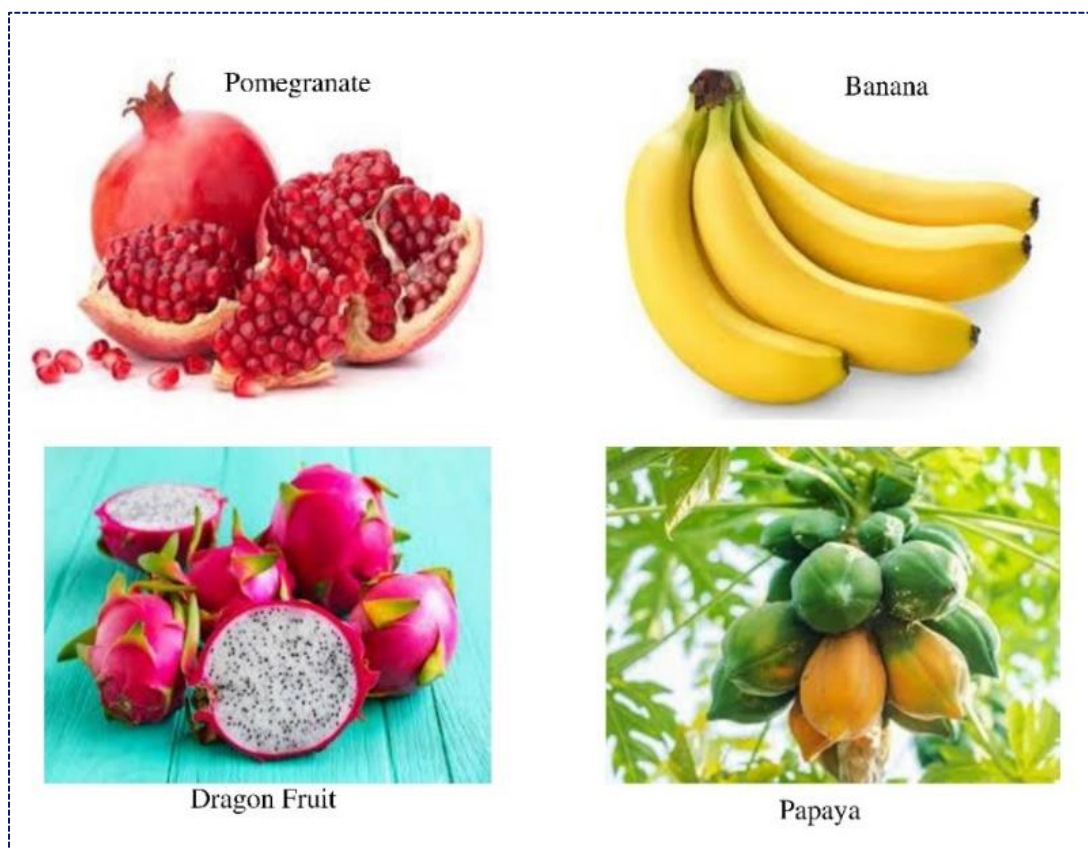


Fig. 1. Source of different bio-mediated peel extracts

2.2 Methods

AgNPs are synthesized by the main three possible routes physical methods, chemical methods and biological methods. The three routes follow the possible approach such as the top-down approach and the bottom-up approach [27]. The atoms are submerged in the bottom-up approach and in another way, the bulks are decomposed into smaller ones in a top-down approach [27] expressed in Table 1.

The bio-mediated peels were cut into little pieces and peels were then cleaned three times using tap water and distilled water to get rid of any external dirt impurities [28]. On paper towels, the peels were then taken off and allowed to dry. After adding 50.0 ml of double-distilled water to a 100.00 ml beaker with about 25.0 g of peel, the mixture was brought to a boil at 800.0 °C for 10.0 minutes [28]. The peel was then

filtered twice using Whatman filter paper to exclude macromolecules. As a self-reducing agent in this, banana and papaya peel extract work. To reduce silver nitrate into AgNPs, around 5.0 ml of filtered bio-peel extract is collected, added to 1.0 mM of pure aqueous silver nitrate solution and agitated for 1.0 hour [28]. The solution changes colour from yellow to brownish yellow to deep brown as a result of the reduction process of Ag^+ to Ag^0 and confirmed the formation of nanoparticles. The creation of a brown colour indicates that the AgNPs synthesis was finished [28].

A comparable procedure is used to produce AgNPs using different amounts of papaya and banana peel extract from carioca [28] as well as different sources of bacteria, fungus and algae mediated also applied for the synthesized of silver nanomaterials illustrated in Table 2 to Table 4.

Table 1. Synthesis procedure of nanomaterials

Methods	Description	Type	Nature
Physical methods	Laser ablation, high energy ball-milling, electro-spraying, inert gas condensation, physical vapour deposition and laser pyrolysis etc.	Top-down approach	Toxic
Chemical methods	Sol-gel method, microemulsion techniques, hydrothermal analysis, polyol synthesis, chemical vapour synthesis etc.	Bottom-up approach	Toxic
Biological methods	Steam, roots, leaves, latex, buds, flowers, seeds, bacteria, fungi, yeast, microalgae, macroalgae etc.	Bottom-up approach	Nontoxic

Table 2. Bacterial-mediated synthesis of AgNPs

Bacteria	Silver salt	Shape	Size	Application	References
<i>Lactobacillus acidophilus</i>	AgNO ₃	Spherical	10.0-20.0	Antioxidant and antimicrobial activity	[29]
<i>Bacillus cereus</i>	AgNO ₃	Spherical	20.0-40.0	Antioxidant and Antibacterial activity	[30]
<i>Bacillus sp.</i>	AgNO ₃	Spherical	22.0-41.0	Antifungal activity	[31]
<i>Pseudoduganella eburnean</i>	AgNO ₃	Spherical	8.0-24.0	Antimicrobial activity	[32]
<i>Bacillus siamensis</i>	AgNO ₃	Spherical	25.0-50.0	Antibacterial activity	[33]
<i>Phenerochaete chrysosporium</i>	AgNO ₃	Spherical	34.0-90.0	Antibacterial activity	[34]
<i>Bacillus brevis</i>	AgNO ₃	Spherical	41.0-68.0	Antibacterial activity	[35]
<i>Streptomyces sp.</i>	AgNO ₃	Spherical	10.0-30.0	Antibacterial activity and antiviral activity	[36]

Table 3. Fungal medical synthesis of AgNPs

Fungus	Silver salt	Shape	Size	Application	Reference
Talaromyces purpureogenus	AgNO ₃	Spherical	50.0-70.0	Antifungal	[37]
Trichoderma harzianum	AgNO ₃	Spherical	31.13	Antifungal	[38]
Anamorphus bjerkandera	AgNO ₃	Spherical	70.0-90.0	-	[39]
Penicillium verrucosum	AgNO ₃	Spherical	10.0-12.0	Antifungal	[40]
Aspergillus brunneoviolaceus	AgNO ₃	Spherical	0.72-15.21	Antioxidative acidity	[41]
Penicillium oxalicum	AgNO ₃	Spherical	60.0-80.0	Antifungal	[42]
Setosphaeria rostrata	AgNO ₃	Spherical	2.0-20.0	Antifungal	[43]
Fusarium scirpi	AgNO ₃	Spherical	2.0-20.0	Antifungal	[44]

Table 4. Algal-mediated synthesis of AgNPs

Algae	Silver salt	Shape	Size (nm)	Application	Reference
Chaetomorpha Ligustica	AgNO ₃	Spherical	2.0-12.0	Anticancer	[45]
Chlorella vulgaris	AgNO ₃	Spherical	55.0	Photocatalytic dye degradation acidity	[46]
Gelidium Corneum	AgNO ₃	Spherical	20.0-50.0	-	[47]
Noctiluca Scintillans	AgNO ₃	Spherical	4.50	Antibacterial	[48]
Botryococcus braunii	AgNO ₃	Cubical and spherical	40.0-90.0	Antimicrobial	[49]

3. CHARACTERIZATION TECHNIQUE

Different type of techniques was employed for the characterization of AgNPs such as spectroscopic, X-ray and microscopic listed in Table 5. The spectroscopic techniques interact with the nanomaterials which produce different signals that can calculate the optical properties, synthesis and stability of NPs by UV-visible;

investigate the phytochemical's role in NPs synthesis by FTIR and determine the hydrodynamic diameter and polydispersity index of NPs by DLS [50-52]. Determine the crystalline size, shape, structure, lattice parameters, stress, strain, dislocation density, lattice volume and particle size of NPs, surface morphology, shape, size and electrical and mechanical properties of NPs by X-ray [53].

Table 5. Common techniques for the characterization of silver nanoparticles

Techniques	Characterization techniques	Information provided	References
Spectroscopic techniques	UV-visible	Optical properties, synthesis and stability.	[50]
	FTIR	phytochemical's role.	[51]
	DLS	hydrodynamic diameter and polydispersity index.	[52]
X-ray based techniques	XRD, XAS, XRF, XPS	crystalline structure and particle size.	[53]
	AFM	Surface morphology, shape, size, electrical, and mechanical properties.	[53]
Microscopic	SEM	Particle size distribution, morphology and topography.	[54]
	TEM	Morphology, shape, size, elemental composition and electrical conductivity.	[55]

The internal and surface morphology, shape, size, elemental composition, impurities, lattice freeze and electrical conductivity of NPs by scanning electron microscope and transmission electron microscope [55].

mixture's colour from reddish brown to brown increases and conformation nanoparticles are formed [56].

4. RESULTS AND DISCUSSION

4.1 Visible Observation

Fig. 2. shows that the mixture of artificially created AgNPs is made with papaya peel extracts in different concentrations as 5.0 ml, 10.0 ml, 15.0 ml, 20.0 ml and 25.0 ml [56]. Fig. 2. which shows the colour variation of the reaction mixture 1.0 hours after the reaction started, shows how the concentration of *Carica papaya* bio-mediated peel extracts utilized has an affected [56]. With an increase in peel extract concentration from 5.0 ml to 25.0 ml, the reaction

4.2 UV-visible Spectra Analysis

After the 24.0-hour incubation period, the UV visible absorption spectra of AgNPs at five distinct concentrations 5.0 ml, 10.0 ml, 15.0 ml, 20.0 ml and 25.0 ml of the aqueous papaya peel extract at room temperature peaks are found at 410.0 nm, 420.0 nm, 435.0 nm, 422.0 nm and 418.0 nm respectively [57]. The absorption SPR band is detected for 5.0 ml, 10.0 ml, 15.0 ml, 20.0 ml and 25.0 ml concentrations of papaya peel-mediated silver nanoparticles [57]. At 15.0 ml and 25.0 ml concentrations, the SPR peak with maximum and minimum intensity is detected at 435.0 nm and 418.0 nm [57].

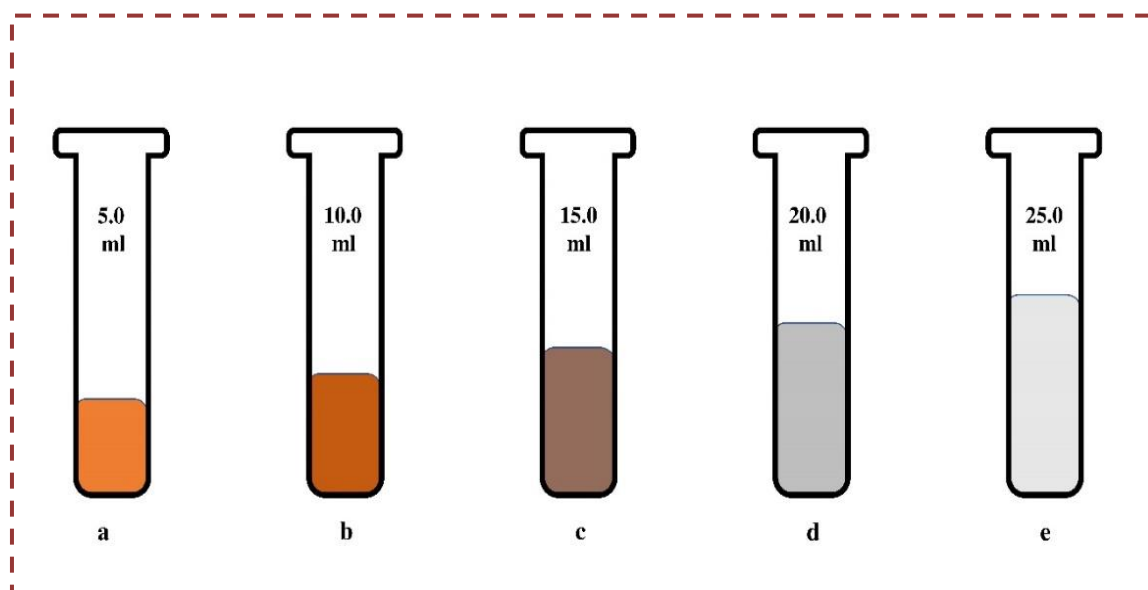


Fig. 2. AgNPs using (a) 5.0 ml, (b) 10.0 ml, (c) 15.0 ml, (d) 20.0 ml, (e) 25.0 ml of *Carica papaya* peel extract after 1.0 h of incubation

Table 6. The optical band gap of papaya peel extracts from *Carica*

Sample	Optical Band Gap (eV)	Reference
05.0 ml	4.9	[56-58]
10.0 ml	4.7	[56-58]
15.0 ml	4.6	[56-58]
20.0 ml	4.7	[56-58]
25.0 ml	4.8	[56-58]
10.0 ml	2.5	[79]
10.0 ml	3.4	[80]

The papaya peel extract concentration rises from 5.0 to 15.0 ml and the optical band gap reduces, confirming that the energy band gap also lowers as particle size increases [58]. The optical band gap is found to rise as the papaya peel extract concentration is increased to 20.0 ml and 25.0 ml, confirming the decrease in the size of the AgNPs for these concentrations which may also be supported by further XRD analysis [58,79].

4.3 FT-IR Analysis

Bio-mediated carica papaya peel extract's FT-IR transmission spectra absorption bands near 2924.09 cm^{-1} , 2862.36 cm^{-1} and 1458.18 cm^{-1} , 979.84 cm^{-1} can be indicative of C–H alkene stretching or bending vibrations [58]. The bands located approximately at 3726.47 cm^{-1} and 918.12 cm^{-1} respectively are ascribed to carboxylic acid vibrations that are either stretching [58]. The bands located approximately at 1188.15 cm^{-1} and 1658.78 cm^{-1} can be attributed to amide I and II N–H bending which result from protein peptide bonds and carbonyl stretching, respectively [59]. When compared to pure carica papaya peel extract, the bands around $3100\text{--}3400\text{ cm}^{-1}$ and $1600\text{--}1650\text{ cm}^{-1}$ respectively due to carboxylic and amine groups are shifted to higher wavelengths due to the

binding of silver ions and the depth of the band decreases [60].

4.4 X-ray Diffraction (XRD) Analysis

The XRD patterns unequivocally demonstrate the crystallographic nature of the AgNPs produced by the bio-reduction of silver ions in papaya peel broth. The phase distribution, crystallinity, dislocation density, lattice parameters and purity of the produced AgNPs are assessed by XRD [81]. The two thetas (2θ) values in the diffractogram of the AgNPs range from 20.0° to 90.0° [81]. There are five unique diffractions for the cubic crystal of AgNPs which are (111), (200), (220), (311) and (222) predominant plane when indexed under the standard [61] [JCPDS] Card [No. 04-783] in Fig. 3. [81].

Peel extract may account for the diffraction seen at 27.0° and 32.0° . A capping chemical stabilizing the nanoparticles may have caused these Braggs diffraction [62]. The crystallite sizes of the AgNPs at different concentrations of papaya peel extract are determined [63] by the Debye-Scherrer model denoted equation 1.

$$D = \frac{k\lambda}{\beta \cos \theta} \text{-----} \quad (1)$$

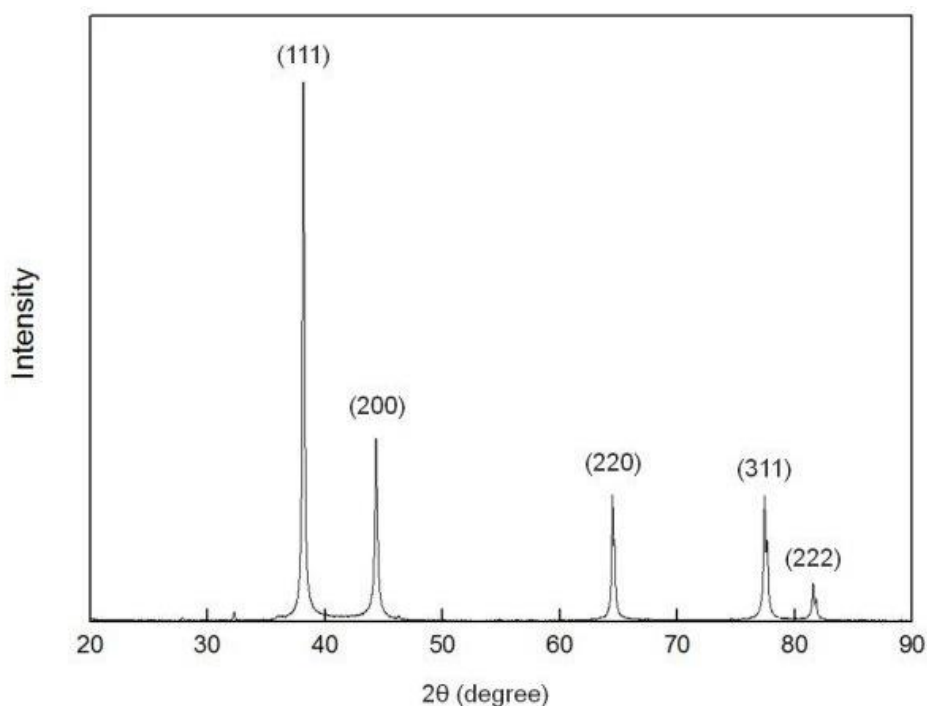


Fig. 3. X-ray diffractogram of AgNPs

The average crystallite size was determined to be 16.1 nm, 16.3 nm, 17.9 nm, 17.8 nm and 17.7 nm respectively for papaya peel extracts varying concentration [63]. The average crystallite size of the particles is found to grow when the papaya peel extract concentration rises. The average crystallite size of the particles then gradually declines as the concentration rises to a low volume [64]. The percentage of crystallinity and lattice parameters [82-90] also investigated the NPs. The UV visible spectrum examination could verify the particle's decreased crystallite size. Further observations reveal that the synthesized AgNPs have a crystallite size that is significantly less than the 28.0 nm reported [64]. This reduction in crystallite size improves the AgNPs characteristics [68].

4.5 SEM Analysis

SEM analysis is performed to study the surface morphology and shapes of AgNPs illustrated in Fig. 4. [78]. For *Carica papaya* peel is observed that the AgNPs are spherical and the concentration of the extract alters the size and shape of the NPs [58].

The particles are uniformly distributed and no aggregations are observed at low concentrations. However, the particles get agglomerated as the concentration of papaya extract and pomegranate peel extract increases for high concentrations [58,78]. The agglomeration of particles leads to the destabilization of AgNPs [58,78].

4.6 TEM Analysis

TEM images of AgNPs synthesized using peel are shown in Fig. 5 [58]. AgNPs size and form in the solution change with extract concentration. Mostly spherical NPs shape is suggested by these image profiles [58]. There are also a few isolated NPs in some areas, suggesting that sedimentation may have occurred later [65,66].

The range of 15.0 nm to 20.0 nm is reported to be the average particle size of AgNPs. Parallely proved with the crystallite size determined by XRD analysis as well as TEM the results show good agreement for argument [66].

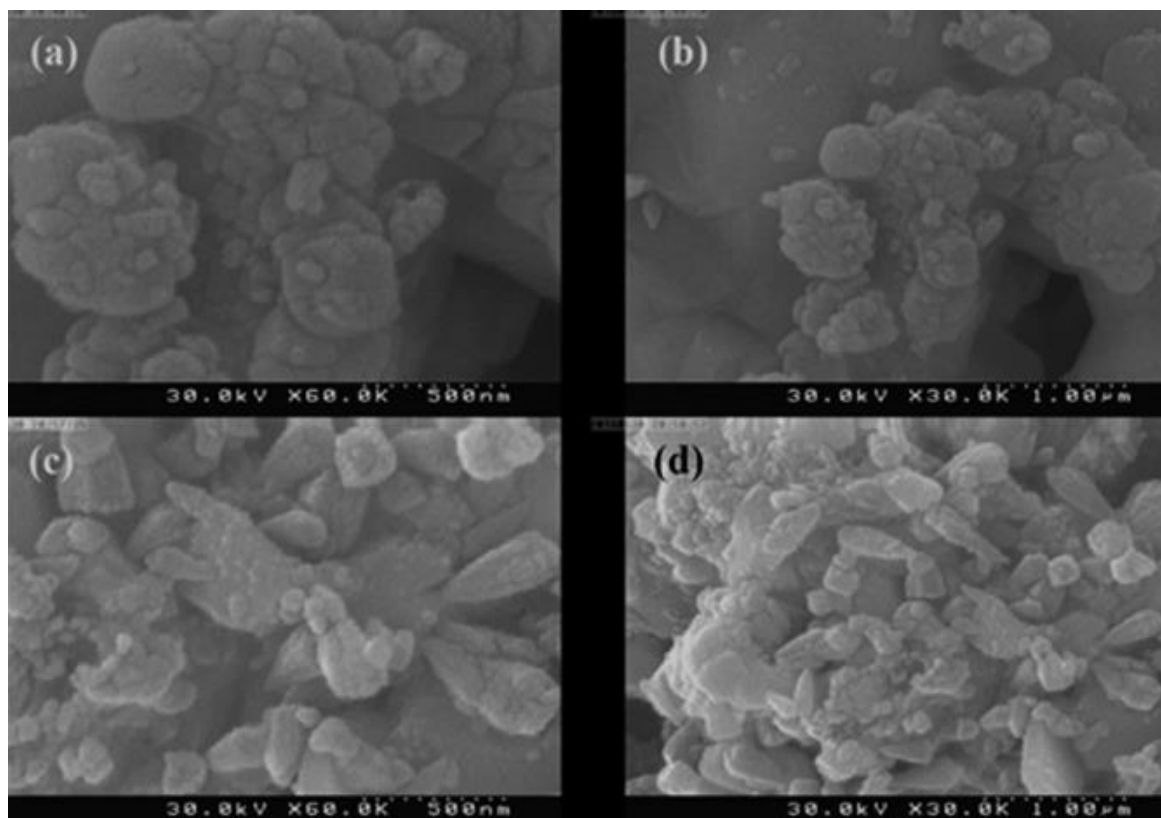


Fig. 4. SEM images of silver nanoparticles using pomegranate peel extract

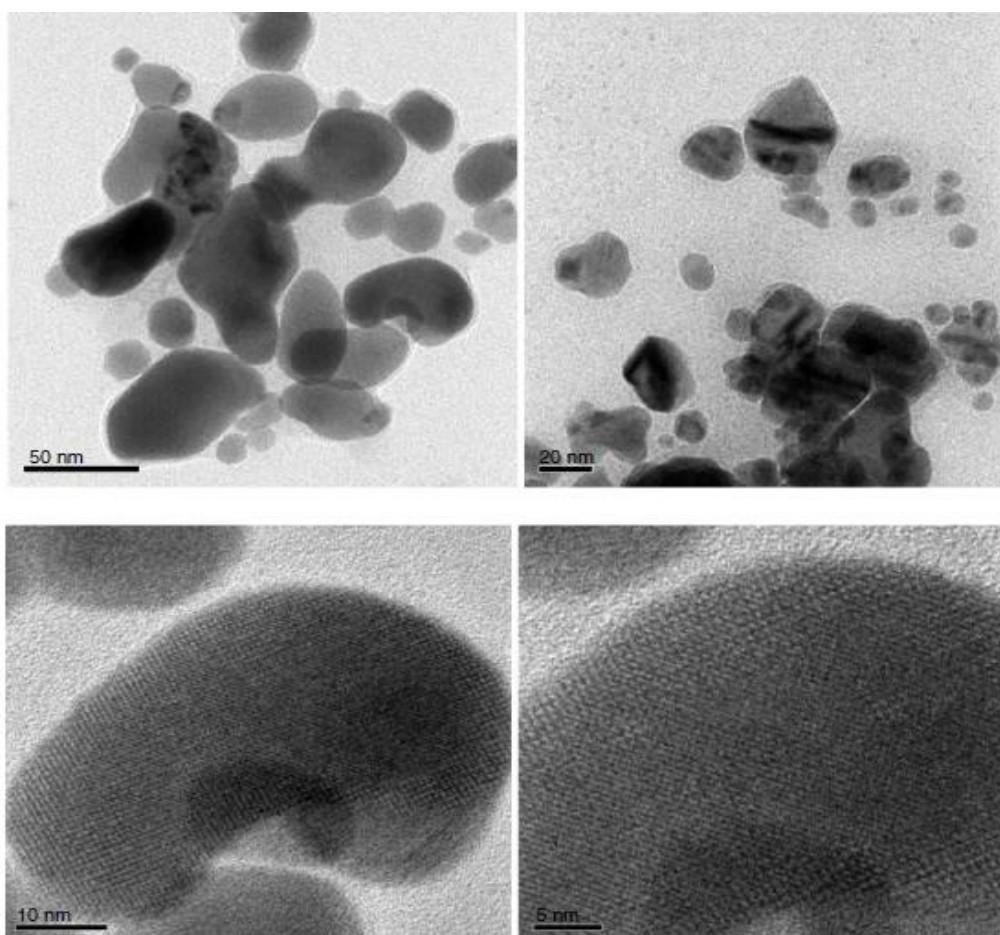


Fig. 5. TEM images of AgNPs using peel extract

5. ANTIMICROBIAL ACTIVITY OF SILVER NANOPARTICLES

The bio-mediated plant parts such as the leaf, root etc into silver species show outstanding antimicrobial, anticancer, antifungal, cytotoxicity

as well as catalytic activity and numerous applications [70-75,91]. The properties also depend on its substrate, shape and size impact this antimicrobial activity as well as the surface-to-volume ratio that is responsible for demineralization listed in Table 7 [76].

Table 7. Antimicrobial activity of silver nanoparticles

Plants	Plant's part	Shape	Substrates	Applications	References
Allium fistulosum, Tabernaemontana divaricata and Basella alba	Leaf	Rod	AgNO ₃	Antimicrobial	[70]
Tridax procumbens	Leaf	Spherical	AgNO ₃	Antimicrobial, anticancer	[71]
Aloysia citrodora	Leaf	Spherical	AgNO ₃	Antifungal	[72]
Alhagi graecorum	Leaf	Spherical	AgNO ₃	Cytotoxicity and antifungal	[73]
Rubus ellipticus	Root	Spherical	AgNO ₃	Antibacterial	[74]
Rhodiola imbricata with ania somnifera	Root	Spherical	AgNO ₃	Catalytic activity	[75]

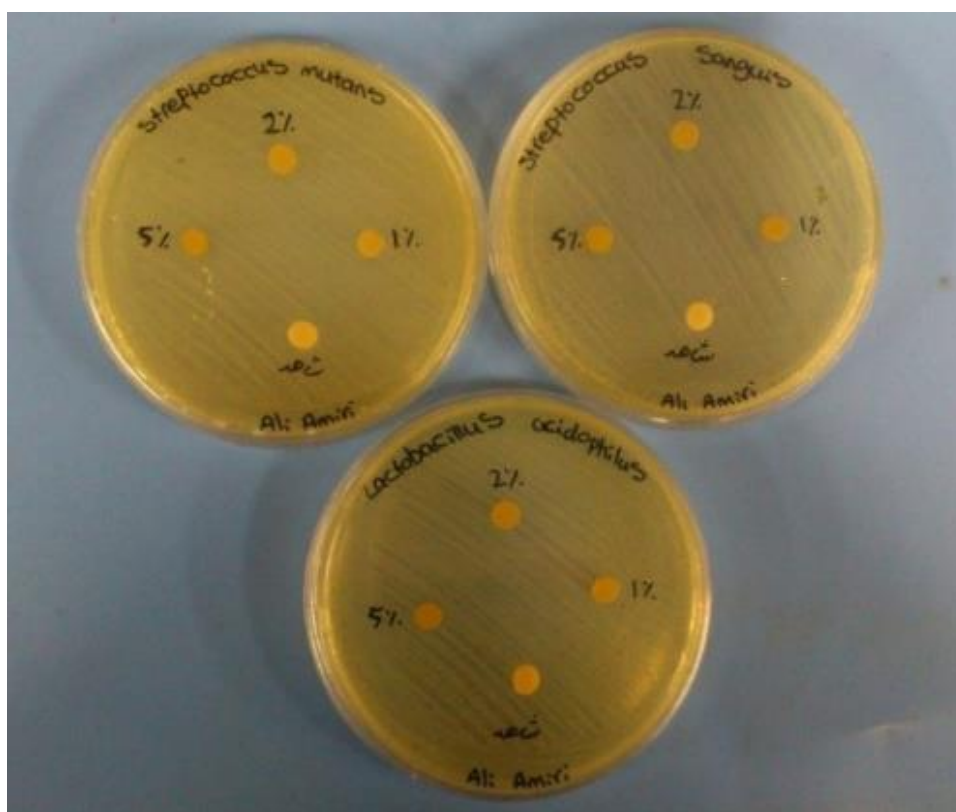


Fig. 6. Growth inhibition zone of microbes

For example, the plant *Allium Fistulosum*, *Tabernaemontana Divaricata* and *Basella Alba* leaf extract produced AgNPs that are rod shape effective for antimicrobial activities [70].

In the agar diffusion test, there was no growth inhibition zone around in disks with 1.00 % and 2.00 % concentrations. However, in Fig. 6. a growth inhibition zone was seen in 5.00 % concentration, with a diameter of 9.50 ± 0.70 mm for *S. mutans*, 8.50 ± 0.70 mm for *S. sanguis* and 8.00 ± 1.40 for *L. acidophilus* [77]. So, the AgNPs show outstanding microbial properties.

6. CONCLUSION

Different doses of bio-mediated peel extract as the reducing agent and capping agent are discussed for the effective green production of AgNPs. These NPs are entirely safe and kind to the environment. The absorption peaks in the UV visible spectra of AgNPs for varying doses are explained. When the peel extract concentration is low then the optical band gap decreases and the absorption peaks redshift, indicating an increase in particle size. Furthermore, it is seen that the absorption peaks blue shift and the optical band gap widens as the concentration of peel extract

is high. These observations suggest that the particle size will decrease. By XRD these differences in particle size may also be verified. By displaying the relevant bands that are in charge of converting silver ions into AgNPs, the FTIR spectra verify the existence of different functional groups. The average crystallite diameters of the crystalline AgNPs as revealed by the X-ray diffractograms are found to be between 16.0 and 18.0 nm which is in good agreement with the results of the TEM investigation. Different microbes were investigated for the antibacterial efficacy of AgNPs. It was discovered that bacteria, algae and fungi have a larger zone of inhibition. This might be because there are more AgNPs in the reaction mixture.

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COMPETING INTERESTS

The authors declare that no financial or personal relationship could influence this research manuscript.

REFERENCES

1. Aravind G, Bhowmik D, Duraivel S, Harish G. Traditional and medicinal uses of *Carica papaya*. *Journal of Medicinal Plants Studies*. 2013;1(1):7–15.
2. Rivera Gómez CC, Naranjo LG, Duque AM. From Mary to a sea of reed. Imaginaries of nature in the transformation of the Valle del Cauca landscape between 1950 and 1970. Autonomous University of the West; 2006.
3. Banerjee P, Satapathy M, Mukhopadhyay A, Das P. Leaf extract mediated green synthesis of silver nanoparticles from widely available Indian plants: Synthesis, characterization, antimicrobial property and toxicity analysis. *Bioresources and Bioprocessing*. 2014;1(3):1–10.
4. Joe AW, Yi L, Natarajan A, Le Grand F, So L, Wang J, Rossi FM. Muscle injury activates resident fibro/adipogenic progenitors that facilitate myogenesis. *Nature Cell Biology*. 2010;12(2):153-163.
5. Mohanpuria P, Rana NK, Yadav SK. Biosynthesis of nanoparticles: technological concepts and future applications. *Journal of nanoparticle research*. 2008;10:507-517.
6. Hajizadeh S, Farhadi K, Forough M, Sabzi RE. Silver nanoparticles as a cyanide colourimetric sensor in aqueous media. *Analytical Methods*. 2011;3(11):2599-2603.
7. Ozgur S, Buchwald G, Falk S, Chakrabarti S, Prabu JR, Conti E. The conformational plasticity of eukaryotic RNA-dependent ATPases. *The FEBS Journal*. 2015;282(5):850-863.
8. Kobir MM, Ali MS, Ahmed S, Sadia SI, Alam MA. Assessment of the physicochemical characteristic of wastewater in Kushtia and Jhenaidah Municipal Areas Bangladesh: A Study of DO, BOD, COD, TDS and MPI. *Asian Journal of Geological Research*. 2024;7(1):21-30.
9. Saxena A, Tripathi RM, Zafar F, Singh P. Green synthesis of silver nanoparticles using aqueous solution of *Ficus benghalensis* leaf extract and characterization of their antibacterial activity. *Materials Letters*. 2012;67(1):91-94.
10. Kumar V, Yadav SK. Plant-mediated synthesis of silver and gold nanoparticles and their applications. *Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology*. 2009;84(2):151-157.
11. MubarakAli D, Thajuddin N, Jeganathan K, Gunasekaran M. Plant extract mediated synthesis of silver and gold nanoparticles and its antibacterial activity against clinically isolated pathogens. *Colloids and Surfaces B: Biointerfaces*. 2011;85(2):360-365.
12. Prathna TC, Chandrasekaran N, Raichur AM, Mukherjee A. Biomimetic synthesis of silver nanoparticles by Citrus limon (lemon) aqueous extract and theoretical prediction of particle size. *Colloids and Surfaces B: Biointerfaces*. 2011;82(1):152-159.
13. Oak SN, Parelkar SV, Satishkumar KV, Pathak R, Ramesh BH, Sudhir S, Keshav M. Review of video-assisted thoracoscopy in children. *Journal of Minimal Access Surgery*. 2009;5(3):57-62.
14. Bankar A, Joshi B, Kumar AR, Zinjarde S. Banana peel extract mediated novel route for the synthesis of silver nanoparticles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2010;368(1-3):58-63.
15. Ahmad P, Jaleel CA, Salem MA, Nabi G, Sharma S. Roles of enzymatic and nonenzymatic antioxidants in plants during abiotic stress. *Critical reviews in biotechnology*. 2010;30(3):161-175.
16. Nabikhan A, Kandasamy K, Raj A, Alikunhi NM. Synthesis of antimicrobial silver nanoparticles by callus and leaf extracts from saltmarsh plant, *Sesuvium portulacastrum* L. *Colloids and surfaces B: Biointerfaces*. 2010;79(2):488-493.
17. Gopinath B, Hardy LL, Baur LA, Burlutsky G, Mitchell P. Physical activity and sedentary behaviours and health-related quality of life in adolescents. *Pediatrics*. 2012;130(1):e167-e174.
18. Bankar A, Joshi B, Kumar AR, Zinjarde S. Banana peel extract mediated a novel route for the synthesis of silver nanoparticles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. 2010;368(1-3):58-63.
19. Parmar HS, Kar A. Medicinal values of fruit peels from *Citrus sinensis*, *Punica*

- granatum*, and *Musa paradisiaca* with respect to alterations in tissue lipid peroxidation and serum concentration of glucose, insulin, and thyroid hormones. *Journal of Medicinal Food*. 2008;11(2):376-381.
20. Tewari HK, Marwaha SS, Rupal K. Ethanol from banana peels. *Agricultural wastes*. 1986;16(2):135-146.
 21. Essien JP, Akpan EJ, Essien EP. Studies on mould growth and biomass production using waste banana peel. *Bioresource Technology*. 2005;96(13):1451-1456.
 22. Osma JF, Saravia V, Toca-Herrera JL, Couto SR. Sunflower seed shells: A novel and effective low-cost adsorbent for the removal of the diazo dye Reactive Black 5 from aqueous solutions. *Journal of Hazardous Materials*. 2007;147(3):900-905.
 23. Annadurai G, Juang RS, Lee DJ. Adsorption of heavy metals from water using banana and orange peels. *Water science and technology*. 2003;47(1):185-190.
 24. Choi O, Deng KK, Kim NJ, Ross Jr, L, Surampalli RY, Hu Z. The inhibitory effects of silver nanoparticles, silver ions, and silver chloride colloids on microbial growth. *Water research*. 2008;42(12):3066-3074.
 25. Jeong SH, Yeo SY, Yi SC. The effect of filler particle size on the antibacterial properties of compounded polymer/silver fibres. *Journal of Materials Science*. 2005;40:5407-5411.
 26. Mahendra Rai MR, Alka Yadav AY, Bridge P, Aniket Gade AG. Myconanotechnology: A new and emerging science. *Applied mycology*. 2009;258-267.
 27. Zhu L, Gharib M, Becker C, Zeng Y, Ziefuß AR, Chen L, Chakraborty I. Synthesis of fluorescent silver nanoclusters: Introducing bottom-up and top-down approaches to nanochemistry in a single laboratory class. *Journal of Chemical Education*. 2019;97(1):239-243.
 28. Qamer S, Romli MH, Che-Hamzah F, Misni N, Joseph NM, Al-Haj NA, Amin-Nordin S. Systematic review on biosynthesis of silver nanoparticles and antibacterial activities: Application and theoretical perspectives. *Molecules*. 2021;26(16):5057.
 29. Rodríguez-Serrano C, Guzmán-Moreno J, Ángeles-Chávez C, Rodríguez-González V, Ortega-Sigala JJ, Ramírez-Santoyo RM, Vidales-Rodríguez LE. Biosynthesis of silver nanoparticles by *Fusarium scirpi* and its potential as antimicrobial agent against uropathogenic *Escherichia coli* biofilms. *Plos one*. 2020;15(3):e0230275.
 30. Mujaddidi N, Nisa S, Al Ayoubi S, Bibi Y, Khan S, Sabir M, Qayyum A. Pharmacological properties of biogenically synthesized silver nanoparticles using endophyte *Bacillus cereus* extract of *Berberis lyceum* against oxidative stress and pathogenic multidrug-resistant bacteria. *Saudi journal of biological sciences*. 2021;28(11):6432-6440.
 31. Ajaz S, Ahmed T, Shahid M, Noman M, Shah AA, Mehmood MA, Li B. Bioinspired green synthesis of silver nanoparticles by using a native *Bacillus* sp. strain AW1-2: Characterization and antifungal activity against *Colletotrichum falcatum* Went. *Enzyme and microbial technology*. 2021;144:109745.
 32. Huq MA. Green synthesis of silver nanoparticles using *Pseudoduganella eburnea* MAHUQ-39 and their antimicrobial mechanisms investigation against drug resistant human pathogens. *International Journal of Molecular Sciences*. 2020;21(4):1510.
 33. Ibrahim E, Fouad H, Zhang M, Zhang Y, Qiu W, Yan C, Chen J. Biosynthesis of silver nanoparticles using endophytic bacteria and their role in inhibition of rice pathogenic bacteria and plant growth promotion. *RSC advances*. 2019;9(50):29293-29299.
 34. Saravanan M, Arokiyaraj S, Lakshmi T, Pugazhendhi A. Synthesis of silver nanoparticles from *Phenerochaete chrysosporium* (MTCC-787) and their antibacterial activity against human pathogenic bacteria. *Microbial pathogenesis*. 2018;117:68-72.
 35. Saravanan M, Barik SK, Mubarak Ali D, Prakash P, Pugazhendhi A. Synthesis of silver nanoparticles from *Bacillus brevis* (NCIM 2533) and their antibacterial activity against pathogenic bacteria. *Microbial pathogenesis*. 2018;116:221-226.
 36. Haggag EG, Elshamy AM, Rabeh MA, Gabr NM, Salem M, Youssif KA, Abdelmohsen UR. Antiviral potential of green synthesized silver nanoparticles of *Lampranthus coccineus* and *Malephora lutea*. *International journal of nanomedicine*. 2019;6217-6229.
 37. Sharma A, Sagar A, Rana, J, Rani R. Green synthesis of silver nanoparticles and its antibacterial activity using fungus *Talaromyces purpureogenus* isolated from

- Taxus baccata* Linn. Micro and Nano Systems Letters. 2022;10(1):2.
38. El-Ashmony RM, Zaghoul NS, Milošević M, Mohany M, Al-Rejaie SS, Abdallah Y, Galal AA. The biogenically efficient synthesis of silver nanoparticles using the fungus *Trichoderma harzianum* and their antifungal efficacy against *Sclerotinia sclerotiorum* and *Sclerotium rolfsii*. Journal of Fungi. 2022;8(6):597.
 39. Osorio-Echavarría J, Osorio-Echavarría J, Ossa-Orozco CP, Gómez-Vanegas NA. Synthesis of silver nanoparticles using white-rot fungus Anamorphous *Bjerkandera* sp. R1: Influence of silver nitrate concentration and fungus growth time. Scientific Reports. 2021;11(1):3842.
 40. Yassin MA, Elgorban AM, El-Samawaty AERM, Almunqedhi BM. Biosynthesis of silver nanoparticles using *Penicillium verrucosum* and analysis of their antifungal activity. Saudi Journal of Biological Sciences. 2021;28(4):2123-2127.
 41. Mistry H, Thakor R, Patil C, Trivedi J, Bariya H. Biogenically proficient synthesis and characterization of silver nanoparticles employing marine procured fungi *Aspergillus brunneoviolaceus* along with their antibacterial and antioxidative potency. Biotechnology Letters. 2021;43:307-316.
 42. Feroze N, Arshad B, Younas M, Afridi MI, Saqib S, Ayaz A. Fungal mediated synthesis of silver nanoparticles and evaluation of antibacterial activity. Microscopy Research and Technique. 2020;83(1):72-80.
 43. Akther T, Khan MS, Hemalatha S. Biosynthesis of silver nanoparticles via fungal cell filtrate and their anti-quorum sensing against *Pseudomonas aeruginosa*. Journal of Environmental Chemical Engineering. 2020;8(6):104365.
 44. Rodríguez-Serrano C, Guzmán-Moreno J, Ángeles-Chávez C, Rodríguez-González V, Ortega-Sigala JJ, Ramírez-Santoyo RM, Vidales-Rodríguez LE. Biosynthesis of silver nanoparticles by *Fusarium scirpi* and its potential as antimicrobial agent against uropathogenic *Escherichia coli* biofilms. Plos one. 2020;15(3):e0230275.
 45. Al-Zahrani SA, Bhat RS, Al Rashed SA, Mahmood A, Al Fahad A, Alamro G, Al Daihan S. Green-synthesized silver nanoparticles with aqueous extract of green algae *Chaetomorpha ligustica* and its anticancer potential. Green Processing and Synthesis. 2021;10(1):711-721.
 46. Rajkumar R, Ezhumalai G, Gnanadesigan M. A green approach for the synthesis of silver nanoparticles by *Chlorella vulgaris* and its application in photocatalytic dye degradation activity. Environmental Technology & Innovation. 2021;21:101282.
 47. Öztürk BY, Gürsu BY, Dağ İ. Antibiofilm and antimicrobial activities of green synthesized silver nanoparticles using marine red algae *Gelidium corneum*. Process Biochemistry. 2020;89:208-219.
 48. Elgamouz A, Idriss H, Nassab C, Bihi A, Bajou K, Hasan K, Patole SP. Green synthesis, characterization, antimicrobial, anti-cancer, and optimization of colorimetric sensing of hydrogen peroxide of algae extract capped silver nanoparticles. Nanomaterials. 2020;10(9):1861.
 49. Arya A, Mishra V, Chundawat TS. Green synthesis of silver nanoparticles from green algae (*Botryococcus braunii*) and its catalytic behavior for the synthesis of benzimidazoles. Chemical Data Collections. 2019;20:100190.
 50. Punjabi K, Choudhary P, Samant L, Mukherjee S, Vaidya S, Chowdhary A. Biosynthesis of nanoparticles: A review. Int. J. Pharm. Sci. Rev. Res. 2015;30(1):219-26.
 51. Gudikandula K, Charya Maringanti S. Synthesis of silver nanoparticles by chemical and biological methods and their antimicrobial properties. Journal of experimental nanoscience. 2016;11(9):714-721.
 52. True H, Christiansen AH, Knutz SE, Rasmussen LB. On the dynamics of a four-axle railway vehicle with dry friction yaw damping. International Journal of Heavy Vehicle Systems. 2020;27(5):600-621.
 53. Uvarov V, Popov I. Metrological characterization of X-ray diffraction methods at different acquisition geometries for determination of crystallite size in nano-scale materials. Materials Characterization. 2013;85:111-123.
 54. Akbari B, Tavandashti MP, Zandrahimi M. Particle size characterization of nanoparticles—A practical approach. Iranian Journal of Materials Science and Engineering. 2011;8(2):48-56.
 55. Aygün A, Özdemir S, Gülcan M, Cellat K, Şen F. Synthesis and characterization of Reishi mushroom-mediated green synthesis of silver nanoparticles for biochemical applications. Journal of

- pharmaceutical and biomedical analysis. 2020;178:112970.
56. Kumar V, Singh A, Mithra SA, Krishnamurthy SL, Parida SK, Jain S, Mohapatra T. Genome-wide association mapping of salinity tolerance in rice (*Oryza sativa*). DNA research. 2015;22(2):133-145.
 57. Rivera-Pastrana DM, Gardea AA, Yahia EM, Martínez-Téllez MA, González-Aguilar GA. Effect of UV-C irradiation and low-temperature storage on bioactive compounds, antioxidant enzymes and radical scavenging activity of papaya fruit. Journal of Food Science and Technology. 2014;51:3821-3829.
 58. Balavijayalakshmi J, Ramalakshmi V. Carica papaya peel mediated synthesis of silver nanoparticles and its antibacterial activity against human pathogens. Journal of applied research and technology. 2017;15(5):413-422.
 59. Ali MS, Ahmed S, Islam MR, Ahamed MS, Rahaman MA, Khatun M, Alam MA. Diabetes mellitus control including fruits in diet: Exhaustive review and meta-analysis. Asian Journal of Food Research and Nutrition. 2024;3(1):43-59.
 60. Sivakumar T. A modern review of silver nanoparticles mediated plant extracts and its potential bioapplications. Int. J. Bot. Stud. 2021;6(3):170-175.
 61. Saravanakumar A, Ganesh M, Jayaprakash J, Jang HT. Biosynthesis of silver nanoparticles using Cassia tora leaf extract and its antioxidant and antibacterial activities. Journal of Industrial and Engineering Chemistry. 2015;28:277-281.
 62. Ibrahim HM. Green synthesis and characterization of silver nanoparticles using banana peel extract and their antimicrobial activity against representative microorganisms. Journal of radiation research and applied sciences. 2015;8(3):265-275.
 63. Rajeshkumar S, Malarkodi C, Gnanajobitha G, Paulkumar K, Vanaja M, Kannan C, Annadurai G. Seaweed-mediated synthesis of gold nanoparticles using *Turbinaria conoides* and its characterization. Journal of Nanostructure in Chemistry. 2013;3:1-7.
 64. Ramesh PS, Kokila T, Geetha D. Plant-mediated green synthesis and antibacterial activity of silver nanoparticles using *Emblica officinalis* fruit extract. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy. 2015;142:339-343.
 65. Nasiriboroumand M, Montazer M, Barani H. Preparation and characterization of biocompatible silver nanoparticles using pomegranate peel extract. Journal of Photochemistry and Photobiology B: Biology. 2018;179:98-104.
 66. Kale R, Barwar S, Kane P, More S. Green synthesis of silver nanoparticles using papaya seed and its characterization. Int. J. Res. Appl. Sci. Eng. Technol. 2018;6:168-174.
 67. Alam MA, Munni SA, Mostafa S, Bishwas RK, Jahan SA. An investigation on synthesis of silver nanoparticles. Asian Journal of Research in Biochemistry. 2023;12(3):1-10.
 68. Alam MA, Mostafa S, Bishwas RK, Sarkar D, Tabassum M, Jahan SA. Low-temperature synthesis and characterization of high crystalline 3c-Ag nanoparticle. Available at SSRN 4446717.
 69. Islam MR, Ahmed S, Sadia SI, Sarkar AK, Alam MA. Comprehensive review of phytochemical content and applications from *Cestrum nocturnum*: A comparative analysis of physicochemical aspects. Asian Journal of Research in Biochemistry. 2023;13(4):43-58.
 70. Vinodhini S, Vithiya BSM, Prasad TAA. Green synthesis of silver nanoparticles by employing the *Allium fistulosum*, *Tabernaemontana divaricate* and *Basella alba* leaf extracts for antimicrobial applications. Journal of King Saud University-Science. 2022;34(4):101939.
 71. Pungle R, Nile SH, Makwana N, Singh R, Singh RP, Kharat AS. Green synthesis of silver nanoparticles using the Tridax Procumbens plant extract and screening of its antimicrobial and anticancer activities. Oxidative Medicine and Cellular Longevity; 2022.
 72. Hassanisaadi M, Bonjar AHS, Rahdar A, Varma RS, Ajalli N, Pandey S. Eco-friendly biosynthesis of silver nanoparticles using *Aloysia citrodora* leaf extract and evaluations of their bioactivities. Materials Today Communications. 2022;33:104183.
 73. Hawar SN, Al-Shmgani HS, Al-Kubaisi ZA, Sulaiman GM, Dewir YH, Rikisahedew JJ. Green synthesis of silver nanoparticles from *Alhagi graecorum* leaf extract and evaluation of their cytotoxicity and antifungal activity. Journal of Nanomaterials. 2022;1-8.

74. Khanal LN, Sharma KR, Paudyal H, Parajuli K, Dahal B, Ganga GC, Kalauni SK. Green synthesis of silver nanoparticles from root extracts of *Rubus ellipticus* Sm. and comparison of antioxidant and antibacterial activity. *Journal of Nanomaterials*. 2022;1-11.
75. Kandiah M, Chandrasekaran KN. Green synthesis of silver nanoparticles using *Catharanthus roseus* flower extracts and the determination of their antioxidant, antimicrobial, and photocatalytic activity. *Journal of Nanotechnology*. 2021;1-18.
76. Teixeira JA, Santos Júnior VED, Melo Júnior PCD, Arnaud M, Lima MG, Flores MAP, Rosenblatt A. Effects of a new nano-silver fluoride-containing dentifrice on demineralization of enamel and *Streptococcus mutans* adhesion and acidogenicity. *International Journal of Dentistry*; 2018.
77. Mirhashemi A, Bahador A, Sodagar A, Pourhajibagher M, Amiri A, Gholamrezayi E. Evaluation of antimicrobial properties of nano-silver particles used in orthodontics fixed retainer composites: An experimental in-vitro study. *Journal of Dental Research, Dental Clinics, Dental Prospects*. 2021;15(2):87.
78. Goudarzi M, Mir N, Mousavi-Kamazani M, Bagheri S, Salavati-Niasari M. Biosynthesis and characterization of silver nanoparticles prepared from two novel natural precursors by facile thermal decomposition methods. *Scientific reports*. 2016;6(1):32539.
79. Aziz A, Khalid M, Akhtar MS, Nadeem M, Gilani ZA, Asghar HUH, Saleem M. structural, morphological and optical investigations of silver nanoparticles synthesized by sol-gel auto-combustion method. *Digest Journal of Nanomaterials & Biostructures (DJNB)*. 2018;13(3).
80. Das AJ, Kumar R, Goutam SP, Sagar SS. Sunlight irradiation induced synthesis of silver nanoparticles using glycolipid bio-surfactant and exploring the antibacterial activity. *J. Bioeng. Biomed. Sci*. 2016; 6(5).
81. Ju Park E, Won Lee S, Bang IC, Park H.W. Optimal synthesis and characterization of Ag nanofluids by electrical explosion of wires in liquids. *Nanoscale research letters*. 2011;6:1-10.
82. Bishwas RK, Mostofa S, Alam MA, Jahan SA. Removal of malachite green dye by sodium dodecyl sulfate modified bentonite clay: Kinetics, thermodynamics and isotherm modeling. *Next Nanotechnology*. 2023;3:100021.
83. Rahman MM, Maniruzzaman M, Yeasmin MS, Gafur MA, Shaikh MAA, Alam MA, Quddus MS. Adsorptive abatement of Pb²⁺ and crystal violet using chitosan-modified coal nanocomposites: A down flow column study. *Groundwater for Sustainable Development*. 2023;23: 101028.
84. Tabassum M, Alam MA, Mostofa S, Bishwas RK, Sarkar D, Jahan SA. Synthesis and crystallinity integration of copper nanoparticles by reaction medium. *Journal of Crystal Growth*. 2024;626: 127486.
85. Alam MA, Bishwas RK, Mostofa S, Jahan SA. Low-temperature synthesis and crystal growth behavior of nanocrystal anatase-TiO₂. *Materials Letters*. 2024;354:135396.
86. Alam MA, Tabassum M, Mostofa S, Bishwas RK, Sarkar D, Jahan SA. The effect of precursor concentration on the crystallinity synchronization of synthesized copper nanoparticles. *Journal of Crystal Growth*. 2023;621:127386.
87. Alam MA, Mobashsara MT, Sabrina SM, Bishwas RKB, Debasish DS, Shirin SAJ. One-pot low-temperature synthesis of high crystalline Cu nanoparticles. *Malaysian Journal of Science and Advanced Technology*. 2023;122-127.
88. Moulick SP, Hossain MS, Al Mamun MZU, Jahan F, Ahmed MF, Sathee RA, Islam F. Characterization of waste fish bones (*Heteropneustes fossilis* and *Otolithoides pama*) for photocatalytic degradation of Congo red dye. *Results in Engineering*. 2023;20:101418.
89. Hasan MR, Abdur R, Alam MA, Shaikh MAA, Aziz S, Sujana A, Hossain M. Exploring the effects of different parameters on the incorporation of K⁺ ions in eggshell-derived CaO reveals highly variable catalytic efficiency for biodiesel conversion. *South African Journal of Chemical Engineering*. 2024;47:67-74.
90. Kobir MM, Tabassum S, Ahmed S, Sadia SI, Alam MA. Crystallographic benchmarking on diffraction pattern profiling of polymorphs-TiO₂ by WPPF for pigment and acrylic paint. *Archives of Current Research International*. 2024;24(1):62-70.
91. Sarkar AK, Ahmed S, Sadia SI, Kobir MM, Tabassum S, Islam MR, Alam MA. Overview of the skeleton significance of toothpaste formulation, evaluation and

historical perspectives: Insights from
Bangladesh's toothpaste industry.
Journal of Materials Science

Research and Reviews. 2024;7(1):
80–101.
