Chapter 16
Green Engineering of Silver Nanoparticles to Combat Plant and Foodborne Pathogens: Potential Economic Impact and Food Quality

Maluta Steven Mufamadi and Rofhiwa Bridget Mulaudzi

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M. Mufamadi (✉)
NABIO Consulting (Pty) Ltd , Pretoria, 0183, South Africa

R. B. Mulaudzi
Agricultural Research Council (ARC),Vegetable and Ornamental Plants Africa Private Bag X293, Pretoria, 0001, South Africa

Romukhu (Pty)Ltd, Doornpoort, Pretoria, 0186, South Africa

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16.1 Introduction

Plant diseases are the major economic burden in agricultural food production, caused by bacteria, viruses, and fungi. Most plant diseases, which are caused by bacteria, can cause severe economic damage from crop losses due to spots, mosaic patterns, or pustules on leaves and fruits leading to the death of plants. Some bacteria cause hormone-based distortion of leaves and shoots; others cause crown gall, which is a proliferation of plant cells that produces swelling at the intersection of stem and soil and roots (Nivas et al. 2016).

The use of synthetic chemicals has been found to be effective in controlling plant diseases; however, the use of these chemicals induces genetic resistance in fungal and bacterial populations and creates hazardous environment for both human beings and other flora and fauna because of their nonbiodegradable nature. Therefore, the protection of plants from pathogens remains a major concern of agricultural scientists. Technologies such as bacteriophages and systemic acquired resistance have been under investigation for several years to manage plant disease; these technologies have been showing promising outcomes in managing plant diseases (Obradovic et al. 2005; Huang et al. 2012). According to Ocsoy et al. (2013), bacteriophages pose a challenge to field conditions due to limited phage viability and the specific environmental requirements for their multiplication.

Economic losses arising from crop diseases caused by phytopathogenic organisms are principally associated with yield reductions affecting crop quality and safety as well as undermining both consumer confidence and profitability to the producers (Kavitha and Satish 2011). Control of plant diseases is very critical to the reliable production of food, and it provides significant reductions in agricultural use of land, water fuel, and other inputs (Pal and Gardener 2006). Integrated Pest and Disease Management (IPDM) has recognized the importance of medicinal plants and their derivatives (extracts, essential oils, and decoctions) in crop protection (Ragsdale 2000). The potential of medicinal plants as source for new botanicals, fungicides, or bactericides is still largely unexplored. Exploitation of naturally available chemicals from plants, which retards the reproduction of undesirable microorganisms, would be a more realistic and ecologically sound method for plant protection and will play a prominent role in the development of future commercial pesticides and crop protection strategies (Gottlieb et al. 2002).

According to Aromal and Philip (2012), plant crude extract contains novel secondary metabolites such as phenolic acid, flavonoids, alkaloids, and terpenoids in which these compounds are mainly responsible for the reduction of ionic into bulk metallic nanoparticle formation. Kuppusamy et al. (2016) reported that primary and secondary metabolites are constantly involved in the redox reaction to synthesize eco-friendly nanosized particles. Biological methods of nanoparticle synthesis using microorganisms, enzymes, fungi, and plants extracts have been suggested as possible eco-friendly alternatives to chemical and physical methods (Ponneerselvam et al. 2012; Prasad et al. 2016, 2018a; Abdel-Aziz et al. 2018). Synthesis of nanoparticles using plant extracts can be beneficial over other biological processes by elimi-

nating the elaborate processes of maintaining microbial cultures (Ponneerselvam et al. 2012; Prasad 2014; Shankar et al. 2004).

Foodborne diseases encompass a wide spectrum of illnesses and are a growing public health hazard worldwide. They are the result of ingestion of foodstuffs contaminated with microorganisms or chemicals. Foodborne diseases have been noticed as serious threats to public health all over the world. In foodborne pathogen studies, four major pathogens have emerged significantly important in terms of human health and disease. These include *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Salmonella typhimurium*, and *Vibrio parahaemolyticus.* These organisms have frequently been associated with food products and linked to a number of human illness cases (Zarei et al. 2014). The worldwide statistics on foodborne diseases published for 2011–2012 by the Centers for Disease Control and Prevention reported a total of 1632 outbreaks, 29,112 affected patients, 1750 hospitalizations, and 68 deaths. *Salmonella* (31%), *Listeria* (28%), *Campylobacter* (5%), and *Escherichia coli* O157:H7 (3%) pathogens are reported to cause some of the foodborne diseases and eventual death (Inbaraj and Chen 2016).

The impact of foodborne disease is a significant economic and clinical issue, despite recent advances in food safety (Billington et al. 2014). It has been concluded by Joint Food and Agriculture Organization/World Health Organization Expert committee on food safety that illness due to contaminated food was perhaps the most widespread health problem in the contemporary world and important cause of reduced economic productivity (Käferstein et al. 1997). Reducing the occurrence of foodborne illness through the use of rapid, cost-effective detection procedures and new ways to control pathogens are the focus of much current research (Billington et al. 2014).

Nanotechnology is an emerging field of interdisciplinary research that includes all spheres of science starting from physics, chemistry, biology, and especially biotechnology (Natarajan et al. 2010), which collectively describes the technology and science involving nanoparticles. Nanoparticles are a group of materials synthesized from a number of metals or nonmetal elements with distinct features and extensive applications in different fields of science and medicine (Matei et al. 2008). Nanoparticles also have potential biological applications, such as biosensing, catalysis, drug delivery, imaging, nanodevice fabrication, and for use as antimicrobial agents and in medicine (Ghosh et al. 1996; Geddes et al. 2003; Nair and Laurencin 2007; Jain et al. 2008; Sharma et al. 2009; Zargar et al. 2014; Prasad et al. 2016, 2018a, b; Patra and Baeke 2017).

Green synthesis of metal nanoparticles has been achieved using environmentally acceptable solvents from plant extracts has been achieved with the benefit of rapid, low-cost, eco-friendly, and a single-step method for biosynthesis process (Ponneerselvam et al. 2012; Huang et al. 2007). Plant extracts have recently been used for green synthesis of nanoparticles, since they are rich in bioactive compounds. The potential of biomolecules present in plant extracts to reduce metal ions to NPs in a single-step green synthesis process is very important (Benakashani et al. 2016). Several metal ions, such as Ag^{+}, Au^{3+}, Zn^{2+}, and Cu^{2+}, have been used to inactivate bacterial growth; among the different types of nanoparticles, Ag NPs have been used as effective biocides against a variety of pathogens, fungi, and viruses

(Ocsoy et al. 2013). Ag NPs release Ag^+ ions that interact with the thiol groups in bacterial proteins and affect the DNA replication, resulting in the destruction of bacteria (Marini et al. 2007). Additionally, nanoparticles have been shown to have potential antibacterial activity and significantly higher synergistic effects when applied with many antibiotics (Devi and Joshi 2018; Aziz et al. 2015, 2016).

This chapter reviews the latest research development and mechanism of action during green synthesis of silver nanoparticles (Ag NPs) utilizing of plants extract, the antimicrobial activity, and mechanism of action of Ag NPs against agriculture (phytopathogens) and foodborne pathogens. Second, the benefits of using green synthesis of Ag NPs as new antimicrobial agent are explored. Finally, we highlight the potential impacts of plant-mediated synthesized Ag NPs on agriculture and food sector and economic benefits in sub-Saharan Africa (SSA) countries.

16.2 Green Synthesis of Silver Nanoparticles Using Plant Extract

16.2.1 Plant Broth Preparation from Plant Extract

Different plant materials have been used for the preparation of plant broth for green synthesis of Ag NPs such as seeds, roots, stems, leaves, flowers, and fruits (Phanjom et al. 2012; Prasad 2014; Ahmed et al. 2016; Dhayalan et al. 2017; Khan et al. 2018).

In order to prepare plant broth for green syntheses of Ag NPs, the following simple steps have to be pursued:

- *Step 1*: Collection of plant materials is the first step for the preparation of plant broth from plant materials.
- *Step 2*: Washing step, part 1; in this step, plant materials are washed with tap water to remove epiphytes and necrotic plants. This process can be done twice or more.
- *Step3*: Washing step, part 2; this is another washing step; however, in this step, plant materials are washed with sterile distilled water in order to remove any debris or potential contaminants.
- *Step 4:* Drying stage; in this stage, materials are kept in the shade for 10–15 days until they dried; this is done in order to protect degradation of plant materials.
- *Step 5*: Preparation of plant extract/powder; in this step, plant materials are blended with domestic blender in order to obtain dried powder.
- *Step 6*: Preparation of plant broth; in order to prepare plant broth from dried powder, 10 g of powder or plant extract was boiled in 100 ml of deionized water or using sunlight as the primary source of energy.
- *Step 7*: Filtration; in this step all insoluble materials are filtered out using micro-filter until all insoluble materials are no longer visible in the plant broth (Fig. 16.1).

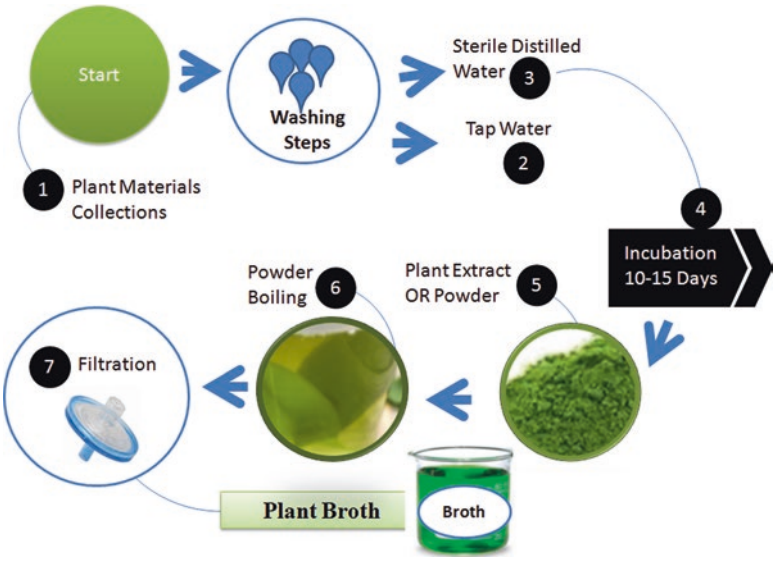

Fig. 16.1 Schematic illustration of seven (7) steps for preparation of plant broth from plant extract

16.2.2 Single-Step Method for Green Synthesis of Silver Nanoparticles Using Plant Extract

Green synthesis is a simple synthesis technique that utilizes microorganisms and plant extract to form metallic nanoparticles with different sizes and shapes. This technique does not require any chemical reducing agent for the formulation of metal nanoparticles, because they contain highly toxic substances (Roy and Das 2015).

Single-step technique for the synthesis process of Ag NPs involved the mixing 1 mM final concentration of silver nitrate ($AgNO_3$) solution and plant broth (plant extract) through magnetic stirrer at room temperature or using sunlight (Bindhani and Panigrahi 2015). The formation of Ag NPs is confirmed by color change in the mixture due to the reduction of pure Ag^+ ions to zero valent state Ag 0 just after 2–5 minutes (Fig. 16.2). UV-visible spectra analysis showed a strong surface plasma resonance and absorption property that confirmed the formation of nanoparticles. The shape, size, surface area analysis, morphology, oxidation state, and polydispersity of Ag NPs were characterized using various techniques such as dynamic light scattering (DLS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), auger electron spectroscopy (AES), X-ray diffraction (XRD), low energy ion scattering (LEIS), energy dispersive spectroscopy (EDS), and Fourier-transform infrared spectroscopy (FTIR) (Kumar et al. 2007; Aguilar-Mendez et al. 2010; Banerjee et al. 2014; Park 2014; Bindhani and Panigrahi 2015; Lateefa et al. 2016; Joshi et al. 2007; Joshi et al. 2018).

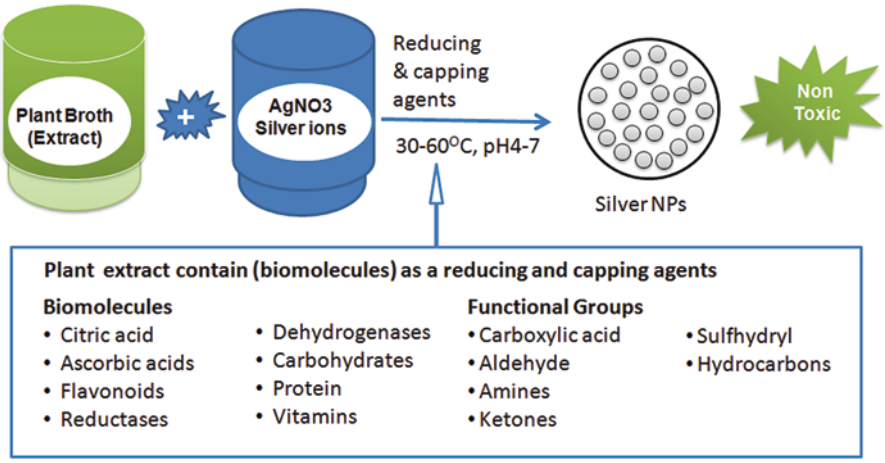

Fig. 16.2 Schematic illustration of green synthesis of silver nanoparticles from plant extracts (Gholami-Shabani et al. 2017)

16.2.3 The Mechanism of Silver Nanoparticle Synthesis Using Plant Extracts

The mechanism of synthesis of Ag NPs using plant extracts is influenced by biomolecules such as flavonoids, protein, vitamins, citric acid, ascorbic acids, carbohydrates, carboxylic acids, aldehydes, hydrocarbons, amides, and ketones (Fig. 16.2). The reduction of pure Ag (+) ions into Ag(0) nanoparticles is could be achieved by blending of silver ions together with plant extracts, which can act as reducing and stabilizing agents (Prabhu and Poulose 2012; Kulkarni and Muddapur 2014). A study conducted by Tran et al. (2013) showed that the presence of carbonyl group of amino acid and proteins facilitated the reduction and capping of metal ions to form Ag NPs that are very stable. Another study conducted by Makarov et al. (2014) showed that the presence of free aldehyde group of glucose used to facilitate ion reduction during the formation of Ag NPs. Roopan et al. (2013) indicated that the presence of hydrocarbons as a stabilizing agent influenced the formation of stable Ag NPs. The concentration of $AgNO_3$ and different experimental environments (e.g., temperature and pH) also shown to govern ion reduction process during nanoparticle synthesis. The temperature improves the reaction rate and efficiency of nanoparticle synthesis. Different pH values of the biomolecules from various plant extracts showed to influence capping process during nanoparticle formation (Makarov et al. 2014; Mohammadlou et al. 2016).

16.2.4 Green Synthesis Approaches to Synthesis of Silver Nanoparticles

Many plant extracts have been used for green synthesis of Ag NPs (Table 16.1), such as *Moringa oleifera* (Moodley et al. 2018), Buchu plant extracts (Chiguvare et al. 2016), stem bark hydrosol of *Acacia mearnsii* (Avoseh et al. 2017), root bark aqueous extract of *Annona muricata* Linn (Ezealisiji et al. 2017), plant extract from *Ziziphus spinachristi* and *Garcinia kola* (Abalaka et al. 2017), aqueous leaf extract of *Costus afer* (Elemike et al. 2017), and pod extract of *Cola nitida* (Lateef et al.

Table 16.1 Plant-mediated synthesis of silver nanoparticles

No.	Plants	Extracts	Size of NPs (nm)	Shape of NPs	References
1	*Moringa oleifera*	Leaf	9–11	Spherical	Moodley et al. (2018)
2	*Momordica charantia*	Stem	27.81 ± 1.64	Quasi-spherical	Akinsiku et al. (2018)
3	*Aloe vera*	Plant	3–14	Spherical	Vélez et al. (2018)
4	*Curcuma amada*		160–240	Spherical	Khairunnisa and Anjana (2018)
5	*Imperata cylindrica*	Leaf	22–37	Spherical	Bonnia et al. (2018)
6	*Ocimum tenuiflorum* (Tulsi)	Leaf	5–10	Spherical	Singh et al. (2018)
7	*Jatropha curcas*	Leaves	17.12 ± 2.9	Quasi-spherical	Francis et al. (2018)
8	*Hydnocarpus pentandra*	Leaf	141–202	Spherical	Kumar et al. (2018)
9	*Wedelia chinensis*	Leaf	31.68	Spherical	Das et al. (2018)
10	*Ocimum sanctum and Ocimum americanum*	Leaf	40–95	Spherical	Yadav et al. (2018)
11	*Coriandrum sativum*	Leaf	6.45	Spherical	Khan et al. (2018)
12	*Monotheca buxifolia*	Plant	40–78	Spherical	Anwar et al. (2018)
13	*Nelumbo nucifera* (Lotus)	Vegetable	12.9 ± 3.7	Quasi-spherical	He et al. (2018)
14	*Buddleja globosa*	Plant	16	Spherical	)
15	*Bacopa monnieri, Coleus blumei, Cichorium intybus*		40.3, 5.05, 3.16	Spherical	Badrelden et al. (2018)
16	*Phyllanthus acidus*	Leaf	65–250	Spherical	Sowmya et al. (2018)
17	*Echinochloa crus-galli* (waste grass)	Grass	15	Quasi-spherical	Khatami et al. (2018)
18	*Costus afer*	Leaf	20	Spherical	Elemike et al. (2017)
19	*Origanum vulgare*		2–25	Spherical	Shaik et al. (2018)
20	*Mint*	Leaf	26	Spherical	Aziz and Jassim (2018)
21	*Embelia ribes*	Seed	20–30	Spherical	Dhayalan et al. (2017)

(continued)

Table 16.1 (continued)

No.	Plants	Extracts	Size of NPs (nm)	Shape of NPs	References
22	*Agathosma betulina* (Buchu plant)	Leaf	19.95 ± 7.76	Spherical	Chiguvare et al. (2016)
23	*Thevetia peruviana*	Leaf	18.1	Spherical	Oluwaniyi et al. (2016)
24	*Pelargonium endlicherianum*	Root	Different size	Spherical	Karatoprak et al. (2017)
25	*Millettia pinnata*	Flower	16–38	Spherical	Rajakumar et al. (2017)
26	*Pedalium murex*	Leaf	50	Spherical	Anandalakshmi et al. (2016)
27	*Centella asiatica*	Leaf	3–30	Spherical	Vuong et al. (2017)
28	*Cerasus serrulata*	Leaf	10–50	Spherical	Karthik et al. (2016)
29	*Saraca indica*	Leaf	23 ± 2	Spherical	Perugu et al. (2016)
30	*Hydrocotyle asiatica*	Leaf	21	Spherical	Devi et al. (2016)
31	*Cucumis sativus*	Fruit	8–10	Spherical	Roy et al. (2015)
32	*Cydonia oblonga*	Leaf	38	Cubic	Zia et al. (2016)
33	*Euphorbia amygdaloides*	Plant	7–20	Spherical	Cicek et al. (2015)
34	*Trachyspermum ammi*	Seed	36	Cubic	Chouhan and Meena (2015)
35	*Emblica officinalis*	Fruit	10–70		Ramesh et al. (2015)
36	*Syzygium alternifolium*	Fruit	4–48	Spherical	Yugandhar et al. (2015)
37	*Eucalyptus globulus*	Leaf	1.9–4.3 and 5–25	Spherical	Ali et al. (2015)
38	*Phlomis*	Leaf	19–30	Spherical	Allafchian et al. (2016)
39	*Alpinia calcarata*	Root	5–15	Spherical	Pugazhendhi et al. (2015)
40	*Leptadenia reticulata*	Leaf	50–70	Spherical	Swamy et al. (2014)
41	*Ocimum sanctum*	Leaf	18	Spherical	Ramteke et al. (2013)
42	*Ixora coccinea*	Flower	5–10	Spherical	Nalvolthula et al. (2015)
43	*Psoralea corylifolia*	Seed			Sunita et al. (2014)
44	*Tithonia diversifolia*	Leaf			Tran et al. (2013)
45	*Memecylon edule*	Leaf	20–50	Hexagonal	Elavazhagan and Arunachalam (2011)
46	*Santalum album*	Leaf	80–200	Spherical	Swamy and Prasad (2012)
47	*Syzgium cumini*	Leaf	100–160	Spherical	Prasad et al. (2012)
46	*Syzgium cumini*	Bark	20–60	Spherical	Prasad and Swamy (2013)
47	*Nicotiana tabaccum*	Leaf	8		Prasad et al. (2011)
48	*Carissa Carandas*	Berry	10–60		Joshi et al. (2018)
49	*Trianthema decandra*	Root	10–50	Hexagonal	Geethalakshmi and Sarada (2010)

2016). Moodley et al. (2018) reported green synthesis of Ag NPs from the leaf extracts of *Moringa oleifera*. The study demonstrated the use of sunlight as the primary source of energy during the reaction mixture of 1 mM aqueous $AgNO_3$ and aqueous plant extract. The FTIR study confirmed the presence of biomolecules from the extract to be flavones, polysaccharides, and terpenoids. The biomolecules have been shown to be responsible for both reduction and capping of silver ions during the formation of Ag NPs. The formation of Ag NPs was confirmed by color change from initial reagent yellow solutions to dark brown mixture solution and validated by surface plasmon resonance peak between 450 nm and 440 nm. The nanoparticle sizes were confirmed by X-ray diffraction analysis and DLS and were found to have particle size ranging from 3 to 50 nm. Chiguvare et al. (2016) have reported a green synthesis of Ag NPs from Buchu plant extracts from South Africa. Phytochemical screening of the crude using FTIR revealed the presence of proteins, flavonoids, alkaloids, and saponins. The presence of phytochemicals facilitated the reduction of silver ions during the formation of Ag NPs. The TEM analysis confirmed the morphology of Ag NPs as spherical in shape and particles size in a range between 19.95 and 7.76 nm, respectively. Avoseh et al. (2017) demonstrated a rapid green synthesis of Ag NPs using stem bark hydrosol of *Acacia mearnsii* within 15 minutes at 60 °C. The presence of plant extract facilitated ion reduction and capping process during the formation of Ag NPs. TEM images confirmed that the presence of spherical Ag NPs with the diameter in the range of 19.95 ± 7.76 nm. Ezealisiji et al. (2017) also reported green synthesis of Ag NPs using the root bark aqueous extract of *Annona muricata* with an average particle size of 22 ± 2 nm. In this study, Malvern Nano ZS was used to reveal zeta potential of – 27.90 ± 0.01 mV, a negative surface charge, and the polydispersity index (PDI) of 0.44 ± 0.02. Abalaka et al. (2017) reported synthesis of Ag NPs using plant extract from *Ziziphus spinachristi* and *Garcinia kola.* The plant extract acted as reducing and capping agent; however, in this study, hyaluronic acid was added to enhance particle stability and to prevent aggregation during synthesis. The presence of nanoparticles, particle size, and shape was determined by TEM. Elemike et al. (2017) reported synthesis of Ag NPs employing aqueous leaf extracts of *Costus afer* with a mean diameter of 20 nm. Loo et al. (2012) reported the synthesis of Ag NPs using tea leaf extract of Chinese tea from *Camellia sinensis*, *with* a particle size of 4 nm. Lateef et al. (2016) demonstrated the synthesis of Ag NPs employing pod extracts of *Cola nitida*. The formation of Ag NPs was observed by the color change in the solution from yellow brown to dark brown. The presence of nanoparticles was confirmed by UV-visible spectroscopy and TEM images with a spherical shape and the diameter in a range between 12 and 80 nm. Yadav et al. (2018) reported the synthesis of spherical Ag NPs with a size ranging from 40 to 95 nm using leaf extract of *Ocimum sanctum* and *Ocimum americanum.* Sowmya et al. (2018) reported synthesis of Ag NPs from leaf extract of *Phyllanthus acidus.* The physicochemical characterization revealed the formation of Ag NPs with a spherical shape, and the average size ranged from 65 to 250 nm. Very recently, Singh et al. (2018) reported synthesis of Ag NPs using dried tulsi leaves. The catalytic activity during the formation of Ag NPs was evaluated through the reduction of 4-nitrophenol to 4-aminophenol in alkaline medium. The

formation Ag NPs was revealed by UV-visible spectrum with peak at 430 nm and TEM image with the average diameter of 5–10 nm. The study conducted by Balashanmugam et al. (2016) showed synthesis of Ag NPs to be influenced by different physicochemical conditions. Highly stable Ag NPs were synthesized with 1.0 mL of *C. roxburghii* leaf extract and 1.0 mM AgNO3 (pH 7.0) at 37 °C. The synthesized Ag NPs were characterized by XPS, DLS, and ZETA potential. In DLS and ZETA potential analysis, the average size of Ag NPs was 35 nm, and the zeta potential was −18.3 mV. The studies by Chahardooli et al. (2014) showed green synthesis of Ag NPs characterized by UV-visible spectroscopy gave surface plasmon resonance for synthesized Ag NPs peak at 415–445 nm. Further, the Ag NPs showed an effective antibacterial activity toward plant pathogenic bacteria (*Pectobacterium carotovorum*, *Ralstonia solanacearum*, *Erwinia amylovora*, and *Xanthomonas citri*). The synthesized Ag NPs were characterized using UV-visible spectroscopy, dynamic light scattering spectroscopy (DLS), Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy. The DLS study revealed the surface charge of the resulting nanoparticles that was highly negative, i.e., −25.0 ± 7.84 mV, and the size was 74.56 ± 0.46 nm. The phytochemical and FTIR analysis confirmed the role of water-soluble phyto-compounds for the reduction of silver ions to silver nanoparticles. The biosynthesized Ag NPs were characterized by UV-visible spectrophotometry with surface plasmon resonance at 450 nm followed by the analysis using scanning electron microscope, X-ray diffraction, Fourier-transform infrared spectroscopy, and thermogravimetric analysis.

16.2.5 The Advantages of Using Green Synthesis of Silver Nanoparticles

Metallic nanoparticle synthesis using green chemistry route has recently received a lot of attention as nanofactories over the conventional methods. The conventional methods such as chemical and physical synthesis involving toxic chemicals are harmful to humans and the environment (Patra and Baek 2014). The use of plant extracts and microorganisms toward biosynthesis of Ag NPs promises to overcome setbacks associated with conventional synthesis. Green synthesis for the formation of Ag NPs employs aqueous plant extracts as reducing and stabilizing agents during the synthesis of Ag NPs (Suna et al. 2014; Sadeghi and Gholamhoseinpoor 2015; Mohammadlou et al. 2016). This approach offers simplicity, rapid synthesis, and inexpensive biological procedure for nanoparticle fabrication and is environment friendly and nontoxic (Ahmed et al. 2016). Additionally, green synthesis approaches are easy to scale up for large-scale production of nanoparticles and are economically viable. Although plant and microbiological approach promises to overcome the setbacks associated with conventional methods during metallic nanoparticle synthesis, the use of plant extract during green synthesis is considered to be more advantageous and safer over microorganism approach. During metallic nanoparticle synthesis, plant extracts are able to reduce and cap metal ions faster than bacteria,

fungi, and viruses (Iravani 2011). Additionally, microorganisms are associated with biohazards and have setbacks toward nanoparticle isolation and identification. The approach is not eco-friendly particularly toward maintaining cell culture processes for microorganisms (Kalishwaralal et al. 2010; Roy and Das 2015). The toxicity of Ag NPs is shown to influence the type of plant extract used and also by nanoparticle size, concentration, dosage, pH of the medium, and exposure time to pathogens (Banerjee et al. 2014; Das et al. 2018; Kumar et al. 2018). In addition, green synthesis of Ag NPs is biocompatible to the human cell line and nontoxic to mammalian cells (Ahmed et al. 2016). The study conducted by Balashanmugam et al. (2016) showed synthesis of Ag NPs to be influenced by different physicochemical conditions. Highly stable Ag NPs were synthesized with 1.0 mL of *C. roxburghii* leaf extract and 1.0 mM $AgNO_3$ (pH 7.0) at 37 °C. The synthesized AgNPs were characterized by XPS, DLS, and ZETA potential. In DLS and ZETA potential analysis, the average AgNPs size was 35 nm, and the zeta potential was −18.3 mV. Chahardooli et al. (2014) reported green synthesis of Ag NPs using *Protium serratum* leaf extract. UV-visible spectroscopy confirmed the formation of Ag NPs with surface plasmon resonance peak at 415–445 nm. The synthesized Ag NPs were characterized using UV-visible spectroscopy, dynamic light scattering spectroscopy (DLS), Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy. The DLS study revealed the surface charge of the resulting nanoparticles that was highly negative, i.e., -25.0 ± 7.84 mV, and the size was 74.56 ± 0.46 nm. The phytochemical and FTIR analysis confirmed the role of water-soluble phyto-compounds for the reduction of silver ions to silver nanoparticles. The biosynthesized AgNPs were characterized by UV-visible spectrophotometry with surface plasmon resonance at 450 nm followed by the analysis using scanning electron microscope, X-ray diffraction, Fourier-transform infrared spectroscopy, and thermogravimetric analysis. The AgNPs displayed moderate antibacterial activity (9.26–11.57 mm inhibition zone) against all five foodborne pathogenic bacteria. Patra and Baeke (2017) reported biosynthesis of Ag NPs using the aqueous extract of corn leaf waste of *Zea mays*. Ag NPs were characterized by UV-visible spectrophotometry with surface plasmon resonance at 450 nm followed by the analysis using scanning electron microscope, X-ray diffraction, Fourier-transform infrared spectroscopy, and thermogravimetric analysis.

16.3 Plant and Foodborne Pathogens

Pathogenic microorganisms affecting plant health are a major and chronic threat to food production and ecosystem stability worldwide. As agricultural production intensified over the past few decades, producers became more and more dependent on agrochemicals as a relatively reliable method of crop protection helping with economic stability of their operations. However, increasing use of chemical inputs causes several negative effects, i.e., development of pathogen resistance to the applied agents and their nontarget environmental impacts (Compant et al.

2005). Foodborne pathogens are also posing a big threat to the public health and food security. Bacteria, fungi, viruses, and parasites are the main cause of foodborne disease worldwide. *Salmonella typhimurium*, *Escherichia coli, Listeria monocytogenes, Vibrio parahaemolyticus, Vibrio cholera, Pseudomonas aeruginosa,* and *Streptococcus pyogenes* are the major bacterial pathogens that cause foodborne illness. Current traditional antibacterial and disinfection agents are facing the challenge of bacterial resistance, which result in food spoilage and outbreaks with high mortality. *Escherichia coli* O157:H7 has been reported to be resistant to ampicillin and *Streptococcus pyogenes* resistant to erythromycin (Armstrong et al. 1996; Jay 2000; Lara et al. 2010). In the agriculture and food industry, microbial pathogens are threatening food production, food quality, and food security by failing to protect plant crops, maintaining food quality, and shortening food shelf life (Tareq et al. 2017; Prasad et al. 2017). Therefore, there is an urgent need to develop a new generation of antimicrobial agents that are effective against both plant and foodborne pathogens. In sub-Saharan Africa countries, where the economy of the majority of the countries is heavily dependent on agriculture and food production, and where there are no appropriate systems to deal with foodborne disease outbreaks or advanced analytical tools to analyze food samples, developing a new generation of antimicrobial agents is an issue of high priority. Ag NPs promise to overcome challenges associated with plant and foodborne pathogens by offering an effective antimicrobial agent that could protect crops, extend food shelf life, and maintain food quality for a longer period (Lara et al. 2010; Zandi et al. 2013; Rajeshkumar and Malarkodi 2014; Zarei et al. 2014; Tareq et al. 2017).

16.4 Antimicrobial Activity of Silver Nanoparticles on Plant and Foodborne Pathogens

Green synthesis of Ag NPs promises to offer an effective antimicrobial agent against plant and foodborne pathogens (Jo et al. 2009). According to Jo et al. (2009) and Conrad et al. (1999), silver particles display multiple modes of inhibitory action to microorganisms, it may be used for controlling various plant pathogens in a relatively safer way compared to synthetic fungicides (Park et al. 2006). Ag NPs exhibit new or improved properties depending upon their size, morphology, and distribution, which can be achieved through different (physical and chemical) methods that are employed for the synthesis of metal nanoparticles (Shankar et al. 2004; Panacek et al. 2006). Krishnaraj et al. (2012) tested the inhibitory effect of fungal plant pathogens, namely, *Alternaria alternata, Sclerotinia sclerotiorum, Macrophomina phaseolina, Rhizoctonia solani, Botrytis cinerea,* and *Curvularia lunata* using different concentrations of Ag NPs. Interestingly, 15 mg concentration of Ag NPs showed excellent inhibitory activity against all the tested pathogens. Thus, the obtained results clearly suggest that Ag NPs may have important applications in controlling various plant diseases caused by fungi. Balashanmugam et al. (2016) exhibit no

antifungal activity using Ag NPs comparing with the conventional antifungal drug amphotericin B against all the tested plant fungal pathogens *R. solani, Fusarium oxysporum,* and *Curvularia* sp. Chahardooli et al. (2014) showed good antibacterial activity against the foodborne pathogens *Pseudomonas aeruginosa* (74.26 ± 0.14 μg/ml), *Escherichia coli* (84.28 ± 0.36 μg/ml), and *Bacillus subtilis* (94.43 ± 0.4236 μg/ml). This finding displayed the potential use of *Protium serratum* leaf extract as a good bioresource for the biosynthesis of Ag NPs and their implementation in diverse applications, specifically as antibacterial agent in food packaging and preservation to combat against various foodborne pathogenic bacteria (Mohanta et al. 2017). Menon et al. (2017) synthesized silver nanoparticles by using the medicinal plant *Acalypha indica*, which was characterized using various advanced tools with the help of UV-visible spectrophotometer. The food pathogen strain *Aspergillus fumigates* showed ZOI (Zone of inhibition) of 133% at 75 μl of concentration proving that Ag NPs can act effectively against this strain when compared to other strains even at low concentrations. The study concluded that Ag nanoparticle can be used for therapeutic purposes and for large-scale synthesis in food industries for food preservation or packaging. Patra and Baeke (2017) evaluated synthesized Ag NPs for their antibacterial activity against foodborne pathogenic bacteria (*Bacillus cereus* ATCC 13061, *Listeria monocytogenes* ATCC 19115, *Staphylococcus aureus* ATCC 49444, *Escherichia coli* ATCC 43890, and *Salmonella Typhimurium* ATCC 43174). The anticandidal activity of Ag NPs was evaluated against *Candida* species (*C. albicans* KACC 30003 and KACC 30062, *C. glabrata* KBNO6P00368, *C. geochares* KACC 30061, and *C. saitoana* KACC 41238). The AgNPs displayed moderate antibacterial activity (9.26–11.57 mm inhibition zone) against all five foodborne pathogenic bacteria. When Ag NPs were mixed with standard antibacterial or anticandidal agent, they displayed strong synergistic antibacterial (10.62–12.80 mm inhibition zones) and anticandidal activity (11.43–14.33 mm inhibition zones). The findings of Patra and Baeke highlighted the potential use of maize industrial waste materials in the synthesis of Ag NPs and their utilization in various applications, particularly as an antibacterial substance in food packaging, food preservation to protect against various dreadful foodborne pathogenic bacteria together with its biomedical, pharmaceutical-based activities. Chahardooli et al. (2014) displayed moderate antibacterial activity (9.26–11.57 mm inhibition zone) against all five foodborne pathogenic bacteria using green synthesis of Ag NPs using *Protium serratum* leaf extract.

Table 16.2 shows the effect of Ag NPs against other microbes. Emamifar et al. (2011) showed antimicrobial effect and improved preservation of orange juice storage for more than 112 days against bacteria strain, *Lactobacillus plantarum.* Min et al. (2009) showed sclerotial germination and growth inhibition against plant pathogens, *Sclerotinia minor* and *Sclerotinia sclerotiorum.* Mahdizadeh et al. (2015) showed mycelial growth inhibition caused by plant pathogen, *Macrophomina phaseolina.* Lara et al. (2010) exhibited bactericidal effect against multidrug-resistant bacteria, namely, *Listeria monocytogenes, Escherichia coli* O157:H7, *Salmonella typhimurium*, and *Vibrio parahaemolyticus*. Zarei et al. (2014) showed antibacterial effects on four important foodborne pathogens, namely, *Listeria monocytogenes, Escherichia coli*

Table 16.2 Effect of plant-mediated silver nanoparticles against plant and foodborne pathogens

Purpose	Pathogens	Microbial strain	Antimicrobial activity	References
Plant disease control *[Pathogens]*	*Macrophomina phaseolina*	Fungi	Mycelial growth inhibition	Mahdizadeh et al. (2015)
	Sclerotinia minor and *Sclerotinia sclerotiorum*	Fungi	Sclerotial germination and growth inhibition	Min et al. (2009)
	Bacillus megaterium	Bacteria	Effective against agricultural pathogens	Tareq et al. (2017)
Foodborne diseases control *[Pathogens]*	*Escherichia coli*, *Salmonella typhi,* and *Pseudomonas aeruginosa*	Bacteria	Antibacterial against foodborne and human pathogens	Abalaka et al. (2017)
	Listeria monocytogenes, Escherichia coli O157:H7, Salmonella typhimurium, and *Vibrio parahaemolyticus*	Bacteria	Antibacterial effects on four important foodborne pathogens	Zarei et al. (2014)
	Pseudomonas aeruginosa, Escherichia coli O157:H7, and *Streptococcus pyogenes*	Bacteria	Exhibited bactericidal effect against multidrug-resistant bacteria	Lara et al. (2010)
	Pseudomonas aeruginosa, Escherichia coli, and *Bacillus subtilis*	Bacteria	Act as antibacterial agent in food packaging and preservation	Mohanta et al. (2017)
	Lactobacillus plantarum	Bacteria	Showed antimicrobial effect and improved preservation of orange juice storage for more than 112 days	Emamifar et al. (2011)
	Aspergillus niger, Aspergillus flavus, Aspergillus fumigates	Fungi	Showed antifungicidal activity, and potential to use for food preservation and packaging	Menon et al. (2017)

O157:H7, Salmonella typhimurium, and *Vibrio parahaemolyticus.* Abalaka et al. (2017) demonstrated the antibacterial against both foodborne and human pathogens such as *Escherichia coli*, *Salmonella typhi, and Pseudomonas aeruginosa.*

16.4.1 Mechanisms of Action of Silver Nanoparticles on Microbial Pathogens

Silver ion is known to have microbial effect on a broad range of microorganisms (Bragg and Rainnie 1974; Brown and Smith 1976; Liau et al. 1997); however, the mechanisms of action of Ag NPs on microbes to cause the microbicidal effect is only partially understood (Richards 1981; Russell and Hugo 1994; Matsumura et al.

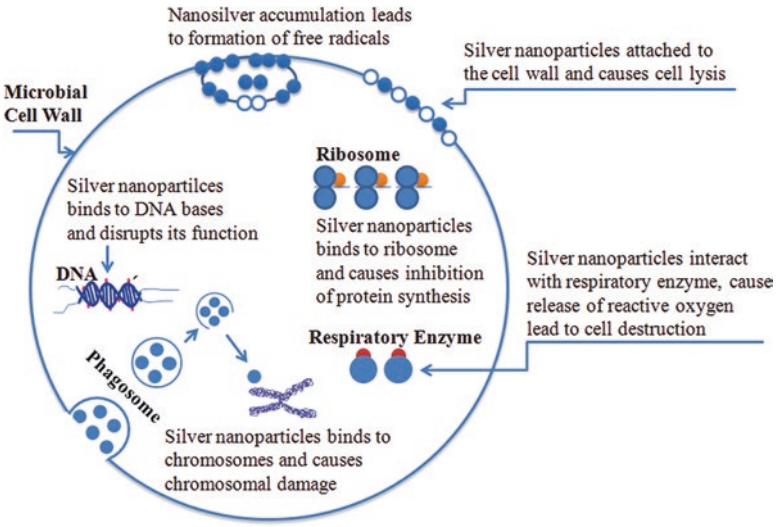

Fig. 16.3 Mechanism of action of Ag NPs on microbes (Prabhu and Poulose 2012)

2002; Morones et al. 2005; Kim et al. 2007; Feng et al. 2008; Dallas et al. 2011; Nasrollahi et al. 2011). Some hypotheses suggest that Ag NPs attached to cell wall cause cell lysis, resulting in structural damage, and cause disturbance to its proper functioning that can lead to the termination of microbial cell life (Rai et al. 2009). Figure 16.3 shows different bactericidal and fungicidal mechanisms using Ag NPs. The study by Morones et al. (2005) showed bactericidal effects employing Ag NPs with size range between 1 and 10 nm against *E. coli, P. aeruginosa,* and *S. typhus*. The study showed the accumulation of Ag NPs on the surface of the cell membrane leads to the formation of free radicals, which increased membrane permeability and make it porous resulting into cell death. In addition, Ag NPs were able to penetrate inside the bacteria and bind to DNA bases and disrupt bacteria functions such as DNA replication, respiratory chain, and cell division ultimately leading to cell death (Dallas et al. 2011; Aziz et al. 2014, 2015, 2016). Another study by Prabhu and Poulose (2012) showed another mechanism by which the cells die using Ag NPs; in this study, cell death was showed to be influenced by Ag NPs that bind to ribosome and cause inhibition of protein. Also, it was proposed that Ag NPs enter the cell membrane and interact with respiratory enzyme, cause release of reactive oxygen, and lead to cell damage (Inoue et al. 2002; Choi and Hu 2008). In another study by Kumar et al. (2017), it was proposed that Ag NPs enter into fungal cell membrane and nucleus through phagosome process, then binds to chromosomes and cause chromosomal damage. Many studies showed that the microbial properties of Ag NPs to be more effective and influenced by nanoparticle size. Nanoparticles with a diameter of 1–10 nm are shown to have direct interaction with the cellular components such as cell membrane, DNA, protein, enzymes, and chromosomes, and also have an effect on microbial growth ultimately leading to cell death.

16.5 The Potential Benefits of Using Green Synthesis of Silver Nanoparticles in Agriculture and Food Sectors

Applications of nanotechnology in agriculture and the food sector have many benefits. Nanotechnology has many potential benefits in improving food quality and safety, reduction of agricultural inputs, and enrichment of absorbing nanoscale nutrients from the soil (Prasad et al. 2017; Sangeetha et al. 2017a, b). Furthermore, Prasad et al. (2017), Gruère (2012), Mukhopadhyay (2014), Prasad et al. (2014) explain that agriculture, food, and natural resources are a part of those challenges like sustainability, susceptibility, human health, and healthy life; therefore, the importance of nanomaterials in agriculture is to reduce the amount of spread chemicals, minimize nutrient losses in fertilization, and increase yield through pest and nutrient management. In the food industry, Ag NPs promises to overcome the followings setbacks: disinfection during food processing, packaging materials, preservation, food additives, and supplements. In agriculture, nanomaterials can also be used to control agricultural pathogens and protect crops and seeds (Bhattacharyya et al. 2016; Ismail et al. 2017; Gupta et al. 2018). In healthcare, nanomaterials such as Ag NPs promised to impact in medical health device, diagnostic devices, and pharmaceuticals (Zandi et al. 2013). Microbial resistance to current antibiotics and disinfection agents resulting into food spoilage due to foodborne pathogens pose threat to the public health and food security. Therefore, there is an urgent need to develop a new generation of antimicrobial agents that are effective against foodborne pathogens (Parihar et al. 2008; Rajeshkumari and Malarkodi 2014; Zarei et al. 2014).

Green synthesis of Ag NPs are very much stable, environment friendly, biocompatible to the human cell line, and have a low systemic toxicity to humans (Ahmed et al. 2016; Aziz et al. 2019). In food industries, Ag NPs gain attention due to the excellent antimicrobial and antioxidant properties and have been used in food process, food packaging materials, preservation, and also as disinfectant agents. As a disinfectant agent, Ag NPs showed significant effect against foodborne pathogens such as *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Salmonella typhimurium,* and *Vibrio parahaemolyticus (*Zarei et al. 2014). However, *L. monocytogenes,* Gram-positive bacteria, show some resistance against Ag NPs when compared to Gram-negative bacteria such as *E. coli* O157:H7. The study agreed with Kim et al. (2007) that suggested that the effect of Ag NPs as antibacterial agent could be influenced by differences in bacterial cell walls; Gram-negative bacteria have thin cell walls and Gram-positive bacteria have thick cell walls. In addition, Ag NPs could be used for cleaning equipments and surface areas in food-related environments. In the food packaging industry, the presence of Ag NPs showed to have bactericidal effect against foodborne pathogenic bacteria such as *Bacillus subtilis*, *Klebsiella planticola, Klebsiella pneumoniae, Serratia nematodiphila,* and *Escherichia coli* (Rajeshkumari and Malarkodi 2014). The study conducted by Rajeshkumari and Malarkodi (2014) showed the bactericidal effect against foodborne pathogenic bacteria such as *Bacillus subtilis*, *Klebsiella planticola, Klebsiella pneumoniae, Serratia*

nematodiphila, and *Escherichia coli* at a high (750 μl) concentration of Ag NPs. As a result, Ag NPs could be used during surface coating of packing material to improve the lifespan of food products and ensure food safety by eliminating bacterial pathogens in food products. Zandi et al. (2013) showed improvement in food quality post-harvest, food preservation, and increased storage life for more than 10–12 days (Zandi et al. 2013). Emamifar et al. (2011) showed antimicrobial effect on the inactivation of *Lactobacillus plantarum* in orange juice stored in packaging materials made up of nanocomposite films containing Ag NPs over a period of 112 days. A recent study by Menon et al. (2017) showed the antifungal activity employing green-synthesized Ag NPs using plant extract against the food pathogens such as *Aspergillus niger, Aspergillus flavus* and *Aspergillus fumigatus.* The study showed significant maximum inhibition of *Aspergillus fumigatus* at 75 μl of Ag NPs. Due to antioxidant properties and fungicidal activity, green synthesis of Ag NPs have the potential to prevent food spoilage caused by foodborne pathogens such as fungi.

16.6 Nanotechnology in Agriculture and the Food Sector: Potential Economic Impact

As silver possesses antibacterial and antifungal properties, Ag NPs have been incorporated into more than 200 consumer products, including clothing, cosmetics, ceramics, car paints, and medical products. According to the Lux Research report 2015 estimates that nanoproducts to have markets value of USD 2.84 trillion (Lux Research 2004; Smith 2008). However, nanoproducts in the agrifood sector are facing challenges when it comes to consumer acceptance; this could be due to risks not clearly communicated to the consumers and uncertainty around nanomaterial toxicity.

In SSA, nanotechnology ensures to impact on low- and middle-income countries, particularly in agriculture and the food sectors. Majority of SSA countries' economics are heavily dependent on agriculture and food production. However, agricultural pathogens affecting plant health and foodborne pathogens are associated with food wastage, which posed threat to food production, quality, food security, and Africa's economic growth (Cozzini et al. 2008; Kiaya 2014). The report compiled from national workshop by Nanotechnology Research Group at Nigeria's Ladoke Akintola University of Technology indicates that inadequate funding on nanotechnology research is a major challenge for nanotechnology development in Africa. In addition, the report also indicates that African countries are too slow in embracing nanotechnology despite the potential benefits it has toward the continent (Rateng 2017). Therefore, African countries need urgently to look at their nanotechnology strategies in order to strengthen Africa's competitive position in nanotechnology and in order improve the food quality and improve their economy.

16.7 Conclusion

Plant and foodborne diseases pose immense threat to the agricultural food production, food quality, and economic growth for developing countries, particularly for regions such as SSA. Nanotechnology is an emerging technology that is promising to the development of a new generation of antimicrobial agents to fight and prevent disease at atomic scale and molecular level. The use of Ag NPs as a new generation of antimicrobial agents enables the inhibition of harmful pathogens to grow, multidrug-resistant bacteria, antioxidant property, improve food quality, packaging, storage, and plant disease control. The generation of Ag NPs using plant extracts promises to offers inexpensive, rapid, environment friendly, and biocompatible to human cell line and low systemic toxicity to humans. In addition, green synthesis approaches are easy to scale up for large-scale production of nanoparticles. Although, green synthesis promises nanotherapy with low toxicity, there is a need for the analysis of commercial viability and economic value associated with the use of nanoparticles generated through plant extracts. Further, in-depth study on the mechanism of action and the properties of Ag NPs against antibacterial and antifungal agents in the mammalian immune system is required. SSA countries need to begin prioritizing on nanotechnology in order improve their agricultural food production and food quality and for their economic growth.

References

Abalaka ME, Akpor OB, Osemwegie OO (2017) Green synthesis and antibacterial activities of silver nanoparticles against *Escherichia coli*, *Salmonella typhi*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Adv Life Sci 4:60–65

Abdel-Aziz S.M., Prasad R., Hamed A.A., Abdelraof M. (2018) Fungal Nanoparticles: A Novel Tool for a Green Biotechnology?. In: Prasad R., Kumar V., Kumar M., Wang S. (eds) Fungal Nanobionics: Principles and Applications. Springer, Singapore, pp 61–87

Aguilar-Mendez AM, Martı n-Martı´nez ES, Ortega-Arroyo L, Cobia´n-Portillo G, Sa´nchez-Espı´ndola E (2010) Synthesis and characterization of silver nanoparticles: effect on phytopathogen *Colletotrichum gloesporioides*. J Nanopart Res 13:2525–2532

Ahmed S, Ahmad M, Swami BL, Ikram S (2016) A review on plants extract mediated synthesis of silver nanoparticles for antimicrobial applications: a green expertise. J Adv Res 7:17–28

Akinsiku AA, Dare EO, Ajanaku KO, Adekoya JA, Ayo-Ajayi J (2018) Green synthesized optically active organically capped silver nanoparticles using stem extract of African cucumber (*Momordica charantia*). J Mater Environ Sci 9:902–908

Ali K, Ahmed B, Dwivedi S, Saquib Q, Al-khedhairy AA, Musarrat J (2015) Microwave accelerated green synthesis of stable silver nanoparticles with *Eucalyptus globulus* leaf extract and their antibacterial and antibiofilm activity on clinical isolates. PLoS One 10(10):e0131178. eCollection 2015. https://doi.org/10.1371/journal.pone.0131178

Allafchian AR, Mirahmadi-Zare SZ, Jalali SAH, Hashemi SS (2016) Green synthesis of silver nanoparticles using phlomis leaf extract and investigation of their antibacterial activity. J Nanostruct Chem 6:129–135

Anandalakshmi K, Venugobal J, Ramasamy V (2016) Characterization of silver nanoparticles by green synthesis method using *Pedalium murex* leaf extract and their antibacterial activity. Appl Nanosci 6:399–408

Anwar N, Khan A, Shah M, Anwar S (2018) Green synthesis of silver nanoparticles using an aqueous extract of *Monotheca buxifolia* (Flac.) Dcne. Russ J Phys Chem A 92:124–131

Armstrong GL, Hollingsworth J, Morris JG (1996) Emerging foodborne pathogens: *Escherichia coli* O157:H7 as a model of entry of a new pathogen into the food supply of the developed world. Epidemiol Rev 18:29–51

Aromal SA, Philip D (2012) Green synthesis of gold nanoparticles using Trigonella foenum-graecum and its size dependent catalytic activity. Spectrochim Acta A Mol Biomol Spectrosc 97:1–5

Avoseh ON, Oyedeji OO, Aremu O, Nkeh-Chungag BN, Songca SP, Oyedeji AO, Sneha Mohan S, Oluwafemi OS (2017) Biosynthesis of silver nanoparticles from *Acacia mearnsii* De Wild stem bark. Green Chem Lett Rev 10(2):59–68

Aziz WJ, Jassim HA (2018) Green chemistry for the preparation of silver nanoparticles using mint leaf leaves extracts and evaluation of their antimicrobial potential. WNOFNS 18:163–170

Aziz N, Fatma T, Varma A, Prasad R (2014) Biogenic synthesis of silver nanoparticles using *Scenedesmus abundans* and evaluation of their antibacterial activity. J Nanoparticles:689419. https://doi.org/10.1155/2014/689419

Aziz N, Faraz M, Pandey R, Sakir M, Fatma T, Varma A, Barman I, Prasad R (2015) Facile algae-derived route to biogenic silver nanoparticles: synthesis, antibacterial and photocatalytic properties. Langmuir 31:11605–11612. https://doi.org/10.1021/acs.langmuir.5b03081

Aziz N, Pandey R, Barman I, Prasad R (2016) Leveraging the attributes of Mucor hiemalis-derived silver nanoparticles for a synergistic broad-spectrum antimicrobial platform. Front Microbiol 7:1984. https://doi.org/10.3389/fmicb.2016.01984

Aziz N, Faraz M, Sherwani MA, Fatma T, Prasad R (2019) Illuminating the anticancerous efficacy of a new fungal chassis for silver nanoparticle synthesis. Front Chem 7:65. https://doi.org/10.3389/fchem.2019.00065

Badrelden AM, Elmaksoud AIA, El-Maaty REA, Hassan A, Mohamed AAB, Elebeedy D (2018) Green synthesis of silver nanoparticles mediated extract of various *in vitro* plants (*Bacopa monnieri*, *Coleus blumei*, *Cichorium intybus*). Biosci Res 15:01–11

Balashanmugam P, Balakumaran MD, Murugan R, Dhanapal K, Kalaichelvan PT (2016) Phytogenic synthesis of silver nanoparticles, optimization and evaluation of in vitro antifungal activity against human and plant pathogens. Microbiological Research 192:52–64

Banerjee P, Satapathy M, Mukhopahayay A, Das P (2014) Leaf extract mediated green synthesis of silver nanoparticles from widely available Indian plants: synthesis, characterization, antimicrobial property and toxicity analysis. Bioresour Bioprocess 1:3

Benakashani F, Allafchian AR, Jalali SAH (2016) Biosynthesis of silver nanoparticles using *Capparis spinosa* L. leaf extract and their antibacterial activity. Karbala Int J Mod Sci 2:251–258

Bhattacharyya A, Duraisamy P, Govindarajan M, Buhroo AA, Prasad R (2016) Nanobiofungicides: emerging trend in insect pest control. In: Prasad R (ed) Advances and applications through fungal nanobiotechnology. Springer International Publishing, Cham, pp 307–319

Billington C, Hudson JA, D'Sa E (2014) Prevention of bacterial foodborne disease using nanobiotechnology. Nanotechnol Sci Appl 7:73–83

Bindhani BK, PanigrahI AK (2015) Biosynthesis and characterization of silver nanoparticles (SNPs) by using leaf extracts of *Ocimum Sanctum* L (Tulsi) and study of its antibacterial activities. J Nanomed Nanotechnol S6. https://doi.org/10.4172/2157-7439

Bonnia NN, Fairuzi AA, Akhir RM, Yahya SM, Rani MA, Ratim S, Rahman NA, Md Akil H (2018) Comparison study on biosynthesis of silver nanoparticles usingfresh and hot air oven dried *Imperata cylindrical* leaf. IOP Conf Series: Mater Sci Eng 290. https://doi.org/10.1088/1757-899X/290/1/012002

Bragg PD, Rainnie DJ (1974) The effect of silver ions on the respiratory chain of *Escherichia coli*. Can J Microbiol 20:883–889

Brown T, Smith D (1976) The effects of silver nitrate on the growth and ultrastructure of the yeast *Cryptococcus albidus*. Microbios Lett 3:155–162

Chahardooli M, Khodadadi E, Khodadadi E (2014) Green synthesis of silver nanoparticles using oak leaf and fruit extracts (Quercus) and its antibacterial activity against plant pathogenic bacteria. Int J Biosci 4:97–103

Chiguvare H, Oyedeji OO, Matewu R, Aremu O, Oyemitan IA, Oyedeji AO, Nkeh-Chungag BN, Songca SP, Mohan S, Oluwafemi OS (2016) Synthesis of silver nanoparticles using Buchu plant extracts and their analgesic properties. Molecules 21:774. https://doi.org/10.3390/molecules21060774

Choi O, Hu Z (2008) Size dependent and reactive oxygen species related nanosilver toxicity to nitrifying bacteria. Environ Sci Technol 42:4583–4588

Chouhan N, Meena RK (2015) Biosynthesis of silver nanoparticles using *Trachyspermum ammi* and evaluation of their antibacterial activities. Int J Pharma Biol Sci 62:1077–1086

Cicek S, Gungor AA, Adiguzel A, Nadaroglu H (2015) Biochemical evaluation and green synthesis of nano silver using peroxidase from Euphorbia (*Euphorbia amygdaloides*) and its antibacterial activity. J Chem Article ID 486948, 7 pages. https://doi.org/10.1155/2015/486948

Compant S, Duffy B, Nowak J, Clément C, Ait Barka E (2005) Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. Appl Environ Microbiol 71:4951–4959

Conrad AH, Tramp CR, Long CJ, Wells DC, Paulsen AQ, Conrad GW (1999) Ag+ alters cell growth, neurite extension, cardiomyocyte beating, and fertilized egg constriction. Aviat Space Environ Med 70:1096–1105

Cozzini P, Ingletto G, Singh R, Asta CD (2008) Mycotoxin detection plays "Cops and robbers": Cyclodextrin chemosensors as specialized police. Int J Mol Sci 9:2474–2494

Dallas P, Sharma VK, Zboril R (2011) Silver polymeric nanocomposites as advanced antimicrobial agents: classification, synthetic paths, applications, and perspectives. Adv Colloid Interf Sci 166:119–135

Das MP, Livingstone JR, Veluswamy P, Das J (2018) Exploration of *Wedelia chinensis* leaf-assisted silver nanoparticles for antioxidant, antibacterial and in vitro cytotoxic applications. J Food Drug Anal 26:917–925

Devi TA, Ananthi N, Amaladhas TP (2016) Photobiological synthesis of noble metal nanoparticles using *Hydrocotyle asiatica* and application as catalyst for the photodegradation of cationic dyes. J Nanostrut Chem 6:75–92

Devi LS, Joshi SR (2018) Antimicrobial and Synergistic Effects of Silver Nanoparticles Synthesized Using Soil Fungi of High Altitudes of Eastern Himalaya. Mycobiology 40(1):27–34

Dhayalan M, Denison MIJ, Jegadeeshwari AL, Krishnan K, Gandhi NN (2017) In vitro antioxidant, antimicrobial, cytotoxic potential of gold and silver nanoparticles prepared using *Embelia ribes*. Nat Prod Res 31:465–468

Elavazhagan T, Arunachalam KD (2011) Memecylon edule leaf extract mediated green synthesis of silver and goldnanoparticles. Int J Nanomedicine 6:1265–1278

Elemike EE, Fayemi OE, Ekennia AC, Onwudiwe DC, Ebenso EE (2017) Silver nanoparticles mediated by *Costus afer* leaf extract: synthesis, antibacterial, antioxidant and electrochemical properties. Molecules 22:701. https://doi.org/10.3390/molecules22050701

Emamifar A, Kadivar M, Shahedi M, Soleimanian-Zad S (2011) Effect of nanocomposite packaging containing Ag and ZnO on inactivation of *Lactobacillus plantarum* in orange juice. Food Control 22:408e413

Ezealisiji KM, Noundou XS, Ukwueze SE (2017) Green synthesis and characterization of monodispersed silver nanoparticles using root bark aqueous extract of *Annona muricata* Linn and their antimicrobial activity. Appl Nanosci 7:905–911

Feng Q, Wu J, Chen GQ, Cui FZ, Kim TN, Kim JO (2008) A mechanistic study of the antibacterial effect of silver ions on *Escherichia coli* and *Staphylococcus aureus*. J Biomed Mater Res 52:662–668

Francis S, Koshy E, Mathew B (2018) Microwave aided synthesis of silver and gold nanoparticles and their antioxidant, antimicrobial and catalytic potentials. J Nanostruct 8:55–66

Geddes JR, Carney SM, Davies C, Furukawa TA, Kupfer DJ, Frank E et al (2003) Relapse prevention with antidepressant drug treatment in depressive disorders: a systematic review. Lancet 361:653–661. https://doi.org/10.1016/S0140-6736(03)12599-8

Geethalakshmi R, Sarada DVL (2010) Synthesis of plant mediated silver nanoparticles using *Trianthema decandra* extract and evaluation of their antimicrobial activities. Int J Eng Sci Technol 2:970–975

Gholami-Shabani M, Gholami-Shabani Z, Shams-Ghahfarokhi M, Jamzivar F, Razzaghi-Abyaneh M (2017) Green nanotechnology: biomimetic synthesis of metal nanoparticles using plants and their application in agriculture and forestry. Nanotechnology:133–176

Ghosh PK, Saxena TK, Gupta R, Yadav RP, Davidson S (1996) Microbial lipases: production and applications. Sci Prog 79:119–157

Gottlieb OR, Borin MR, Brito NR (2002) Integration of ethnobotany and phytochemistry: dream or reality. Phytochemistry 60:145–152

Gruère GP (2012) Implications of nanotechnology growth in food and agriculture in OECD countries. Food Policy 37:191–198

Gupta N, Upadhyaya CP, Singh A, Abd-Elsalam KA, Prasad R (2018) Applications of silver nanoparticles in plant protection. In: Abd-Elsalam K, Prasad R (eds) Nanobiotechnology applications in plant protection. Springer International Publishing AG, pp 247–266

He Y, Li X, Zheng Y, Wang Z, Ma Z, Yanga Q, Yao B, Zhao Y, Zhang H (2018) A green approach for synthesizing silver nanoparticles, and their antibacterial and cytotoxic activities. New J Chem 42:2882–2888

Huang J, Li Q, Sun D, Lu Y, Su Y, Yang X, Wang H, Wang Y, Shao W, He N (2007) Biosynthesis of silver and gold nanoparticles by novel sundried *Cinnamomum camphora* leaf. Nanotechnology 18:105–104

Huang CH, Vallad GE, Zhang S, Wen A, Balogh B, Figueiredo JFL, Behlau F, Jones JB, Momol MT, Olson SM (2012) Effect of application frequency and reduced rates of Acibenzolar-S-Methyl on the field efficacy of induced resistance against bacterial spot on tomato. Plant Dis 96:221–227

Inbaraj BS, Chen BH (2016) Nanomaterial-based sensors for detection of foodborne bacterial pathogens and toxins as well as pork adulteration in meat products. J Food Drug Anal 2:15–28

Inoue YM, Hoshino H, Takahashi T, Noguchi T, Murata Y, Kanzaki HH, Sasatsu M (2002) Bactericidal activity of Ag-zeolite mediated by reactive oxygen species under aerated condition. J Inorg Biochem 92:37–42

Iravani S (2011) Green synthesis of metal nanoparticles using plants. Green Chem 13:2638–2650

Ismail M., Prasad R., Ibrahim A.I.M., Ahmed A.I.S. (2017) Modern Prospects of Nanotechnology in Plant Pathology. In: Prasad R., Kumar M., Kumar V. (eds) Nanotechnology. Springer, Singapore, pp 305–317

Jain PK, Huang X, El-Sayed IH, El-Sayed MA (2008) Noble metals on the nanoscale: optical and photothermal properties and some applications in imaging, sensing, biology, and medicine. Acc Chem Res 41:1578–1586

Jay JM (2000) Modern food microbiology, 6th edn. Aspen Publishers, Singapore

Jo YK, Kim BH, Jung G (2009) Antifungal activity of silver ions and nanoparticles on phytopathogenic fungi. Plant Dis 93:1037–1043

Joshi PS, Ramesh G, Packiyam JE, Jayanna SK (2007) Green synthesis and evaluation of silver nanoparticles using leaf extract from *Calotropis gigantean*. Int J Curr Biotechnol 5:1–5

Joshi N, Jain N, Pathak A, Singh J, Prasad R, Upadhyaya CP (2018) Biosynthesis of silver nanoparticles using *Carissa carandas* berries and its potential antibacterial activities. J Sol-Gel Sci Techn 86(3):682–689. https://doi.org/10.1007/s10971-018-4666-2

Käferstein FK, Motarjemi Y, Bettcher DW (1997) Foodborne disease control: a transnational challenge. In World Health Organization, Geneva, Switzerland. Emerg Infect Dis 3:503–510

Kalishwaralal K, Deepak V, Pandian RK, Kottaisamy M, BarathManiKanth S, Kartikeyan B, Gurunathan S (2010) Biosynthesis of silver and gold nanoparticles using Brevibacterium casei. Colloids Surf B Biointerfaces 77 (2):257–262

Karatoprak GS, Aydin G, Altinsoy B, Altinkaynak C, Kos M, Ocsoy I (2017) The effect of *Pelargonium endlicherianum* Fenzl root extracts on formation of nanoparticles and their antimicrobial activities. Enzy Micro Technol 97:21–26

Karthik R, Hou Y, Chen S, Elangovan A, Ganesan M (2016) Eco-friendly synthesis of Ag-NPs using *Cerasus serrulata* plant extract- its catalytic, electrochemical reduction of 4-NPh and antibacterial activity. J Ind Eng Chem 37:330–339

Kavitha HU, Satish S (2011) Eco-friendly management of plant pathogens by some medicinal plant extracts. J Agric Technol 7:449–461

Khairunnisa CM, Anjana M (2018) Green synthesis and characterization of silver nanoparticles using *Curcuma amada* and evaluation of their antimicrobial activity. IOSR-JP 13:01–05

Khan MZH, Tareq FK, Hossem MA, Roki MN (2018) Green synthesis and characterization of silver nanoparticles using *Coriandrum sativum* leaf extract. J Eng Sci Tech Rev 13:158–166

Khatami M, Sharifi I, Nobre MAL, Zafarnia N, Aflatoonian MR (2018) Waste-grass-mediated green synthesis of silver nanoparticles and evaluation of their anticancer, antifungal and antibacterial activity. Green Chem Lett Rev 11(2):125–134

Kiaya V (2014) Post-harvest losses and strategies to reduce them. Technical Paper on Postharvest Losses, Action Contre la Faim (ACF)

Kim J, Kuk E, Yu K, Kim JH, Park SJ, Lee HJ, Kim SH, Park YK, Park YH, Hwang CY, Kim YK, Lee YS, Jeong DH, Cho MH (2007) Antimicrobial effects of silver nanoparticles. Nanomedicine 3:95–101

Krishnaraj C, Ramachandran R, Mohan K, Kalaichelvan PT (2012) Optimization for rapid synthesis of silver nanoparticles and its effect on phytopathogenic fungi. Spectrochim Acta A Mol Biomol Spectrosc 93:95–99

Kulkarni N, Muddapur U (2014) Biosynthesis of metal nanoparticles: a review. J Nanotechnol:1–8

Kumar AS, Abyaneh MK, Gosavi SW, Kulkarni SK, Pasricha R, Ahmad A, Khan MI (2007) Nitrate reductase-mediated synthesis of silver nanoparticles from $AgNO_3$. Biotechnol Lett 29:439–445

Kumar R, Sharma P, Bamal A, Negi S, Chaudhary S (2017) A safe, efficient and environment friendly biosynthesis of silver nanoparticles using *Leucaena leucocephala* seed extract and its antioxidant, antimicrobial, antifungal activities and potential in sensing. Green Process Synth 6:01–18

Kumar KK, Kumar D, Ramesh RP (2018) Green synthesis of silver nanoparticles using *Hydnocarpus pentandra* leaf extract *in-vitro* cyto-toxicity studies against MCF-7 cell line. J Young Pharm 10:16–19

Kuppusamy P, Yusoff MM, Maniam GP, Govindan N (2016) Biosynthesis of metallic nanoparticles using plant derivatives and their new avenues in pharmacological applications – an updated report. Saudi Pharm J 24:473–484

Lara HH, Ayala-Nunez NV, del Carmen I, Turrent L, Padilla CR (2010) Bactericidal effect of silver nanoparticles against multidrug-resistant bacteria. World J Microbiol Biotechnol 26:615–621

Lateef A, Azeez MA, Asafa TB, Yekeen TA, Akinboro A, Oladipo IC, Azeez L, Ajibade SE, Ojo SA, Gueguim-Kana EB, Beukesf LS (2016) Biogenic synthesis of silver nanoparticles using a pod extract of *Cola nitida*: antibacterial and antioxidant activities and applications a paint additive. J Taibah Univ Sci 10:551–562

Liau SY, Read DC, Pugh WJ, Furr JR, Russell AD (1997) Interaction of silver nitrate with readily identifiable groups: relationship to the antibacterial action silver ions. Lett Appl Microbiol 25:279–283

Loo YL, Chieng BW, Nishibuchi M, Son Radu S (2012) Synthesis of silver nanoparticles by using tea leaf extract from *Camellia Sinensis*. Int J Nanomedicine 7:4263–4267

Lux R (2004) The nanotech report 2004: investment overview and market research for nanotechnology, 3rd edn. Lux Research, New York

Mahdizadeh V, Safaie N, Khelghatibana F (2015) Evaluation of antifungal activity of silver nanoparticles against some phytopathogenic fungi and *Trichoderma harzianum*. J Crop Prot 4(3):291–300

Makarov VV, Love AJ, Sinitsyna OV, Makarova SS, Yaminsky IV, Taliansky ME, Kalinina NO. (2014) "Green" nanotechnologies: synthesis of metal nanoparticles using plants. Acta Naturae. 6(1):35–44

Marini M, De Niederhausern N, Iseppi R, Bondi M, Sabia C, Toselli M et al (2007) Antibacterial activity of plastics coated with silver-doped organic-inorganic hybrid coatings prepared by sol-gel processes. Biomacromolecules 8:1246–1254

Matei A, Cernica I, Cadar O, Roman C, Schiopu V (2008) Synthesis and characterization of ZnO-polymer nanocomposites. Int J Mater Form 1:767–770

Matsumura Y, Yoshikata K, Kunisaki S, Tsuchido T (2002) Mode of bacterial action of silver zeolite and its comparison with that of silver nitrate. Appl Environ Microbiol 69:278–4281

Menon S, Agarwal H, Kumar SR, Kumar SV (2017) Green synthesis of silver nanoparticles using medicinal plant *Acalytpha Indica* leaf and its application as an antioxidant and antimicrobial agent against foodborne pathogens. Int J App Pharm 9:42–50

Min JS, Kim KS, Kim SW, Jung JH, Lamsal K, Kim SB, Jung M, Lee YS (2009) Effects of colloidal silver nanoparticles on sclerotium-forming phytopathogenic fungi. Plant Pathol J 25(4):376–380

Mohammadlou M, Maghsoudi H, Jafarizadeh-Malmiri H (2016) Review on green silver nanoparticles based on plants: synthesis, potential applications and eco-friendly approach. Food Res Int 23:446–463

Mohanta YK, Panda SK, Bastia AK, Mohanta TK (2017) Biosynthesis of silver nanoparticles from *Protium serratum* and investigation of their potential impacts on food safety and control. Front Microbiol 8:626. https://doi.org/10.3389/fmicb.2017.00626

Moodley JS, Krishna SRN, Pillay K, Govender S, Govender P (2018) Green synthesis of silver nanoparticles from *Moringa oleifera* leaf extracts and its antimicrobial potential. Adv Nat Sci Nanosci Nanotechnol l 9:1–9

Morones JR, Elechiguerra JL, Camacho A, Holt K, Kouri J, Ram'ırez JT, Yacaman MJ (2005) The bactericidal effect of silver nanoparticles. Nanotechnol 16:2346–2353

Mukhopadhyay SS (2014) Nanotechnology in agriculture: prospects and constraints. Nanotechnol Sci Appl 7:63–71

Nair LS, Laurencin CT (2007) Silver nanoparticles: synthesis and therapeutic applications. J Biomed Nanotechnol 3:301–316

Nalvolthula R, Merugu R, Rudra MPP (2015) Phytochemical analysis; synthesis; antitumor and antimicrobial activity of silver nanoparticles using flower extracts of *Ixora coccinea*. Inter J Chem Tech Res 7:2374–2380

Nasrollahi A, Pourshamsian K, Mansourkiaee P (2011) Antifungal activity of silver nanoparticles on some of fungi. Int J Nano Dimens 1:233–239

Natarajan K, Selvaraj S, Ramachandra MV (2010) Microbial production of silver nanoparticles. Dig J Nanomater Biostruct 5:135–140

Nivas D, Kannan K, Kannan VR, Bastas KK (2016) Bacteriophages emerging biocontrol agents for plant pathogenic bacteria. In: Kannan VR, Bastas KK (eds) Sustainable approaches to controlling plant. Pathogenic bacteria. CRC Press, Boca Raton

Obradovic A, Jones JB, Momol MT, Olson SM, Jackson LE, Balogh B, Guven K, Iriarte FB (2005) Integration of biological control agents and systemic acquired resistance inducers against bacterial spot on tomato. Plant Dis 89:712–716

Ocsoy I, Paret ML, Ocsoy MA, Kunwar S, Chen T, You M, Tan W (2013) Nanotechnology in Plant Disease Management: DNA-Directed Silver Nanoparticles on Graphene Oxide as an Antibacterial against. ACS Nano 7(10):8972–8980

Oluwaniyi OO, Haleemat I, Alabi B, Bodede O, Labulo Ayomide H, Oseghale CO (2016) Biosynthesis of silver nanoparticles using aqueous leaf extract of Thevetia peruviana Juss and its antimicrobial activities. Appl Nanosci 6:903

Pal KK, Gardener BM (2006) Biological control of plant pathogens. Plant Health Instructor. https://doi.org/10.1094/PHI-A-2006-1117-0

Panacek A, Kvitek L, Prucek R, Kolar M, Vecerova R, Pizurova N, Sharma VK, Nevecna T, Zboril R (2006) Silver colloid nanoparticles: synthesis, characterization, and their antibacterial activity. J Phys Chem B 110:16248–16253

Parihar VS, Barbuddhe SB, Danielsson-Tham ML, Tham W (2008) Isolation and characterization of Listeria species from tropical seafoods. Food Cont 19:566–569
Park Y (2014) A new paradigm shift for the green synthesis of antibacterial silver nanoparticles utilizing plant extracts. Toxicol Res 30:169–178
Park HJ, Kim SH, Kim HJ, Choi SH (2006) A new composition of nanosized silica-silver for control of various plant diseases. Plant Pathol J 22:295–302
Patra JK, Baek KH (2014) Green nanobiotechnology: factors affecting synthesis and characterization techniques. J Nanomater. https://doi.org/10.1155/2014/417305
Patra JK, Baek KH (2017) Antibacterial activity and synergistic antibacterial potential of biosynthesized silver nanoparticles against foodborne pathogenic bacteria along with its anticandidal and antioxidant effects. Front Microbiol 8:1–14
Perugu S, Nagati V, Bhanoori M (2016) Green synthesis of silver nanoparticles using leaf extract of medicinally potent plant *Saraca indica*: a novel study. Appl Nanosci 6:747–753
Phanjom P, Zoremi DE, Mazumder J, Saha M, Baruah SB (2012) Green synthesis of silver nanoparticles using leaf extract of *Myrica esculenta*. Int J Nano Sci Nanotechnol 3(2):73–79
Ponarulselvam S, Panneerselvam C, Murugan K, Aarthi N, Kalimuthu K, Thangamani S (2012) Synthesis of silver nanoparticles using leaves of *Catharanthus roseus* Linn. G. Don and their antiplasmodial activities. Asian Pac J Trop Biomed 2:574–580
Prabhu S, Poulose EK (2012) Silver nanoparticles: mechanism of antimicrobial action, synthesis, medical applications, and toxicity effects. Int Nano Lett 2:32
Prasad R (2014) Synthesis of silver nanoparticles in photosynthetic plants. J Nanoparticles:963961. https://doi.org/10.1155/2014/963961
Prasad R, Swamy VS (2013) Antibacterial activity of silver nanoparticles synthesized by bark extract of *Syzygium cumini*. J Nanoparticles. https://doi.org/10.1155/2013/431218
Prasad KS, Pathak D, Patel A, Dalwadi P, Prasad R, Patel P, Kaliaperumal SK (2011) Biogenic synthesis of silver nanoparticles using *Nicotiana tobaccum* leaf extract and study of their antibacterial effect. Afr J Biotechnol 9(54):8122–8130
Prasad R, Swamy VS, Varma A (2012) Biogenic synthesis of silver nanoparticles from the leaf extract of *Syzygium cumini* (L.) and its antibacterial activity. Int J Pharma Bio Sci 3(4):745–752
Prasad R, Kumar V, Prasad KS (2014) Nanotechnology in sustainable agriculture: present concerns and future aspects. Afr J Biotechnol 13:705–713
Prasad R, Pandey R, Barman I (2016) Engineering tailored nanoparticles with microbes: quo vadis. WIREs Nanomed Nanobiotechnol 8:316–330. https://doi.org/10.1002/wnan.1363
Prasad R, Bhattacharyya A, Nguyen QD (2017) Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives. Front Microbiol 8:1–13
Prasad R, Jha A, Prasad K (2018a) Exploring the realms of nature for nanosynthesis. Springer International Publishing (ISBN 978-3-319-99570-0) (in press) https://www.springer.com/978-3-319-99570-0
Prasad R, Kumar V, Kumar M, Wang S (2018b) Fungal nanobionics: principles and applications. Springer Nature Singapore Pte Ltd. (ISBN 978-981-10-8666-3) https://www.springer.com/gb/book/9789811086656
Pugazhendh S, Kirubha E, Palanisamy PK, Gopalakrishnan R (2015) Synthesis and characterization of silver nanoparticles from *Alpinia calcarata* by green approach and its applications in bactericidal and nonlinear optics. Appl Surf Sci 357:1801–1808
Ragsdale NN (2000) The impact of the food quality protection act on the future of plant disease management. Annu Rev Phytopathol 38:577–596
Rai M, Yadav A, Gade A (2009) Silver nanoparticles as a new generation of antimicrobials. Biotechnol Adv 27:76–83
Rajakumar G, Gomathi T, Thiruvengadam M, Rajeswari VD, Kalpana VN, Chung IM (2017) Evaluation of anti-cholinesterase, antibacterial and cytotoxic activities of green synthesized silver nanoparticles using from *Millettia pinnata* flower extract. Micro Pathol 103:123–128
Rajeshkumar S, Malarkodi C (2014) In vitro antibacterial activity and mechanism of silver nanoparticles against foodborne pathogens. Bioinorg Chem Appl 581890:10. https://doi.org/10.1155/2014/581890

Ramesh PS, Kokila T, Geetha D (2015) Plant mediated green synthesis and antibacterial activity of silver nanoparticles using *Emblica Officinalis* fruit extract. Spectrochim Acta A Mol Biomol Spectrosc 142:339–343

Ramteke C, Chakrabarti T, Sarangi BK, Pandey R (2013) Synthesis of silver nanoparticles from the aqueous extract of leaves *of Ocimum sanctum* for enhanced antibacterial activity. J Chem:7. https://doi.org/10.1155/2013/278925

Rateng B (2017) Nanotech holds promise for Africa, but not prioritized. Sci Dev Net 18/10/17, https://www.scidev.net/sub-saharan-africa/r-d/news/nanotech-africa-prioritised.html

Richards RM (1981) Antimicrobial action of silver nitrate. Microbios 31:83–91

Roopan SM, Madhumitha RG, Rahuman AA, Kamaraj C, Bharathi A, Surendra TV (2013) Low-cost and eco-friendly phyto-synthesis of silver nanoparticles using Cocos nucifera coir extract and its larvicidal activity. Industrial Crops and Products 43:631–635

Roy S, Das TK (2015) Plant mediated green synthesis of silver nanoparticles-a review. Int J Plant Biol Res 3:1044

Roy K, Sarkar CK, Ghosh CK (2015) Single-step novel biosynthesis of silver nanoparticles using *Cucumis sativus* fruit extract and study of its photocatalytic and antibacterial activity. Dig J Nanomater Bios 10:107–115

Russell AD, Hugo WB (1994) Antimicrobial activity and action of silver. Prog Med Chem 31:351–370

Sadeghi B, Gholamhoseinpoor F (2015) A study on the stability and green synthesis of silver nanoparticles using *Ziziphora tenuior* (Zt) extract at room temperature. Spectrochim Acta Part A: Mol Biomol Spectrosc 134:310–135

Sangeetha J, Thangadurai D, Hospet R, Harish ER, Purushotham P, Mujeeb MA, Shrinivas J, David M, Mundaragi AC, Thimmappa AC, Arakera SB, Prasad R (2017a) Nanoagrotechnology for Soil Quality, Crop Performance and Environmental Management. In: Prasad R., Kumar M., Kumar V. (eds) Nanotechnology. Springer, Singapore, pp 73–97

Sangeetha J, Thangadurai D, Hospet R, Purushotham P, Karekalammanavar G, Mundaragi AC, David M, Shinge MR, Thimmappa SC, Prasad R, Harish ER (2017b) Agricultural Nanotechnology: Concepts, Benefits, and Risks. In: Prasad R., Kumar M., Kumar V. (eds) Nanotechnology. Springer, Singapore, pp 1–17

Shaik MR, Khan M, Kuniyil M, Al-Warthan A, Alkhathlan HZ, Siddiqui MR, Shaik JP, Ahamed A, Mahmood A, Khan M, Adil SF (2018) Plant-extract-assisted green synthesis of silver nanoparticles using *Origanum vulgare* L. extract and their microbicidal activities. Sustainability 10:913. https://doi.org/10.3390/su10040913

Shankar SS, Rai A, Ahmad A, Sastry M (2004) Rapid synthesis of Au, Ag, and bimetallic Au coreeAg shell nanoparticles using Neem (*Azadirachta indica*) leaf broth. J Colloid Interface Sci 275(2):496e502

Sharma VK, Yngard RA, Lin Y (2009) Silver nanoparticles: green synthesis and their antimicrobial activities. Adv Colloid Interf Sci 145:83–96

Singh J, Mehta A, Rawa TM, Basu S (2018) Green synthesis of silver nanoparticles using sun dried tulsi leaves and its catalytic application for 4-Nitrophenol reduction. J Environ Chem Eng 6:1468–1474

Smith (2008) cites projections from *Nanotechnology: A Global Strategic Business Report* (Global Industry Analysts). For more information see: http://www.researchandmarkets.com/reports/338364/nanotechnology_global_strategic_business_report

Sowmya C, Lavakumar V, Venkateshan N, Ravichandiran V, Saigopal DVR (2018) Exploration of *Phyllanthus acidus* mediated silver nanoparticles and its activity against infectious bacterial pathogen. Chem Central J 12:42

Suna Q, Cai X, Li J, Zheng M, Chen Z, Yu CP (2014) Green synthesis of silver nanoparticles using tea leaf extract and evaluation of their stability and antibacterial activity. Colloid Surf A: Physicochem Eng Aspects 444:226–231

Sunita D, Tambhale D, Parag V, Adhyapak A (2014) Facile green synthesis of silver nanoparticles using *Psoralea corylifolia* seed extract and their in-vitro antimicrobial activities. Int J Pharm Biol Sci 5:457–467

Swamy VS, Prasad R (2012) Green synthesis of silver nanoparticles from the leaf extract of *Santalum album* and its antimicrobial activity. J Optoelectron Biomed Mater 4(3):53–59

Swamy MK, Sudipta, KM, Jayanta K, Balasubramanya S (2014) The green synthesis, characterization, and evaluation of the biological activities of silver nanoparticles synthesized from *Leptadenia reticulata* leaf extract. Appl Nanosci 1–9

Tareq FK, Fayzunnesa M, Kabir MS (2017) Antimicrobial activity of plant-median synthesized silver nanoparticles against food and agricultural pathogens. Microb Pathog 109:228–232

Tran TTT, Vu TTH, Nguyen TH (2013) Biosynthesis of silver nanoparticles using *Tithonia diversifolia* leaf extract and their antimicrobial activity. Mater Lett 105:220–223

Vélez E, Campillo G, Morales G, Hincapié C, Osorio J, Arnache O (2018) Silver nanoparticles obtained by Aqueous or Ethanolic *Aloe vera* extracts: an assessment of the antibacterial activity and mercury removal capability. J Nanomater:1–7. https://doi.org/10.1155/2018/7215210

Vuong LD, Luan ND, Ngoc DD, Anh PT, Bao VQ (2017) Green synthesis of silver nanoparticles from fresh leaf extract of centella asiatica and their applications. Int J Nanosci 16:1–8

Yadav A, Kaushik A, Josh A (2018) Green synthesis of silver nanoparticles using *Ocimum sanctum* L. and *Ocimum americanum* L. Int J Life Sci Pharma Res 8:42

Yugandhar P, Haribabu R, Savithramma N (2015) Synthesis, characterization and antimicrobial properties of green-synthesised silver nanoparticles from stem bark extract of *Syzygium alternifolium* (Wt.) Walp. 3Biotech 5:1031–1039

Zandi K, Weisany W, Ahmadi H, Bazargan I, Naseri L (2013) Effect of nanocomposite-based packaging on postharvest quality of strawberry during storage. Bull Env Pharmacol Life Sci 2:28–36

Zarei M, Jamnejad A, Khajehali E (2014) Antibacterial effect of silver nanoparticles against four foodborne pathogens. Jundishapur J Microbiol 7:8720–8724

Zargar M, Shameli S, Reza Najafi G, Farahani F (2014) Plant mediated green biosynthesis of silver nanoparticles using *Vitex negundo* L. extract. J Ind Eng Chem 20:4169–4175

Zia F, Ghafoor N, Iqbal M, Mehboob S (2016) Green synthesis and characterization of silver nanoparticles using *Cydonia oblong* seed extract. Appl Nanosci 6:1023–1029