GREEN NANOTECHNOLOGICAL APPROACH FOR THE SYNTHESIS AND CHARACTERIZATION OF SILVER NANOPARTICLES USING GARLIC (*ALLIUM SATIVUM*) LEAVES

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ABSTRACT

The escalating demand for clean, low-cost and non-hazardous nanomaterial fabrication has drawn significant interest towards plant-mediated (green) synthesis. In the present investigation, silver nanoparticles (AgNPs) were prepared through an entirely aqueous, environmentally benign route in which the leaf extract of *Allium sativum* (garlic) served simultaneously as the bioreducing and the capping–stabilizing agent, thereby avoiding toxic chemical reductants. When the pale-yellow extract was combined with silver nitrate solution, a progressive shift in colour towards dark brown was observed, providing the first visual evidence of the reduction of Ag^+ ions and the excitation of surface plasmon resonance (SPR). The biosynthesized nanoparticles were characterized by ultraviolet–visible (UV–Vis) spectroscopy, Fourier-transform infrared (FTIR) spectroscopy, scanning electron microscopy (SEM) and transmission electron microscopy (TEM). UV–Vis analysis displayed a characteristic SPR absorption band in the 350–420 nm region, confirming AgNP formation, while FTIR spectra identified the phenolic, aliphatic and carbonyl functionalities of garlic phytoconstituents that mediated reduction and surface stabilization. Electron microscopy revealed well-dispersed, predominantly spherical particles of nanoscale dimension with limited aggregation. The synthesized AgNPs exhibited appreciable antibacterial activity against *Staphylococcus aureus*, producing a clear zone of inhibition in the agar-well diffusion assay. The findings establish garlic leaves as an inexpensive, renewable and eco-friendly bioresource for AgNP production and highlight the promise of these nanoparticles for pharmaceutical, biomedical and antimicrobial applications.

Keywords: Green synthesis; Silver nanoparticles; *Allium sativum*; Surface plasmon resonance; Antibacterial activity; Green chemistry.

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1. INTRODUCTION

Nanotechnology has developed into one of the most influential interdisciplinary domains of contemporary science because it permits the deliberate manipulation of matter at the nanometre scale, where materials acquire physicochemical and biological characteristics that differ markedly from those of their bulk forms. Metallic nanoparticles, in particular silver nanoparticles (AgNPs), occupy a central place in this field owing to their distinctive optical, electronic, catalytic and antimicrobial behaviour. Their extremely large surface-area-to-volume ratio, together with the phenomenon of surface plasmon resonance, endows AgNPs with high reactivity and versatile functionality that has been exploited across the pharmaceutical, environmental, diagnostic and healthcare sectors.1–6

Traditionally, AgNPs have been produced by chemical-reduction and physical methods. Although these routes are well established, they frequently rely on hazardous reducing agents and organic solvents, demand high energy input and generate toxic by-products that pose environmental and health risks.4,7 Because of these limitations, the search for sustainable and eco-compatible fabrication strategies has become a priority in modern nanomaterial research.7,8 Biological, or "green", synthesis employing plant-derived biomolecules has consequently emerged as an attractive alternative, offering operational simplicity, low cost, biocompatibility and inherent environmental safety.9–13

A wide variety of plant extracts and microbial systems has been reported to mediate the reduction of silver ions into stable nanoparticles. Extracts derived from neem, aloe, *Morinda citrifolia*, *Tribulus terrestris*, *Iresine herbstii* and numerous other species have all been shown to yield AgNPs of controllable size and morphology,14–19 while fungal and bacterial cultures provide additional biogenic routes to the same materials.20,21 The reducing power of such extracts is attributed to their rich complement of secondary metabolites, which act concurrently as electron donors and as surface-capping ligands.

Garlic (*Allium sativum*) is one of the most extensively studied medicinal plants, and its leaves are particularly abundant in bioactive phytochemicals, including flavonoids, phenolic acids, organosulfur compounds, allicin and a range of antioxidants. These constituents are well suited to function as reducing, stabilizing and capping agents during nanoparticle formation, allowing silver ions to be converted into stable nanoparticles without recourse to hazardous additives.22–24 Moreover, garlic-derived molecules are themselves recognized for pronounced antimicrobial, antioxidant and broader therapeutic activities, which may act synergistically to reinforce the biological efficacy of the resulting AgNPs.25–32

In the present study, silver nanoparticles were synthesized through a simple green route using an aqueous garlic-leaf extract and were subsequently characterized by UV–Vis spectroscopy, FTIR spectroscopy, SEM and TEM in order to evaluate their optical response, surface chemistry, morphology and particle-size distribution.33–36 The principal objective was to establish an environmentally responsible protocol for AgNP fabrication and to examine the antibacterial potential of the biosynthesized particles, thereby contributing to the wider advancement of sustainable nanotechnology and biomedical research.37–40

Fig. 1: Fresh leaves of Allium sativum (garlic) used for extract preparation.

2. MATERIALS AND METHODS

2.1 Chemicals and Plant Material

Fresh garlic leaves (*Allium sativum*) were collected from the local market of Chandrapur, Maharashtra, India. Analytical-grade silver nitrate ($AgNO_3$) and deionized water were used throughout the work without any further purification. All glassware was washed thoroughly and rinsed several times with deionized water before use to eliminate possible contaminants that could interfere with nanoparticle formation.

2.2 Preparation of Garlic Leaf Extract

The collected leaves were rinsed repeatedly with distilled water to remove adhering dust and surface impurities. Approximately 200 g of the cleaned leaves were finely homogenized and transferred to 100 mL of deionized water. The mixture was heated at 80–90 °C for 10 min to facilitate the release of soluble phytoconstituents and was then allowed to cool to room temperature. The cooled suspension was filtered through Whatman No. 1 filter paper to obtain a clear, phytochemical-rich aqueous filtrate, which acted as both the reducing and the stabilizing medium in the subsequent synthesis (Fig. 2 and Fig. 3).

Fig. 2: (a) Homogenized garlic-leaf suspension during extract preparation; (b) filtration of the aqueous garlic-leaf extract.

Fig. 3: (a) Clear filtrate of the garlic-leaf extract; (b) reaction mixture showing the onset of AgNP formation.

2.3 Green Synthesis of Silver Nanoparticles

An aqueous silver nitrate solution (0.1 N) was freshly prepared and mixed with the garlic-leaf extract in equal volumetric proportions under continuous magnetic stirring. The reaction mixture was incubated at ambient temperature for 24 h in the dark to allow complete bioreduction. The formation of silver nanoparticles was signalled by a distinct colour transition of the mixture from pale yellow to dark brown, a change that arises from the excitation of surface plasmon resonance (SPR) associated with colloidal silver (Fig. 4). The resulting nanoparticles were separated by filtration, washed several times with deionized water to remove unreacted species and dried for subsequent characterization (Fig. 5).

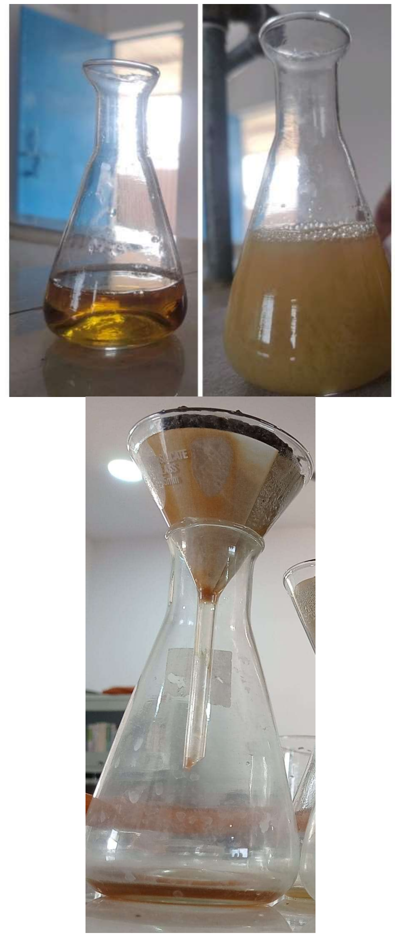

Fig. 4: (a) Reaction mixture before addition of $AgNO_3$ solution; (b) after addition of $AgNO_3$ and filtration of the synthesized AgNPs.

Fig. 5: Silver nanoparticles synthesized from Allium sativum leaf extract.

2.4 Characterization of AgNPs

The biosynthesized silver nanoparticles were characterized using a complementary set of spectroscopic and microscopic techniques.33–35 UV–Vis spectroscopy, recorded over the 200–800 nm range, was employed to confirm nanoparticle formation through the appearance of the characteristic SPR absorption band. FTIR spectroscopy was used to identify the functional groups of the garlic phytoconstituents responsible for the reduction of silver ions and for the stabilization of the particles. Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were performed to examine the surface morphology, particle shape, size range and state of dispersion of the AgNPs.36

2.5 Evaluation of Antibacterial Activity

The antibacterial efficacy of the synthesized AgNPs was assessed against the Gram-positive pathogen *Staphylococcus aureus* using the agar-well diffusion technique.40,42 Mueller–Hinton agar plates were uniformly inoculated with the bacterial culture, and wells cut into the agar were loaded with the AgNP suspension. The plates were incubated at 37 °C for 24 h, after which the diameter of the zone of inhibition formed around each well was measured to quantify the antimicrobial response.

3. RESULTS AND DISCUSSION

3.1 Visual Observation of AgNP Formation

The reduction of Ag+ ions to zero-valent silver nanoparticles was first evident from a gradual change in the colour of the reaction mixture from pale yellow to dark brown. This colour development is a well-recognized qualitative indicator of AgNP formation and originates from the collective oscillation of the conduction electrons at the nanoparticle surface, a phenomenon described as surface plasmon resonance.7,16 The intensification of the brown colour with increasing incubation time reflected the continued bioreduction of silver ions by the garlic phytoconstituents and confirmed the successful progress of the synthesis.

3.2 UV–Visible Spectroscopic Analysis

The UV–Vis spectrum of the colloidal suspension exhibited a well-defined absorption band between 350 and 420 nm, corresponding to the SPR of silver nanoparticles. The emergence of this intense band provided unambiguous confirmation of the bioreduction of silver ions and the formation of stable AgNPs.3,17 The absence of additional broad or secondary peaks indicated a relatively narrow particle-size distribution and good colloidal stability, consistent with effective capping of the nanoparticles by the biomolecules present in the garlic-leaf extract (Fig. 6).

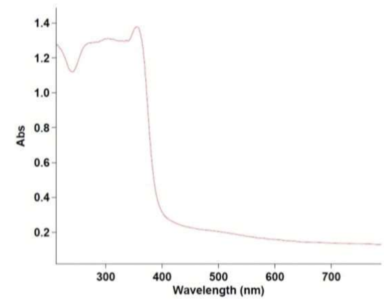

Fig. 6: UV–Vis absorption spectrum of AgNPs synthesized from 0.1 N $AgNO_3$ with aqueous Allium sativum leaf extract.

3.3 FTIR Spectroscopic Analysis

FTIR spectroscopy was used to identify the biomolecules involved in the reduction and stabilization of the nanoparticles. The spectrum displayed prominent absorption bands at 3406, 2897, 1669, 1492, 738 and 599 cm−1. The broad band near 3406 cm−1 is assigned to O–H stretching vibrations of phenolic and alcoholic groups, while the band at 2897 cm−1 corresponds to aliphatic C–H stretching. The absorption at 1669 cm−1 is characteristic of carbonyl (C=O) functionalities, and the band at 1492 cm−1 reflects aromatic C=C skeletal vibrations. The low-frequency band at 599 cm−1 is attributed to Ag–O interactions associated with nanoparticle formation. These observations confirm that phenolic, carbonyl and organosulfur-bearing biomolecules of the garlic extract actively participated both in the reduction of Ag+ ions and in the surface capping of the resulting particles (Fig. 7; Table 1).22,28

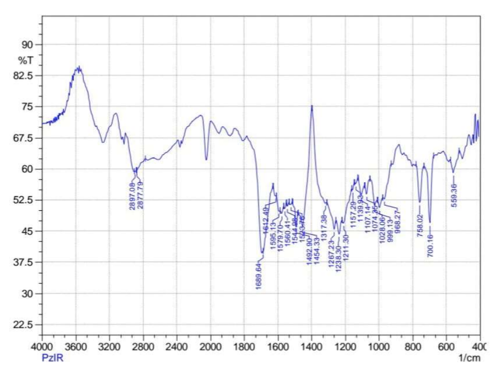

Fig. 7: FTIR spectrum of AgNPs synthesized from 0.1 N $AgNO_3$ with aqueous Allium sativum leaf extract.

Table 1: FTIR band assignments for AgNPs synthesized using Allium sativum leaf extract.

Wavenumber (cm^{-1})	Assigned functional group / vibration
3406	O–H stretching of phenolic and alcoholic groups
2897	Aliphatic C–H stretching vibration
1669	C=O stretching of carbonyl functionalities
1492	Aromatic C=C skeletal stretching
738	C–H out-of-plane bending / fingerprint region
599	Ag–O interaction associated with nanoparticle formation

3.4 Morphological Analysis by SEM

Scanning electron microscopy revealed the formation of well-dispersed nanoparticles with a comparatively homogeneous surface morphology. The particles appeared largely discrete, with only limited clustering, which indicates that the phytoconstituents of the garlic extract provided an effective capping layer that restricted uncontrolled aggregation. Such uniform dispersion is desirable because it is generally associated with reproducible physicochemical behaviour and enhanced biological performance of the nanoparticles.

3.5 Morphological Analysis by TEM

Transmission electron microscopy provided more detailed insight into the size and shape of the biosynthesized AgNPs. The TEM images showed predominantly spherical particles of nanoscale dimension with minimal aggregation.8,36 The observed morphology is consistent with efficient capping of the nanoparticles by garlic-derived biomolecules, which not only govern particle shape but also improve stability and dispersibility by preventing interparticle coalescence (Fig. 8).

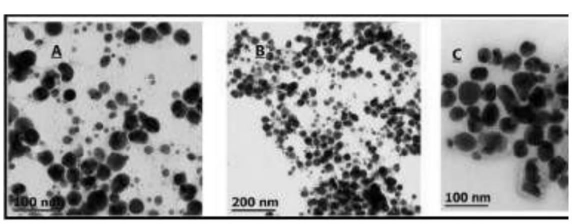

Fig. 8: TEM images of silver nanoparticles synthesized from Allium sativum leaf extract.

3.6 Antibacterial Activity

The biosynthesized AgNPs displayed appreciable antibacterial activity against *Staphylococcus aureus*. A distinct zone of inhibition of approximately 5 mm radius developed around the wells loaded with the nanoparticle suspension, confirming the inhibitory effect of the particles on bacterial growth (Fig. 9). This antibacterial action can be ascribed to several complementary mechanisms: direct interaction of the AgNPs and released Ag+ ions with the bacterial cell membrane, the generation of reactive oxygen species (ROS) that induce oxidative stress, disruption of essential metabolic and respiratory functions, and interference with DNA replication.5,6,40,42,43 The nanoscale size and spherical morphology of the particles, which maximize the available reactive surface, are likely to have further enhanced this antimicrobial response.

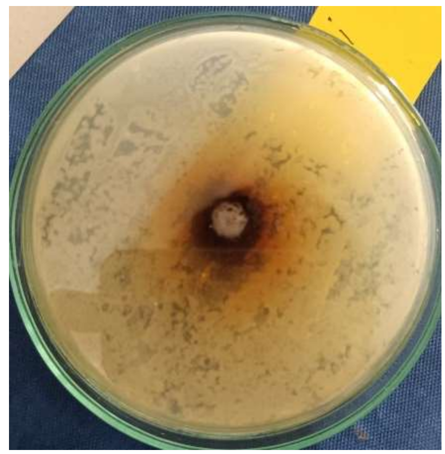

Fig. 9: Zone of inhibition produced by AgNPs against Staphylococcus aureus in the agar-well diffusion assay.

3.7 Proposed Mechanism of Nanoparticle Formation

The overall synthesis can be rationalized as a two-stage phytochemical process. In the first stage, electron-rich biomolecules of the garlic extract—principally phenolics, flavonoids and organosulfur compounds—donate electrons to Ag+ ions, reducing them to zero-valent silver atoms that nucleate into small clusters. In the second stage, the same biomolecules adsorb onto the growing nuclei and act as capping ligands, limiting further growth and providing steric and electrostatic stabilization that prevents aggregation.9,24 The FTIR evidence of phenolic, carbonyl and Ag–O signatures supports this dual reducing-and-capping role and explains the narrow size distribution and colloidal stability observed spectroscopically and microscopically.

Table 2: Summary of the key experimental observations recorded during green synthesis and characterization of AgNPs.

Parameter	Observation
Colour of garlic-leaf extract	Light green

Parameter	Observation
Colour after addition of $AgNO_3$	Dark brown
UV–Vis SPR absorption band	350–420 nm
Major FTIR peaks	3406, 2897, 1669, 1492, 738, 599 cm^{-1}
SEM analysis	Uniformly distributed nanoparticles
TEM analysis	Predominantly spherical nanoparticles
Antibacterial activity	Clear inhibition zone against S. aureus

3.8 Overall Discussion

Taken together, the spectroscopic and microscopic data provide consistent and mutually reinforcing evidence for the successful green synthesis of silver nanoparticles using garlic-leaf extract. The visual colour change and the SPR band at 350–420 nm establish the formation of colloidal silver; the FTIR spectrum identifies the phenolic, carbonyl and organosulfur biomolecules that mediate reduction and capping; and SEM and TEM confirm that the particles are nanoscale, largely spherical and well dispersed. The demonstrated inhibitory activity against *Staphylococcus aureus* further indicates that the biosynthesized particles retain the functional antimicrobial character expected of silver nanomaterials. These outcomes are in broad agreement with earlier reports on plant-mediated AgNP synthesis and reinforce the view that *Allium sativum* leaves constitute an effective, renewable and inexpensive bioresource for nanoparticle production. Beyond their antibacterial potential, the particles may find application in biomedical coatings, wound-healing formulations, antimicrobial packaging and other pharmaceutical products, illustrating how the integration of green-chemistry principles with nanotechnology can deliver functional nanomaterials with a reduced environmental footprint.

4. CONCLUSION

The present investigation successfully established a simple, green and sustainable route for the biosynthesis of silver nanoparticles using the leaf extract of *Allium sativum*. The phytochemicals present in garlic leaves effectively mediated both the reduction of silver ions and the stabilization of the resulting nanoparticles, entirely eliminating the need for hazardous chemical reductants. Characterization by UV–Vis spectroscopy, FTIR spectroscopy, SEM and TEM confirmed the formation of stable, nanosized and predominantly spherical silver particles with favourable physicochemical properties. The biosynthesized AgNPs exhibited promising antibacterial activity against *Staphylococcus aureus*, underscoring their potential utility in biomedical, pharmaceutical and antimicrobial applications. Overall, the developed protocol represents an environmentally responsible and economically viable strategy that could be extended towards the scalable production of functional silver nanomaterials and, in future work, evaluated against a wider panel of microorganisms and for cytocompatibility and drug-delivery performance.

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CONFLICT OF INTEREST

The author declares no conflict of interest with respect to the research, authorship or publication of this article.

REFERENCES

1. Zhang XF, Liu ZG, Liu Y, Gurunathan S. Silver nanoparticles: synthesis, characterization, properties, applications, and therapeutic approaches. Int J Mol Sci. 2016;17(9):1534.
2. Rai M, Gade A, Yadav A. Biogenic nanoparticles: an introduction to what they are, how they are synthesized and their applications. In: Rai M, Duran N, editors. Metal nanoparticles in microbiology. Berlin: Springer; 2011. p. 1–16.
3. Sondi I, Salopek-Sondi B. Silver nanoparticles as antimicrobial agent: a case study on Escherichia coli as a model for Gram-negative bacteria. J Colloid Interface Sci. 2004;275(1):177–82.
4. Chernousova S, Epple M. Silver as antibacterial agent: ion, nanoparticle, and metal. Angew Chem Int Ed. 2013;52(6):1636–53.
5. Li WR, Xie XB, Shi QS, Zeng HY, Ou-Yang YS, Chen YB. Antibacterial activity and mechanism of silver nanoparticles on Escherichia coli. Appl Microbiol Biotechnol. 2010;85(4):1115–22.
6. Carlson C, Hussain SM, Schrand AM, Braydich-Stolle LK, Hess KL, Jones RL, et al. Unique cellular interaction of silver nanoparticles: size-dependent generation of

reactive oxygen species. J Phys Chem B. 2008;112(43):13608–19.

7. Sharma VK, Yngard RA, Lin Y. Silver nanoparticles: green synthesis and their antimicrobial activities. Adv Colloid Interface Sci. 2009;145(1–2):83–96.
8. Raj S, Trivedi R, Soni V. Biogenic synthesis of silver nanoparticles, characterization and their applications—a review. Surfaces. 2021;5(1):67–90.
9. Niraimathi KL, Sudha V, Lavanya R, Brindha P. Biosynthesis of silver nanoparticles using Alternanthera sessilis extract and their antimicrobial and antioxidant activities. Colloids Surf B Biointerfaces. 2013;102:288–91.
10. Sathish Kumar G, Gobinath C, Karpagam K, Hemamalini V, Premkumar K, Sivaramakrishnan S. Phytosynthesis of silver nanoparticles using Morinda citrifolia and evaluation of antimicrobial activity. Colloids Surf B Biointerfaces. 2012;95:235–40.
11. Prabakar K, Sivalingam P, Mohamed Rabeek SI, Muthuselvam M, Devarajan N, Arjunan A, et al. Evaluation of antibacterial efficacy of phytofabricated silver nanoparticles against drug-resistant Gram-negative bacterial pathogens. Colloids Surf B Biointerfaces. 2013;104:282–8.
12. Dipankar C, Murugan S. Green synthesis, characterization and biological activities of silver nanoparticles synthesized from Iresine herbstii leaf extract. Colloids Surf B Biointerfaces. 2012;98:112–9.
13. Gopinath V, Mubarak Ali D, Priyadarshini S, Meera Priyadharsshini N, Thajuddin N, Velusamy P. Biosynthesis of silver nanoparticles from Tribulus terrestris and evaluation of antimicrobial activity. Colloids Surf B Biointerfaces. 2012;96:69–74.
14. Khan Z, Hussain JI, Hashmi AA. Shape-directing role of cetyltrimethylammonium bromide in green synthesis of silver nanoparticles using neem leaf extract. Colloids Surf B Biointerfaces. 2012;95:229–34.
15. Devaraj P, Kumari P, Aarti C, Renganathan A. Synthesis and characterization of silver nanoparticles using cannonball leaves and their cytotoxic activity against MCF-7 cell line. Int J Biomater. 2013;2013:598328.
16. Song JY, Kim BS. Rapid biological synthesis of silver nanoparticles using plant leaf extracts. Bioprocess Biosyst Eng. 2009;32(1):79–84.
17. Zhang Y, Cheng X, Zhang Y, Xue X, Fu Y. Biosynthesis of silver nanoparticles using aqueous aloe leaf extract and evaluation of antibacterial properties. Colloids Surf A Physicochem Eng Asp. 2013;423:63–8.
18. Rashid MU, Bhuiyan MKH, Quayum ME. Synthesis of silver nanoparticles and their application in quantitative analysis of vitamin C tablets. Dhaka Univ J Pharm Sci. 2013;12(1):29–33.
19. Rose GK, Soni R, Rishi P, Soni SK. Optimization of biological synthesis of silver nanoparticles using Penicillium oxalicum and evaluation of antimicrobial activity. Green Process Synth. 2019;8(1):144–56.
20. Mukherjee P, Ahmad A, Mandal D, Senapati S, Sainkar SR, Khan MI, et al. Fungus-mediated synthesis of silver nanoparticles and their immobilization in the mycelial matrix: a novel biological approach to nanoparticle synthesis. Nano Lett. 2001;1(10):515–9.
21. Gurunathan S, Kalishwaralal K, Vaidyanathan R, Venkataraman D, Pandian SRK, Muniyandi J, et al. Biosynthesis, purification and characterization of silver nanoparticles using Escherichia coli. Colloids Surf B Biointerfaces. 2009;74(1):328–35.
22. Bhandari SR, Jung JW, Kang YG, Lee JG, Baek NI. Chemical composition and antioxidant activity of garlic (Allium sativum L.) leaves. Food Sci Biotechnol. 2015;24(1):123–9.
23. Siddiqi SS, Rahman MA, Haque MA. Synthesis and characterization of silver nanoparticles from garlic extract and its antimicrobial activity. J Nanomater. 2016;2016:1–8.
24. Harris PWP, Frederik PWJM. Characterization of silver nanoparticles synthesized using garlic extract and their antibacterial activity. J Microsc Ultrastruct. 2018;6(1):31–7.
25. Sovova M, Sova P. Pharmaceutical importance of Allium sativum L.: hypolipemic effects in vitro and in vivo. Ceska Slov Farm. 2004;53(3):117–23.
26. Petrovska BB, Cekovska S. Extracts from the history and medical properties of garlic. Pharmacogn Rev. 2010;4(7):106–10.
27. Agarwal KC. Therapeutic actions of garlic constituents. Med Res Rev. 1996;16(1):111–24.
28. Dziri S, Hassen I, Fatnassi S, Mrabet Y, Casabianca H, Hanchi B, et al. Phenolic constituents, antioxidant and antimicrobial activities of rosy garlic. J Funct Foods. 2012;4(2):423–32.
29. Lawson LD, Hunsaker SM. Allicin bioavailability and bioequivalence from garlic supplements and garlic foods. Nutrients. 2018;10(7):812.
30. Lawson LD, Ransom DK, Hughes BG. Inhibition of whole blood platelet aggregation by compounds in garlic clove extracts and

commercial garlic products. Thromb Res. 1992;65(2):141–56.

31. Nagae S, Ushijima M, Hatono S, Imai J, Kasuga S, Matsuura H, et al. Pharmacokinetics of the garlic compound S-allylcysteine. Planta Med. 1994;60(3):214–7.
32. Berginc K, Milisav I, Kristl A. Garlic flavonoids and organosulfur compounds: impact on hepatic pharmacokinetics. Drug Metab Pharmacokinet. 2010;25(6):521–30.
33. Lin PC, Lin S, Wang PC, Sridhar R. Techniques for physicochemical characterization of nanomaterials. Biotechnol Adv. 2014;32(4):711–26.
34. Sapsford KE, Tyner KM, Dair BJ, Deschamps JR, Medintz IL. Analyzing nanomaterial bioconjugates: a review of current and emerging purification and characterization techniques. Anal Chem. 2011;83(12):4453–88.
35. Pleus R. Nanotechnologies—guidance on physicochemical characterization of engineered nanoscale materials for toxicologic assessment. Geneva: ISO Publishing; 2012.
36. Albanese A, Tang PS, Chan WCW. The effect of nanoparticle size, shape, and surface chemistry on biological systems. Annu Rev Biomed Eng. 2012;14:1–16.
37. Gurunathan S, Park JH, Han JW, Kim JH. Comparative assessment of the apoptotic potential of silver nanoparticles synthesized by Bacillus tequilensis and Calocybe indica in MDA-MB-231 human breast cancer cells: targeting p53 for anticancer therapy. Int J Nanomedicine. 2015;10:4203–22.
38. Gurunathan S, Han JW, Kim ES, Park JH, Kim JH. Reduction of graphene oxide by resveratrol: a novel and simple biological method for the synthesis of an effective anticancer nanotherapeutic molecule. Int J Nanomedicine. 2015;10:2951–69.
39. Li CY, Zhang YJ, Wang M, Zhang Y, Chen G, Li L, et al. In vivo real-time visualization of tissue blood flow and angiogenesis using Ag2S quantum dots in the NIR-II window. Biomaterials. 2014;35(1):393–400.
40. Pelgrift RY, Friedman AJ. Nanotechnology as a therapeutic tool to combat microbial resistance. Adv Drug Deliv Rev. 2013;65(13–14):1803–15.
41. Bohara RA, Pawar SH. Innovative developments in bacterial detection with magnetic nanoparticles. Appl Biochem Biotechnol. 2015;176(4):1044–58.
42. Salem W, Leitner DR, Zingl FG, Schratter G, Prassl R, Goessler W, et al. Antibacterial activity of silver and zinc nanoparticles against Vibrio cholerae and enterotoxic Escherichia coli. Int J Med Microbiol. 2015;305(1):85–95.
43. Greulich C, Diendorf J, Simon T, Eggeler G, Epple M, Koller M. Uptake and intracellular distribution of silver nanoparticles in human mesenchymal stem cells. Acta Biomater. 2011;7(1):347–54.
44. Yokohama K, Welchons DR. The conjugation of amyloid beta protein on gold colloidal nanoparticle surfaces. Nanotechnology. 2007;18(10):105101.